TCRP E-07 Establishing a National Transit Industry Rail Vehicle Technician Qualification Program: Building for Success

Appendixes A to D

Transportation Learning Center
Silver Spring, MD
February 2014

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Appendix A: National Rail Vehicle Training Standards Committee – Membership List

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Rail Training Standards
Vehicles Committee

Membership List

Committee Co-Chairs

John Costa
International Vice President, ATU

Jayendra Shah
NYCMTA, Co-Chair of APTA Rail Vehicle and Maintenance Committee

Committee Members

Wendell	Hardy	Instructor Railcar Maintenance, MARTA	Atlanta, GA
Frank	Harris	Executive Board Member, ATU 732	Atlanta, GA
Mike	Keller	Executive Board Member, ATU 589	Boston, MA
Robert	Perry	Maintenance Instructor, MBTA	Boston, MA
James	Plomin	Manager, Maintenance & Training (retired), CTA	Chicago, IL
Phil	Eberl	Manager, Light Rail Vehicle Maintenance, RTD	Denver, CO
James	Avila	Maintenance Supervisor, LACMTA	Los Angeles, CA
Gary	Dewater	Sr. Rail Maintenance Instructor, LACMTA	Los Angeles, CA
Jim	Lindsay	Recording Secretary, ATU 1277	Los Angeles, CA
Jerry	Blackman	Acting Assistant Director, Miami-Dade Transit	Miami, FL
Dan	Wilson	Chief, Miami-Dade Transit	Miami, FL
Steve	Cobb	QA Maintenance Training Instructor, Metro Transit	Minneapolis, MN
Jack	Shaw	Shop Forman, Metro Transit	Minneapolis, MN
Paul	Swanson	QA Maintenance Training Supervisor, Metro Transit	Minneapolis, MN
Frank	Grassi	Car Inspector, TWU 100	NY, NY
Hector	Ramirez	Director, Training and Upgrade Fund TWU 100	NY, NY
Phil	Lowe	First Class Electrician, TWU 234	Philadelphia, PA
Brian	Miley	Chief Instructor, Technical Training, SEPTA	Philadelphia, PA
John	Remark	Maintenance Training Coordinator, ATU	Pittsburg, PA
Adam	Williams	Rail Technician, ATU 85	Pittsburg, PA
Joe	Ruffin III	Liaison Officer, ATU 757	Portland, OR
Bertrand	Alexander	Light Rail Technician, IBEW 1245	Sacramento, CA
Kerry	Kopp	Light Rail Maintenance Trainer, SacRT	Sacramento, CA
James	Brooks	Manager of Rail Vehicle Maintenance, UTA	Salt Lake City, UT
Richard	Simons	Rail Maintenance Technician, UTA	Salt Lake City, UT
Greg	Bushner	Light Rail Maintenance Instructor, VTA	San Jose, CA
Scott	Owens	Light Rail Maintenance Electro-Mechanic, VTA	San Jose, CA
Esker	Bilger	Financial Secretary-Treasurer, ATU 689	Washington, DC
Matthew	Bryan	Executive Board Member, ATU 689	Washington, DC
Eric	Peterson	Manager – Technical Training , WMATA	Washington, DC

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Appendix B: Building Capacity for Transit Training: International and Domestic Comparisons

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Working Paper – December 2008[1]

Building Capacity for Transit Training
International and Domestic Comparisons

Executive Summary

As the US public transportation industry continues to make strides toward more effective workforce development systems to address pervasive skills challenges, an important opportunity exists to identify useful lessons from the most effective industry-wide training programs in other countries and other US industries. The "Best in Class" among these other industry-wide training systems share a number of common features that contribute to their quality and effectiveness. These common features include industry-wide and local training partnerships, data-driven curriculum and courseware development, high quality integrated delivery of classroom and on-the-job training and certification, and secure sources of adequate funding. Understanding these distinctive features of successful industry-wide training systems in other countries and industries can contribute to enhancing workforce training in this country as part of ongoing innovations in transit workforce development.

This working paper provides an initial overview of the findings from ongoing research at the Transportation Learning Center[2] regarding strong industry-wide workforce development systems in six other countries and in several US industries. Its focus is on training systems for blue collar employees whose counterparts in the United States generally receive less investment in developing their knowledge, skills and abilities. It identifies key features that could be adapted for use within an emerging system of more effective US transit training. Detailed comparisons with training systems of other countries and other US industries will be published by the Center in 2009.

Introduction

The transit industry and its workforce development systems find themselves at an historic crossroads as the calendar turns to 2009. The industry is facing the challenges of an aging workforce and a smaller, more diverse population for recruitment, global warming, oil dependency, and economic meltdown and recovery with an opportunity to creatively address its long-brewing skills crisis.

The principal drivers of public transportation's skills crisis include:

- Rapidly changing technology, as digital, electronic and telecommunications-based systems and new energy-efficient propulsion systems are becoming pervasive.
- Pending retirement, with 40 percent of skilled technical workers reaching retirement age in the next five years. A limited national

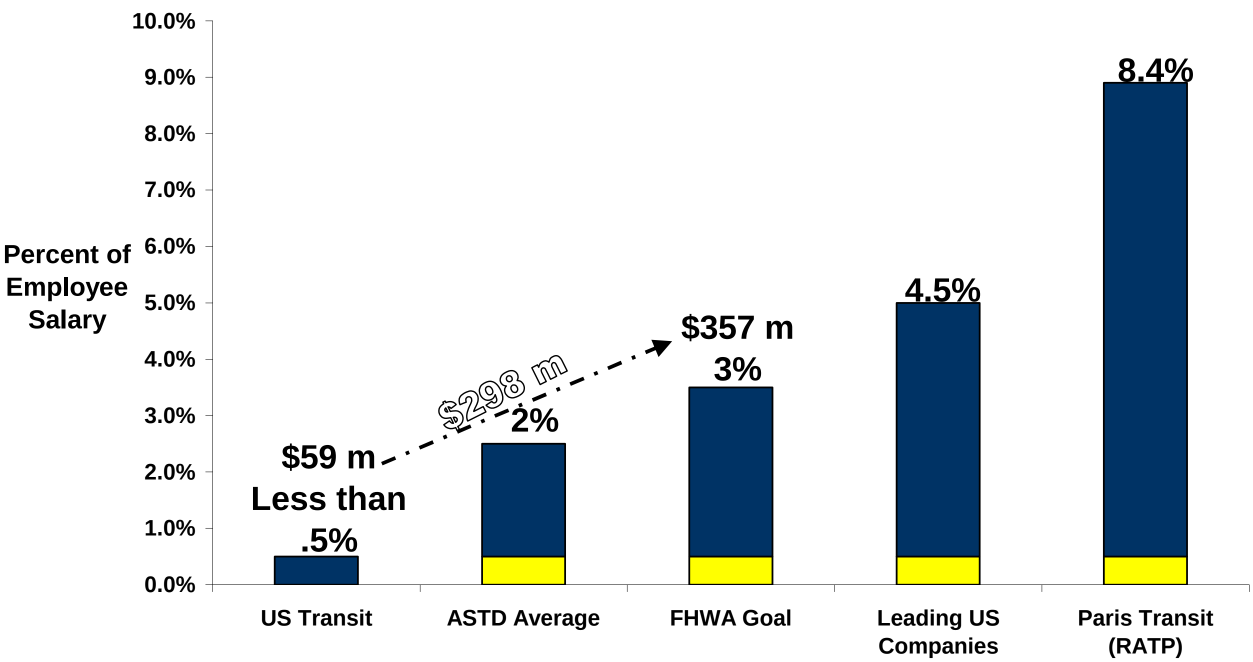
investment in education and training opportunities for Americans not headed to four-year colleges heightens the challenge.

- Record increases in transit ridership, more than 25 percent nationally since 1995, with more future growth predicted.

The transit industry's ability to respond to these challenges has been hampered by limited training capacity, low investment in the human capital needed to support the industry's enormous investments in the physical capital of buses, trains and infrastructure, the local focus of transit systems and unions, and a failure to consistently collaborate nationally on issues of joint concern to management and labor.

In spite of these clear challenges, transit continues to dramatically under-invest in workforce development, with less than ½ of one percent of industry payroll going to workforce training – far lower than found in other benchmark industries in the US and in other countries. Transit's training investment is far below the 2 percent of payroll invested by other US industries, the 3 percent goal set by the Federal Highway Administration, and the 8.4 percent payroll invested by the Paris regional transit system (though the Paris system is clearly not the whole French industry). The US industry is spending less than $59 million annually on training – a number that would need to rise to by $298 million to reach the FHWA goal of 3 percent of payroll - $357 million for transit training.

Chart 1: Transit Behind the Curve on Training Investment



Source: Transportation Research Board and Transportation Learning Center.

In addition to low levels of financial investment in human capital, there has historically been no collective approach to workforce training in the industry. By not having the opportunity to rely on an industry-focused system of training, leaders of individual transit systems and local unions have had to determine for themselves, on their own, the kind of training needed. In most cases they develop courseware and deliver that training in the context of their own individual properties. With each local organization conceiving, designing, engineering and manufacturing its own wheel, the industry's training "system" is highly inefficient and expensive. It entails considerable cost for those systems willing to take on the effort. In the absence of a system of national curriculum, shared courseware and effective joint standards for certification, local training programs are often quite different from one another, with very different levels of quality.

The good news is that the US transit industry has begun to meet these challenges. A brief historical review can highlight the progress now being made.

After the mid-1990s, with growing recognition of the industry's emerging skills crisis,[3] leading national public transportation organizations called for much greater focus on the industry's training needs. Emphasis was placed on joint labor-management approaches to address the workforce challenge.

In 2000 the Board of Directors of the American Public Transportation Association (APTA) launched its Workforce Development Initiative (WDI), and the WDI's leaders invited labor representatives to participate in the WDI task force. WDI's report, *Workforce Development: Public Transportation's Blueprint for the 21st Century*, called for much greater focus on the people side of the industry – its human capital – and welcomed opportunities for leaders from transit management and labor to work together in addressing these challenges.

The Amalgamated Transit Union and the Transport Workers Union, the two unions with the largest membership in public transportation, both called for greater training opportunities for their members, specifically through joint labor-management training partnerships. Working with transit executives, they formed a joint national nonprofit, the Transportation Learning Center, and successfully accessed in-state training funds originating with the US Department of Labor – funding that by federal legislation requires union signoff on training projects involving a union-represented work force.

Since 2000, a series of local and national innovations in transit workforce training have built on this progress, with decisive leadership from key national and local figures in transit labor and management. Supported in part by public investments from US Departments of Transportation and Labor and the Transportation Research Board, this joint leadership helped launch very positive labor-management training partnerships in a number of states that have:

- Provided new training for thousands of transit workers,
- Moved workers up career ladders as they have enhanced their skills, and
- Saved transit agencies millions of dollars by achieving greater equipment reliability, eliminating unnecessary parts usage, reducing spare equipment requirements, and increasing the efficiency of core maintenance activities[4] as summarized in *Transit Partnership Training: Metrics of Success.*

Building on the momentum of these new local, regional and statewide training partnerships, transit's joint leadership also sponsored a nationwide partnership among hundreds of transit system union and management representatives to develop jointly supported national training guidelines. As of the end of 2008 national training guidelines have been proposed for five technical maintenance occupations along with a national framework for apprenticeship (see *Working Together: A Systems Approach for Transit Training*, Transportation Learning Center, October 2008). These national resources for the first time provide a system framework for a common training curriculum, objective skill gap analysis, assessment of gaps in available training programs, sharing existing courseware across locations to fill gaps in training capacity, and developing new courseware in areas where no good training materials currently exist.

These recent practical developments provide a good beginning for the broader changes necessary to ensure effective training opportunities for the operations and maintenance work force in the US transit industry. Equally important is the contribution of these new training partnerships to changing and modernizing the culture within transit agencies. Successful partnerships for training have helped support industry leaders in framing the possibility of intentionally building a new culture of cooperation and mutual respect within the transit industry. These leaders of transit labor and management are moving toward transcending the top-down, ultra-hierarchical and long obsolete command-and-control military model in favor of a modern workplace culture based on partnership and joint problem solving. From Philadelphia and the rest of Pennsylvania to Los Angeles, Atlanta, Portland, Louisville and Albany, from Salt Lake City to the San Francisco Bay Area and New York City, transit executives and labor leaders are finding new ways to work together for developing their workforce and modernizing their organizations.

With the newly emerging setting of joint training activities, national training resources and consensus training guidelines, US public transportation leaders can now look realistically, perhaps for the first time ever, at how best to adapt the key features of successful training systems in other countries and industries.

Research Approach

The focus of this paper is training for the transit industry's blue collar hourly work force. This group makes up at least 75 percent of total transit employment, with union membership exceeding 90 percent in the largest systems.[5] It has been estimated in the Transportation Labor Relations Guide reports that 95 percent of these workers are represented by labor unions, including the Amalgamated Transit Union (ATU), Transport Workers Union (TWU), Electrical Workers (IBEW), Machinists (IAM) and the Service employees (SEIU) among others.

This working paper previews the findings of research undertaken over the past several years with support from the US Department of Labor, US Department of Transportation and the Transportation Research Board's Transit Cooperative Research Program. More detailed analyses of comparisons with other countries and with other US industries will be published by the Center in 2009.

Comparative Benchmarks. How can the transit industry – labor and management working together – find and implement the best solutions to its skills challenges and opportunities? Where can transit look to better understand its options for success?

An essential first step to understanding the possibilities for better approaches to training systems in the US transit industry is to analyze relevant comparison cases. Studying and understanding what works in other countries or other industries is of course only a starting point. The comparative method should not be used to justify simply copying what works for others. What's needed is careful learning, consciously adapted to the circumstances in our own country and industry. With that caveat in mind the US transit industry has an opportunity to learn many useful lessons from effective industry-based, customer-driven training and certification systems elsewhere.

There are three sets of useful comparisons for helping understand how to improve US transit training:

I. Comparisons with training systems for blue collar technical employees in **other countries**. The public transportation industries in the countries with strong national training systems follow general nationwide training models that are then implemented in each major industry.

II. Comparisons with the handful of **other industries** or crafts in the US that have effective nationwide joint labor-management industry training systems. A number of these industries have similar workforce characteristics to public transportation, including comparable union density among the hourly blue collar work force served by their training programs.

III. Comparisons with **recent best practice innovations in US transit** training programs can clarify the current starting point for future developments in the industry workforce development.

I. Effective Industry-wide Training Systems in Other Countries

In comparing other countries' systems of workforce training and certification to those that exist in the US transit industry, we must recognize the significant difference between the industry-wide, organized participative systems of training that bring together employers, unions and educators in those countries. The US transit industry – like most US industries – lacks any systematic approach to help employers and their workers efficiently identify and deliver quality curriculum in effective training settings.

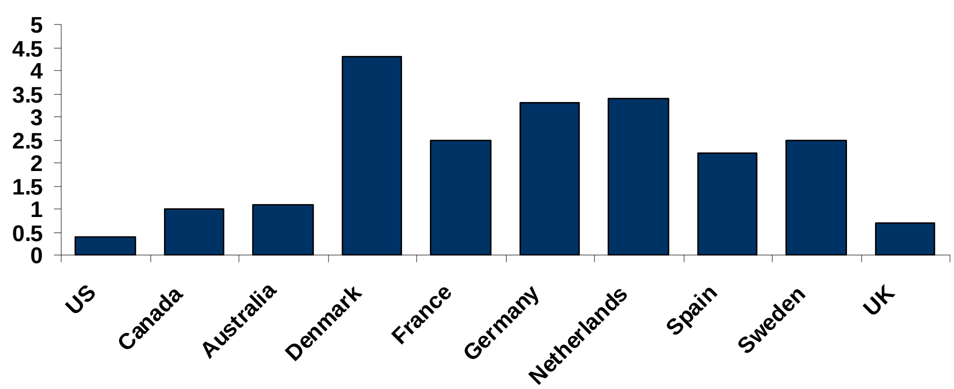
A. International Differences: the US Lags in Training Investments

There is a strong correlation between the level of well managed investment that countries make in blue collar workforce development and the degree to which workforce training has succeeded. In general, countries that spend more on well planned and coordinated workforce training – both governmental expenditure and employer expenditure – have highly developed systems for workforce training. In the US transit industry, until quite recently, this correlation occurs, but in reverse: Average expenditures fall at the low end of the international spectrum of investment in workforce training, and the industry's training overall has not been developed as a coherent, self-reinforcing system.

1. US public investment in workforce development is one of the lowest among industrialized economies. US public investment in training – see chart 2, Public Expenditures on Labor Market Programs – is 0.4 percent of gross domestic product – a figure that ties the US with South Korea for last among OECD member countries. By contrast the countries with the strongest public investments in workforce training, such as Germany, Denmark and the Netherlands, spend eight to ten times as much.[6]

2. US employer expenditures on workforce training are also relatively low among other industrialized countries, despite the significantly downward trend in performance of US high school graduates in

Chart 2: Public Expenditures on Labor Market Programs as a Percent of GDP, 2005-2006



learning in math, science and other fields, compared to other countries. Since 70 percent of the US work force will not go on to earn a 4-year college degree, there is a significant need to further develop the skills – the human capital – of the US work force. The fact that the transit industry finds itself at the low end of the spectrum for employer investment in workforce training further highlights the depth of its workforce investment challenge.

B. International Differences: Industry-Specific Training Systems in Other Countries.

Countries with a high priority for training demonstrate the highest levels of investment in workforce training and are generally considered to have the most effective systems of workforce training. While more funding alone can not create an effective training program, nor guarantee strong results in a new setting, the countries that have the most training resources tend to have well organized, effective training systems. The Center research team has studied these examples as part of its project to identify useful lessons the US might be able to adapt to circumstances in this country.

The European countries with the strongest investments in workforce development – such as Germany, Denmark and the Netherlands – have similarly well-developed sector training partnerships that are deeply rooted in law and custom. These countries feature sector-focused, partnership-based training systems that address all aspects of workforce training on an inclusive, collaborative basis—from curriculum design and training delivery to certification,

These national systems provide:

- A template that is implemented across the full spectrum of industries and occupations within each country, providing coverage for public transportation and its main occupations for maintenance and operations
- Sector partnerships that develop curriculum
- Secure sources of funding
- Validated tracks linking work-based training with classroom education
- Apprenticeship and skill certification for young new entrants as well as adult job changers or lateral entrants from other industries

In Denmark, this template spans across seven main groups of vocational occupations. The German approach to training youth, commonly known as the dual system because it involves coordinated learning at work and in school, covers 356 occupations. The Netherlands organizes occupations in broad sectors, such as services, healthcare and agriculture.

In Denmark and Germany, costs for training are split between the public and private sectors. Government provides funding for education in vocational schools while firm-based learning costs are absorbed by employers and

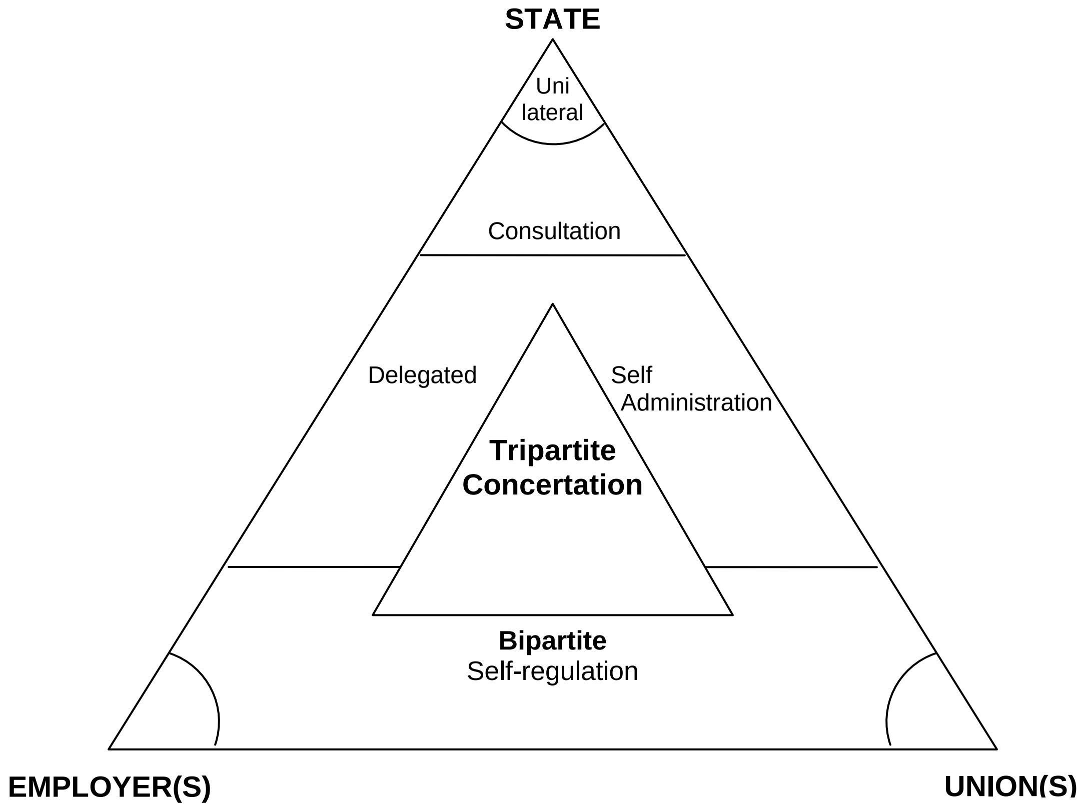
Chambers of Industry and Commerce or Chambers of Crafts. By law, every employer must have membership in a Chamber and their dues are used in large part to fund the training system. The result of this arrangement is to use the authority of the government to raise funds but keep it in private hands. Denmark also has a Collective Employer Fund (AER), which pays for school-based training when no agreement on education was met with the company. In the Netherlands, the guilds of the craft trades were eradicated by the process of industrialization to a higher degree than in either Germany or Denmark. With less workplace institutional capacity to oversee apprenticeship training in the Netherlands, school-based training dominates.

In Denmark, a core level of apprenticeship includes 50 weeks of school-based training for new entrants and 37 weeks for adult job changers. Continuing education courses of study are organized as modules or thematic units, making it much easier for workers to be assessed for prior learning. The Danish system allows for formal certification for skills learned through prior job experience. The German system is also moving in this direction.

In each of these countries, the training and certification systems are tripartite in composition at the national and state or provincial level, bringing together representatives of employers, labor, and relevant government entities (including education but also governmental departments relevant to each industry). Workers have meaningful input into training both through their works councils and through their unions. At the level of the individual firm or workplace, labor and management work together in bipartite partnership structures characterized by 100 percent worker participation in the locally elected works council – regardless of the degree of union representation in their industry or firm.

In the following chart mapping potential structures of training partnerships, these Northern European models are clearly in the central tripartite area at the national level, with bipartite implementation locally. In the European Union, management and labor are commonly referred to as “social partners” in governing and implementing workforce training; this language underscores the depth of the labor-management partnership for training and its recognition throughout these cultures.

Range of Variation in Participation in Training Systems



Source: Bernhard Ebbinghaus, 2005, "Variations in Social Governance and Institutional Change"

The training systems of the major English-speaking industrial countries outside the US – Australia, Canada and the UK – are similar to the Northern European countries in that they are:

- Sector focused on a national basis
- Partnership based, though the depth of partnership integration is less than in continental Europe.

In Canada occupations and training are organized by sectors in a very structured manner within the National Occupational Classification – subdivided at four levels including skill type, skill level, etc. Both Canada and Australia divide occupations into six skill levels, while the UK has five – each one having a higher level of responsibility.

The main ways these countries differ from the Northern European countries are that:

- They are reasonably new systems
- Union involvement isn't nearly as strong.

The Canadian system has been in existence for 45 years. The UK adopted this newer system less than 30 years ago, with the Thatcher Administration. The Australian system was instituted in 1992 in a major effort to upgrade workforce training as part of a national strategy to strengthen international competitiveness of the Australian economy.

Training in all three countries is governed at the national level on a tripartite basis, with involvement from labor, management and government. The difference in these examples is with the relative roles of the national partners. In the UK for example, decision making is strongly weighted toward the governmental entities. In Australia, government involvement is very limited – government observes and influences but does not sit on the skills council board. Industries with high levels of union membership have stronger levels of union involvement; this higher degree of union involvement is evident in the transportation industry. Australia's resemblance to the Northern European examples should not be surprising as it was explicitly modeled on the German plan. Canada lies somewhere in the middle, with a relatively smaller role for labor.

The industry-wide training systems in these other countries share important features with each other. It turns out that some of the most important of these common features are also found in the best training systems in other US industries.

II. Best Practices Across US Industries

In comparing the US economy to these other countries, the US overall clearly has a much more modest approach to workforce training. There are important islands of excellence of US industry-wide training, but they are more the exception than the rule. As transit and other industries face the challenges of growing workforce retirements and new workplace technologies, these more developed models in the US (and in other countries) have received more attention.

Sector partnerships

The most fully effective industry-based training systems in the US are in the handful of US industries and occupations that have created national sector-focused partnership systems of training. Unlike their counterparts in the other countries considered here, US sector training programs are generally governed on a labor-management or bipartite basis, with government's role limited to state or federal short-term grant funding. Over the past two decades there have been important, if limited, developments of sector-based training consortia in the US, mostly at the state, local or regional levels, and often with little or no involvement by labor. The 1990s saw a major push for voluntary labor-management development of national industry skill standards, but outside of general manufacturing and metalworking skills most of that effort has dissipated.

Joint partnership-based training and apprenticeship systems

By far the strongest nationwide training programs for skilled crafts in the US are found in the joint partnership-based training and apprenticeship systems developed in construction and several other industries. Construction crafts provided 204,000, or nearly 70 percent, of the total of 292,000 apprentices in the entire US in 2007. Beyond construction, well developed national systems of training and apprenticeship are especially prominent in other US transportation sectors such as the maritime trades, railroad crafts, and airlines as well as utility workers and industry-based craft workers such as tool and die makers and machinists in important segments of American manufacturing. Local or regional joint systems have been developed very effectively in the health care and hospitality industries.

The largest and best documented US industry-wide training systems have been developed by labor-management partnerships in the construction trades. Construction apprenticeships were developed on a tradition of construction craft apprenticeship with deep roots in European history. US construction unions and employers have institutionalized modern sector-focused, partnership-based systems for apprenticeship and training that produce very high skill levels for the employees of union-represented firms.[7]

Best Practice in US Nationwide Sector Training Programs Shares Common Features with Best Practice in Other Countries

The structure and operating principles of construction apprenticeship and training systems are similar across a range of crafts. National Joint Apprenticeship and Training Committees (JATCs) and counterpart local JATCs function in most major US regions for the crafts of electrical work, plumbing and pipefitting, carpentry, sheet metal work, masonry, structural iron work, heavy equipment operations, painting and other crafts. These partnerships are formally registered at the national level with the US Department of Labor's (US DOL) Office of Apprenticeship and at the state level with regional offices of US DOL or with state apprenticeship agencies. A few states offer partial funding for related classroom instruction, and some states provide grants to help start apprenticeship and training programs, but in general public funds are not available to sustain the ongoing operations of training and apprenticeship systems in US private industry.

The core features of these most effective national joint industry-focused systems in the US bear an important resemblance to the most effective industry training systems in other countries. These universally shared features include:

1. **Sector-Wide Training Partnership**
    - At the national level, a sector-focused national partnership bringing together labor and management coordinates and governs the

overall industrial or craft training system. This is embodied in a separate joint institution that is distinct from both management and labor organizations, the National Joint Apprenticeship Committee. Their functions include developing and maintaining current standards of the knowledge, skills and abilities needed for the covered occupations (see below). They provide training and certification for trainers in local JATC programs through national joint training centers. They interface or partner with universities, other research organizations and equipment/materials manufacturers that are developing the next generations of workplace technologies. They organize industry training seminars and conferences, review the quality and consistency of the training and certification provided by local training partnerships and maintain current information with the US Department of Labor. [8]

- At the level of the individual work place, and sometimes on a statewide or regional basis, a local JATC carries out workforce training, typically at a joint training center funded through the collective bargaining process by negotiated contributions for each hour worked by covered employees. The negotiated contribution to joint training funds is based on cents or dollars per hour worked in the industry. Local JATCs assure that their trainers are kept current on new industry technologies and work techniques by sending them to the national JATC's national training center. Trainers are typically recruited from among the best craftworkers in the area, with additional training provided to build their skills as trainers and course developers. Local JATCs coordinate closely with employer and customer needs as dictated by the particular circumstances of their local labor market, geography, climate, equipment, etc. They provide training for new entrants into the industry (typically, but not exclusively, relatively young workers) as well as training to update and expand the skills of experienced workers who have already reached the journeyperson level. They work with community groups and educational institutions to recruit new entrants into their craft or industry, often coordinating with broader efforts of the national JATC to promote industry recruitment and image building.

2. Maintaining Curriculum Content through a Data-Driven System

- Developing curriculum and courseware matched to the current technologies and equipment of their industry is accomplished by working teams of subject matter experts – the best craftspeople, instructors and knowledgeable supervisors – working together and with manufacturers and developers of the industry's equipment. Periodic reviews and updates of curriculum are undertaken to keep it up date with changing technology and practices. Interestingly, the union-side participants in these efforts are typically the ones advocating for the most stringent training and certification standards.

3. Providing a Secure Source of Funding

- Funding for construction training and apprenticeship systems is provided by negotiated cents-per-hour contributions within local collective bargaining agreements. In most cases these contributions have expanded over dozens of two and three-year contracts, yielding substantial flows of funds available for workforce training. In the construction trades, the hourly contributions range from a few cents for each hour worked in the industry up to $2 per hour. To take just two examples, the national joint training system for the electrical industry (IBEW and National Electrical Contractors Association), spends over $100 million on training annually for a covered membership of about 600,000, of whom just under 44,000 are apprentices receiving relatively intensive training. The joint program for the plumbing and pipefitting industry (jointly between the United Association and the plumbing and pipefitting contractors) spends $130 million for a membership of about 300,000 and just under 19,000 active apprentices.
- JATCs' funding through negotiated contributions provides a needed stable base of income for training activities. In addition, some JATCs also seek federal, state or local government grants to explore new areas for training development. When they choose to pursue such grant opportunities, JATCs can demonstrate a high level of quality and positive training outcomes through their core training programs.

4. Training and Certification for New Hires – Training and Apprenticeship

- The traditional core activities of local JATCs are recruitment and training of new hires – typically relatively young people – who are ready to launch a career in the particular industry or craft. It is noteworthy that in the industries that have these training systems workers can expect to pursue a long career within the industry, thus justifying for both employer and employee the time and expense of the training; this same long job tenure is also found in technical occupations in the transit industry. The training program combines on-the-job learning (OJL) with related classroom instruction over a progression that typically lasts from three to six years. Through each year the trainee moves up a ladder of instruction and hands-on experience, with on-the-job mentoring by more experienced craftspeople and detailed workplace checklists of activities to be mastered that correspond to the topics covered in classroom education.

- As trainee/apprentices progress, their wages increase. They finally achieve the full journeyperson rate when they complete their training and the typical dual certification evidenced by written knowledge and hands-on demonstration of skills. From an economic perspective, trainees contribute to the cost of the instruction by agreeing to receive a lower wage while they are learning. Their pay increases as skills and productivity advance.
- An important element of many current apprenticeship programs is providing college credit to their students as they learn. Through local or national arrangements, training systems negotiate college credit for their apprenticeship graduates that often fulfills most of the course requirements for a college associate degree. Similar college credit is also arranged for the more advanced instruction given to industry trainers for their certification. A benefit of this coordination is that learners are not forced to choose between an occupational or educational track; they can move up the academic credentials ladder in tandem with progress up the industry career ladder.

5. **Training and Certification for Lateral Entrants and Experienced Incumbents**
   - Under US Department of Labor regulations, all apprenticeship systems provide for advanced placement and "testing out" for employees who already have meaningful related work experience and learning. In the past decade most of the construction training and apprenticeship systems have substantially expanded their availability to lateral entrants – job changers entering their industry after acquiring experience in other industries, the military or other sectors of the same industry outside the reach of the joint training system. Construction local JATCs have expanded their use of formal assessment of lateral entrants – through both written and hands-on tests – so they can identify gaps in skills or knowledge and provide training tailored to the areas where a lateral entrant needs further instruction. This practice can lead to relatively rapid completion of journeyperson training and certification for new hires.
   - With the accelerating introduction of new workplace technologies, national training partnerships have expanded their use of required upgrade or refresher training for incumbent journeypersons. This refresher training typically focuses on new technologies and on technical issues that pose specific current challenges in the workplace.

III. Conclusion: Workforce Development Potential in the US Public Transportation Industry

The best innovations in transit training for blue collar workers over the past eight years are a very good fit with the best practices in other countries and other US industries.

As indicated at the beginning of this paper, since the year 2000 national labor leaders and senior executive leaders in the transit industry have encouraged and developed a broad series of national and local workforce training initiatives. These include:

- Initiatives for joint local and statewide training partnerships now operating in five states and pending in a half-dozen other states
- Joint development of national training guidelines and curricula for five priority technical occupations and a related framework for apprenticeship, using a high quality data-driven process
- Joint exploration of significant funding for transit workforce development – to provide adequate investments in human capital to match the industry's large and growing investments in physical capital of buses, trains and infrastructure
- A jointly developed national framework for transit apprenticeship training that can provide training and certification both for new entrants and lateral hires, and which can provide needed stability to local training initiatives.

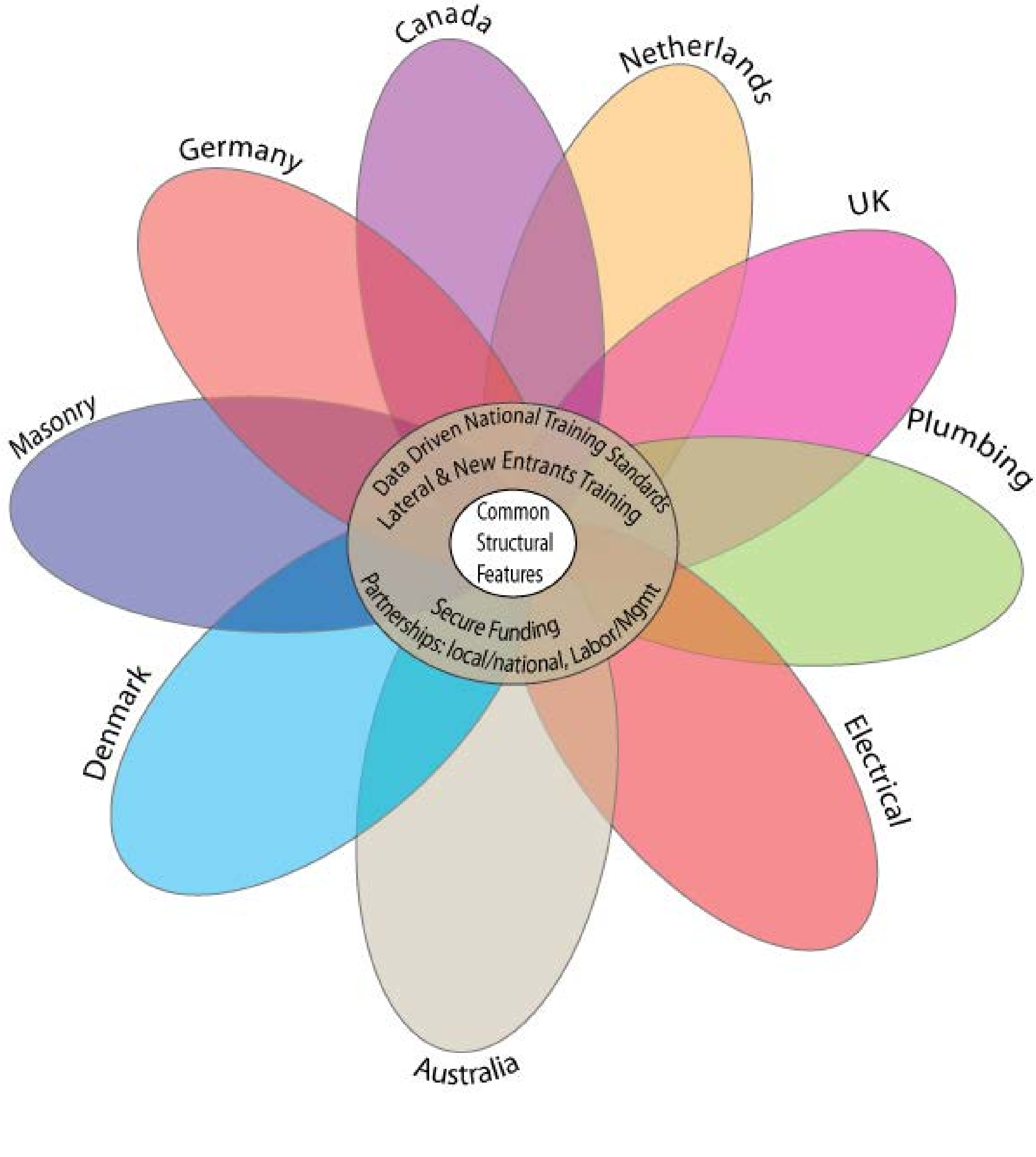
The table on the following page provides a high level overview of the training systems reviewed in this summary along with the changing baseline of training practices and possibilities in the US industry. It shows:

- The training systems in other countries with much stronger histories of effective workforce development
- The national industry-wide training systems in the US construction trades and other effective industry-based training partnership systems
- The historic baseline of fragmented training in the US transit industry
- The direction of recent joint innovations for workforce training in the US public transportation industry
- Potential goals for the further development of a partnership-based, data-driven training system for the US industry.

Another view of these comparisons is found in the chart 3 on the subsequent page. This Venn diagram shows how the most effective industry-wide training systems share a set of core common features. This area of overlapping features deserves careful attention from those interested in implementing effective systems for transit industry training in the United States.

Table: International and Domestic Comparisons of Training Systems

Region	Sector partnerships: National & statewide	Local partnerships	Data Driven training: classroom & on-the-job curriculum	Secure Funding	Youth & New entrants: training/certification	Lateral Entrants: training/certification and Incumbents: Refresher Training
International: **Northern Europe** **Australia** **UK** **Canada**	Tripartite	Bipartite	National and/or regional for major industries & occupations	Secure blend of public and work-related funding via legislation & bargaining	Training and apprenticeship	Well provided in some countries (Denmark, the Netherlands, etc.) weaker in others
US: industry-wide partnerships	Bipartite	Bipartite	Through Nat'l JATCs, local JATCs	Negotiated in contracts	Strong apprenticeship training systems	Testing and fill-in-the-gap training, certification
US Transit: Traditional Baseline	None	Few, and unstable	None (or a few local uncoordinated initiatives)	No	Sporadic, local variation	Sporadic, local variation
Recent US Transit Innovations	Bipartite – Transportation Learning Center; National framework for apprenticeship	PA, NY, UT, GA, N. CA, and other states in the pipeline	Joint national training guidelines for 5 maintenance occupations 2008	TBD – could be addressed in re-authorization of federal Transit and Highway bill	Implement national guidelines with courseware sharing; 3rd party	Testing and fill-in-the-gap training and certification under new apprenticeship
Possible Future US System	Broader implementation	In all states	Completed guidelines for all occupations	Stable Combination of public and bargained funds	Complete system, articulate with school programs	Extended


Canada
Netherlands
Germany
UK
Masonry
Plumbing
Denmark
Electrical
Australia
Data Driven National Training Standards
Lateral & New Entrants Training
Common Structural Features
Secure Funding
Partnerships: local/national, Labor/Mgmt

Progress in US Transit Training, 2000 and Today

These comparisons suggests that – contrary to any reasonable expectations in the year 2000 – US transit leaders today are actually within sight of being able to create a top quality partnership-based system of workforce training.

<u>The Way We Were in 2000.</u> The practical starting point for US transit training as a snapshot in 2000 – before the recent innovations in transit training – shows considerable variation in level of investment and quality of workforce development systems. As indicated earlier, overall levels of investment in workforce development are very low – less than one half of one percent. Some transit systems operate well above that average level. Eighteen US transit agencies and their unions, for instance, had created joint maintenance apprenticeship training systems, but these have proven to be unstable institutional innovations. While several of these apprenticeship systems were registered with state apprenticeship councils or even the US Department of Labor, none enjoyed the stabilizing effects of regional, state or national level joint industry councils that could provide support and guidance. In fact, of the several transit apprenticeships hailed as promising models by the Transportation Research Board between 1995 and 2002, by 2007 one large one had been completely dismantled and another very large one had become inactive (though it was later revived with new local leadership).

Before the very promising and cost-effective innovations since 2000 in building joint transit career ladder partnerships and national curriculum guidelines for training in technical occupations, many transit systems had little or no training activity beyond the short introductions provided by equipment vendors when procurements brought in new vehicles. In fact the US public transportation industry found itself in the same position as most other US industries for training their work force: local employers and local unions are essentially left to their own devices to determine what training should be provided, develop their own curriculum and courseware independently, train their own expert trainers and design their own training delivery system. Obviously this "system" – or relative lack of system – dramatically raises costs and undermines cost-effectiveness in US transit training. These inefficiencies also contribute to the very low levels of investment in transit workforce training, since the cost of the investment is high and the outcome is relatively uncertain.

In this "legacy" context, hundreds of smaller transit agencies have very limited access to training – with no trainers, not to mention training departments. With no meaningful federal or state funding for workforce training, most medium-sized agencies were often unable to fund more than a single trainer position, if that. And while most large transit systems had training departments, almost all lacked a comprehensive training for new hires and upgrades for incumbents. In at least one very large agency there were no technical trainers on staff at all.

In addition to the new local, regional and statewide transit labor-management training partnerships and the national guidelines for transit training, the US industry has seen other workforce training innovations. Southern California and Florida have regional training partnerships linking transit agencies and local colleges, but excluding labor unions. ASE transit tests have been adopted in collective bargaining in a number of locations as the basis for wage premiums, but new training promised for incumbents prior to ASE testing, and demanded by transit labor, has generally not been forthcoming. The transit bus mechanic training guidelines jointly developed by the transit industry cover the material in the ASE tests but go to greater depth as required for developing highly qualified technicians.

Path to a Successful Future

US transit's emerging integrated framework of partnership-based data-driven solutions combines local, regional and statewide training partnerships with a national industry-wide framework of consensus training curriculum. This combined framework leads to significant value-added opportunities in applications such as:

- Conducting a skill gap analysis to identify training priorities for each work force and support career ladder advancement through learning
- Mapping existing training courseware against the national guidelines
- Sharing courseware among training programs to fill local training courseware gaps
- Developing regional training networks, especially for smaller properties
- Developing new courseware to fill national gaps in transit training materials

There is solid evidence that this partnership-based, data-driven, system-based approach can achieve better training at lower cost and with better outcomes for transit stakeholders throughout the public transportation industry. The business case for investment in high quality data-driven, partnership-based training is well demonstrated, with return on investment exceeding 300 percent annually, and therefore increasingly being adopted.[9]

The work accomplished since 2000 answers the questions that might have been raised as serious challenges eight years ago. One such question might be called "the problem of missing union density." Are comparisons with countries with higher levels of union density relative for the US? The United States does have lower levels of overall union membership compared to the countries of northern Europe, Australia or Canada. Yet, while there are real differences in overall levels of density, 95 percent of the hourly operations and maintenance workforce in the US public transportation industry are already represented by labor unions. It is hard to argue that the US transit industry does not have sufficient density to support an effective training partnership. The major unions representing US transit workers support a partnership approach for transit training, as did APTA's Workforce Development Initiative in 2001 and many transit executives since then. To highlight a related potential concern, it is also important to note that unions in the statewide transit training partnerships developed since 2000 are all quite comfortable having their partnerships provide training to transit workers in small systems who are not union members.

Joint labor-management systems as a method for workforce training have unique sources of program effectiveness that have been demonstrated time and time again. National studies of construction industry training by the US Government Accountability Office, among others, and state-level studies by several research organizations have documented that joint training programs have higher enrolment, better graduation and retention rates, greater success with women and people of color, and greater durability and flexibility than counterpart programs operated by employers and education providers without union participation.[10] The success of recent joint workforce development innovations in the US public transportation industry derives in large part from the fact that – particularly in the union-represented work environment – training developed with active workforce (and union) participation is more likely to succeed. Training developed and implemented on a partnership basis is much more likely to reflect the full range of knowledge, concerns and priorities of both workers and managers. Many transit executives have come to recognize that training developed with this constituent participation is more likely to be supported by the work force and their unions when it comes to implementation.

Establishing a secure and reliable source of funding for the workforce training needed by the US transit industry is a challenge that requires special attention.

The strong industry-wide partnerships for apprenticeship and training that are already functioning in the US have been established and improved through many rounds of collective bargaining over the last fifty to eighty years. In beginning to make up for missing decades of developing partnership-based industry-wide training institutions, the US industry can take advantage of the fact that public transportation is clearly a public service. It is a public good for which government at all levels recognizes its public responsibility to provide funding to assure safe, quality transportation service. Nowadays the public interest in a sustainable environment, livable communities and independence from unstable petroleum exporters adds even greater urgency to that governmental responsibility. The U.S. Department of Transportation has provided just under $10 billion annually to the transit industry. The overwhelming majority of that federal investment goes to support purchases of physical capital – the capital equipment of buses, trains and infrastructure. For all practical purposes none of this public funding is directed toward supporting the needed complementary investments in human capital - the people, knowledge and skills essential to provide reliable, safe, environmentally sound transportation services. Both the major transit unions and the American Public Transportation Association have established funding for transit training as an important goal for the reauthorization of the highway and transit bill that expires in September 2009. With major blue-ribbon commissions proposing that public funding for transit needs to be doubled or tripled, it seems reasonable to provide funding for workforce training that will protect and maintain this investment and pay back the public several times over. A data-based target would be to increase transit training investments from not quite 0.5 percent today toward three percent – a six fold increase that would cost an additional $298 million annually.

It would also be beneficial for local collective bargaining agreements to institutionalize joint approaches to directing expanded training. Negotiated pennies per hour could help stabilize funding transit training, alongside ongoing public investment in transit workforce development. Combined with the other beneficial developments in the near-term future, providing this public-private financial support may be able to move workforce training in the US transit industry decisively toward the most effective models in other countries and other US industries.

<u>A Good Solution Requires More than Funding.</u> A fundamental lesson from analyzing the experience of other countries and other US industries is that success involves much more than just sufficient financial resources, vital as they are. The keys to secure success include effective operating partnerships between labor and management, nationally as well as locally. Success requires a consensus-based determination of what knowledge, skills and abilities workers need to operate at the highest levels of proficiency. Success in workforce development means solid, effective courseware matched to consensus curriculum, with training and certification provided delivered in settings that coordinate classroom and on-the-job learning and that work for young new hires and more mature lateral entrants to the industry. As much as anything long-term stable innovation requires developing organizational capacity and expert personnel within transit agencies and unions. Building the capacity of the partner organizations is a key to success.

Adaptive Learning through International and Domestic Comparisons

While the US transit industry can learn from other countries and industries, the US transit context is distinct. As emphasized at the outset, it can not be a question of copying what others do. What will work best here is to apply adaptive learning from the successful experience of others. We can adapt what works well in other contexts – their structures, processes and organizational approaches – to the particular circumstances of this industry. That we can do.

Major differences between US transit and other countries and industries do not mean that their experience is irrelevant.

The United States does not have a statutory or customary framework that requires joint problem solving around training and other issues outside the realm of collective bargaining. But in recent years the US transit industry on a voluntary basis has made a good start down the road toward pragmatic labor-management partnerships and an integrated framework for industry training.

The US transit unions do not have the exclusive jurisdiction found in the US construction trades, so there is no feasible option for an industry-wide partnership associated with associated with a single union as in the construction joint apprenticeship and training committees. But the diverse unions representing US transit workers have been able to work cooperatively in building statewide, regional and national training partnerships, even extending the benefits of regional training partnerships to transit workers who are not represented by unions. Transit's industry-wide multi-union labor-management training partnership is a new precedent in this country, but one that is working well.

The US transit industry does not have secure sources of adequate funding for workforce training, but it can develop them over time.

With these and other challenges the US transit industry – labor and management working together – has already begun to build a national framework for training, apprenticeship and certification that bears a strong family resemblance to the best training systems of other countries and industries. Hopefully these international and domestic comparative studies can help the US industry make further progress in building capacity for an effective system of workforce training.

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[1] The Center wants to recognize in particular the contributions to this research by Robert Glover, Research Scientist at the Ray Marshall Center for the Study of Human Resources at the LBJ School of Public Affairs, University of Texas at Austin, and Dr. Moira Nelson at the Hertie School of Management in Berlin. The Center's internal research team is headed by Brian J. Turner and includes Mark Dysart, Julie Deibel and Shapell Randolph.

[2] Formerly known as the Community Transportation Development Center.

[3] The Transportation Learning Center in 2008 published selections from six studies from the Transportation Research Board and its Transit Cooperative Research Program as *People Make the Hardware Work* (www.TransportCenter.org/publications)*.:*

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[4] See Transportation Learning Center, 2008, *Working Together: A Systems Approach for Transit Training*, for an overview of new national training guidelines and how they can be used, and 2007, *Transit Training Partnerships: Metrics of Success*, for quantitative analysis of effectiveness of data-drive partnership-based transit training, including savings from different sources and analysis of return on investment.

[5] At New York City Transit, total union membership is 90.37 percent of total employment. This includes union membership among first tier supervisors.

[6] US Department of Labor, *International Chartbook*, January 2008, p 30.

[7] U.S. Government Accountability Office (GAO) (2005) *Registered Apprenticeship Programs: Labor Can Better Use Data to Target Oversight* GAO-05-886. Washington, D.C.

Bilginsoy, Cihan (1998) *Apprenticeship Training in the U.S. Construction Industry*. Salt Lake City, UT: Department of Economics, University of Utah. (September).

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Glover, Robert W. and Cihan Bilginsoy (2005) "Registered Apprenticeship Training in the U.S. Construction Industry," *Education+Training, vol. 47, no. 4/5* (July), pp. 337-349.

[8] Some national training partnerships operate a broad nonprofit (501(c)3) that undertakes industry research and promotion, going beyond the usual training activities of a joint 501(c)6 labor-management training partnership**.**

[9] See Transportation Learning Center, 2006, *Measuring Up*, and 2007, *Transit Training Partnerships: Metrics of Success*. Robert Glover, 2007, “Developing a Joint System of Training and Apprenticeship in American Transit: Lessons from the Experience in Other Industries” (Ray Marshall Center for the Study of Human Resources, University of Texas at Austin).

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Appendix C: TCRP E-07 Multiyear Work Plan

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E-7: Initiating a National Joint Transit Industry Rail Vehicle Technician Qualification Program: Building for Success - Five Year Work Plan

Introduction

Based on input from the TCRP Panel and industry feedback before the end of Year 2, the TCRP's E-7 project, *Initiating a National Joint Transit Industry Rail Vehicle Technician Qualification Program: Building for Success*, has been renamed the *Initiating a National Joint Transit Industry Rail Vehicle Technician Qualification Program: Building for Success.* This document reviews accomplishments in Years 1 and 2, and projects work plans for Years 3 to 5.

For purposes of this project, *qualification* means a jointly developed National Transit Rail Vehicle Technician Standard system of instruction, training and examination programs. Under this definition, a *qualified perso*n is someone who has completed the necessary instruction, training and examination programs to successfully demonstrate the skills and knowledge described in the Rail Vehicle Technician Standard. The change of name is designed to reflect a consensus agreement, from both labor and management stakeholders, to clarify that developing a system of effective technician qualification training which includes a fair system for assessing technician knowledge and skills, not just assessments themselves, is the focus of this E-7 project.

This change in terminology also emphasizes the important connection between technical training and safety. For additional information, a detailed description of the term "qualification" and its relationship to industry and regulatory safety standards is provided in the Appendix.

This E-7 project brings together expert management and labor representatives to help design and implement a new joint system for developing and qualifying the skills of transit technicians – transit rail vehicle technicians in this first instance. The E-7 project necessarily builds upon and links to other elements in an emerging joint system of training and apprenticeship for technical jobs in the transit industry. This effort derives from a broader joint program for developing a comprehensive system of consensus standards for transit technical training and a national joint framework for transit apprenticeship.

There has been a well grounded consensus among transit labor and management that development and implementation of a national system of skills-based assessments only makes sense if it is preceded by the development and implementation of training at the national and local levels. With this foundation, and with the E-7 Panel's commitment to joint industry participation, this project aims to achieve the goal of widespread adoption of this emerging joint national system of qualification through locally bargained collective agreements. As this work progresses, jointly recommended language on qualification from the E-7 Panel for coordinated local agreements will be submitted for review, adaptation and adoption in local collective bargaining agreements.

Progress made in Year 1 – 2008-2009

During E-7's first year the project fully succeeded in:

- Publishing an important research report on best practices in training, apprenticeship and qualification in other industries and other countries (*International and Domestic Comparisons: Building Capacity for Transit Training*)

- Developing a feasibility study of a proposed national training and qualification system for rail car technicians that works for transit agencies, employees and their unions. This feasibility plan was reviewed and approved by the joint E-7 Project Panel members.
- Completing the proposed national training standards for transit rail car technicians.

Progress in Year 2 – 2009-2010

In Year 2 the E-7 project has:

- Submitted proposed national training standards for industry final review. This will result in an unprecedented coordinated adoption of transit training standards by APTA and the two principal transit unions, the Amalgamated Transit Union and the Transport Workers Union.
- Launched an extensive program for validating agencies' transit rail car training against the national standards
- Developed a system for sharing validated courseware among transit rail agencies with little or no cost
- Drafted national guidelines for mentoring and apprenticeship
- Started pilot training with validated training materials at the 100 level in four transit systems
- Developed approximately 400 proposed assessment questions for pilot review as written and hands-on assessments in the future qualification system
- Devised a reliable methodology to assure non-discrimination in national qualification assessments
- Developed a comparative evaluation and making a recommendation for a technology-based Learning Information Management System (LIMS) to coordinate data on transit training and qualifications
- Developed analyses and recommendations for consideration in local collective bargaining agreements that can effectively implement the proposed national system for training, apprenticeship and qualification.

Phases 3-5 – 2010-13

In its final three years the project will develop, pilot and roll out a jointly developed system of qualification for transit rail car mechanics integrated with training validated against national training standards. With continuing support from DOT/FTA, the Transportation Learning Center will facilitate ongoing validation of training programs and materials and the sharing and delivery of validated training materials on an industry-wide basis. This final system will have been pre-vetted by senior representatives of transit management and transit labor organizations and should, therefore, be readily available for widespread implementation through collective bargaining throughout the industry. This final program will include a variety of components essential to a smoothly functioning, system including:

- Training materials validated against national standards at all levels and courseware sharing across locations at little or no cost
- A system of federally registered apprenticeship for transit rail car technicians that is available for use in locations across the country
- Banks of validated written and hands-on assessment questions available for randomized immediate download at participating locations
- A Learning Information Management System for national and local use to track training and qualifications

- Recommended practices and language for consideration in implementation of systems of training, apprenticeship and qualification for transit rail car mechanics and, potentially, for other technical occupations

Summary

Success of the E-7 project in developing a joint approach for qualification linked to training standards will pave the way to a high quality, highly cost-effective system of training, apprenticeship and qualification across a wide range of key operating and maintenance occupations. With increasing emphasis on transit safety and the state of good repair, this timely investment in building an industry-wide partnership system of training and qualification will contribute significantly to the future of the transit industry.

APPENDIX: Use of Qualification Terminology in Regulatory and Industry Standards

Regulatory Standards

The term *qualified person* is used by both the Federal Rail Administration (FRA) and the Occupational Safety and Health Administration (OSHA) to indicate that someone has successfully completed training to be able to demonstrate knowledge, skills and ability for a given subject area:

49 CFR Part 217.4 Railroad Operating Rules:

A person that has successfully completed all instruction, training and examination programs required by the railroad and this part, and that the person, therefore, has actual knowledge or may reasonably be expected to have knowledge on the subject on which the person is expected to be competent.

29 CFR Part 1910 Subpart S - Electrical 1910.399:

One who has received training in and demonstrated skills and knowledge in the construction and operation of electric equipment and installations and the hazards involved.

Note 1: Whether an employee is considered to be a “qualified person” will depend on various circumstances in the workplace. For example, it is possible and in fact, likely for a person to be considered “qualified” with regard to certain equipment in the workplace, but “unqualified” as to other equipment.

Note 2: An employee who is undergoing on-the-job training and who, in course of such training, has demonstrated an ability to perform duties safely at his or her level of training and who is under the direct supervision of a qualified person is considered to be a qualified person for the performance of those duties.

Industry Standards

Industry standards use similar language requiring for individuals to have been trained and able to demonstrate their knowledge, skills and ability:

NFPA 70E® Electrical Safety in the Workplace

One who has skills and knowledge related to construction and operation of the electrical equipment and installations and who has received safety training to recognize and avoid the hazards involved (NFPA 2008).

In addition, NFPA 70E states that the training required for Electrical Safety Work Practices shall be classroom or on-the job type, or a combination of the two. The degree of training provided shall be determined by the risk to the employee.

In the human relations profession, qualification training programs are defined as using hands-on task performance instruction to qualify an incumbent in a specific duty position. Qualification training maybe combined with on-the-job training to provide the performance skills required to do the job. (Reynolds 1993).

References

29 CFR Part 1910 Subpart S - Electrical 1910.399

49 CFR Part 217.4 Railroad Operating Rules

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Appendix D: 200 Level Primers

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RAIL VEHICLE LEVEL 200
SUBJECT OVERVIEW

Module: 201 – Couplers

Note: All 200 level courses should be delivered only after completion of 100 level training

About the Author

Kerry Kopp is employed as the Light Rail Maintenance Trainer by the Sacramento Regional Transit District in Sacramento California. His career started in the United States Navy serving six years as an Electronic Technician troubleshooting and repairing satellite communication, HF, UHF communication systems and TACAN. He worked as a civilian technician for the Department of the ARMY repairing and overhauling Signal Intelligence systems and Artillery and Mortar Detecting RADAR systems. He worked for the Department of the Air Force as a civilian repairing and maintaining manufacturing plant equipment including machine tools, CNC controls, autoclave and industrial ovens and physical plant equipment. He is a graduate of the US Navy Service School Command where he studied electronics. He earned an Associate of Science Degree in Electronics from American River College in Sacramento California. He earned his B.S. Degree in Management from the University of Phoenix.

Overview/Purpose

This training document provides students with an overview of the devices used to mechanically and electrically connect rail vehicles. In order for two or more rail vehicles or cars to be connected together in a train couplers are provided to make the physical connection and provide electrical signal connection. Couplers allow for travel on vertical and horizontal curves and allow for rotational movements.

The automatic coupler enables automatic coupling of railway vehicles. Coupling of two units is achieved without manual assistance by driving one unit up to a second unit. Automatic coupling is even possible, if the two units horizontally and vertically are not in alignment. The coupler permits coupled trains to negotiate vertical and horizontal curves and allows rotational movements. The rubber cushion draw gear contains a combined draw and buff gear consisting of a rubber cushion draw gear and a buffer. Each coupler assembly is provided with electric heads to achieve electric coupling. Uncoupling is done automatically by remote control from the driver's cab or manually from trackside. After uncoupling and separation of the cars, the coupler is again ready to couple.

Coupler System Characteristics

American Society of Mechanical Engineers, Standards Committee on Rail Transit Vehicles RT-2 8/20/03

"The design of the coupler system, including drawbars, draft gear and attachments to the car body, shall respond to normal and overload conditions in a predictable manner. The coupler system shall be capable of absorbing the compression and tension forces encountered in normal vehicle operation in a train, including coupling and uncoupling, without damage."

"The coupler system shall also contain a shearback design consisting of an energy-absorbing release mechanism to respond to compressive overload conditions. In a collision, the draft gear elements shall first fully compress, followed by activation of the release mechanism which shall allow the coupler system to absorb additional energy and retract a sufficient distance to permit the car body anticlimbers to engage. If the collision forces are sufficiently high such that compression continues following the full retraction of the coupler system, the coupler system shall then be disconnected from the anchorage in a safe manner so as to not impede the CEM response of the car body overload conditions". (CEM Crash Energy Management)

Table of Contents

Suggested Tools/Training Aids:

- o Recommended Practice for Coupler System Periodic Inspection and Maintenance APTA RT-RP-VIM-006-02

Topics Covered:

Topics listed below are covered in this introduction of rail vehicle couplers. A full copy of the National Training Standards from which these topics were taken is attached.

1.0 Introduction to Couplers

2.0 Coupler – Mechanical:
A device, which as part of a coupler assembly makes the physical connection between rail transit vehicles. It consists of a face plate with alignment pins holes to mate to a like device on another transit vehicle. It is also referred to as the mechanical coupler head.

3.0 Coupler – Pneumatic:
A self-sealing valve assembly mounted to a coupler assembly that allows for air pressure equalization between coupled rail vehicles.

4.0 Coupler – Electrical:
An electrical device mounted to a mechanical coupler assembly that makes the electrical circuit connections between rail transit vehicles through a series of mating contacts.

Definitions, Abbreviations and Acronyms

For the purposes of this lesson, the following glossary of terms, definitions, acronyms, and abbreviations shall apply. They are not all inclusive, and the reader is encouraged to explore the text, footnotes and bibliography sources for further information.

Definitions

With a diversity of manufacturers and rail transit agencies, it is necessary to establish a common vocabulary to describe components that are identical or similar in nature and function. For the purposes of clarity the following terms and definitions will be used in this document: (APTA)

Anchorage- Bearing Shell- At the rear of the mechanical coupler the Anchorage is bolted to the vehicle undercar frame, the attachment device.

Buffer: A spring assembly, gas-hydraulic self re-setting energy absorption device, crushes cartridge assemblies, or series of elastomeric elements within some coupler assemblies, which can absorb a high impact coupling or severe buff loads.

Buff Force: Compressive coupler forces that occur during a slack bunched condition

Centering device: A device that prevents or limits a free or uncoupled coupler assembly from moving in its normal lateral range.

Coupler control box/panel: A device from which commands/signals are generated to initiate a coupling or uncoupling sequence of events and the isolation/connection of electric train line circuits.

Coupler – electrical: A mechanical device mounted to a mechanical coupler assembly that makes the electrical circuit connections between rail transit vehicles through a series of mating contacts.

Coupler – mechanical: A device, which as part of a coupler assembly makes the physical connection between rail transit vehicles. It consists of a face plate with alignment pins and matching holes to mate to a like device on another rail transit vehicle. It is also known as the mechanical coupler head. The mechanical coupler includes subassemblies, (1) an anchor casting through which the mechanical coupler is physically connected to the frame of the car, (2) a draft gear which serves to absorb energy of coupling and the slack action, (3) a mechanical support which is attached to the anchor pin and which the coupler can swing laterally and move vertically, (4) a coupler center detent to position the mechanical coupler at the car centerline.

Coupler – pneumatic: A self-sealing valve assembly mounted to a coupler assembly that allows for air pressure equalization between coupled rail vehicles**.**

Coupler switch box: A termination point for electrical circuits to the electric coupler heads. Also known as a Jumper/Drum Switch.

Coupler system/assembly: A mechanical device optionally consisting of a mechanical coupler, electrical coupler, pneumatic coupler, drafts gear, yoke, and energy absorber.

Deformation tube: A two-section tube as part of a coupler assembly, which upon unusual severe impact collapses one into the other for dissipation of energy and momentum. It acts as an energy absorption device. It is not repairable and must be replaced when activated.

Definitions (continued)

Draft Force: Pulling force (tension) on couplers and draft gear during a stretched condition

Draft gear: A device enclosed within a coupler assembly that transmits draft and buff loads to the car body. The draft gear serves to bear the load of railcars being pulled or pushed, absorb minor impacts, and restrict the amount of slack between cars.

Drawbar: A metal bar/tube connected directly to the anchorage castings used to connect rail transit vehicles together without the option of an uncoupling device. This device normally has a draft gear.

Earthing- The grounding bonds from the coupler to the train car body.

Emergency release ring/plate: A metal section encased within the coupler assembly into which shear/tension bolts are threaded.

Emergency release/tension bolts: Threaded devices, which are designed to break under a specified load, when subjected to severe buff loads as a result of a collision or other causes. Also known as shear pin/bolts.

Energy absorption cylinder: A device used within a coupler assembly to absorb a high impact coupling or severe buff loads. It is not self re-setting.

Guiding Horn- A guiding horn is arranged on the face of the coupler head and serves to increase the gathering range in case of vertical and horizontal mismatch of the couplers.

Hydraulic- Operated by the pressure of water or other liquids (oil). Hydraulic systems, such as hydraulic brakes, allow mechanical force to be transferred along curved paths (through pipes or tubes) that would be difficult for solid mechanisms, such as levers or cables, to negotiate efficiently.

Link bar: A metal bar/tube used to connect rail transit vehicles together. It generally connects to the coupler yokes of the cars it is connecting, replacing the respective mechanical couplers. It is not equipped with a quick release device for uncoupling.

Pedestrian Barrier- The pedestrian barrier protects the operating gear against atmosphere and pollution. The pedestrian barrier cap is fixed to the upper side of the mechanical head.

Pneumatic- Run by or using compressed air: a pneumatic tool
Filled with air, especially compressed air: a pneumatic cylinder

Radius/radial carrier bar: A flat steel bar mounted to the underside of a vehicle used to support the coupler assembly at the end opposite of the anchorage connection. It allows for full lateral movement within the couplers normal range.

Definitions (continued)

Vertical / Coupler support: Provides for vertical centering of the coupler head. The coupler is maintained in the horizontal position by the centering device.

Yoke: A mechanical articulation connection as part of a coupler assembly that allows for normal limited movement in the vertical plane, horizontal plane, and rotation about the longitudinal axis to compensate for the natural varied orientation of coupled rail transit vehicles in motion.

Abbreviations and Acronyms

AAR: Association of American Railroads

ANSI: American National Standards Institute

CFR: Code of Federal Regulations

MSDS: Material Safety Data Sheet

OEM: Original Equipment Manufacturer

OSHA: Occupational Safety and Health Administration

Introductory Text by Topic Area

1.0 Coupler Overview

The automatic coupler enables automatic coupling of railway vehicles. Coupling of two units is achieved without manual assistance by driving one unit up to a second unit. Automatic coupling is even possible, if the two units horizontally and vertically are not in alignment. The coupler permits coupled trains to negotiate vertical and horizontal curves and allows rotational movements. The rubber cushion draw gear contains a combined draw and buff gear consisting of a rubber cushion draw gear and a buffer. Each coupler assembly is provided with electric heads to achieve electric coupling. Uncoupling is done automatically by remote control from the driver's cab or manually from trackside. After uncoupling and separation of the cars, the coupler is again ready to couple.

Coupler Function
Provides a mechanical connection between two rail cars
Provides electrical connection between two rail cars
Allows for travel on vertical and horizontal curves
Allows rotational movement

Electrical Coupler Heads: An electrical device mounted to a mechanical coupler assembly that makes the electrical circuit connections between rail transit vehicles through a series of mating contacts.
Electrical head covers protect the electrical heads when not connected to another rail vehicle. Leading cab ends and trailing cab ends not coupled will have covers protecting the electrical heads. Electrical head covers swing open to expose the electric contacts as two LRV couplers.

Pneumatic Coupler: A self-sealing valve assembly mounted to a coupler assembly that allows for air pressure equalization between coupled rail vehicles.

Mechanical Coupler: A device, which as part of a coupler assembly makes the physical connection between rail transit vehicles. It consists of a face plate with alignment pins holes to mate to a like device on another transit vehicle. It is also known as the mechanical coupler head.

2.0 Electric Coupler Heads

Actuators/Motor

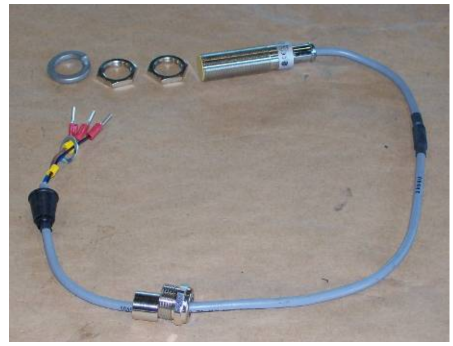
Actuator: Electrical, hydraulic, or pneumatic device (such as a relay) that controls the flow of power or current.

Motor: A device that converts electrical or another form of energy into mechanical energy

Suspension and Linkage

Vertical / Coupler support: Provides for vertical centering of the coupler head. The coupler is maintained in the horizontal position by the centering device.

Bearing Shell - Anchorage: At the rear of the mechanical coupler the Anchorage is bolted to the vehicle under-car frame, attachment device.



Limit/Proximity Switches

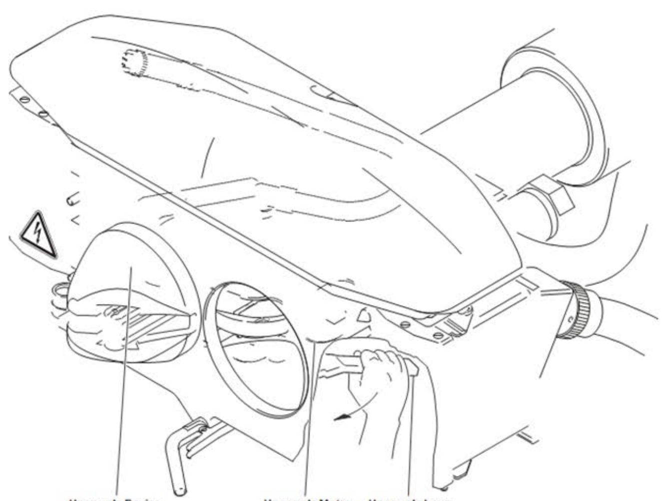
A switch designed to cut off power automatically at or near the limit of travel of a moving object controlled by electrical means. The switch pictured is a magnetically operated proximity switch (pictured to the right).

Proximity switches open or close an electrical circuit when they make contact with or come within a certain distance of an object. Proximity switches are most commonly used in manufacturing equipment robotics, and security systems. There are four basic types of proximity switches: infrared, acoustic, capacitive, and inductive.

Reed Switch-The reed switch is enclosed in a small tube, which is controlled by a magnet or magnetic field. It works with the help of an additional magnet, which is placed within close range of the switch. When the magnets make contact, they pull together and complete an electrical circuit. This results in a change in the contacts to an opposite state.

Release Mechanism

The release mechanism or the uncouple device enables release of the coupler locks. Coupler release is usually initiated by remote control from the operators cab (pressing the uncouple switch) to power the uncouple circuit. The uncouple motor is powered on by pressing the uncouple switch, the motor turns the hooked plate so that the coupling links are released. Manual release can be activated trackside in an emergency or in case or failure of the remote control. An uncouple lever or cable manually moves the hooked plate causing it to release the coupling links.



Train Line Cables
The electrical head serves to connect the train lines by means of different types of contacts. The train line cables attach to the electrical heads using different types of contacts. The train line cables are attached to the electrical heads through water tight connections. The train line cables are strain relieved. The train line cables through the electrical heads provide connectivity of the electrical signals used to control and operate the train.

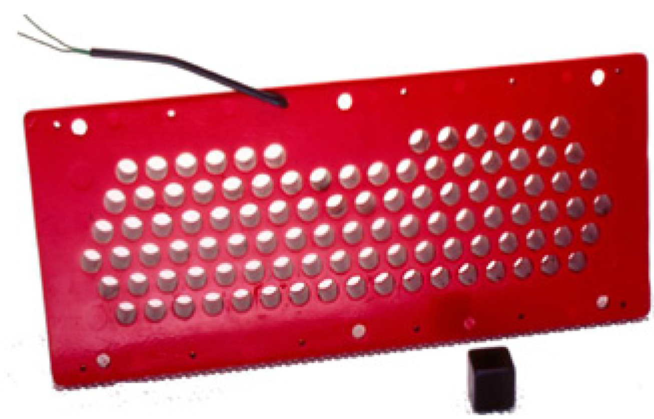
Drum/Uncoupling Switch
A switch used to manually reverse a motor circuit. A drum switch mounts moving contacts on a rotating shaft.

Heaters and Temperature Sensors

Temperature
Temperature, when measured in Kelvin degrees, is a number that is directly proportional to the average kinetic energy of the molecules in a substance. So, when the molecules of a substance have a small average kinetic energy, then the temperature of the substance is low.

Heaters
Snow and ice build-up on couplers can cause malfunction of the coupled rail vehicles and increase the risk of damage to coupler components. Coupler heater systems help to eliminate service interruptions and equipment failure caused by compaction and compression of ice and snow on couplers and the electrical heads.

Contact Pin/Tip Assembly (insulated block)
"Coupler Heater Pin Blocks" patented by Cox, provide heat directly to the coupler pins by means of an integral heater (thermostatically controlled if needed) in the coupler pin block. These heaters keep the pin block and the pins free from ice and moisture under all operating temperatures and environmental conditions."



Coupling Sensor

Typically mounted on the coupler head the coupler sensor is usually a proximity switch that detects the presence of another coupler. The coupling sensor enables an internal switch allowing electrical continuity to power the electrical coupler heads.

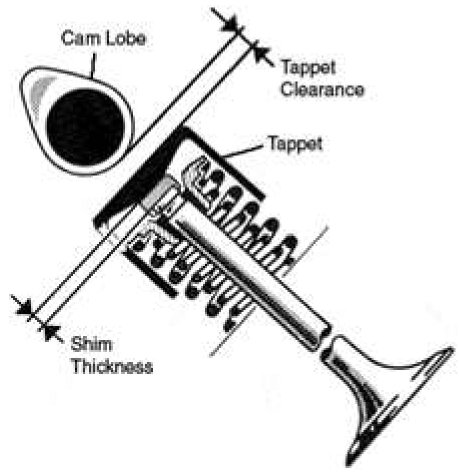
3.0 Pneumatic Coupler

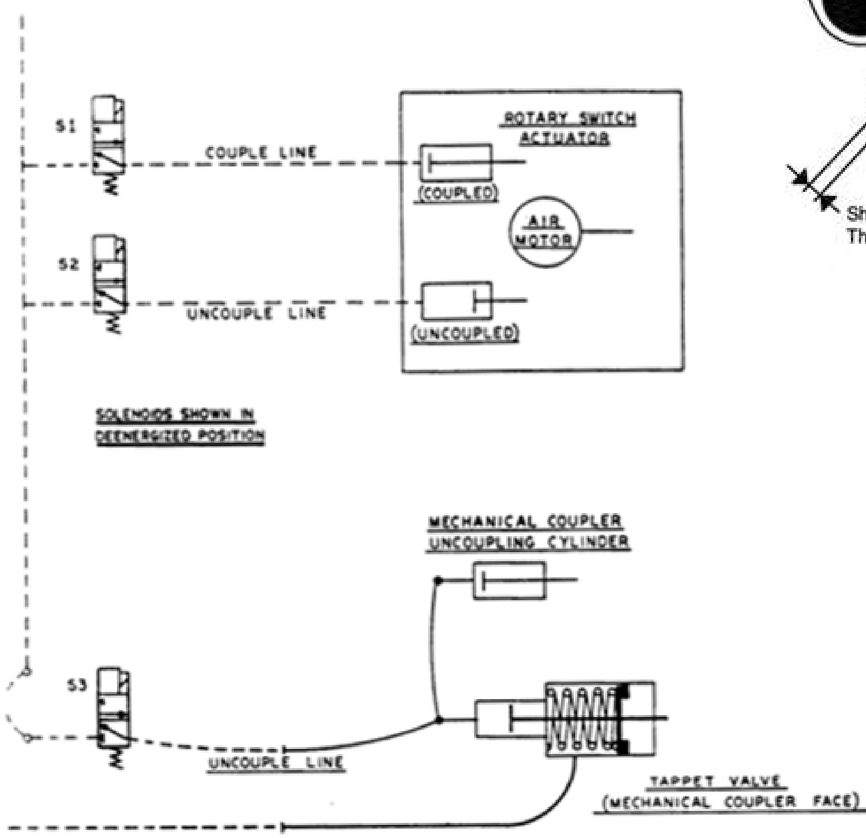
Pneumatic Brake Line (Coupling / Uncoupling)

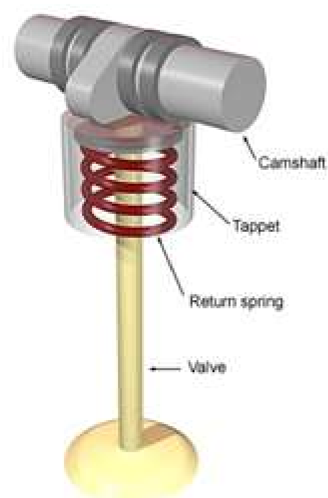
Automatic air line couplers are provided for train line of the brake pipe. At the point of mechanical coupling, the air line couplers automatically train line the brake pipe. At the point of uncoupling, the couplers close-off the brake pipes to prevent excessive loss of air.

Tappet valves

A lever or projecting arm that moves or is moved by contact with another part, usually to transmit motion, as between a driving mechanism and a valve.





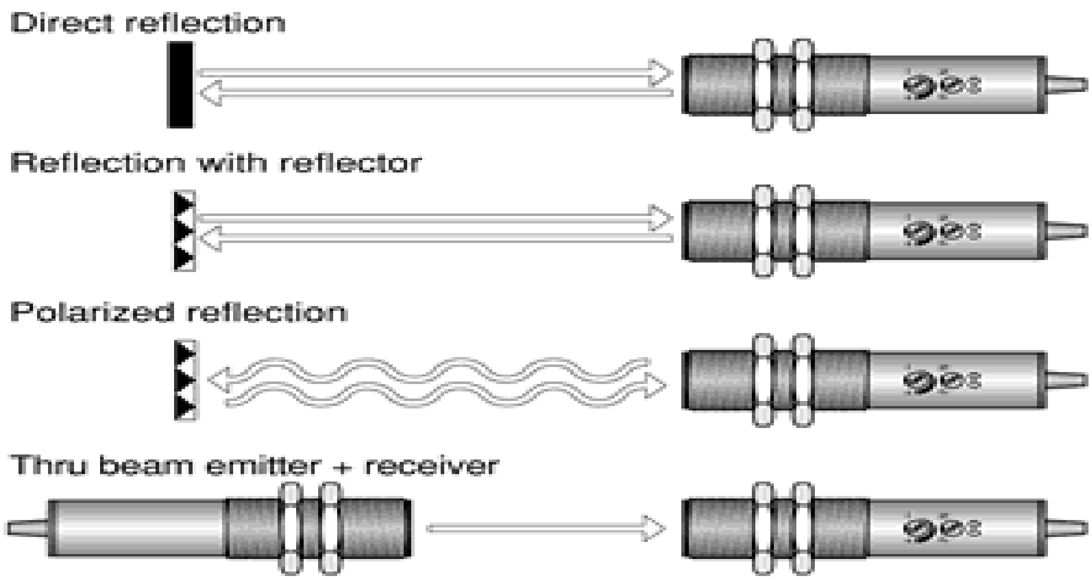


Acoustic proximity sensors

One often used method of avoiding hazards is via sonar ranging. In this method, acoustic signals ("pings) are sent out, with the time of echo return being a measure of distance to an obstacle. This does, unfortunately, require fairly accurate timing circuitry -- so acoustic sensors really require a processor of some sort to drive them. Also note that acoustic sensing essentially requires the use of commercial sensors,

Infrared proximity sensors

Infrared proximity sensors work by sending out a beam of IR light, and then computing the distance to any nearby objects from characteristics of the returned (reflected) signal. There are a number of ways to do this, each with its own advantages and disadvantages:



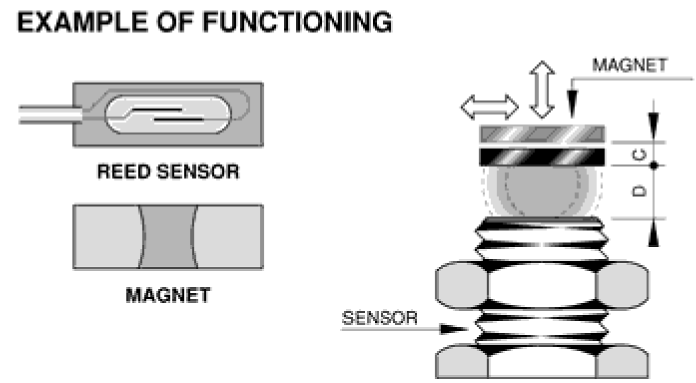
Direct Reflection (Diffused) - emitter and receiver are housed together and use the light reflected directly off the object for detection. In the use of these photocells, it is important to bear in mind the color and the type of surface of the object. With opaque surfaces, the sensing distance is affected by the color of the object. Light colors correspond to the maximum distances and vice versa. In the case of shiny objects, the effect of the surface is more important than the color. The sensing distance in the technical data is related to matte white paper.

Reflection with Reflector (Retroreflective) - emitter and receiver are housed together and requires a reflector. An object is detected when it interrupts the light beam between the sensor and reflector. These photocells allow longer sensing distances, as the rays emitted are almost totally reflected towards the receiver.

Polarized Reflection with Reflector - similar to Reflection with Reflector, these photocells use an anti-reflex device. The use of such a device, which bases it’s functioning on a polarized band of light, offers considerable advantages and secure readings even when the object to be sensed has a very shiny surface. They are not in the technical data affected by random reflections.

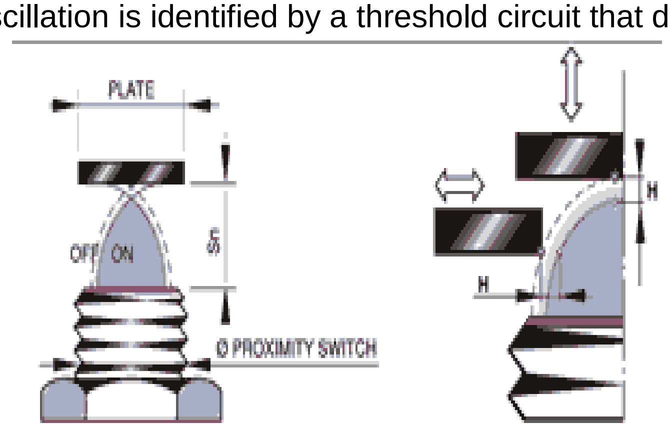
Thru Beam - emitter and receiver are housed separately and detect an object when it interrupts the light beam between the emitter and receiver. These photocells allow for the longest distances. (Fargo Controls)

Inductive proximity sensors (Magnetic)
Inductive proximity sensors gauge distance to objects through the use of induced magnetic fields. The primary problem with this method is that it is largely confined to sensing metallic objects. Magnetic sensors are actuated by the presence of a permanent magnet. Their operating principle is based on the use of reed contacts, which consist of two low reluctance ferro-magnetic reeds enclosed in glass bulbs containing inert gas. The reciprocal attraction of both reeds in the presence of a magnetic field, due to magnetic induction, establishes an electrical contact. Magnetic sensors compared to traditional mechanical switches have the following advantage: Contacts are well protected against dust, oxidization and corrosion due to the hermetic glass bulb and inert gas; contacts are activated by means of a magnetic field rather than mechanical parts. (Fargo Controls)



D: Max switching distance in relation to the magnet used.
C: Differential stroke.
D + C: Distance of contact re-opening during the removal magnet.

Capacitive proximity sensors
Capacitive proximity sensors are used for non-contact detection of metallic objects & nonmetallic objects (liquid, plastic, wooden materials and so on). Capacitive proximity sensors use the variation of capacitance between the sensor and the object being detected. When the object is at a preset distance from the sensitive side of the sensor, an electronic circuit inside the sensor begins to oscillate. The rise or the fall of such oscillation is identified by a threshold circuit that drives an amplifier for the operation of an external load. A screw placed on the backside of the sensor allows regulation of the operating distance. This sensitivity regulation is useful in applications, such as detection of full containers and non-detection of empty containers. The operating distance of the sensor depends on the actuator shape and size and is strictly linked to the nature of the material. (Fargo Controls)



Solenoid Valve
A solenoid is an electromechanical device which allows for an electrical device to control the flow of a gas or liquid. The electrical device causes a current to flow through a coil located on the solenoid valve This current flow in turn results in a magnetic field which causes the displacement of a metal actuator. The actuator is mechanically linked to a mechanical valve inside the solenoid valve. The valve then changes state, either opening or closing to allow a liquid or gas to either flow through or be blocked by the solenoid valve. A spring is used to return the actuator and valve back to their resting state when the current flow is removed.

Pneumatic Filters

“A pneumatic filter is a device which removes contaminants from the compressed air stream. Typical commercial pneumatic filters will remove particles as small as 5 micrometers from the air. The filters protect pneumatic devices from damage that would be caused by these contaminants. These contaminants include lubricant particles ejected by the compressor, dirt particles and small water droplets. Secondary filters are used for a variety of applications and can remove particles as small as 50 nanometers in size. In addition special air dryer devices are used to condense moisture from humid air and deliver a clean, dry supply of air “(WordIQ)

Train line (brake pipe)
The pipe used to control train brakes on vehicles fitted with automatic air or vacuum brake systems. In the US, often referred to as the 'train line'. On air braked trains, when charged, the brake pipe causes the train brakes to be released and the reservoirs (called auxiliary reservoirs) used to apply brakes to be automatically replenished. When pressure in the brake pipe is reduced, train brakes are applied. (Railway)

Drum switch/Air actuator (Pneumatic actuator)
A drum switch is a type of switch in which the electrical contacts are made on pins, segments, or surfaces on the periphery of a rotating cylinder or sector, or by the operation of a rotating cam.
An air actuator or **pneumatic actuator** converts energy (in the form of compressed air) into motion. The motion can be rotary or linear, depending on the type of actuator.

Uncoupling air system
A compressor has a motor driven pump mounted on a locomotive or train to supply compressed air for the operation of brakes, uncouple feature of pneumatically operated coupler, and other pneumatic systems on the train. The air pressure is normally supplied in a range of between 90-110 and 130-140 psi. or roughly 7 - 10 bar (metric). The operation of the compressor is usually automatic, being controlled by a pressure switch or "compressor governor". The pressure switch switches on the compressor when air pressure falls to its lowest permitted level, say 90 psi and switches it off when it has reached its highest permitted level, say 110 psi. At least one reservoir, called the Main Reservoir, is provided on the vehicle to store the compressed air.

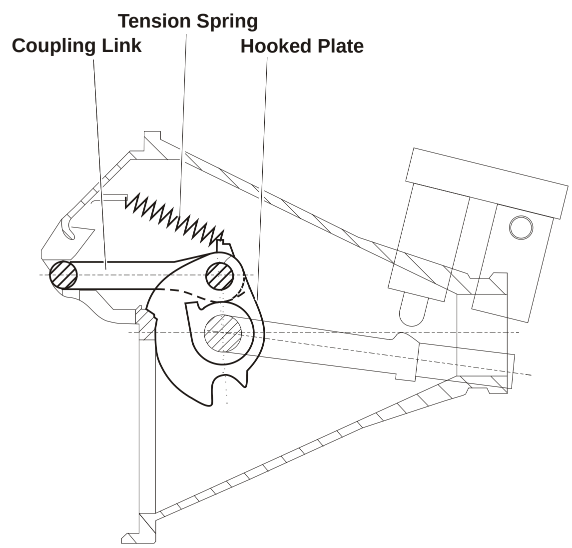
4.0 Mechanic Coupler

The draft gear connects the coupler to the car under frame and cushions the shock caused when cars are coupled or train speed is suddenly changed. A certain amount of slack is purposely left in the couplers of standing train so that it can be started one car at a time. Cars are usually coupled at a speed of about 5 miles per hour. You can imagine what would happen if a heavily loaded freight car, standing on a siding, was struck in the coupling by a group of cars moving at 5 miles per hour with a solid connection between the coupler and the under frame. Something would have to give! It is at the end of this run-in and run-out of slack that the shock occurs; the draft gear, placed between the coupler and the under frame, is designed to cushion such shocks. The two basic types of draft gear used in the United States are the friction and rubber.

Suspension and linkage components

Linear actuators: A device that converts some kind of power, such as hydraulic or electric power, into linear motion.

Knuckle and slide lock
Hook and Plate
The hook or coupling link locks in to the hooked plate on the coupler on the opposing rail vehicle, forming the mechanical connection between 2 rail vehicles.

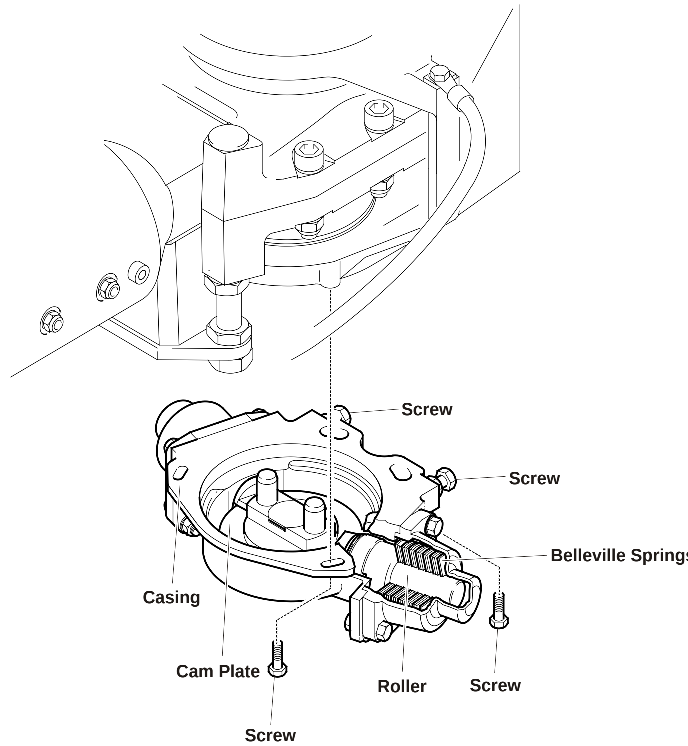


Limit Switches
A switch designed to cut off power automatically at or near the limit of travel of a moving object controlled by electrical means.

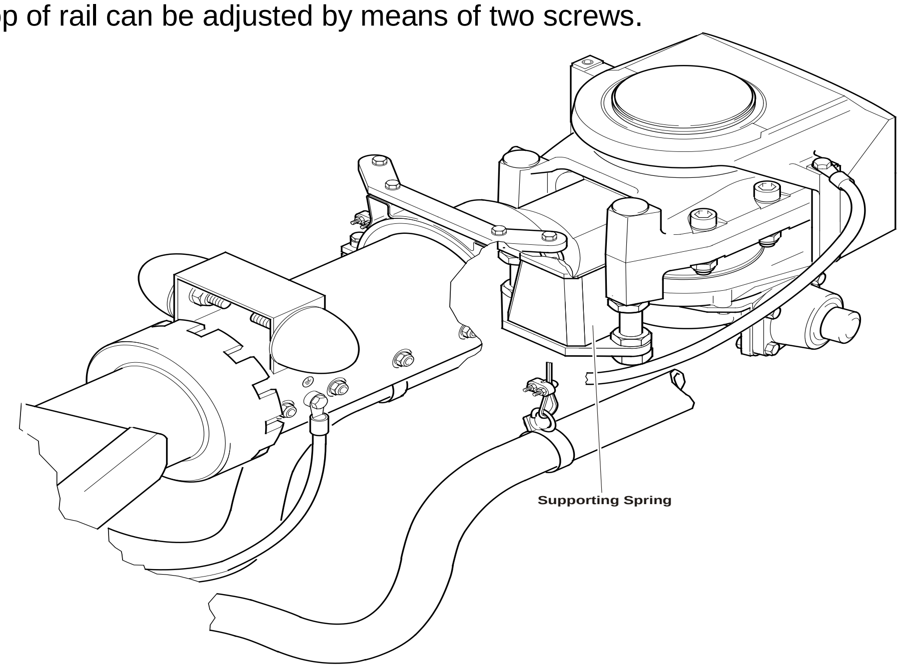
Centering Device
The centering device holds the uncoupled coupler in the longitudinal car axis and prevents it from swinging transversally. Shown below is the centering device of a Scharfenberg Coupler. The centering device is fastened under the bearing bracket of the draw gear. A rotating cam plate is installed inside the casing which is rigidly connected to the draw gear pivot that rotates when the coupler swings horizontally. The cam plate is provided with two peripheral recesses into which two stems with roller are pressed by means of Belleville springs that keep the coupler in the longitudinal car axis. After uncoupling and driving cars apart the coupler is automatically centered within the centering angle of ± 15°. Beyond this angle, the coupler remains swung out In order to allow coupling on very tight curves, where the gathering range of the automatic coupler is exceeded (e.g. in the workshop), the coupler can be swung out manually.

Anchor, Alignment, and Suspension

Anchor: At the rear the mechanical coupler the unit is supported and attached to the vehicle by and anchorage. The coupler anchorage is bolted to the undercar frame by the car builder.



Suspension/ Coupler Support: The coupler support provides for vertical centering of the coupler head. The coupler suspension holds the weight of the coupler keeping it suspended in the vertical plane (Pictured below: Vertical Support on Scharfenberg Coupler) The mass of the coupler and the vertical load acting upon it are cushioned by the rubbers and by an additional supporting spring which is fixed under the draw gear by means of two hexagon screws. The supporting spring prevents the coupler, when uncoupled, from bouncing during operation of the trains. The height of the coupler above top of rail can be adjusted by means of two screws.



Heaters and temperature sensors

The heating element is used to keep the face surface and coupling mechanism free of ice and snow in the winter and ensure the coupling function. Heaters are installed into central buffer couplings in order to ensure trouble-free operation during the winter. In particular, integrated heaters are to ensure that the frontal face plate remains free of snow and ice so as to secure reliable function of the coupling.

Temperature sensors: A device designed to respond to temperature stimulation.

Resistance Temperature Detector (RTD): a device with a significant temperature coefficient (that is, its resistance varies with temperature). Temperature sensors that contain a resistor that changes resistance value as its temperature coefficient define the resistance vs. temperature characteristics for the RTD sensor.

Release mechanism: Refer to section 2.4

Electrical pin door/shutter/gasket: The electrical pin door/shutter protects the electrical coupler head when the coupler is not engaged. The door covers the electrical head and the gasket forms an air and water tight seal around the electrical head sealing it from the outside elements.

Draw bar/Link bar (married pairs): A linkbar is a permanent drawbar used to connect two or more cars in a pair or set. A married pair is a set of two railroad cars which are permanently coupled and treated as if they were a single unit.

5.0 Tools

Wear gauges (go/no-go gauge) Attribute Gauges: Attribute gauges (go/no-go gauge) is used often during manufacturing. The attribute gauge is a trusted method to measure a product's conformance to a tolerance and in many cases is the best and fastest method to confirm functional fit. Most often these gauges come in pairs (or should) with one called the Go and another called the Not Go or No-Go member. As their names clearly define a part in tolerance should fit the Go gauge while not fitting the NoGo gauge.

Head alignment tools: Special tools used for coupler head alignment and leveling. Refer to coupler manufactures requirements for specialty tools.

Contact/pin replacement tools: Special tools used to remove and install pin contacts on the electrical heads of couplers.

Vertical press: A machine in which a large force is exerted on the larger of two pistons in a pair of hydraulically coupled cylinders by means of a relatively small force applied to the smaller piston.

Bushing: A fixed or removable cylindrical metal lining used to constrain, guide, or reduce friction.

Bushing Driver: This tool is used to remove and install bushings. The driver fits the bushing and will allow force to be applied to the bushing for the purpose of seating the bushing. (Pictured to the left is the bushing driver used for a DELNER bearing shell/ anchorage)
Reamer: A reamer is a tool for enlarging holes and is used in metalworking. It may be used as a hand tool or may have a specialized drive end. For production machine tools the drive will usually be a standard taper. For hand tools the drive will usually be a square drive, intended for use with the same type of wrench used to turn a tap for the cutting of threads.

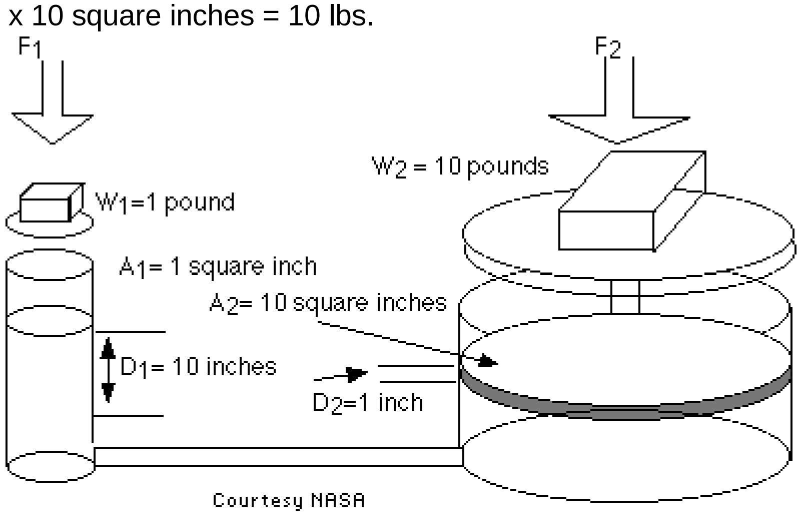
A reamer consists of a set of parallel cutting edges along the length of a cylindrical body. Each cutting edge is ground at a slight angle and with a slight undercut below the cutting edge. Reamers must combine both hardness in the cutting edges, for long life, and toughness, so that tool does not fail under the normal forces of use. (WordIQ)

Coupler Repair Stand: Coupler repair stand is a specialized fixture designed to support the weight of the coupler. The coupler repair stand allows for repair and overhaul of the coupler off the train on a stable platform.

Hydraulic Jack: A jack used for lifting, pulling, or forcing, consisting of a compact portable hydrostatic press, with its pump and a reservoir containing a supply of liquid, as oil.

An enclosed fluid under pressure exerts that pressure throughout its volume and against any surface containing it. That's called 'Pascal's Principle', and allows a hydraulic lift to generate large amounts of FORCE from the application of a small FORCE.

Assume a small piston (one square inch area) applies a weight of 1 lbs. to a confined hydraulic fluid. That provides a pressure of 1 lbs. per square inch throughout the fluid. If another larger piston with an area of 10 square inches is in contact with the fluid, that piston will feel a force of 1 lbs/square inch x 10 square inches = 10 lbs.



So we can apply 1 lbs. to the small piston and get 10 lbs. of force to lift a heavy object with the large piston. Is this 'getting something for nothing'? Unfortunately, no. Just as a lever provides more force near the fulcrum in exchange for more distance further away, the hydraulic lift merely converts work (force x distance) at the smaller piston for the SAME work at the larger one. In the example, when the smaller piston moves a distance of 10 inches it displaces 10 cubic inch of fluid. That 10 cubic inch displaced at the 10 square inch piston moves it only 1 inch, so a small force and larger distance has been exchanged for a large force through a smaller distance (Paul Walorski, BA Part-time Physics Instructor, Physicslink.com).

Overhead Cranes: A lifting device used for the lifting and lowering and horizontal movement of a load with a hoisting mechanism. Cranes can be fixed or mobile and can be driven manually or powered.

Lift tables: A lift table is a work platform that can raise and lower people and materials. They are commonly used when work must be done at a height without conventional access. Several types of lift tables operate with different mechanisms:

- **Scissor lifts** - raised on linked, folding supports that draw together to lift.
- **Screw lifts** - uses screw like threads. Rack and pinion lifts utilize a pinion that drives a straight-toothed rack.

Spirit Level: a device for setting horizontal surfaces, consisting of an accurate block of material in which a sealed slightly curved tube partially filled with liquid is set so that the air bubble rests between two marks on the tube when the block is horizontal

Telescoping lifts: have multiple overlapping sections that move into and out of one another.

Articulated lifts: use multiple jointed sections that unfold to lift a platform or bucket. Cherry pickers typically employ this form. (WordIQ)

Forklift and coupler adapter: Forklift is a small vehicle used in manufacturing that contains a platform for lifting and transporting heavy loads. Forklift coupler adapter is a special device that mounts to a forklift's forks and will allow a coupler to be connected; the adapter is used for removal and installation of a coupler.

Continuity tester: A continuity tester is a device that tells whether a circuit is capable of carrying electricity. A continuity tester is an electrical test instrument used to determine if an electrical path can be established between two or more points. The circuit under test is de-energized prior to connecting the tester between 2 points. The tester consists of an indicator in series with a source of electrical power - normally a battery, terminating in two test leads. If complete circuit is established between the test-leads, the indicator is activated. The indicator is often an electric light; a testing device might also be fitted with a buzzer or a beeper. The digital voltmeter can be used as a continuity checker and the use of the built in beeper functions provides audible indication for circuit continuity.

Breakout box: A device inserted into a multiple-line cable for testing purposes that provides an external connecting point for each wire. A small LED may be attached to each line, which glows when a signal is present. A small device that can be connected into a multicore cable for testing the signals in a transmission. Small LEDs in the breakout box indicate when a signal is transmitted over one of the lines. Switches or short jumper cables can be used to reroute these signals to other pins as required for troubleshooting.

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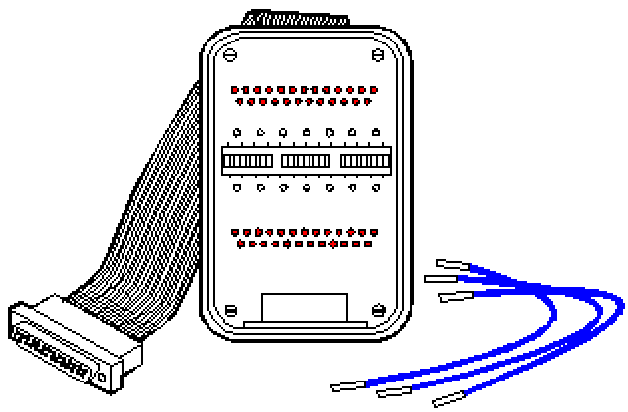


Auxiliary power supply: An alternative source of energy used to power electrical devices often used for testing purposes. A battery charger is a common auxiliary power supply used to supply low voltage Direct Current. A system that converts AC current from the wall outlet into the DC currents required by electronic circuits

Connector tester: A connector/cable tester is used to verify that all of the intended connections have proper continuity and that there are no unintended connections in the cable being tested. When an intended connection is missing it is said to be "open" (an open in the circuit) When an unintended connection exists it is said to be a "short" (a short circuit). If a connection "goes to the wrong place" it is said to be "miswired" (the connection has two faults: it is open to the correct contact and shorted to an incorrect contact).
Generally, the testing is done in two phases. The first phase, called the opens test makes sure each of the intended connections is good. The second phase, called the shorts test makes sure there are no unintended connections.
There are two common ways to test a connection:

1. A continuity test current is passed down the connection. If there is current the connection is assumed to be good. This type of test can be done with a series combination of a battery (to provide the current) and a light bulb/buzzer (that lights or sounds when there is a current).
2. A resistance. A known current is passed down the connection and the voltage that develops is measured. From the voltage and current the resistance of the connection can be calculated and compared to the expected value

Digital multi-meter: “An instrument designed to measure electrical quantities. A typical multimeter can measure alternating- and direct-current potential differences (voltages), current, and resistance, with several full-scale ranges provided for each quantity. Sometimes referred to as a volt-ohm meter (VOM), it is a logical development of the electrical meter, providing a general-purpose instrument. Many kinds of special-purpose multimeters are manufactured to meet the needs of specialists.” (Answers.com)

Torque wrench: A torque wrench provides a mechanic exact tightness capability when using the tool as a socket wrench. This feature is particularly important when working on assemblies that must have factory-setting tightness on various nuts and bolts holding parts together. Too much and the threads in could strip, too little and the parts can come loose or cause leaks, deteriorating performance. Using a torque wrench ensures the assembly work is done right the first time. However, torque wrenches come in different types, some being better than others when it comes to exact measurements (EHOW).

Beam Type-Torque Wrench: Beam-type torque wrenches represent the bargain-bin version of the tool. Their cost is relatively low but the exact measurements are usually off or hard to keep correct. The beam wrench uses a long lever that bends as the wrench is tightened. This bending triggers a mechanism in the tool that compares to another lever that stays the same regardless of the tool being used. As the first beam moves away from the second, the user can, in theory, measure the torque being applied (EHOW).

The Dial Version-Torque Wrench: The dial version uses a mechanism similar to that in a beam wrench. However, with the dial version the pressure exerted is translated to a dial at the top of the wrench near the handle which displays the pressure relative to a dial chart. The tighter the wrench is pulled, the more the dial moves to reflect the torque measurement. This version also relies on a human eye to determine when to stop (EHOW).

Electronic Dial-Torque Wrench: Electronic dial wrenches use the same approach but display the torque setting digitally. At least in these versions the human eye is taken out of the equation. The simple computer in the wrench displays the torque readings produced when using the wrench (EHOW).

The Clicker Type-Torque Wrench: Long reputed as the correct torque wrench to use for engine applications, the click-type wrench has a mechanism that actually pops in the wrench when the correct tightness is applied. This click signals to the user to stop tightening. Preset measurements are cast on the side of the handle to adjust the wrench for a desired tightness. Then the wrench is applied and the mechanism clicks when the preset torque is reached. These tools are typically cast in all metal, similar to a normal socket wrench, and come in protective cases to avoid impact or banging which can disrupt the tool's accuracy settings (EHOW).

Dial indicator: The term "dial indicator" refers to a type of measuring device whose components incorporate a spindle, gears, and a dial with pointer on the dial. The gears drive the pointer to allow the individual using the dial indicator to take readings of measurements marked on the dial face (EHOW).

6.0 Coupler Variations

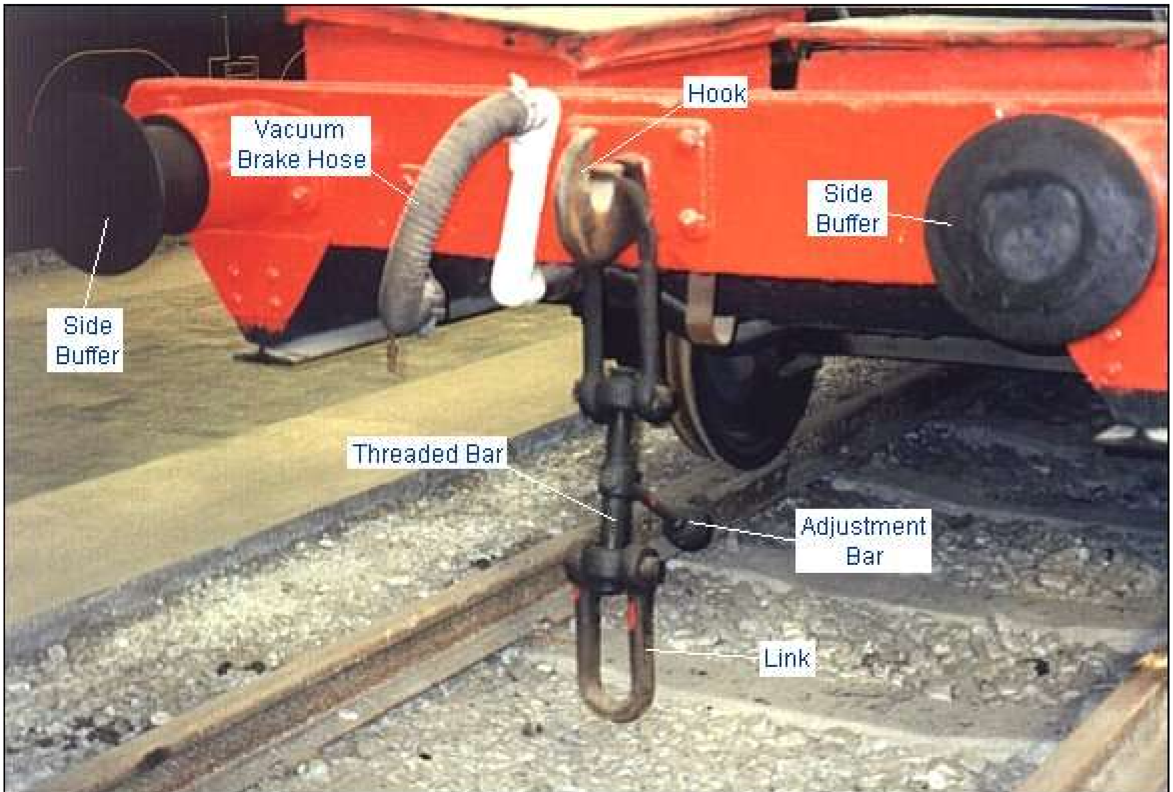
Many types of couplers are used for both freight trains and passenger trains. This section looks at several types of couplers and the evolution of the coupling process for trains. While the coupler used for freight cars (the Janney coupler) and its many variations is widely used, there are numerous other kinds. Most common for passenger vehicles are various “tight coupling” mechanisms, also known as “multi-function couplers” because the combine physical connections between cars with automatic connection of brake, power, and control lines as well such as the Scharfenberg coupler.

Link and pin

The 'link and pin' coupling was the original style of coupling used on American railways, surviving after conversion to Janney couplings on forestry railways. While simple in principle, the link and pin coupling suffered from a lack of standardization regarding size and height of the links.

The link and pin coupler consisted of a tube like body that received an oblong link. During coupling, a rail worker had to stand between the cars as they came together and guide the link into the coupler pocket. Once the cars were joined, the employee inserted a pin into a hole a few inches from the end of the tube to hold the link in place. This procedure was exceptionally dangerous and many brakemen lost fingers or entire hands when they did not get their hands out of the way of the coupler pockets; many more were killed as a result of being crushed between cars or dragged under cars that were coupled too quickly.

Brakemen were issued with heavy clubs that could be used to hold the link in position, but many brakemen would forgo the club's use and risk injury. The link and pin coupler ultimately proved unsatisfactory because: It made a loose connection between the cars, with too much slack action. There was no standard design, and train crews often spent hours trying to match pins and links. While coupling an employee inserted a pin into a hole a few inches from the end of the tube to hold the link in place. The link and pin coupler, though widely used, ultimately proved unsatisfactory...



A screw coupling showing the principal parts. To secure the coupling to the next vehicle, the link is placed over the hook of the next vehicle and the threaded bar is turned by turning the adjustment bar. This has the effect of tightening the coupling between the vehicles.

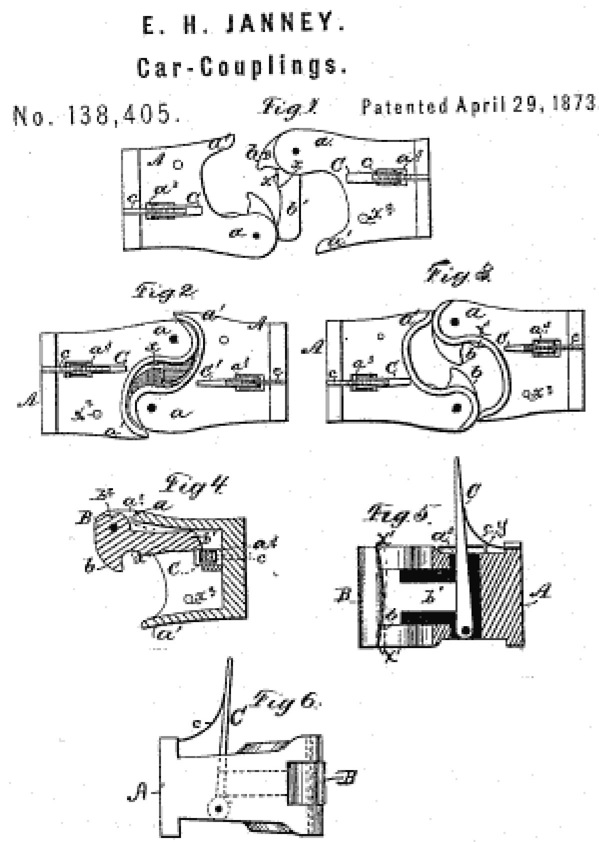
Source: **ALLABOUT.com (http://inventors.about.com/library/inventors/bljannycoupler.htm)**

Railroad cars in a train are connected by couplers located at both ends of each car. A coupler consists of a knuckle joined to the end of a drawbar, which itself is fastened to a housing mechanism on the car. A knuckle is a clamp that interlocks with its mate, just as two cupped hands--placed palms together with the fingertips pointing in opposite directions--interlock when the fingers are curled. When cars come together, the open knuckle on one car engages a closed knuckle on the other car, automatically coupling the cars. The drawbar extends the knuckle out from the end of the car and is designed to pivot in its housing, allowing the knuckled end some lateral play to prevent moving cars from derailing on a curved track.

For most of the nineteenth century, the link and pin coupler was the standard coupler used to hook together freight cars. It consisted of a tube like body that received an oblong link. During coupling, a rail worker had to stand between the cars as they came together and guide the link into the coupler pocket.

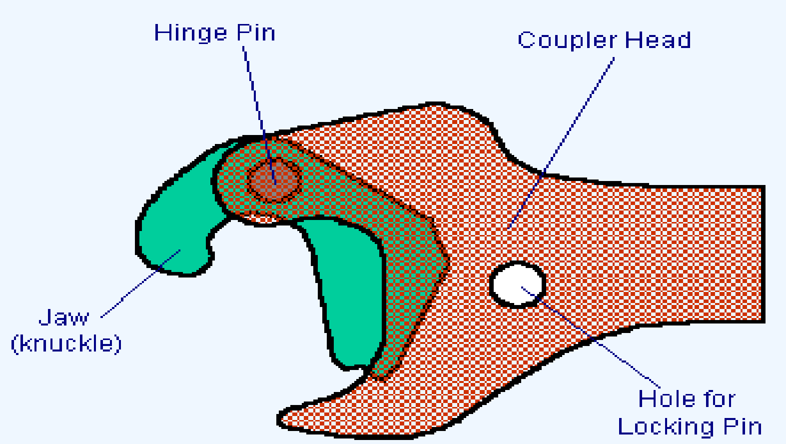
Janney Coupler (Buckeye Coupler)

In 1873, Eli H. Janney patented a knuckle style coupler that was to become the standard for the freight car couplers used even today. The coupler had a bifurcated draw head and a revolving hook, which, when brought in contact with another coupler, would automatically interlock with its mate.



The Janney coupler had several advantages over link and pin couplers. Not only did it alleviate the problem of loose parts that plagued the link and pin coupler, it also allowed rail workers to couple and uncouple cars without having to go between the cars to guide the link and set the pin. One commentator described the automatic coupling operation as follows:

While the cars were apart, the brakeman had to make sure the knuckle of the coupler on the waiting car stood in an open position and that the pin had been lifted into its set position. When the opposite coupler was closed and locked in position, the brakeman was able to stand safely out of the way and signal the engineer to move the cars together. When the knuckle of the coupler of the moving car hit the lever arm of the revolving knuckle on the open coupler, it revolved around the locked one, while concurrently the locking pin dropped automatically from its set position into the coupler, locking the knuckle in place. Although the brakeman had to set up the entire situation by hand, the actual locking operation was automatic and did not require the brakeman to stand between the cars."



Plan view of standard Buckeye or Knuckle coupler. The coupler is made of cast steel and the jaw moves about the hinge pin for coupling and uncoupling action.

Fully Automatic Couplers

More and more railways are using fully automatic couplers. A fully automatic coupler connects the vehicles mechanically, electrically and pneumatically, normally by pushing the two vehicles together and then operating a button or foot pedal in the cab to complete the operation. Uncoupling is done by another button or pedal to disconnect the electrical contact and pneumatic connection and disengaging the coupler mechanically.

Fully automatic couplers are complex and need a lot of maintenance care and attention. They need to be used often to keep them in good working order. There are a number of different designs in use.

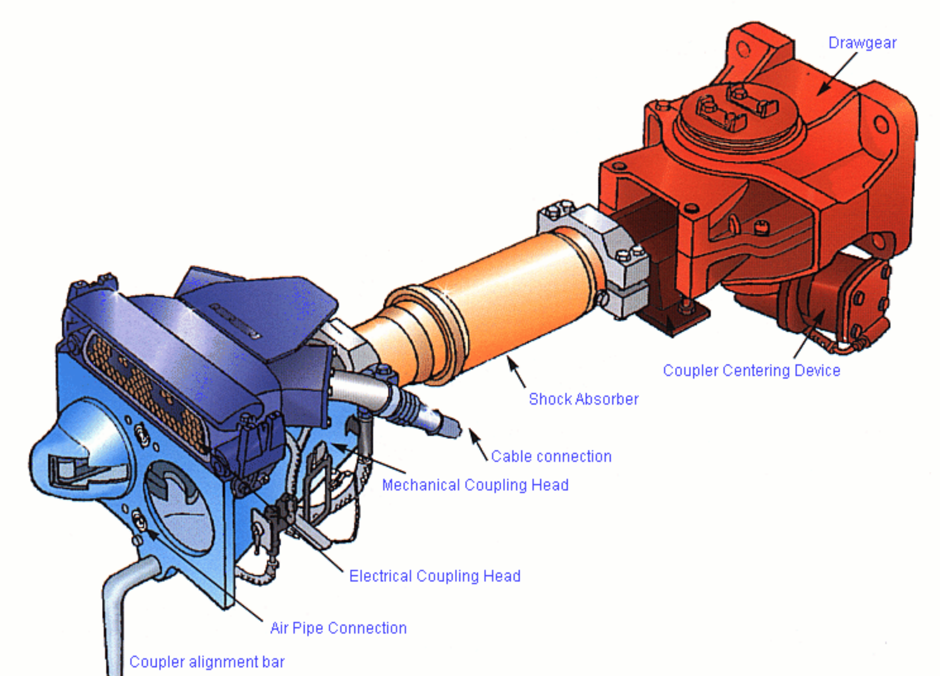
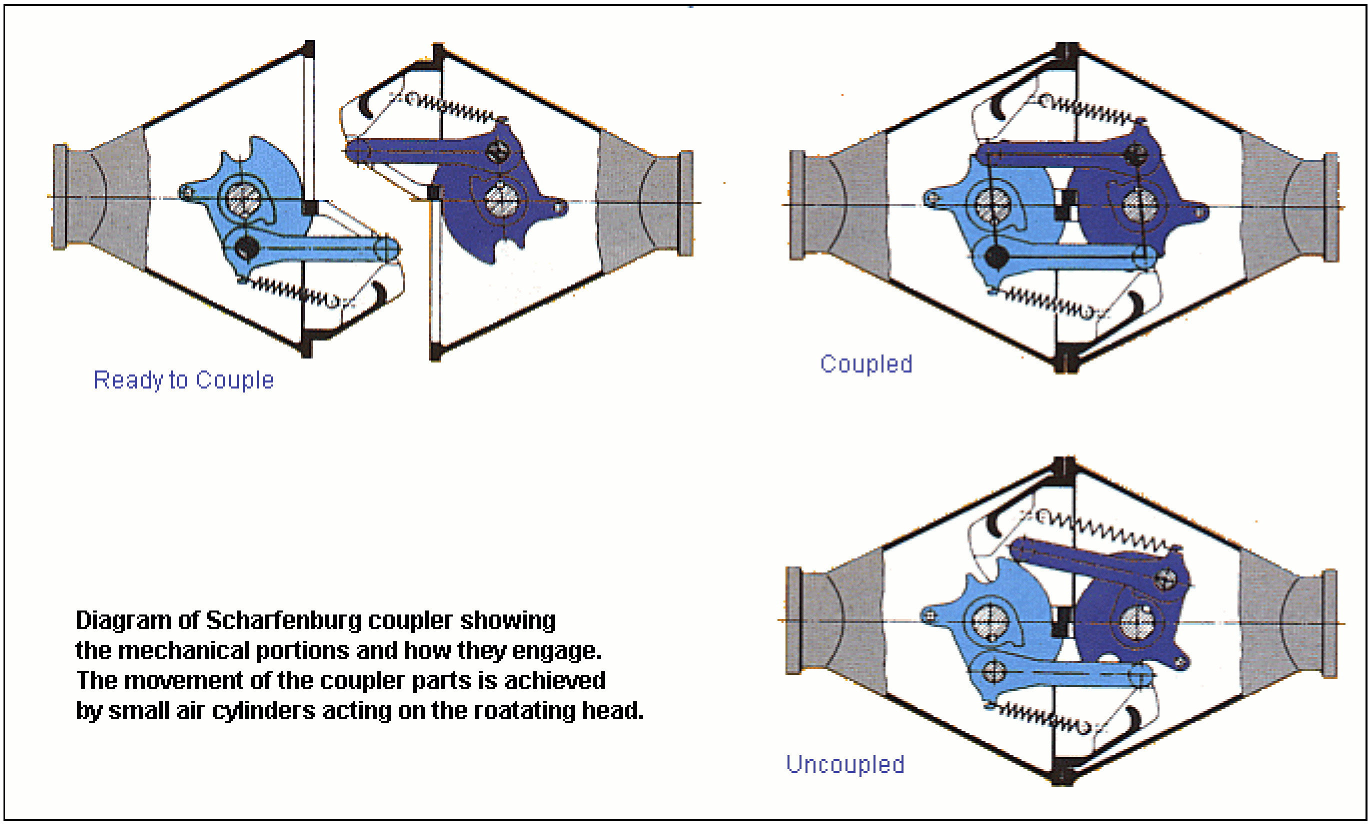


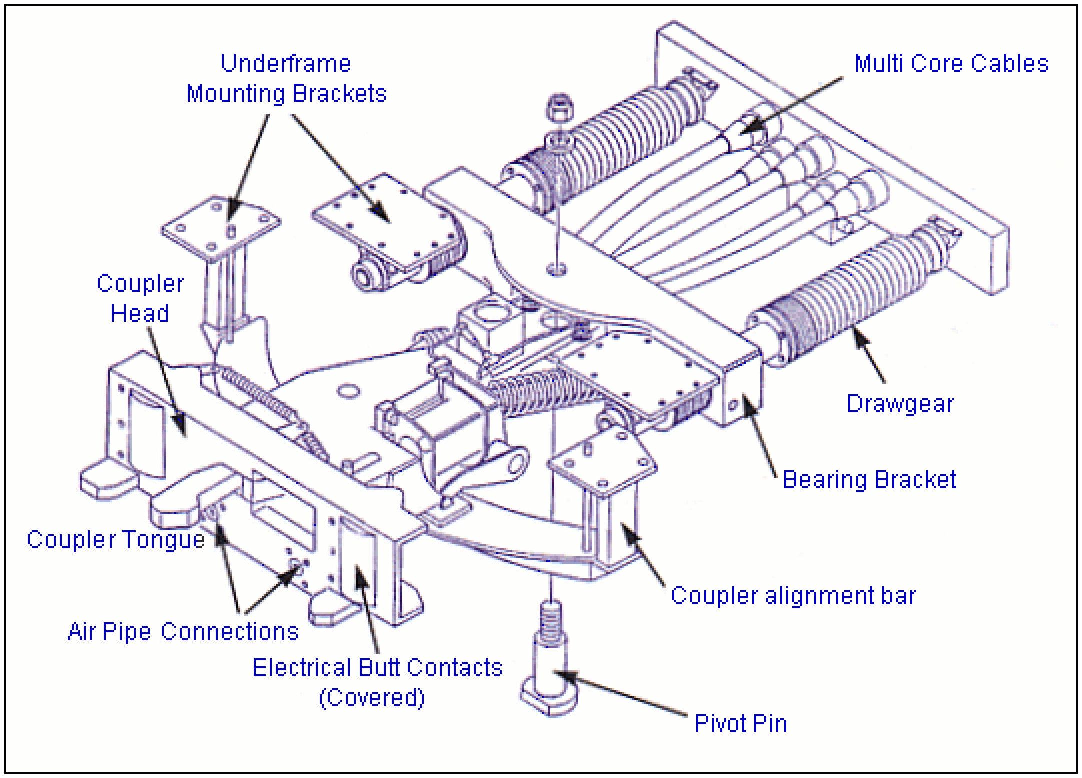
Diagram of Schafenberg automatic coupler showing the main parts.
This example has the electrical coupling above the mechanical head.

The Scharfenberg automatic coupler is a design widely used on European multiple unit rolling stock of all types, ranging from high speed trains to light rail vehicles. The coupler has a mechanical portion with pneumatic and electrical connections. The units are coupled by pushing one onto the other. The electrical contacts mounted under the mechanical coupler are protected by a cover when uncoupled. This drawing is another version of the Scharfenberg coupler which has the electric contacts over the coupler. The electrical contacts can be mounted on the sides of the coupler.

One of the earliest tight coupling mechanisms was the Scharfenberg coupler, (developed in 1903) which is still widely used. It's most serious problem is that it's not very strong, limited to about 1,000 tons, and thus only suitable for slower-speed passenger trains (not high-speed trains, and definitely not freight trains).

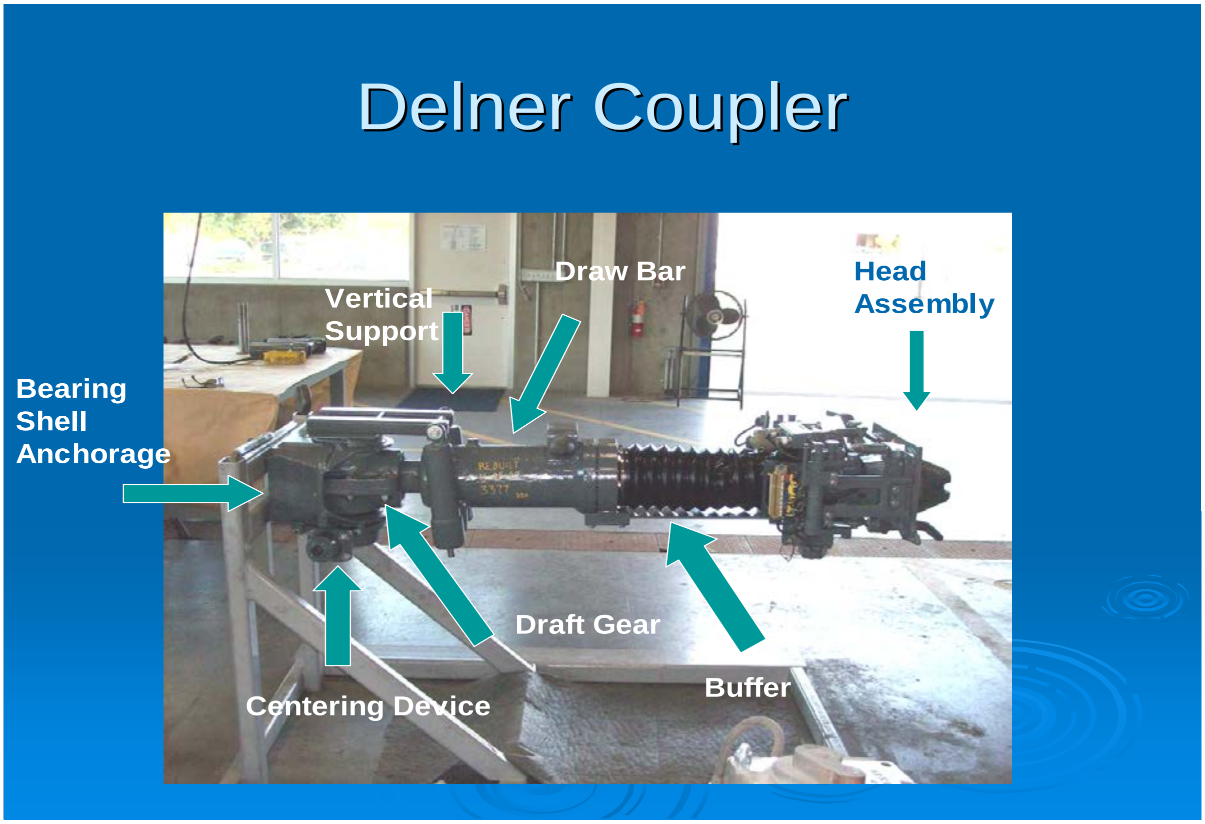


A drawing of the mechanical portion of the Scharffenberger coupler showing how the two couplers engage and uncouple.



London Underground uses a unique type of automatic coupler known as the Wedgelock. It was first introduced in 1935 and has remained little changed since. It provides full mechanical, electrical and pneumatic connections. Older versions were fully automatic, being released from a pushbutton in the driver's cab. More recent versions use a hand operated release which has to be operated in each cab.

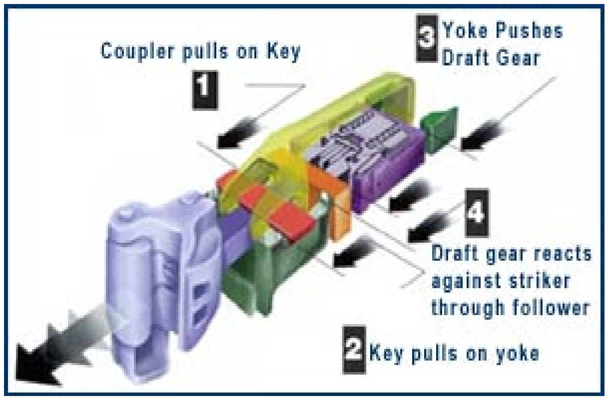
The trouble with this coupler was that, in its original form, it was too complicated. It would only uncouple if the couplers on the two vehicles released at the same moment and this only happened if both the air operated disconnecting cylinders worked at the same time. Often, this did not happen. Some bizarre rituals had to be gone through to get units to uncouple, including attempts to manually lift both uncouple valves (one on each unit) with two staff calling out "one, two, three, lift" in order to make sure they did it together. If this failed, they would drain all the air off the train and try to force the coupler pistons back against the springs by using long crowbars. Finally, if that failed, the fitters would reverse the air pipe connections to try to force air into the uncouple cylinders permanently which the train was driven apart. More recent versions have had some improvements, including manual operation from each unit. Standard railway couplers would be difficult to use on tube cars because of the clearances, which is why the Wedgelock design has survived for so long. (www.trainweb.org/tubeprune/dictionary.htm)



The Delner Coupler is mounted to the train by the Bearing Shell (Anchorage is another term). The Centering Device has internal springs to keep the coupler centered in the horizontal plane, it allows for movement side to side when coupled. The Draft Gear absorbs the buff forces (compressive forces during a slack bunched condition). The Draft Gear also receives the draft forces when trains are in a stretched (pulling) condition. The Vertical support holds the coupler level in the vertical plane the mounting bridge connects to the spring loaded hanger assembly which supports the Draw Bar holding the weight of the assembly. The Draw Bar is the metal tube which connects to the Anchorage by way of the Draft Gear. The Buffer is a spring assembly which absorbs the impact of coupling and buff loads. The Head Assembly (Coupler Head) is mounted to the buffer and the electrical heads in this case will mount to the coupler head.

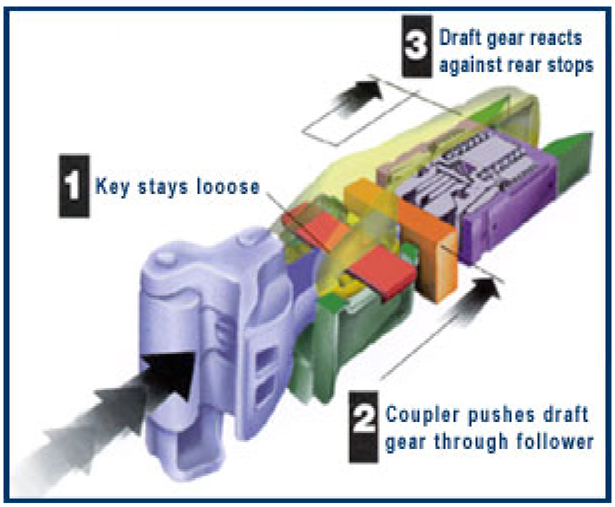
Draft

While in draft mode, the yoke straps are placed in tension as the gear is compressed between the rear of the yoke and the striker. (The striker is part of the car body structure and the path of the force is through the follower.)



Buff

While in buff, the coupler, which acts through the follower, places the gear in compression against the car body's rear stops.



The purpose of the yoke is two-fold:

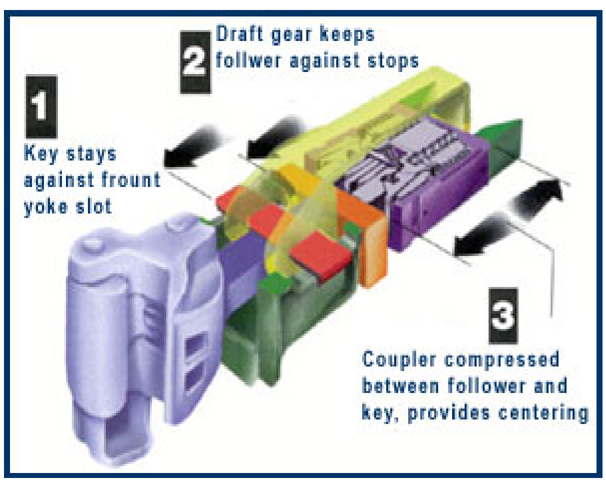
It provides a pivotal (controlling) connection that facilitates both draft (pulling) and buff (pushing) motions. It also accommodates the draft gear, a shock-absorbing device, in such a way that both draft and buff forces compress the draft gear.

In both draft and buff modes, excess forces compress the draft gear, thus controlling the force by dissipating the excess energy.

All coupling systems are designed so that they can repeatedly withstand maximum buff and draft forces that occur during interchange service. All of these coupling systems are required to meet these extreme AAR specified draft loads.

At Rest

While at rest, the coupler remains compressed between the follower and the key to provide centering.



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WorldIQ.com http://www.wordiq.com/definition/Coupling (railway)
http://en.wikipedia.org/wiki/Coupling (railway)
Coupler Dynamics (www.mcconway.com/rail_prod/coupler_dynamics.htm)

Relevant OEM Contact Information

OEM	Website	Contact Information
Dellner Couplers Inc	http://www.dellner.se/	8334 - H Arrowridge Blvd. Charlotte, N.C: 28273 Phone: +1 704 527 21 21 Fax: +1 704 527 21 25
Wabtec Corporation	http://www.wabtec.com/home.asp	1001 Air Brake Avenue Wilmerding, PA 15148 - USA Phone: 412-825-1000 Fax: 412-825-1019
Westinghouse (WABCO)	http://www.wabco-auto.com/	Contact Form

Attachment: Industry Training Standard

Module 201: Couplers

201. Couplers: Introduction and Preventive Maintenance

201.1 Electric Coupler Heads

Inspecting and maintaining linear actuators/motors

- Inspect linear actuators/motors
- Service actuators/motors
- Perform basic repairs on linear actuators/motors
- Replace linear actuators/motors
- Test linear actuators/motors

Inspecting and maintaining coupler suspension and linkage

- Check linkages for wear
- Check suspension height
- Lubricate coupler and/or linkage
- Perform basic repairs on coupler suspension and linkage
- Test coupler suspension and linkage
- Replace coupler and/or linkage

Inspecting and maintaining limit/proximity switches

- Adjust limit/proximity switches using appropriate gauge
- Perform basic repairs on limit/proximity switches
- Test limit/proximity switches
- Replace limit/proximity switches

Inspecting and maintaining release mechanism

- Adjust release mechanism, if applicable
- Inspect release mechanism
- Lubricate release mechanism, if applicable
- Perform basic repairs on release mechanism
- Replace release mechanism
- Test release mechanism

Inspecting and maintaining train line cables

- Inspect train line cables
- Perform basic repairs on train line cables
- Replace train line cables
- Test train line cables

Inspecting and maintaining drum/uncoupling switch

- Inspect drum/uncoupling switch
- Perform basic repairs on drum/uncoupling switch
- Replace drum/uncoupling switch
- Test drum/uncoupling switch (electric test)

Inspecting and maintaining heaters and temperature sensors

- Inspect heaters and temperature sensors
- Perform basic repairs on heaters
- Perform basic repairs on temperature sensors
- Replace heaters
- Replace temperature sensors
- Test heaters and temperature sensors

Inspecting and maintaining contact pin/tip assembly (insulated block)

- Check contact pin/tip assembly (insulated block) for physical damage
- Clean contact pin/tip assembly (insulated block)

- Identify proper parts
- Identify proper solvents and lubricants
- Inspect fixed and mobile contacts
- Inspect gaskets
- Replace fixed and mobile contacts and /or contact assembly
- Test fixed and mobile contacts and/or contact assembly

201 Inspecting and maintaining coupling sensor

- Check adjustment of coupling sensor
- Inspect coupling sensor
- Perform basic repairs on coupling sensor
- Replace coupling sensor
- Test coupling sensor

201.2 Pneumatic Coupler

Inspecting and maintaining tappet valves

- Clean tappet valves
- Replace tappet valves
- Test tappet valves

Inspecting and maintaining heaters and temperature sensors

- Inspect heaters and temperature sensors
- Perform basic repairs on heaters
- Perform basic repairs on temperature sensors
- Replace heaters
- Replace temperature sensors
- Test heaters and temperature sensors

Inspecting and maintaining solenoid valves

- Inspect solenoid valves
- Replace solenoid valves
- Test solenoid valves

Inspecting and maintaining valve filters

- Clean valve filters
- Replace valve filters

Inspecting and maintaining train line (brake pipe)

- Inspect train line (brake pipe)
- Replace train line (brake pipe)
- Test train line (brake pipe)

Inspecting and maintaining drum switch/air actuator

- Adjust drum switch/air actuator
- Inspect drum switch/air actuator
- Replace drum switch/air actuator
- Test drum switch/air actuator

Inspecting and maintaining uncoupling air system

- Inspect uncoupling air system
- Lubricate uncoupling air system
- Replace air cylinder
- Replace uncoupling air system
- Test air cylinder and uncoupling air system

201.3 Mechanical Coupler

Inspecting and maintaining suspension and linkage components

- Check linkages for wear

- Check suspension height and level
- Replace linkages
- Replace suspension and linkage components

Inspecting and maintaining linear actuators
- Inspect linear actuators
- Lubricate linear actuators
- Replace linear actuators

Inspecting and maintaining knuckle and slide lock
- Inspect for wear, damage and proper locking
- Gauge tightness
- Lubricate mechanism

Inspecting and maintaining hook and plate
- Inspect hook plate assembly
- Lubricate hook plate assembly
- Replace hook plate assembly

Inspecting and maintaining limit switches
- Adjust limit switches
- Inspect limit switches
- Replace limit switches

Inspecting and maintaining alignment, anchor and suspension
- Adjust coupler support
- Check shear device hardware
- Inspect anchor
- Inspect buffer tubes, draft gear and absorption cartridge
- Inspect centering device and springs
- Inspect coupler support
- Inspect shear device assembly
- Replace buffer tubes, draft gear and absorption cartridge
- Replace centering device and springs
- Replace coupler support
- Replace shear device

Inspecting and maintaining heaters and temperature sensors
- Inspect heaters and temperature sensors
- Perform basic repairs on heaters
- Perform basic repairs on temperature sensors
- Replace heaters
- Replace temperature sensors
- Test heaters and temperature sensors

Inspecting and maintaining release mechanism
- Inspect release mechanism
- Lubricate release mechanism
- Replace release mechanism

Inspecting and maintaining electrical pin door/shutter/gasket
- Clean electrical pin door/shutter/gasket
- Inspect electrical pin door/shutter/gasket
- Lubricate electrical pin door/shutter/gasket
- Replace electrical pin door/shutter/gasket
- Test electrical pin door/shutter/gasket

Inspecting and maintaining draw bar (married pairs)
- Inspect draw bar (married pairs)
- Lubricate draw bar (married pairs)

- Replace draw bar (married pairs)
- Check shear device hardware
- Inspect buffer tubes and draft gear

201.4 Tools

NOTE: Can be integrated in other parts of module or taught separately.

Demonstrate proper use of wear gauges (go/no-go gauge)
Demonstrate proper use of head alignment tools
Demonstrate proper use of contact/pin replacement tools
Demonstrate proper use of vertical press
Demonstrate proper use of bushing driver
Demonstrate proper use of reamer
Demonstrate proper use of coupler repair stand
Demonstrate proper use of pneumatic/hydraulic jacks
Demonstrate proper use of overhead cranes
Demonstrate proper use of lift tables
Demonstrate proper use of forklift and adapter
Demonstrate proper use of continuity tester/breakout box
Demonstrate proper use of auxiliary power supply/connector tester
Demonstrate proper use of digital multimeter
Demonstrate proper use of torque wrench
Demonstrate proper use of dial indicator

RAIL VEHICLE LEVEL 200
SUBJECT OVERVIEW

Module: 202 – Trucks and Axles

Note: All 200 level courses should be delivered only after completion of 100 level training

Overview/Purpose

The purpose of this document is to introduce students to rail vehicle trucks and axles. There are several components of rail car trucks that are covered in other level 200 introductions in greater detail than in this overview. After reading this document the student should be able to identify the common elements of a railcar truck and discuss their functions.

This material provides a general overview of rail vehicle trucks and axles to give technicians a basic introduction to the subject and prepare them for national qualification testing.

Material presented here is intended only as a primer to the subject, keeping in mind that rail systems have different characteristics. It follows the National Training Standards established jointly by representatives from both labor and management. As a primer additional knowledge will be needed to become fully qualified on this subject. Material presented here does not address every possible aspect because rail car trucks and axles vary at each transit agency.

Table of Contents

Suggested Tools/Training Aids:

- power point presentations
- transparencies
- manuals
- schematics
- mock-up/live-coupler
- video/animations
- tour of truck shop
- overhead crane
- press

Topics Covered

Topics listed below are covered in this introduction of Trucks and Axles. A full copy of the National Training Standards from which these topics were taken is attached.

- AC Traction Motor
- DC Traction Motor
- Gearboxes
- Axles
- Wheel and Tires
- Primary Suspension
- Frame
- Bolster/Secondary Suspension
- Tools

Definitions, Abbreviations and Acronyms

For the purposes of this lesson, the following glossary of terms, definitions, acronyms, and abbreviations shall apply. They are not all inclusive, and the reader is encouraged to explore the text, footnotes and bibliography sources for further information.

Definitions

- **Axle boxes:** A wheel set assembly component that centers the axle through the bearing, and the interface to the primary suspension.
- **Gearbox**: Found only on motor trucks, is a component in the propulsion axle assembly that transmits the torque of the motor through to the hollow shaft coupling into the axle.
- **Ground Brushes:** The primary return circuits are grounded to the axles per the ground brushes and carry ground fault return currents to the rail. Their function is to provide a protection for the axle box bearings for all types of current.
- **Suspension:** Primary suspension is a flexible connection between the nearly unsuspended axle (resilient wheel) and the truck frame.
- **Shock Absorber:** A friction or hydraulic device used to dampen oscillations, also known as a snubber or damper (e.g. truck to bolster yaw oscillations).
- **Wheel Chock**: An anti-roll device that prevents the vehicle from moving
- **Traction Unit:** Partly suspended from the axle by the coupling is comprised the following components: a motor, gearbox and coupling.
- **Torque Stripe:** Registration marks painted across a fastener and an adjacent stationary reference surface immediately after the specified tightening torque has been applied. Marks subsequently found out of registration indicate relative motion, probable loosening and reduced clamping forces.
- **Wheel Profile Gauges**: Instruments for determining the deviation of the observed, actual wheel profile from the new or ideal wheel profile.

Acronyms

- **ANSI:** American National Standards Institute
- **OEM:** Original Equipment Manufacturer
- **MSDS** material safety data sheet
- **PPE**: Personal Protective Equipment
- **PSI**: Pounds per Square Inch
- **TBU**: Tapered bearing units
- **WBU:** Wheel brake unit
- **ASC:** Atchison Steel Casting and Machining
- **AW0:** Average Weight (Tare Weight = empty vehicle)

Introductory Text by Topic Area

1.0 AC Traction Motor
2.0 DC Traction Motor
3.0 Gearboxes
4.0 Axles
5.0 Wheel and Tires
6.0 Primary Suspension
7.0 Frame
8.0 Bolster/Secondary Suspension
9.0 Tools

I. Introduction

Preventative maintenance and periodic inspection ensures proper functioning of rail cars. A regular service schedule helps technicians discover any defects and correct them before serious damage or failure occurs. As a result, when trucks and vehicle suspension equipment are properly inspected and maintained they will perform well for over longer periods of time and have fewer breakdowns.

This primer will focus on the two different truck types (motor and center) and describe the function of their main components as well as how these components work together. In addition, an overview of the proper inspection and maintenance of rail car trucks and axles will be covered. It should be noted that there are a number of truck and axle components that have already been covered in other 200 level introductions in greater detail and as such will not be included in this primer.

Trucks and Axle Assembly

Trucks are the heart and soul of the railcar. They include the means by which the car rolls down the track (wheels and axles), is propelled (propulsion motors) and is stopped (brakes). On third-rail systems the power pick-up is located on the truck. The trucks also link the car body to the suspension, isolating passengers from the bumps and noise of steel wheels riding on steel rails, thus providing for a more enjoyable customer experience.

Axles are what rotate allowing the wheels to roll on the rail. Provided below is a diagram of a truck and axle assembly (figure 1).

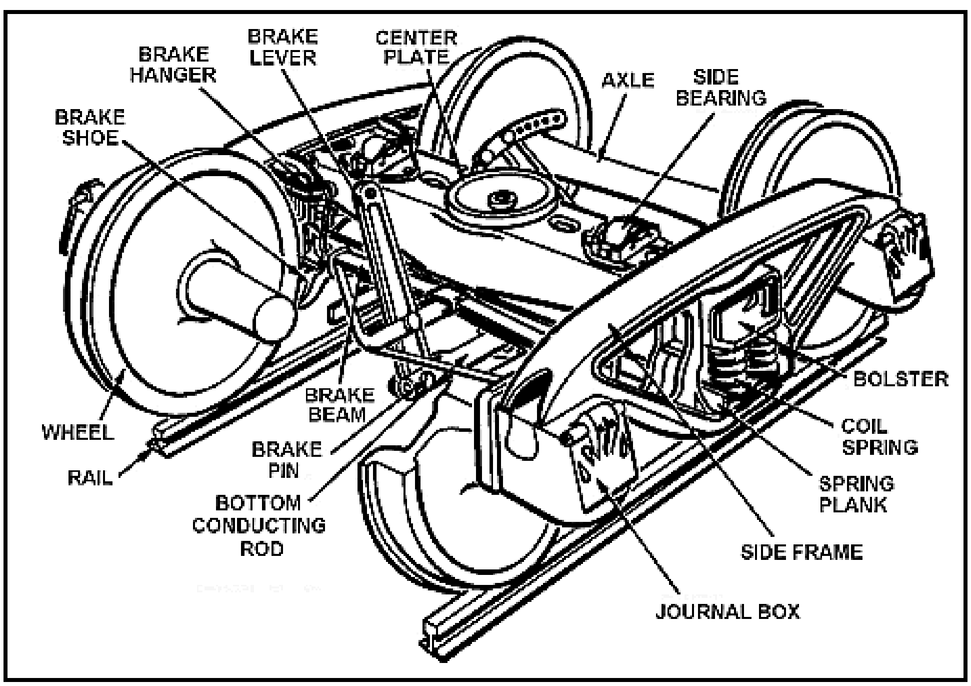

Figure 1: Simplified drawing of a truck and axle assembly

There are two types of trucks, the motor truck (also known as a power truck) and center truck (also known as a trailer truck). The major difference between the two types of trucks is that the center has no motor, while the motor truck is more complex with a motor and two propulsion axle assembly. A center truck could have a stub axle or a full axle. Rail vehicles motor trucks are bidirectional and are located at each the end of the vehicle.

Both motor and center trucks have similar components which will be described in the text below. The motor trucks' AC and DC traction motors are two components not included in this primer as they have been covered in detail in other 200 level primers.

II. Safety Concerns

When performing any operation, inspection or maintenance tasks take care to wear the appropriate personal protective equipment (PPE) – and minimally follow ANSI standards. Below are some safety requirements. Others will be dispersed throughout the text of this primer.

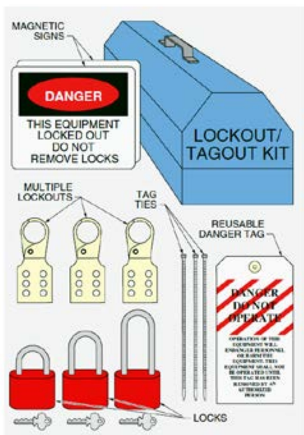

Figure 2: Lockout/Tagout Kit

Voltage: Energy Supply

- To avoid possible injury ensure that the equipment is secured against uncontrolled movement in accordance with rail transit system safety procedures before starting inspection and maintenance procedures.

Lockout/Tagout

- If any corrective or preventative procedures are required, follow lockout/tagout procedures as per your authority (figure 2).
- Verify that electrical power is removed by checking with reliable equipment.
- To avoid possible injury, notify all concerned that equipment is about to be energized before restoring power. If vehicles are coupled and controls are trainline, assure that it is safe for equipment in coupled cars to become operational before energizing any high voltage or battery circuits.

Pinch Points

To avoid possible injury while inspecting friction brakes, keep hands and tools away from pinch points (figure 3).

Figure 3: Pinch Points

Lifting Equipment

To avoid possible injury, use proper lifting equipment to remove and replace heavy components. Be sure that the components are securely fastened to the lifting device.

Cleaning

- To avoid possible injury while using compressed air for dislodging dirt and debris, wear appropriate eye, face, and respiratory protection meeting minimum ANSI or other applicable national industry standards. Keep air pressure at the blowgun nozzle below 30 pounds per square inch (PSI).
- Use only those cleaning products and lubricants proven safe and authorized for use by the rail transit system. Consult OEM and MSDS references for suitability for each application to prevent personal injury and damage to the equipment.

III. Overview: Truck Components

Motor Truck

The motor truck (figure 4) consists primarily of the following components:

- Weld frame made of two longitudinal beams on one transverse beam. Each couple of longitudinal beam ends is equipped with a front beam.
- Secondary suspension assembly consisting of a bolster, two secondary suspension units, two lateral damper, two traction rods and two lateral buffers.
- Truck to body connection, consisting of a central sliding plate and a central pivot assembly.
- Primary suspension
- Wheels which are part of the two propulsion axle assemblies. Note that the other axle assembly components (motor, coupling and brake disc) are not a part of this primer.

In addition, other major truck components that will not be discussed because they have been detailed in other primers include the braking, electrical and auxiliary equipment, and the hydraulic piping assembly.

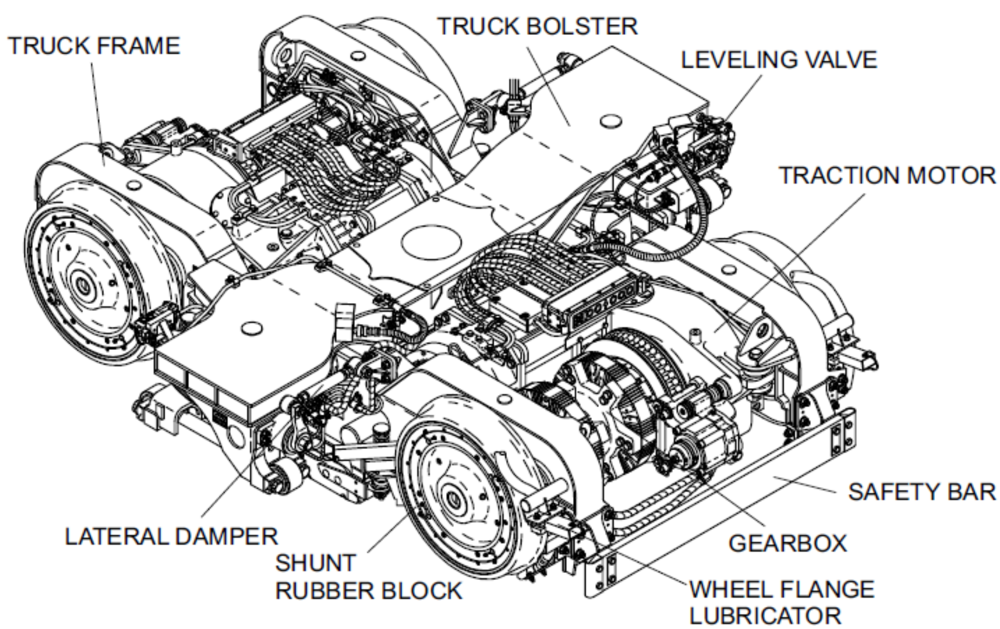

Figure 4: Motor Truck Assembly – Courtesy of Santa Clara VTA LRV

General Inspection and Maintenance: Motor Truck Assembly

SAFETY WARNING: Before beginning any inspection or maintenance on trucks and axle components, be sure to chock the wheels to prevent the car from moving.

Motor truck components (figure 5) are assembled, attached and connected by bolted connections; rubber to metal parts; press fit, such as wheels on axle, rubber bearing in traction rod; clearance fit – central pin of the bolster, axle box to bearing; welds on truck fame and bolster; and quick couplings (hydraulic and electric connections).

Given these many factors, during preventative maintenance checks examine bolted connections. Check for proper tightened, loose or lost bolts. Be sure to check for cracks in welds. With regard to primary suspension, where rubber and metal parts are in contact, check for cracks and height. Ensure press fit has not shifted. Also check to see if there is play in clearance fit. Make sure quick couplings are working properly.

Figure 5: Motor Truck Assembly – Courtesy of PATransit

Center Truck

The center/trailer truck (figure 6) consists primarily of the following components:

- Frame assembly
- Carbody / truck interface including two secondary suspension units, two level sensors, two lateral limit stops, also known as buffers, two horizontal dampers and two parallel traction rods
- Primary suspension
- Four independent wheels mounted on a Wheel Brake Unit (WBU)

Other components that have been covered in other 200 level primers, and as such are not a part of this primer include: the braking, electrical, auxiliary and hydraulic equipment.

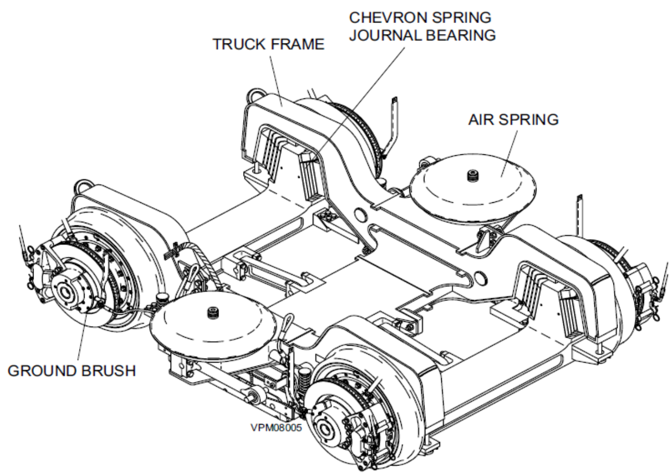

Figure 6: Center Truck Assembly – Courtesy of Santa Clara VTA LRV

IV. Gearbox

The gearbox (figure 7), found only on motor trucks, is one component of the propulsion axle assembly. More specifically, the gearbox along with the motor and coupling comprise the traction unit components. The motor in the traction unit is a self-ventilated air cooled and fully enclosed AC Motor. The motor is oriented in lateral direction inside of the truck frame, and is directly bolted to the gearbox to form a compact drive unit.

The traction unit is partly suspended from the axle by the coupling. All attachment points are at the truck frame which is suspended through the primary suspension which will be covered in the text below. The minimum possible un-sprung mass (the axle with wheels are not suspended) is realized and therefore the acceleration for motor and gearbox is minimal, thus increasing the lifetime of these components and also the running comfort.

The gearbox serves a primary purpose. It transmits the torque of the motor through to the hollow shaft coupling into the axle. The special hollow shaft coupling has a small radial stiffness, so the mass of axle and the traction unit are decoupled. The brake disc is bolted to the hollow shaft of the gearbox and the actuator is bolted to the casting of the gearbox housing. The gearbox is in close proximity to the motor as shown in the diagram (figure 7) below.

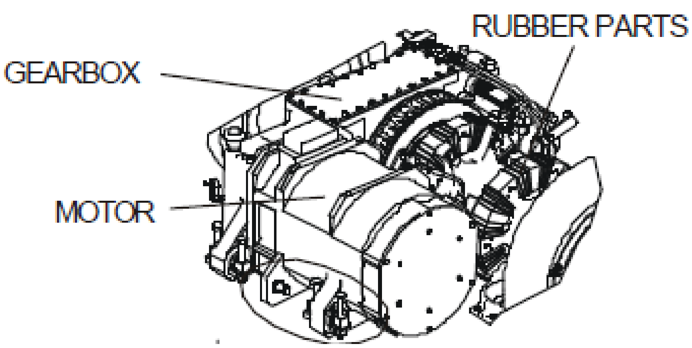

Figure 7: Gearbox and Motor – Courtesy of Hiawatha Transit

Inspection and Maintenance: Gearbox

SAFETY WARNING: To avoid injury during the inspection of the gearbox, safety goggles must be worn to protect the eyes from grease splatter. The axle gearbox and the oil can heat up. To avoid injuries such as burns and scalds, always allow sufficient time for the gearbox to cool down before touching it.

Tools and materials needed for gearbox inspection and maintenance include a standard tool set, lint-free cloth, magnetic dipstick seal ring, and drain plug screw seal ring, approximately one-and-half gallons of lubricant, torque wrench, and red paint.

Begin by visually inspecting the axle gearbox for tightness or oil leakage such as oil dripping from the gearbox housing. Note that light oil residues on labyrinth seals are normal and no cause for concern. Oil dripping from the gearbox housing is a sign of leakage and must be scrutinized carefully. If a leak is found, check the oil level. Too much oil in the axle gearbox can be the cause of the leak. Also, if leaks are detected, check the axle gearbox sump oil level. Maintain the oil level in each gearbox in accordance with OEM guidelines. Note that overfilling the axle gearbox with oil can lead to excessive heat development and oil leaks.

Use oil designated by the OEM and the transit system authority. Be sure to record the amount of make-up oil added on. Tighten covers, replace accessible gaskets or replace gearboxes found with unusual and excessive oil leakage. Review use oil consumption records to identify gearboxes that leak oil excessively.

To remove oil contamination build-up, drain oil and refill gearboxes at regular intervals based on sampled oil or environmental conditions. When removing oil, the magnetic plug should be checked for metal particles. The plug should be wiped clean before reinstallation. Refill the gear unit and install and safety wire filler plug.

When changing the gearbox oil. Always use a lint-free cloth to clean the area around the magnetic dipstick and gearbox oil sump drain plug screw. Place an appropriate waste oil collection container under the drain plug screw. Next, unscrew the drain plug screw and fully drain the waste oil form the axle gearbox into the container. Always dispose of used oil in accordance with transit agency guidelines.

Ground Brush

The primary return circuits are grounded to the axles per the ground brushes and carry ground fault return currents to the rail. Their function is to provide a protection for the axle box bearings for all types of current.

Each motor truck is equipped with three identical ground brush (figure 8) devices.

The assembly is composed principally of two parts:

1) An insulated fixed part ensuring the guiding of three separate brushes and electrical connections. A connecting rod makes the liaison between the external part and the truck frame to avoid the rotation.
2) A mobile part located at the extremity of the axle, near the wheel, ensures a perfect contact for the brushes.

Two ground brush devices are active for current returns. They are placed on both axle one, right side and on axle two, left side. One ground brush is active for the safety grounding and is placed on axle two, right side. Note that specific cabling comes directly from the height tension interface

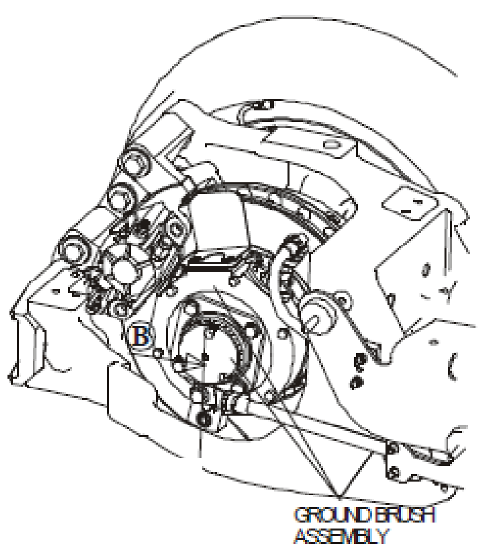

Figure 8: Ground Brush Assembly – Courtesy of Hiawatha Transit

terminal box in the undercar. The two motors groundings are centralized on an isolator to permit only one cable connection on the safety grounding device.

Inspection and Maintenance: Ground Brush Assembly – Motor Truck
During the general inspection and maintenance of the ground brush assembly, remove and inspect each ground brush, and inspect the springs and the brush guide. Verify that each brush slides freely and is retained tightly against its respective slip ring. Be sure to inspect carbody to ground brush housing cables. Replace cables that have torn stranding.

Use a clean lint-free cloth to clean the high and low voltage contact assemblies and the left and right brush housings. Be sure to inspect for loose hardware and damage. Also check contact assemblies for cracks. Examine the condition of the gaskets and inspect the springs which are attached to the assembly covers. If a cover is cracked, a gasket is damaged or a spring is broken, replace the respective cover assembly as required.

Be sure to check all three ground brushes for wear or damage. Examine the wear mark situated on the side of the ground brushes. Replace ground brushes that are shorter than a wear limit witness mark or the wear limit established by the transit system authority. Examine the state of the ground brushes. Check that there are no cracks or chips around the edges, grooves on the running surface, discoloration or any oil, grease and dirt residue. Replace ground brushes with evidence of burning, discoloration or shunt damage. Determine the cause of damaged ground brushes and springs, and repair the cause before replacing the damaged components.

Finally, check the contact plate for grooves, damage, oil, grease and dirt residue. Remove any oil or grease with white alcohol spirits only. To remove dust, do not use a liquid detergent or compressed air instead use a vacuum or soft brush.

V. Axles

Axles and Axle Assembly

As stated previously, axles are what rotate on the truck allowing the wheels to roll on the rail. The two propulsion axle assemblies (figure 9) are key motor truck components. Each axle assembly has a motor, gearbox, brake disc, and two wheels, and each is equipped with four shunts, two axle boxes and two tapered bearings.

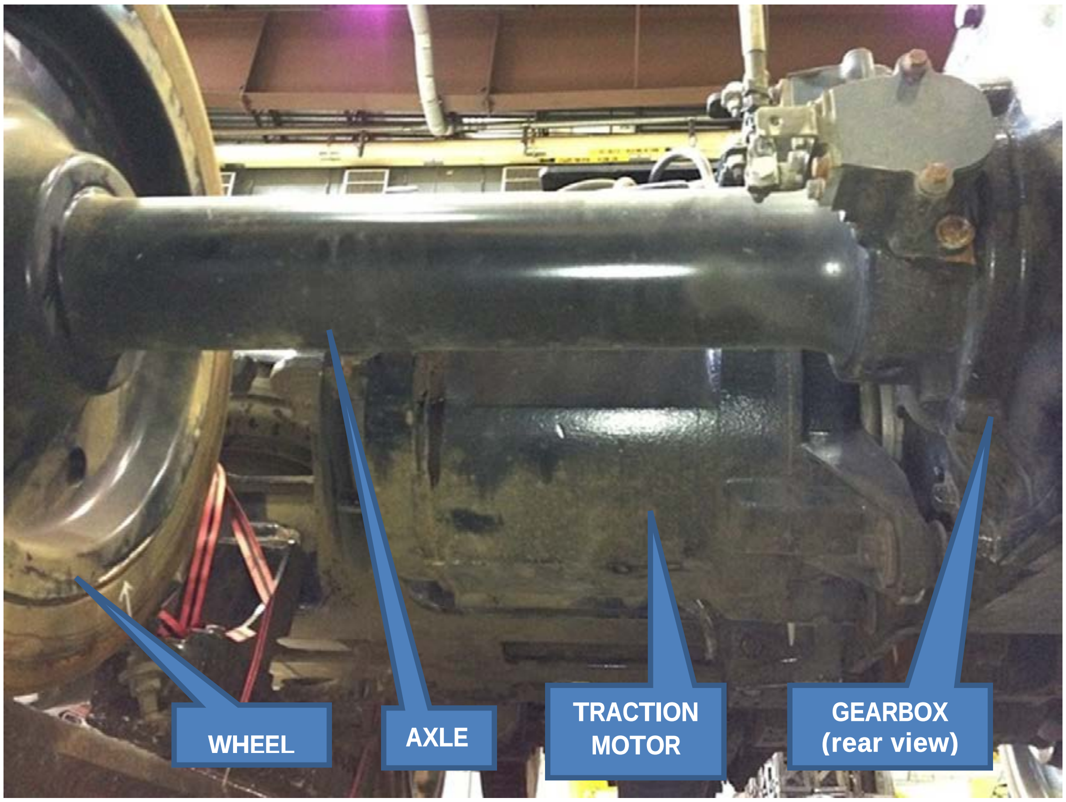

Figure 9: Axle Assembly – Courtesy of PATransit

Wheel set Assembly

The wheel set assembly is comprised of the following components (figure 10):

- 1 Axle
- 2 Axle boxes
- 2 Tapered bearing units (TBU)
- 2 Wheels
- 1 Traction unit consisting of motor, gearbox and coupling.
- 1 Brake disc

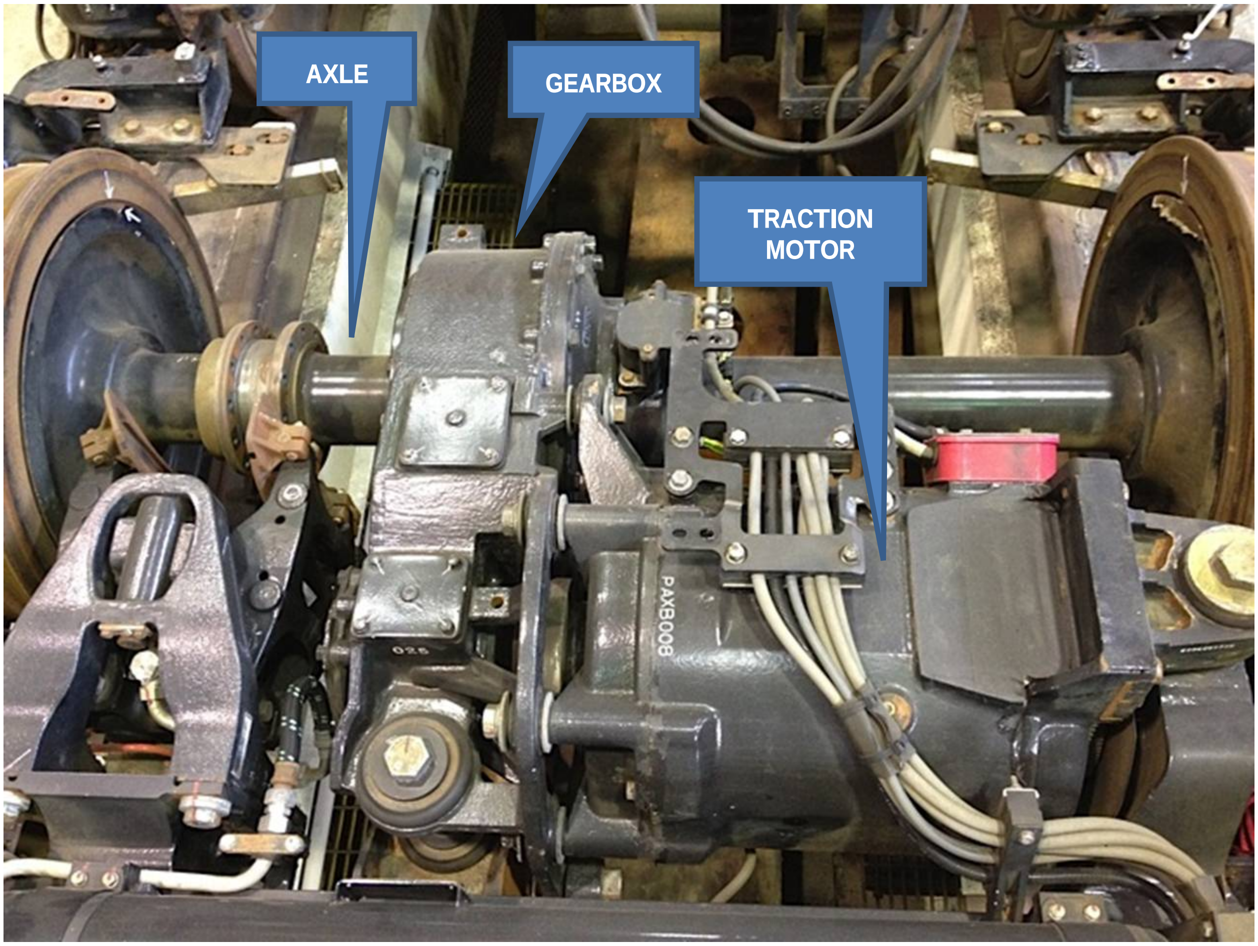

Figure 10: Axle and Wheel Components – Courtesy of PATransit

Axle
The axle is made of AISI 4130. It is a highly stressed part. The nominal axle load is 23,000 lb. All impacts coming from track irregularities are transmitted through the resilient wheel directly into the axle. This means the axle's steel quality must be very good and without any failures.

Both extremities of the axle are provided with a 90 degrees machined face for centering on a wheel lathe center. In addition to this feature, both extremities are also fitted with a centering bore, used for centering the ground brush support. This is attached to the end of the axle and used for securing the end-of-axle ground brush or any additional end-of-axle speed sensor.

One part of the hollow shaft coupling is pressed fitted on the axle as well as the journal bearings and the wheels.

Axle boxes
Two different axle boxes are on one side of the truck. The difference consists of the bore of the axle bearing. The functions of the axle boxes are centering the axle through

the bearing, and the interface to the primary suspension. All loads coming from or to the axle will pass through the axle box into the bearing.

Inspection and Maintenance: Axles

Follow OEM and rail transit system guidelines to determine the disposition of axle defects. During the inspection and maintenance of axles, visually inspect axles for grooves, nicks, or arc burning. Remove indications by polishing, but replace axles with nicks, gouges, arc burns, or circumferential scoring that may become a stress concentration point. Replace axles that have been overheated. Where equipped, check serviceability of temperature indicators installed in axles to detect overheated journal bearings.

Bearing

The axle box is equipped with a tapered bearing unit (TBU). Bearings are high precision parts and need to be treated accordingly.

The inner ring is press fitted on the axle, turning the same revolution as the axle. The out ring has a clearance fit to the axle box, remaining with the axle box always in the same position. In between the inner and outer ring located are the rollers which are kept in their position by the cage.

Note that one factor with regard to the bearing lifetime expectancy is determined by the correct play in the bearing. Both, too much and to less play, will result in a reduced the lifetime. The play can be adjusted by the width of the spacer during a general overhaul.

Another very important factor for the lifetime of a bearing is the lubrication, specifically quality decrease of the grease over the time. Dirt entering the bearing reduces the grease quality dramatically, as well as too high temperatures in the bearing. For that reason the sealing system has a very important function. When the car is cleaned, never directly clean the bearing with a water jet. When re-lubricating the bearing, never use more grease than required because doing so increases the temperature in the bearing and reduces the lifetime of the grease and likewise the bearing.

Inspection and Maintenance: Journal bearings

> SAFETY WARNING:
> To avoid injury during the inspection of the gearbox, safety goggles must be worn to protect the eyes from grease splatter.

Begin the inspection by visually inspecting grease-lubricated journal bearings for evidence of grease leak-off (purging). Check housing for discoloration, cracks or abnormal appearance. Use bearing OEM guidelines for monitoring lubricant purging, repair and re-lubricate or replace bearing as required. Check oil level in the reservoir of oil-lubricated journal bearings. Spin test and listen for unusual noises during rotation.

VI. Wheels and Tires

The wheels are the connection between the car and the track with many important functions.

- The wheel tread is tapered in order to get the wheel back into the middle when it is running out of the center. Because the left and right wheel turn with the same rotational speed (connected by the axle) it is extremely important that the wheel diameters on the right and left wheel are withing small tolerances. If not, one wheel would always have contact with the flange resulting high flange wear. Many different tread damages can occur. If there is a flat on the wheel, it has to be reprofiled immediately. Flats on the wheel cause high fatigue loads for the whole structure, especially for the axle and the bearing.
- The current required for motor (high tension circuit) and other electrical equipment (low tension circuit) passes through the wheel (shunts).
- In order to introduce a first "pre-primary" suspension, the wheels are of a resilient type. A rubber block is damping vibrations from the track with results to participate for a higher vehicle comfort.

  Because of the elasticity in the wheel it is very important that the tire has a certain minimum thickness. The maximum allowed wheel wear is two inches (new diameter 26 in, worn 24 in). Located at the outside of the wheel there is a conemning grove, indicating the minimum diameter. If the nominal wheel diameter reaches this value, the tire and the rubber blocks have to be replaced.

Tires

The wheels are located at the outside of the truck frame so that the tire can be replaced without disconnecting the axle assembly from the truck. For the tire replacement, there is no need to remove the wheel hub. A special disassembly ring allows easy tire replacement.

The main features of the rubber cushioned wheel are:

- Rubber block to provide shock absorption and noise reduction. The rubber bodies are made of heat resisting natural rubber grade FHFN 80. Under normal service and maintenance conditions the natural useful life of the rubber blocks is limited to approximately 10-12 years. After this period of time, which is well above the lifetime of the tire, changes in the physical properties may occur due to aging.
- External shunts to provide electrical conductivity.
- Locking bolts are provided to insure the conical ring remains securely fastened to the wheel assembly.
- Tire and rubber blocks can be replaced while the axle is on the truck and the truck is under the car without removing the wheel from the car.
- The wheels can be trued by under-floor lathes without difficulty.

Inspection and Maintenance: Wheels and Tires
Measure flange and tread wear using gauges appropriate for the wheel profile being inspected. If measuring gauges are used record flange height and thickness, rim thickness or the wheel diameter calculated from a rim reference groove. Record measured dimensions on inspection records to maintain wheel wear history. For DC motor current balance and effective spin/slide detection, maintain propulsion and brake system manufacturer recommendations for wheel diameter matching. Maintain precise wheel diameter matching in accordance with the propulsion system OEM recommendations for wheel sets driven by a common DC-AC inverter drive or for wheel sets mechanically coupled to a common motor.

Severity of wheel defects discovered and their disposition should be determined by OEM and transit authority procedures and guidelines. Always inspect wheel plates and hubs for cracks, gouges, and arc burns. Wheels with hub, plate or rim defects that may cause stress concentrations must be removed from service. Inspect wheel treads for slide flats, spalling, shelling and thermal cracking. Be sure to check rims and plates for discoloration due to overheating.

For ring damped wheels, inspect the ring for damage. For resilient wheels, inspect external shunts connecting the tire to the hubs or cheek plates. Use inspection methods on internal shunt resilient wheels that confirm that ground path impedance across each tire and hub is uniform. Check that tires have not shifted on the hub of two-piece wheels.

Check the wheel profile and diameter of the tires. If the tire diameter is less than 24 inches it needs to be replaced. The wheel should be re-profiled if the flange has worn 1/16 inch or greater. As always follow rail transit agency guidelines to define a minimum diameter wheel and minimum rim thickness.

When inspecting of rubber blocks, check that the tires on the truck as normally assembled, use a flashlight to check for excessive protrusion of the blocks in any one area. Also ensure that there are no cracks with a depth greater than 6 mm (.24 inches) on the blocks.

VII. Primary Suspension

Motor Truck

The primary suspension on motor trucks is a flexible connection between the nearly unsuspended axle (resilient wheel) and the truck frame. It has very important functions. For instance, it influences the running stability (lateral stiffness) of the vehicle, the comfort and also the safety against derailing (vertical stiffness).

The primary suspension itself consists of two conical rubber springs per axle box. They provide proper wheel equalization, and because of the rubber, a self-dampered connection between the axle assemblies and the truck frame. The inner metal part of the spring, a steel center pin is connected to the frame. The steel ring (outer ring) ensures the right interface to the axle box. In between these two parts is the vulcanized rubber compound including a metal interleave, providing the required stiffness, both in vertical and lateral direction.

Note that limit stops in upper and lower direction limit the maximum possible deflection of the truck frame in vertical direction. The upper limit stop is located at the bottom of the primary suspension between a machined area on the axle box and the adapted busher screwed on the spring. The lower stop is integrated into the truck frame to permit a mechanical stop between machined area on the axle box and limits the downward deflection of the truck frame.

Primary Suspension Assembly Components – Center Truck

The main components of the primary suspension assembly on center trucks include:

- (Rectangular) Rubber Spring – located between two machined surfaces. On one side there is the wheel brake unit (WBU), and on the other side the truck frame. In order to limit the maximum downward deflection of the truck frame, a metal stop (low stop) is integrated in the rubber element.
- Pivot Axle / Rubber Bushing – The lever arm of the primary suspension axle is called the pivot axle. The inner part of the rubber bushings is mounted at the pivot axle. The rubber bushings provide the primary suspension with the required horizontal, lateral and cardanical stiffness.
- Axle Housing – The axle housing, center spacing ring and the center screw clamp the inner part of the rubber bushings in order to prevent a torsional movement which must be done in the rubber.
- Center Spacing Ring – The distance between the two independent wheels can be adjusted with the center spacing ring.

Note that because of the independent wheels of the center truck the primary suspension is more complicated compared to the motor. The final vertical stiffness of the system depends on two factors. One is the stiffness of the rectangular rubber spring, the other is the ratio between the lever arm of the pivot axle and the rectangular rubber sign around the wheel axle.

Hub Assembly
The center truck is a rigid truck with four independent wheels (no axle between the wheels) in order to realize the low floor section of the vehicle. A stub axle is integrated in the hub the resilient wheel where the bearing is pressed on. The wheel brake unit (WBU) housing completes the hub assembly. The WBU housing is pressed on the outer part of the bearing and is connected to the truck frame by the primary suspension mounting.

Wheel Brake Unit Housing
The WBU housing is similar to the axle box of the motor truck and has many functions. It is the connection between the wheel and the frame and provides attaching points for the rubber elements of the primary suspension, the brake caliper and connecting rod bracket.

Wheel
Although there is no traction on the center truck due to the lack of a motor (otherwise it would not be a center truck), same statement concerning wheel damage as in the motor truck are also valid. The wheel will have to brake and can slide as well. The tire itself with the rubber and the shunts is also identical. Same behavior as for the motor truck wheels is required. However, there is a big difference concerning the arrangement of the bearings. The bearings are mounted at the hub of the wheel, there is no axle box. The wheel diameter is slightly smaller than on the motor truck.

Bearing
Compared to the motor truck there is no single outer part in the center truck. The bearing consists of two single tapered bearings, in between spacing rings. The inner part of the bearings is directly pressed on the hub of the wheel (press fit), the outer part is in the bore of the wheel brake unit (clearance fit). Note that bearings of motor and center truck are high precision parts and therefore need to be treated very carefully.

Ground Brush Assembly
The ground brush assembly in a center truck ensures the electrical connection between the rotating wheel and the truck frame. Each wheel requires a ground brush installation and each WBU housing (“left” and “right”) requires a corresponding “left” and “right” ground brush installation. The difference between the “left” and the right” version is the form of the ground brush bracket. The ground brush assembly is the same type for all of the wheels. An insulated fixed part, it ensures the guiding and the pressure system of three separate brushes and electrical connections. The brushes are the only connecting point between the rotating contact disc and fixed part. They are pressed by the metal spring to contact disc. The carbon brushes are the principal wearing pieces of the installation and have to examine during maintenance checks.

Inspection and Maintenance: Primary Suspension
Inspect coil spring sets for damaged and broken coils or excessive rust pitting. Replace springs in matched sets only. Replace damaged spring seats and worn journal bearing adapters when springs are replaced. Where equipped, inspect equalizer beams for cracks, arc burns, wear or deformation. Inspect for pedestal liner wear that allows

excessive journal adapter lateral and longitudinal movement. Replace damaged components. Note: Evaluate overall truck condition and wheel size before spot replacing defective journal box springs, equalizer beams, spring seats or bearing adapters. Complete truck replacement and overhaul may be time and cost effective.

Inspect linear or conical bonded rubber primary suspension elements for deformation or evidence of cracks and tearing at the bonded interface. In shock ring applications, inspect for bulging, pinched and deformed elastomer between the axle cap and the journal bearing housing. Replace chevrons in matched sets only. Note: Evaluate overall truck condition and wheel size before spot replacing defective primary suspension elements. Consider that diagonally opposite flange wheel wear and unstable ride quality may be a symptom of deteriorated elastomers in the primary suspension. Investigate poor ride quality reports.

VIII. Frame Assembly

The frame (figure 11) can be considered the backbone of rail vehicle trucks. The frame assembly is a casted steel construction, composed of two same parts welded in the center. The welded fame is made up of two longitudinal beams on one transverse beam. Each couple of longitudinal beam ends are equipped with a front beam. Although made of steel plates and welds are properly designed and controlled during the production and a fatigue test will be done with the frame, welds should be checked if cracks are visible. Note that there is no preventive maintenance possible, if cracks are detected.

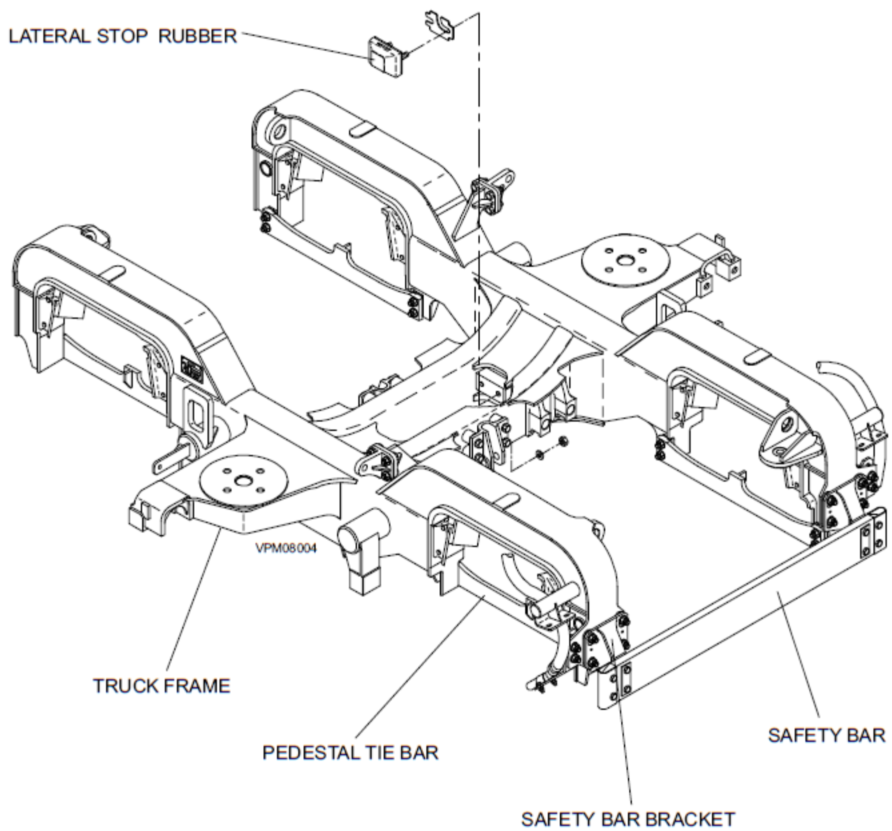

Figure 11: Motor Truck Frame and Safety Bar – Courtesy of Santa Clara VTA LRV

The truck frame is plays a major role in the primary suspension assembly of both types of trucks. As stated previously, the primary suspension is a flexible connection between the axle (resilient wheel) and the frame. And on motor trucks, the secondary suspension unit is installed between the frame and the bolster.

Each truck is equipped with two traction rods installed between the supports at the outer side of the truck frame and at the underside of the bolster. The longitudinal forces are transmitted from the bolster to the frame by means of the two longitudinal rods using optimized elastic rubber bearings in order to reduce the transmission of vibrations to the carbody at a frequency of 20 HZ. The two rods are mounted in opposite position to reduce the truck movements, through the bolster, when the carbody is deflected. The traction rods for motor and trailer truck are identical.

There are two connecting rods, mounted at the front and the read of center trucks. The rods are attached with brackets at the WBU and rigidify the trailer truck assembly. When the back to back distance of the wheels has to be adjusted, the connecting rod has be demounted or at least loosened at the attaching bolts. The connecting rod is attached at both ends to the connecting rod brackets by means of two ball joints (rubber bearings). These are standard rubber bushings to provide a certain elasticity of the mounting.

Inspection and Maintenance: Truck Frames
Inspect truck frame for oil and dirt deposits, corrosion action, misalignment, deformation, paint chafing or deteriorated paint. Clean or repair as required. Carefully inspect welds and the heat-affected zones adjacent to welds for stress induced cracks. Check for broken welds. Carefully inspect slender transition sections and the load bearing transoms of cast steel trucks for fatigue-induced cracks. *Caution:* Always follow all OEM recommendations with respect to welding, drilling and application of heat to truck frames. Heat-treated frames have a higher probability to crack or fail as a result of inappropriate repairs.

Be sure to check for accumulation of moisture. Check pipe and cable clamps, mechanical fasteners, and ground connections. Replace or tighten as required. Examine safety bar and brackets, and gear box safety stop for mechanical integrity, cracks, misalignment or deformation.

The lateral stop will normally be adjusted during truck overhaul maintenance. Periodic inspection of the lateral stop consists of visual checks and physical measurement of the stop.

The rubber bumper inspection includes checking for cracks, scaling and a decrease in thickness. The bumper should be replaced if cracks of 1 mm (.04 inch) or more in depth exist or scaling between the rubber and mounting plate exceeds five percent (5%) of the bonded area, or the thickness loss of the bumper exceeds ten percent (10%) of new bumper thickness.

Inspection of the center bearing includes visual checks and physical measurement of the bushing. Visually inspect for excessive and uneven wear, incorrect seating and abnormal appearances. Physically measure the inside wear of the liner. The wear limit is 0.17 inch (4.25 mm). New liner inside diameter is 6.69 inch (170 mm).

IX. Bolster/Secondary Suspension

The secondary suspension assembly of the motor truck has the following main components:
(Note: There are two of every component accept that there is only one bolster.)

- Bolster (1)
- Traction rods (2)
- Lateral stops (buffers) and lateral stop brackets (2)
- Connecting rod axle fixation (2)
- Secondary suspension units (2)
- Level senor assemblies (2)
- Hydraulic horizontal dampers (lateral shock absorbers) (2)

Bolster
The function of a bolster is that there is a clear interface to the carbody. When the carbody has to be separated from the truck, the whole secondary suspension assembly keeps together like it is. Therefore, the carbody can be separated easily from the truck.

The bolster is a how welded beam which provides all supports and attachment point for the secondary suspension elements and also the truck to carbody elements like the center pivot of the carbody and sliding.

The lateral movement of the bolster and therefore the carbody is limited by two elastic lateral rubber stops and attached on the bolster, acting against stop brackets attached on the truck frame. The clearance between the tops and the truck frame can be adjusted by placing spacers behind the stops.

Inspection and Maintenance: Bolsters
Tools and materials needed during the inspection and maintenance include a standard tool set, grease and a primary suspension tool. Be sure to lubricate lateral damper pins. Inspect the bolster reservoir drain plug area for indications of air leakage and staining. Replace as required. Remove the bolster reservoir drain plug and allow the accumulated moisture to drain out of the bolster reservoir. Make sure to check operation of the pressure-balancing valve. Also, check lateral rubber stop for cracks, scaling and wear. Replace if crack depth is 1mm (.04 in.) or larger.

If detrucked, lubricate the air spring pivot; check center bearing wear plate for cracks and wear and check center pivot pin for wear and galling. In addition, lubricate bolster anchor, center pivot bushing and center bearing wear plate when detrucked.

Finally, bolster anchor (radius) isolation rubber inspection includes checks for cracks and separation of rubber from the shaft. Cracks of 0.0394 inch (1.0 mm) in depth or less are allowable. Shrinkage must not exceed ten percent of new isolation rubber thickness. The design thickness is 3.346 inch (85 mm). Replaced as required. Also, inspect the bolster anchor rod safety wire for ear at the wire entrance holds. Replace as required.

Air Spring
Note that each truck bolster is supported by a secondary suspension system consisting of two air springs (airbags). The air springs are augmented by elastomeric stops to support the carbody in the event of air spring failure. Safe operation of the vehicle is assured at all speeds and car loading conditions when any or all air springs are inoperative. Air spring pressure with AW0 vehicle weight (empty vehicle) does not exceed 55 psi.

Vertical and lateral damping of spring action required to meet the specified ride quality, and not provided by the air springs and air-spring orifices, is provided by hydraulic shock absorbers. Shock absorbers are non-adjustable.

Lateral stops are installed to restrict carbody motions. They are provided with elastomeric cushions providing not less than 1/2 in. of compression and a spring characteristic appropriate to attainment of the specified ride quality. Any truck parts contacted by elastomeric cushions are provided with stainless steel wearing surfaces.

A cut-out cock (one per truck) is provided in the air supply line to the air springs of each truck to vent both springs and to close the air supply to the springs. The cut-out cock is located adjacent to each truck and is readily accessible from one side of the vehicle without going under the vehicle. The letters "ASC" 1-1/8 in. high, painted in permanent, black glossy enamel on the side sill immediately adjacent to the cut-out cocks identifies their locations. Cut-out cocks are lock-wired in their normal operating position. Note that all air reservoirs provide drainage at their lowest point.

Inspection and Maintenance: Air Springs
Inspect bellows for air leaks at the bead rings, also known as o-rings. Visually check for bulges in the outer ply. Look for abrasion of the plies between convolutions. Replace leaking or physically damaged air bellows if necessary when detrucked. Be sure to check air bellow shrouds for physical damage that may impede operation of the air spring.

Check leveling valves and adjust air spring pressure to specified values after changing a damaged bellow. After checking and adjusting leveling valves, check that valves admit, lap and release air properly. Measure the distance between gauge faces on the truck frame and bolster. A properly adjusted leveling valve and bellows in good condition will have a measurement of 5.2 inches (132 mm). Deviations from this dimension suggest a defective bellows, incorrect functioning of the air supply system, or an incorrectly leveling valve. Determine the cause of sluggish leveling valve operation and repair before returning the car to service.

Check car-leveling heights. It is recommended to periodically check carbody height and level. Secondary suspension shimming adjustments may be required to restore ready-to-run nominal floor height above the running rail.

Steel Springs
Inspect springs for breaks and cracks and rust pitting. Check spring pockets for the accumulation of dirt and debris that retains moisture. Examine the condition of resilient pads located in spring pockets. Replace springs that are broken or corroded in excess of specifications. Replace damaged resilient pads. Secondary springs must be matched so that each spring carries equal load. Check car-leveling heights. Plan to add shims after wheel truing and remove shims when wheels are renewed.

Shock Absorbers/Snubbers
Inspect lateral, vertical and jaw dampening shock absorbers for fluid leaks and secure attachment. Follow OEM or rail transit system guidelines, replace leaking shock absorbers and check that shock absorber mounting hardware is tight. Determine and remedy the cause of broken shock absorber mounting hardware then replace damaged components. Check and replenish oil in rotary shock absorbers in accordance with OEM and rail transit system guidelines.

Traction Rods
Rear fixed on the carbody and in front position on the truck frame there is a connecting rod axle. At this location the inner part of the connecting rod join is attached. All longitudinal loads (traction and braking) are transmitted through these axles.

Level Sensor
The level sensor is attached to the carbody. The connecting rod is fixed to the truck frame. When the carbody level goes up or down due to different passenger load, the sensor gives signals to the electro-hydraulic controller unit (ECU). The unit controls the hydraulic valves included in the supply attached to the underframe of the carbody. The hydraulic suspension leg will be supported with lower and higher hydraulic pressure in order to keep the carbody at constant level.

X. Tools

The majority of tools used during the inspection and maintenance of rail vehicle trucks and axles have been covered in this and other rail vehicle primers. And in accordance with the APTA recommended vehicle inspection and maintenance the standard tools carried by maintenance personnel are sufficient to perform required inspection and maintenance of the majority of components of the trucks and axles described in this primer.

In addition, the necessary tools and materials needed for the inspection and maintenance of rail vehicle trucks and axles were described along with the procedures detailed throughout this primer.

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Hiawatha Corridor LRT Project, Metropolitan Council, Low Floor Rail Vehicle, Training Participant’s Guide (System)

Relevant OEM Contact Information

OEM	Website	Contact Information
Penn Machine	www.pennlocomotivegear.com/	Penn Locomotive Products Division 310 Innovation Drive Blairsville, PA 15717 U.S.A. Phone: 724-459-0302 ext. 322 Fax: 724-459-4869
Siemens	www.mobility.siemens.com/mobility/global/en/rail-solutions/Pages/rail-solutions.aspx	Division Rail Systems Nonnendammallee 101 D-13629 Berlin Phone: +49 (30) 386 0
Nippon Sharyo	www.nipponsharyousa.com	Nippon Sharyo Manufacturing, LLC 1600 Richie Court, Rochelle, IL 61068, USA Phone 1-815-562-8600 Fax: 1-815-561-3630
BOMBARDIER	http://us.bombardier.com/us	Bombardier Transit Corporation 101 Gibraltar Road, Suite 112 Horsham, PA 19044,USA Tel.: +1 215 441 1868 Fax: +1 215 441 9027
ORX	www.orxrail.com/products/	ORX One Park Avenue Tipton, Pennsylvania 16684, USA Phone: 814.684.8484 Fax: 814.684.8400
Alstom	www.alstom.com/transport/	Alstom Transport Headquarters 48, rue Albert Dhalene 93482 Saint-Ouen France Phone: +33 (0) 1 57 06 90 00
Timken	www.timken.com/en-us/solutions/rail/Pages	The Timken Company 1835 Dueber Ave. SW Canton, OH 44706-0932 Phone: 330- 438-3000 Fax: 330-458-6006

Attachment: Industry Training Standard

202. Trucks and Axles: Introduction and Preventive Maintenance

- **202.1 AC Traction Motor**

  Inspecting and maintaining speed/tach sensor
  - Explain how speed sensors work
  - Clean speed/tach sensor
  - Inspect speed/tach sensor
  - Inspect speed/tach sensor for debris
  - Repair speed/tach sensor
  - Replace speed/tach sensor

  Inspecting and maintaining stator
  - Check winding
  - Inspect stator
  - Repair stator
  - Replace stator
  - Test stator

  Inspecting and maintaining internal fan
  - Clean internal fan
  - Inspect internal fan
  - Replace internal fan

  Inspecting and maintaining external fan
  - Clean external fan
  - Inspect external fan
  - Repair external fan
  - Replace external fan

  Inspecting and maintaining bearings
  - Identify different lubricants and their appropriate use
  - Lubricate bearings
  - Check for bearing noise
  - Replace bearings

  Inspecting and maintaining wiring and insulation
  - Inspect wiring and insulation
  - Repair wiring and insulation
  - Replace wiring and insulation
  - Test wiring and insulation

  Inspecting and maintaining coupling
  - Inspect coupling; check for coupling noise
  - Lubricate coupling
  - Remove coupling
  - Replace coupling

  Inspecting and maintaining traction motor
  - Check and torque motor-to-gearbox bolts
  - Check brush holder/spring tension and for free movement of brush in holder
  - Check cable and insulation for cracks, arcing and odor
  - Check cable routing
  - Check ground shunts
  - Clean brush area and brushes
  - Clean traction motor
  - Demonstrate knowledge of commutator motor parts and assembly
  - Inspect air ducts
  - Inspect brushes/brush holders

- **202.1 AC Traction Motor (continued)**

  Inspecting and maintaining traction motor
  - Inspect traction motor
  - Lubricate traction motor where applicable, use proper lubricant and fill to proper level
  - Overhauling traction motor
  - Replace brushes/brush holders

- **202.2 DC Traction Motor**

  Inspecting and maintaining brushes
  - Demonstrate ability to use basic hand tools
  - Demonstrate knowledge of brush and brush holder function
  - Identify brush location
  - Inspect brushes
  - Measure brush wear
  - Remove excess grease
  - Replace brushes

  Inspecting and maintaining brush holders
  - Adjust brush holders
  - Check brush holders
  - Check wear limits
  - Clean off excess carbon
  - Ensure brushes have travel
  - Inspect brush holders
  - Replace brush holders
  - Test spring tension

  Inspecting and maintaining commutator/armature
  - Blow down commutator/armature
  - Check commutator/armature runout
  - Clean commutator/armature
  - Inspect commutator/armature
  - Replace commutator/armature

  Inspecting and maintaining sun gear/coupling
  - Drain sun gear/coupling
  - Inspect sun gear/coupling
  - Lubricate sun gear/coupling
  - Replace sun gear/coupling

  Inspecting and maintaining flash pins/arc horn/pin
  - Adjust flash pins/arc horn/pin
  - Inspect flash pins/arc horn/pin
  - Replace flash pins/arc horn/pin

  Inspecting and maintaining wiring and insulation
  - Inspect wiring and insulation
  - Repair wiring and insulation
  - Replace wiring and insulation
  - Test wiring and insulation

  Inspecting and maintaining field coils/interpoles
  - Clean field coils/interpoles
  - Inspect field coils/interpoles
  - Replace field coils/interpoles
  - Test field coils/interpoles

- **202.2 DC Traction Motor (continued)**
  Inspecting and maintaining bearings
    - Lubricate bearings
    - Check for bearing noise
    - Replace bearings

  Inspecting and maintaining ventilation (internal fan or forced)
    - Change breather
    - Check breather
    - Clean ventilation
    - Inspect ventilation
    - Repair ventilation
    - Replace bellows
    - Replace ventilation

  Inspecting and maintaining temperature sensors
    - Check connections
    - Replace temperature sensors

  Inspecting and maintaining speed sensor
    - Clean speed sensor
    - Inspect speed sensor for debris
    - Repair speed sensor
    - Replace speed sensor

- **202.3 Gearboxes**
  Inspecting and maintaining high-speed coupling
    - Inspect high-speed coupling; check for noise
    - Lubricate high-speed coupling
    - Remove high-speed coupling
    - Replace high-speed coupling

  Inspecting and maintaining worm gear
    - Adjust worm gear
    - Inspect worm gear
    - Repair worm gear
    - Replace worm gear

  Inspecting and maintaining pinion gear
    - Adjust pinion gear; check backlatch
    - Inspect pinion gear
    - Repair pinion gear
    - Replace pinion gear

  Inspecting and maintaining bearings/races
    - Adjust bearings/races
    - Inspect bearings/races
    - Repair bearings/races
    - Replace bearings/races

  Inspecting and maintaining lubrication
    - Change lubrication
    - Check lubrication
    - Replace lubrication
    - Test lubrication

- **202.3 Gearboxes (continued)**
  Inspecting and maintaining inspection plate and sight glass
    - Inspect inspection plate and sight glass
    - Inspect plate and sight glass
    - Replace inspection plate and sight glass
  Inspecting and maintaining housing
    - Bead-blast/clean housing
    - Clean housing
    - Inspect housing
    - Repair housing
    - Replace housing
  Inspecting and maintaining seals
    - Inspect seals for leaks
    - Replace seals
  Inspecting and maintaining spider gears
    - Inspect spider gears
    - Repair spider gears
    - Replace spider gears
  Inspecting and maintaining coupler retainer
    - Inspect coupler retainer
    - Replace coupler retainer
  Inspecting and maintaining breather
    - Clean breather
    - Inspect breather
    - Replace breather
  Inspecting and maintaining spider
    - Inspect spider
    - Replace spider
  Inspecting and maintaining magnetic plugs
    - Clean magnetic plugs
    - Inspect magnetic plugs
    - Replace magnetic plugs
  Inspecting and maintaining loading/support rod
    - Inspect loading/support rod
    - Replace loading/support rod
  Inspecting and maintaining ground bushing housing
    - Clean ground bushing housing
    - Inspect ground bushing housing
    - Replace ground bushing housing
    - Test ground bushing housing

- **202.4 Axles**
  Inspecting and maintaining rotor (brake disc)
    - Inspect rotor
    - Machine rotor
    - Replace rotor
  Inspecting and maintaining wheel assembly
    - Demonstrate ability to follow proper safety procedures
    - Inspect wheel assembly
    - Remove wheel assembly
    - True wheel assembly

- **202.4 Axles (continued)**

  Inspecting and maintaining spider and vulcanized spacers/joint coupling assembly
    - Inspect spider and vulcanized rubber spacers/joint coupling assembly
    - Replace spider and vulcanized rubber spacers/joint coupling assembly

  Inspecting and maintaining tooth gear (speed sensor)
    - Clean tooth gear
    - Inspect tooth gear
    - Replace tooth gear

  Inspecting and maintaining ground brush and housing
    - Clean ground brush and housing
    - Inspect ground brush and housing
    - Replace ground brush and housing
    - Test ground brush and housing

  Inspecting and maintaining hollow shaft
    - Inspect and measure hollow shaft
    - Inspect hollow shaft

  Inspecting and maintaining journal bearings and housing
    - Clean journal bearings and housing
    - Inspect journal bearings and housing
    - Repack journal bearings and housing

- **202.5 Wheel and Tires**

  Inspecting and maintaining shunts
    - Clean connections
    - Inspect shunts
    - Replace shunts
    - Test shunts

  Inspecting and maintaining rubber
    - Inspect rubber
    - Replace rubber

  Inspecting and maintaining bolts
    - Inspect bolts
    - Replace bolts

  Inspecting and maintaining conical ring
    - Inspect conical ring
    - Replace conical ring

  Inspecting and maintaining dampening ring
    - Inspect dampening ring
    - Replace dampening ring

  Perform preventive maintenance on tires
    - Inspect tires
    - Inspect tires and flange for cracks
    - Measure tires
    - Remove tires
    - Replace tires
    - True tires

  Inspecting and maintaining plugs
    - Inspect plugs
    - Replace plugs

- **202.6 Primary Suspension**

  Inspecting and maintaining chevrons/rubber springs
  - Disassemble chevrons/rubber springs
  - Inspect chevrons/rubber springs
  - Measure chevrons/rubber springs
  - Reassemble chevrons/rubber springs
  - Replace chevrons/rubber springs
  - Shim chevrons/rubber springs

  Inspecting and maintaining journal bearing housing
  - Clean bearings
  - Demonstrate knowledge of scratching and pitting bearings
  - Identify and use correct type of grease
  - Inspect journal bearing housing
  - Replace bearings
  - Replace journal bearing housing

  Inspecting and maintaining speed sensors
  - Adjust speed sensors
  - Inspect speed sensors
  - Replace speed sensors
  - Test speed sensors

  Inspecting and maintaining up stops and down stops/pedestal bar
  - Adjust up stops and down stops/pedestal bar
  - Inspect hardware
  - Repair up stops and down stops/pedestal bar
  - Replace up stops and down stops/pedestal bar

- **202.7 Frame**

  Inspecting and maintaining traction/radius rod and bushings
  - Check for cracks in frame
  - Adjust traction/radius rod and bushings
  - Inspect traction/radius rod and bushings
  - Replace traction/radius rod and bushings

  Inspecting and maintaining bovine board/cow catcher/safety board/life guard
  - Inspect bovine board/cow catcher/safety board/life guard
  - Replace bovine board/cow catcher/safety board/life guard

  Inspecting and maintaining transom bearings/front and rear beam
  - Demonstrate ability to use truck lifts
  - Inspect transom bearings/front and rear beam
  - Inspect wiring
  - Replace bushings/bearings
  - Replace transom bearings/front and rear beam

  Inspecting and maintaining antennas
  - Inspect antenna
  - Replace antenna
  - Test antenna

  Inspecting and maintaining speed sensor device
  - Adjust speed sensor device
  - Inspect speed sensor device
  - Replace speed sensor device
  - Test speed sensor device

- **202.7 Frame (continued)**

  Inspecting and maintaining fenders
    - Clean fenders
    - Inspect fenders
    - Repair fenders

  Inspecting and maintaining sanding tubes
    - Adjust sanding nozzle to proper height
    - Adjust sanding tubes
    - Align sanding tubes
    - Disassemble sanding tubes
    - Reassemble sanding tubes
    - Inspect heater nozzles
    - Inspect sanding tubes
    - Repair sanding tubes
    - Replace heater nozzles
    - Test heater nozzles

  Inspecting and maintaining lubricators
    - Adjust lubricators
    - Align lubricators
    - Inspect lubricators
    - Repair lubricators

  Inspecting and maintaining wiring
    - Inspect wiring
    - Repair wiring
    - Replace wiring

  Inspecting and maintaining tripping device
    - Adjust tripping device
    - Inspect tripping device
    - Remove as needed

  Inspecting and maintaining piping
    - Flush piping
    - Inspect piping
    - Inspect piping for leaks
    - Repair piping
    - Replace piping

  Inspecting and maintaining track brake
    - Adjust hangers/support/suspension
    - Adjust pole/segment pieces/brake pads/brake shoes
    - Align hangers/support/suspension
    - Inspect bushings
    - Inspect cabling
    - Inspect guide pads
    - Inspect hangers/support/suspension
    - Inspect pole/segment pieces/brake pads/brake shoes
    - Inspect wiring
    - Repair hangers/support/suspension
    - Repair wiring
    - Replace bushings
    - Replace cabling
    - Replace guide pads

- **202.7 Frame (continued)**

  Inspecting and maintaining track brake (continued)
  - Replace pole/segment pieces/brake pads/brake shoes
  - Replace wiring
  - Test cabling
  - Test wiring

  Inspecting and maintaining debris sweeper
  - Adjust debris sweeper
  - Inspect debris sweeper
  - Replace debris sweeper

  Inspecting and maintaining down hanger (caliper hanger)
  - Inspect down hanger
  - Lubricate down hanger
  - Replace down hanger

  Inspecting and maintaining brake shoe support/brake hanger
  - Inspect brake shoe support/brake hanger
  - Lubricate brake shoe support/brake hanger
  - Repair brake shoe support/brake hanger
  - Replace brake shoe support/brake hanger

  Inspecting and maintaining lateral bumper/stop
  - Inspect lateral bumper/stop
  - Replace lateral bumper/stop

- **202.8 Bolster/Secondary Suspension**

  Inspecting and maintaining coil spring
  - Inspect coil spring
  - Replace coil spring

  Inspecting and maintaining airbags
  - Drain air tanks/reservoir
  - Inspect air tanks/reservoir
  - Inspect airbags
  - Remove airbags
  - Replace bias/check valves
  - Replace bypass/cutoff valves
  - Test bias/check valves
  - Test bypass/cutoff valves

  Inspecting and maintaining leveling device
  - Adjust leveling device
  - Inspect leveling device
  - Replace leveling device

  Inspecting and maintaining load weight sensor
  - Adjust load weight sensor
  - Inspect load weight sensor
  - Inspect wiring
  - Repair wiring
  - Replace load weight sensor
  - Replace wiring
  - Test load weight sensor
  - Test wiring

- **202.8 Bolster/Secondary Suspension (continued)**

  Inspecting and maintaining hydraulic suspension leg
    - Inspect accumulator (hydraulic)
    - Inspect hydraulic suspension leg
    - Replace accumulator (hydraulic)
    - Replace hydraulic suspension leg
    - Test accumulator (hydraulic)

  Inspecting and maintaining vertical stop/lifting rods
    - Adjust vertical stop/lifting rods
    - Inspect vertical stop/lifting rods
    - Replace vertical stop/lifting rods

  Inspecting and maintaining shocks/dampers
    - Adjust shocks/dampers
    - Inspect shocks/dampers
    - Refill oil
    - Replace shocks/dampers
    - Test shocks/dampers

  Inspecting and maintaining piping
    - Flush piping
    - Inspect piping
    - Inspect piping for leaks
    - Repair piping
    - Replace piping

  Inspecting and maintaining friction disc/side bearing
    - Adjust friction disc/side bearings
    - Inspect friction disc/side bearings
    - Replace friction disc/side bearings

  Inspecting and maintaining shims (floor height adjustment/static inspection)
    - Add shims as needed
    - Check shims (floor height adjustment/static inspection)

  Inspecting and maintaining spherical ring/slewing ring
    - Inspect spherical bearing/slewing ring
    - Lubricate spherical bearing/slewing ring
    - Replace spherical bearing/slewing ring

  Inspecting and maintaining articulation support
    - Inspect articulation support
    - Repair articulation support

  Inspecting and maintaining ball and socket
    - Inspect ball and socket
    - Replace Teflon liner

- **202.9 Tools**

  NOTE: Can be integrated in other parts of module or taught separately.

  Demonstrate ability to use an axle press
  Demonstrate ability to use a wheel press
  Demonstrate ability to use a wheel bore
  Demonstrate ability to use a wheel profile gauge
  Demonstrate ability to use a back-to-back gauge
  Demonstrate ability to use a depth gauge

- **202.9 Tools (continued)**
  Demonstrate ability to use a wheel tape/pie tape gauge
  Demonstrate ability to use a steel wheel gauge
  Demonstrate ability to use a dial indicator
  Demonstrate ability to use a car body height gauge
  Demonstrate ability to use a coupler height gauge
  Demonstrate ability to use a tape measure/ruler
  Demonstrate ability to use an armature run-out gauge
  Demonstrate ability to use a coupler level gauge
  Demonstrate ability to use a grease level gauge
  Demonstrate ability to use a feeler gauge
  Demonstrate ability to use a go no-go gauge
  Demonstrate ability to use a current collector gauge
  Demonstrate ability to use a trip device gauge
  Demonstrate ability to use a ultrasonic wheel measuring tool/profile meter
  Demonstrate ability to use a wheel truing machine
  Demonstrate ability to use a truck/tramming press
  Demonstrate ability to use a tire press
  Demonstrate ability to use a journal bearing press
  Demonstrate ability to use an industrial sized bandsaw
  Demonstrate ability to use a lathe
  Demonstrate ability to use undercutters
  Demonstrate ability to use mills
  Demonstrate ability to use a spin/load tester
  Demonstrate ability to use a hydraulic press
  Demonstrate ability to use a hydraulic fluid cleaning machine
  Demonstrate ability to use an inductive bearing heater
  Demonstrate ability to use a truck frame tester
  Demonstrate ability to use a hydraulic test bench/hydraulic caliper test bench/brake force tester
  Demonstrate ability to use portable test equipment
  Demonstrate ability to use a breakout box
  Demonstrate ability to use gearbox specialty tools
  Demonstrate ability to use brake adjustor tools
  Demonstrate ability to use a hydraulic pullers
  Demonstrate ability to use a torque wrench
  Demonstrate ability to use a megger
  Demonstrate ability to use a digital multi-meter
  Demonstrate ability to use a hydraulic vulcanized rubber spacers
  Demonstrate ability to use a parts-per-million brake fluid tester
  Demonstrate ability to use an oven
  Demonstrate ability to use an impregnator
  Demonstrate ability to use a plasma cutter
  Demonstrate ability to use a hoist
  Demonstrate ability to use basic hand tools
  Demonstrate ability to use a laptop and diagnostic software
  Demonstrate ability to use a bearing puller
  Demonstrate ability to use a test stand

RAIL VEHICLE LEVEL 200
SUBJECT OVERVIEW

Module 203: Propulsion and Dynamic Braking

Note: All 200 level courses should be delivered only after completion of 100 level training

About the Author

Frank L Harris II is a Senior Shop Steward, ATU Local 732 at the Metropolitan Atlanta Rapid Transit Authority (MARTA). Frank was born and raised in Atlanta, and served with the United States Air Force in Vietnam. He attended Atlanta Technical College specializing in diesel mechanics, auto mechanic and carpentry. He has worked in several technical positions with Southern Bell as a telephone installer, with Northfolk Southern Railway as a machinist / mechanic, with Earily Rival Motor Express as a bus mechanic, with Lockheed Martin as a structures and final assembler, and now with MARTA as a journeymen mechanic. Frank has been employed with MARTA for 25 years, and serves as a member of the Rail Vehicle Committee.

Overview/Purpose

This material provides a general overview of rail car propulsion and dynamic braking to give technicians a basic introduction to the subject and prepare them for national qualification testing. Propulsion refers to the electrical system that powers transit rail vehicles, while dynamic braking is the use of the same electric traction motors that propels the vehicle as generators when slowing the rail vehicle.

Everything in the universe is being pushed, pulled or propelled. This action is called propulsion. The word is derived from two Latin words: Pro: meaning before or forwards and Pellere: meaning to drive. (1.) There are different types of propulsion systems; mechanical, electrical and chemical. Examples are: bicycle (mechanical) rocket engine (chemical) and locomotives or rail cars (electrical). For this primer electrical propulsion will be the focus. Rail systems utilize several types of electrical propulsion systems. Until recently all were mostly driven by electric motors; that is until Maglev technology was discovered. It is a system of transportation using magnetic levitation to suspend, guild and propel a train. (2). The major difference between train propulsion systems is how the motors are energized. Most use either AC (Alternating Current) or DC (Direct current) systems. Both systems are different in nature but deliver the same result; that is to move the train from one point to another. The major components of each system and their functions will be explained in detail.

Material presented here is intended only as a primer to the subject, keeping in mind that rail systems have different characteristics. It follows the National Training Standards established jointly by representatives from both labor and management. As a primer additional knowledge will be needed to become fully qualified on this subject. Material presented here does not address every possible aspect because propulsion and dynamic braking vary at each transit agency. Supplemental courseware and other resources to help technicians become qualified on this subject are listed below.

Table of Contents

Suggested Tools/Training Aids:

- power point presentations
- transparencies
- manuals
- schematics
- mock-up/live-coupler
- video/animations
- Schematics
- lap top computer
- tools listed in L.O.s
- scope-meter/o-scope

Topics Covered:

Topics listed below are covered in this introduction of propulsion and dynamic braking. A full copy of the National Training Standards from which these topics were taken is attached.

- AC Propulsion: AC propulsion uses alternating current to power rail vehicles. With alternating current the movement of electric charge periodically reverses direction. In rail propulsion applications DC Power is supplied to car from the third rail, pantograph, etc. and is converted to AC Power onboard the cars. AC traction is said to improve passenger comfort and provide cost savings. AC propulsion produces smoother acceleration and braking. Trains also use AC power more efficiently, thereby lowering operating and maintenance costs, and generating less wear and tear on the rails and cars because of the way the power is supplied. Through power regeneration, AC propulsion also offers some power savings. Some of the power used to accelerate the train can be recovered and put back into the third rail when stopping the train. This provides additional power to accelerate other trains and reduces the total amount of energy required to run the system.

- DC Propulsion: DC propulsion uses current directly from the source (third rail, pantograph, etc.) without converting it. DC current flows in one direction in the circuit, not in two directions as is the case with AC systems.

- Dynamic Braking: Dynamic braking uses the electric traction motors of a rail vehicle as generators to slow down the vehicle. It is termed rheostatic braking if the generated electrical power is dissipated as heat in brake grid resistors, and as regenerative braking if the power is returned to the supply line to be reused. Dynamic braking lowers the wear of friction-based braking components, and additionally regeneration can also lower energy consumption. Dynamic braking alone is insufficient to stop a rail car at lower speeds, typically below 10 miles per hour (mph), braking effect rapidly diminishes. Therefore, dynamic braking is used in conjunction with the regular air brake system. This combined system is called blended braking.

Definitions, Abbreviations and Acronyms

For the purposes of this lesson, the following glossary of terms, definitions, acronyms, and abbreviations shall apply. They are not all inclusive, and the reader is encouraged to explore the text, footnotes and bibliography sources for further information.

Definitions: With a diversity of manufacturers and rail transit agencies, it is necessary to establish a common vocabulary to describe components that are identical or similar in nature and function. For the purposes of clarity the following terms and definitions will be used in this document: (as taken from APTA)

- **Inverter:** An electrical device that converts direct current (DC) to alternating current (AC).
- **Master Controller:** A control device used by the train operator to apply or reduce power to the train.
- **Ventilation system:** An electronically-controlled air management system to keep electronic power systems operating at the correct temperature.

Abbreviations and acronyms

- **AC:** Alternating Current
- **ANSI:** American National Standards Institute
- **APTA:** American Public Transportation Association
- **CFR**: Code of Federal Regulations
- **DC:** Direct Current
- **ECU:** Electronic Control Unit
- **GTO:** Gate Turn Off
- **IGBT:** Insulated Gate Bipolar Transistor
- **I/O**: Input/Output
- **MSDS**: Material Safety Data Sheet
- **OEM**: Original Equipment Manufacturer
- **OSHA**: Occupational Safety and Health Administration

Introductory Text by Topic Area

1.0 Alternating Current (AC) Propulsion
2.0 Direct Current (DC) Propulsion
3.0 Dynamic Braking

I. Alternating Current (AC) Propulsion

Alternating current or AC propulsion is a system that takes the Direct Current (DC) being supplied to the train from a power source (typically a third rail or overhead pantograph) and changes it onboard the car into current that is flowing in one direction with the ability to reverse directions in the same circuit. The major components of an AC propulsion system are:

- Inverter
- Master controller
- Train line control
- IGBT/GTO
- Electronic control system
- Software
- Ventilation system
- Capacitor filtering coils
- Chokes/transformers
- High speed circuit breakers
- Ground fault system
- Contactor/arc chutes
- Resistance units
- Knife switch
- DC link
- Traction Motor
- Speed sensors/Tachometer sensors

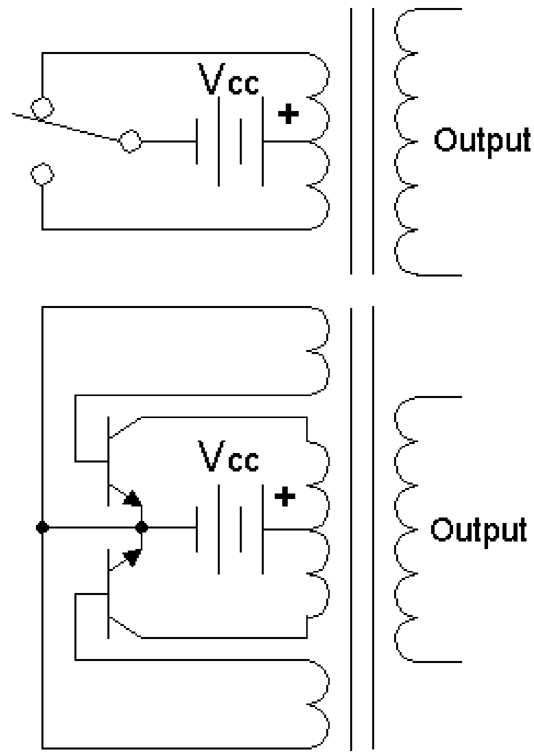


Figure 1: Basic Inverter Circuit

Each component of an AC Propulsion system and its function are described in greater detail below.

Inverter: An electrical device that converts direct current (DC) to alternating current (AC). The converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. Figure 1 shows a basic inverter circuit.

Master Controller: The train operator's (driver's) power control device located in the cab. The driver moves the handle of the master controller to apply or reduce power to the train. Figure 2 is an example.

Figure 2: Master Controller

Figure 3: Insulated Gate Bipolar Transistor (IGBT)

IGBT/GTO: The Insulated Gate Bipolar Transistor (IGBT) is replacing the GTO (Gate Turn Off). It is a type of diode with a controlling gate that allows current to pass through it when the gate is energized. The gate is closed by the current being applied to the thyristor in the reverse direction. Thyristors (also referred to as choppers) are used for traction power control in place of resistance control systems. A GTO thyristor is a system in which current is turned off by applying a pulse of current to the gate.

IGBT is an electronic solid state device capable of controlling the amount of current flowing as well as switching it on and off. In the last few years, a powerful version has been applied to railway traction in the form of the Insulated Gate Bipolar Transistor (IGBT). Its principle advantage over the GTO Thyristor is its speed of switching and that its controls require much smaller current levels. Figure 3 shows an IGBT.

Ventilation System: An electronically-controlled air management system located in the interior of a modern rail vehicle needed to keep the Thyristors and other electronic power systems cool and operating at the correct temperature. The fans are powered by an auxiliary inverter producing 3-phase AC at about 400 volts.

Capacitor Filtering Coils: Devices that are made up of capacitors and coils used to protect the system from electrical surges.

Software: Newer rail cars are control by a computer system that helps the railcar operate more efficiently. The computer systems have written programs known as software that monitor, diagnose and store information that is critical in repairing, upgrading and having a record of what is occurring within the rail car systems.

Electronic control system: All modern transit systems are control with computers. These devices control the train's direction, braking and train spacing, and are needed to avoid collisions and to effectively control the train's arrival and departure times. Figure 4 shows a technician using a laptop computer loaded with software programs to communicate with a rail car.

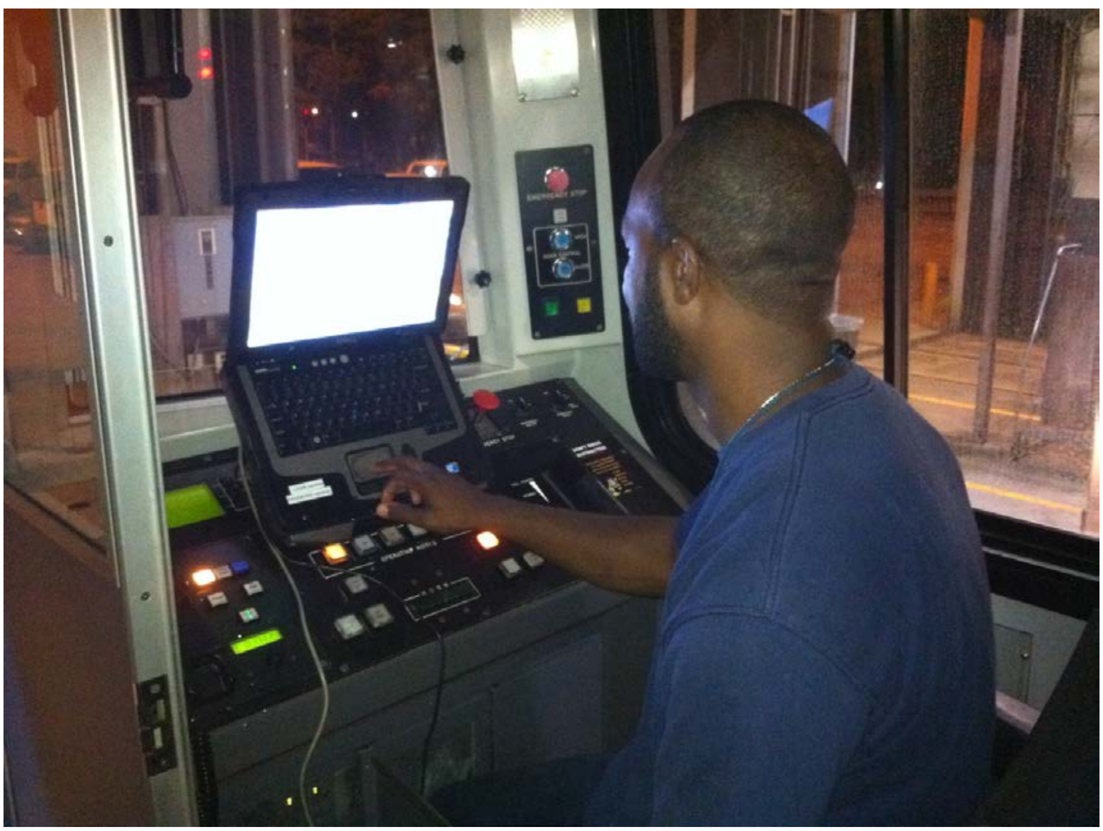


Figure 4: Laptop communication with rail car

Contactor/arc Chutes: Similar to a relay in that it is a remotely operated switch used to control a higher power local circuit. The difference is that contactors normally latch or lock closed and have to be opened by a separate action. A lighting contactor will have two, low voltage operating coils, one to "set" the contactor closed to switch on the lights; the other to "trip" off the lights. Figure 5 is a schematic of a simple contactor operation.

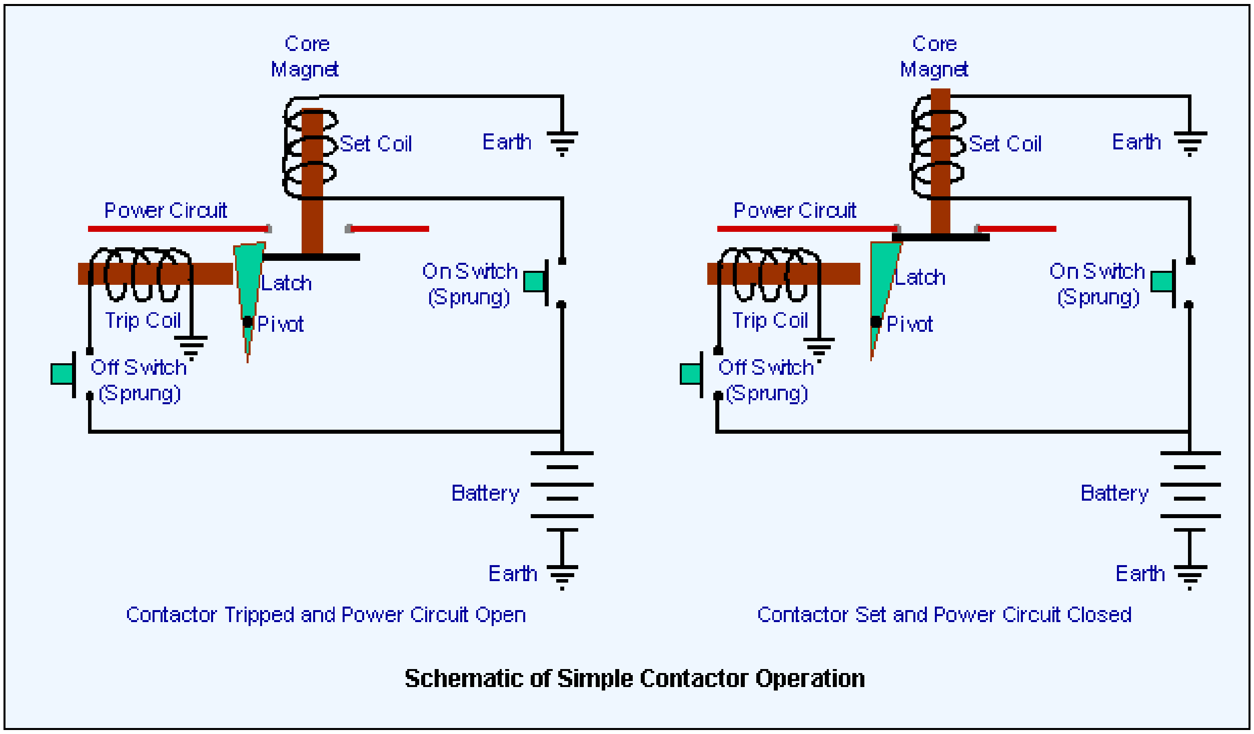


Figure 5: Simple Contactor

Knife switch: A device used to disconnect the electrical current on a railcar from main power (Third Rail or Overhead line) keeping the collector Paddles or contact shoe and traction motors from being energize. This is used when repairs have to be made to the rail car using main power. Figures 6 and 7 show the knife box switch box in the open and closed positions.

Figure 6: Knife switch box open view

Figure 7: Knife box switch close view

(DC link): Used on modern electronic power systems between the single phase rectifier and the 3-phase inverter. It is easier to convert the single phase AC from the overhead line to the 3-phase required for the motors by rectifying it to DC and then inverting the DC to 3-phase AC

Traction Motor: an electric motor providing the primary rotational torque of a machine, usually for conversion into linear motion (traction).

Figure 8: AC Traction Motor

Traction motors are used in electrically powered rail vehicles such as electric multiple units and electric locomotives, other electric vehicles such as electric milk floats, elevators and conveyors as well as vehicles with electrical transmission systems such as diesel-electric, electric hybrid vehicles and battery electric vehicles. Additionally, electric motors in other products (such as the main motor in a washing machine) are described as traction motors. Figure 8 shows an AC tractor motor on display, while Figure 9 shows it mounted in a rail car truck.

Figure 9: Traction Motor mounted in a truck

Speed sensors/Tach sensors: Tach Sensors are device attached to traction motors to monitor the speed of the motors which is relayed to the railcar's logic. Speed sensors are attached to the gearbox housing to monitor the gear and axle speed. Pictured below are examples of a Tach sensor and speed sensor. Figure 10 shows a tach sensor, Figure 11 a speed sensor.

Figure 10: Tach Sensor

Figure 11: Speed Sensor

Chokes/transformers: A set of windings with a magnetic core used to step down or step up voltage from one level to another. The voltage differences are determined by the proportion of windings on the input side compared with the proportion on the output side. An essential requirement for locomotives and trains using AC power is the ability to provide different voltages to different components as needed.

High speed circuit breakers: used to protect the system from high voltage surges.

Ground fault system: An electrical relay provided in diesel and electric traction systems to protect the equipment against damage from earths and so-called "grounds". The result of such a relay operating is usually a shut-down of the electrical drive. This is also sometimes called an Earth Fault Relay.

Resistance units: Method of traction motor control formerly almost universal on DC electric railways whereby the power to the motors was gradually increased from start up by removing resistances from the power circuit in steps. Originally this step control was done manually but it was later automatic, a relay in the circuit monitoring the rise and fall of current as the steps were removed. Many examples of this system still exist but new builds now use solid state control with power electronics.

II. Direct Current (DC) Propulsion

In DC powered trains the current is taken directly from the source without converting it. DC current flows in one direction in the circuit, not in two directions as is the case with AC propulsion systems. The major components of a DC propulsion system include:

- Chopper
- Cam control
- Master controller
- ECU
- Ventilation system
- High speed circuit breaker
- Contactor/arc chutes
- Resistance bank
- Knife switch (DC link)
- Over-current protection

Chopper: An electric traction control that eliminates the need for power resistors by causing the voltage to the traction motors to be switched on and off (chopped) very rapidly during acceleration to ensure motor output is smooth. It is accomplished by the use of thyristors and will give up to 20% improvement in efficiency over conventional resistance control.

Cam control: Another form of speed control used on most DC electric traction power circuits is to use a camshaft to open or close the contactors controlling the resistances of the traction motor power circuit. The camshaft is driven by an electric motor or pneumatic cylinder. The cams on the shaft are arranged to ensure that the contactors open and close in the correct sequence. It is controlled by commands from the driver's cab and regulated by the fall of current in the motor circuit as each section of resistance is cut out in steps. The sound of this camshaft stepping can be heard under many older (pre electronics) trains as they accelerate.

Master controller: Serves the same purpose as in AC system

ECU: The Electronic Control Unit (ECU) contains all of the input/output (I/O) boards used to control and Monitor the various locomotive sensors, plus optional functions such as the integrated Event Recorder. The interface panel displays data for diagnostics, speed control, self-tests, operational and alarm data, and entering setup parameters. Ancillary equipment satisfies the sensing, control, and communication requirements.

Ventilation system: Most DC Motor systems are cooled and ventilated with forced air that is supplied by external blowers or internal mounted blowers. An external blower is shown in Figure 12, while an internal mounted blower motor is shown in Figure 13.

Figure 12: External ventilation blower

Figure 13: Internal ventilation blower

High speed circuit breaker: Sharp spikes of current will quickly damage a DC motor so protective equipment is provided in the form of an "overload relay", which detects excessive current in the circuit and, when it occurs, opens the circuit to avoid damage to the motors. Power is switched off by means of Line Breakers, one or two heavy-duty switches similar to circuit breakers which are remotely controlled. They would normally be opened or closed by the action of the driver's controller but they can also be opened automatically by the action of the overload relay.

Contactor/arc chutes: Similar to a relay in that it is a remotely operated switch used to control a higher power local circuit. The difference is that contactors normally latch or locks closed and has to be opened by a separate action.

Resistance bank: Method of traction motor control formerly almost universal on DC electric railways whereby the power to the motors was gradually increased from start up by removing resistances from the power circuit in steps. Originally this step control was done manually but it was later automatic, a relay in the circuit monitoring the rise and fall of current as the steps were removed. Many examples of this system still exist but new cars now use solid state control with power electronics.

Over-current protection: A power circuit relay which detected excessive current in the circuit and switched off the power to avoid damage to the motors.

III. Dynamic Braking

As mentioned above, dynamic braking uses the electric traction motors of a rail vehicle as generators to slow down the vehicle with two type of systems used: rheostatic braking and regenerative braking.

Before the advent of power electronics, there were some attempts to combine the two forms of what we now call "dynamic braking" so that the generated current would go to the power supply overhead line or third rail if it could be absorbed by other trains but diverted to on-board resistors if not. In the case of diesel-electric locomotives, dynamic braking is restricted to the rheostatic type. Racks of resistors can often be seen on the roofs of heavy-haul locomotives for which dynamic braking is a big advantage on long downhill grades where speed must be maintained at a restricted level for long periods, such as descending a mountain.

Regenerative Braking

Since the DC motor and a DC generator are virtually the same machine mechanically, it was immediately realized that a train could use its motors to act as generators and that this would provide some braking effect if a suitable way could be found to dispose of the energy. The idea formed that if the power could be returned to the source, other trains could use it. Trains were designed therefore, which could return current, generated during braking, to the supply system for use by other trains. Various schemes were tried over many years with more or less success but it was not until the adoption of modern electronics that reliable schemes have been available.

Rheostatic Braking

The major drawback with the regenerative braking system is that the line is not always able to accept the regenerated current. Some railways had substations fitted with giant resistors to absorb regenerated current not used by trains but this was a complex and not always reliable solution. As each train already had resistors, it was a logical step to use these to dispose of the generated current. The result was rheostatic braking. When the driver calls for brake, the power circuit connections to the motors are changed from their power configuration to a brake configuration and the resistors inserted into the motor circuit. As the motor generated energy is dispersed in the resistors and the train speed slows, the resistors are switched out in steps, just as they are during acceleration. Rheostatic braking on a DC motored train can be continued down to less than 20 mph when the friction brakes are used to bring the train to a stop.

Bibliography

APTA RP-I&M-001-98 Rev 1 Recommended Practice for Battery System Periodic Inspection and Maintenance

APTA SS-I&M-008-98 Rev 1 Standard for Electrical Periodic Inspection and Maintenance

APTA RP-E-006-99 Recommended Practice for Diesel Electric Passenger Locomotive Dynamic Brake Control

Relevant OEM Contact Information

OEM	Website	Location
Bombardier/ABB/Adtrans	http://www.bombardier.com/	Horsham, PA
Mitsubishi	http://www.mitsubishielectric-usa.com	Cypress, CA
Breda	http://www.ansaldobredainc.com/contact-us	San Francisco, CA
Siemens	http://www.mobility.siemens.com/usa/	Sacramento, CA
Toshiba Corp.	http://www.tic.toshiba.com	13131 West Little York Rd. Houston, TX 77041
ABB/Adtranz	http://www.abb.us/	Cary, NC
Alstom	http://www.alstom.com/us/	New York, NY
GE	http://www.ge.com/	Erie, PA
Vossloh/Kiepe	http://www.vossloh-usa.com/	Alpharetta, GA

Attachment: Industry Training Standard

203. Propulsion and Dynamic Braking -- Intro and Preventive Maintenance

- **203.1 AC Propulsion**

  Inspecting and maintaining propulsion inverter
  - Clean and blow out inverter enclosure
  - Check for leaking capacitors and oil
  - Demonstrate ability to follow safety procedures
  - Demonstrate ability to read electrical schematics
  - Demonstrate knowledge of three phase motors
  - Torque screws to specifications
  - Use high-pressure on appropriate areas

  Inspecting and maintaining master controller (for AC propulsion system)
  - Check lever for free movement
  - Demonstrate knowledge of pulse width modulation
  - Inspect master controller for debris
  - Lubricate using proper lubricant
  - Overhauling master controller
  - Repair master controller
  - Replace master controller
  - Test master controller

  Inspecting and maintaining train line control
  - Demonstrate knowledge of active high and low
  - Demonstrate knowledge of difference between a short and an open circuit
  - Demonstrate knowledge of grounding
  - Identify correct coupler pins
  - Read and interpret schematics

  Inspecting and maintaining the IGBT/GTO
  - Clean IGBT/GTO
  - Demonstrate knowledge of capacitor charge
  - Demonstrate knowledge of electrostatic discharge
  - Demonstrate knowledge of lock out/tag out
  - Demonstrate proper use of thermal compound
  - Follow procedures for making unit safe to work on
  - Inspect IGBT/GTO for damage and odor
  - Overhaul IGBT/GTO
  - Perform reduced power test
  - Repair module
  - Replace module
  - Test IBGT/GTO using laptop

  Inspecting and maintaining electronic control system
  - Access faults
  - Access history
  - Clean electronic control system
  - Demonstrate ability to read hexadecimal code
  - Demonstrate ability to read the LEDs
  - Demonstrate knowledge of MVFB (multifunction vehicle bus)
  - Inspect electronic control system
  - Overhauling electronic control system

- Read LEDs on propulsion container
- Replace cards
- Replace electronic control system
- Test electronic control system
- Test individual modules
- Test input and output

Inspecting and maintaining software

- Demonstrate ability to use testing functions
- Locate connectors
- Upgrade software
- Ping connectors to read values
- Take measurements using connectors
- Verify correct version of software

Inspecting and maintaining ventilation system

- Blow out sensors and blower fans
- Check airflow direction
- Check all fasteners
- Check fans using reduced power test
- Check pipe routing
- Check TCU for blower faults
- Check ventilation system for debris
- Clean ventilation system
- Identify intake and exhaust ends
- Lubricate ventilation system
- Overhaul ventilation system
- Perform air flow test on ventilation system using proper safety procedures
- Repair fan and motor assembly
- Repair sensors
- Replace fan and motor assembly
- Replace filter following proper safety procedures
- Replace sensors
- Unclog heat sink
- Use proper nozzle for blowout

Inspecting and maintaining capacitor filtering coils

- Identify leaks and bulges
- Inspect capacitor filtering coils for arcing, debris and damage
- Overhaul capacitor filtering coils
- Replace capacitor filtering coils
- Test capacitor filtering coils

Inspecting and maintaining chokes/transformer

- Inspect chokes/transformer
- Overhaul chokes/transformer
- Replace chokes/transformer

Inspecting and maintaining high-speed circuit breaker

- Adjust high-speed circuit breaker
- Check fuse
- Check operation of main solenoid
- Clean high-speed circuit breaker
- Disassemble high-speed circuit breaker

- Inspect high-speed circuit breaker
- Overhaul high-speed circuit breaker
- Test high-speed circuit breaker

Inspecting and maintaining ground fault system

- Change blown fuses
- Check fuses
- Demonstrate ability to read VOD (vehicle operator display)
- Inspect brushes, springs, wires and connectors
- Inspect ground fault system
- Isolate system
- Overhaul ground fault system
- Reset GFS relay
- Test fuses
- Test ground fault system

Inspecting and maintaining contactor/arc chutes

- Adjust contactor/arc chutes
- Clean contactor/arc chutes with compressed air
- Identify different types of connectors
- Identify excessive arcing
- Inspect contactor/arc chutes
- Overhauling contactor/arc chutes
- Replace contactor/arc chutes
- Test contactor/arc chutes

Inspecting and maintaining resistance units

- Check insulators and cage
- Check resistance
- Clean resistance units
- Inspect resistance units for cracks and damage
- Overhaul resistance units
- Replace resistance units

Inspecting and maintaining knife switch (DC link)

- Adjust knife switch
- Clean knife switch
- Inspect knife switch
- Lubricate knife switch
- Overhauling knife switch
- Replace knife switch
- Test knife switch

Inspecting and maintaining traction motor

- Blow out traction motor
- Check cable routing
- Check fasteners
- Clean drain hole
- Clean traction motor
- Demonstrate knowledge of motor parts
- Inspect traction motor
- Lubricate traction motor in proper place using correct lubricant and correct amount
- Overhaul traction motor

Inspecting and maintaining speed sensors/tach sensors

- Adjust speed sensors/tach sensors
- Clean speed sensors/tach sensors
- Inspect speed sensors/tach sensors, wiring and connectors
- Overhaul speed sensors/tach sensors (if done locally)
- Remove speed sensors/tach sensors
- Replace speed sensors/tach sensors

Inspecting and maintaining speed sensor cable

- Test speed sensor cable
- Replace speed sensor cable

Inspecting and maintaining load weight sensors

- Adjust load weight sensors
- Inspect load weight sensors
- Inspect wearable items
- Measure wheel, floor level and load
- Overhaul load weight sensors (if done locally)
- Replace load weight sensors
- Replace wearable items
- Test load weight sensors

Inspecting and maintaining load cell

- Adjust link bar
- Adjust value
- Test value

Inspecting and maintaining overcurrent protection

- Check operation of overcurrent protection
- Clean overcurrent protection
- Overhauling overcurrent protection
- Replace overcurrent protection

Inspecting and maintaining pulse conditioning unit

- Test pulse conditioning unit
- Replace pulse conditioning unit

- **203.2 DC Propulsion**

Inspecting and maintaining chopper

- Check capacitor bank for leaks
- Clean above, around and interior of enclosure
- Clean capacitor bank
- Clean chokes/transformers
- Clean heat sink
- Clean thyristors
- Demonstrate knowledge of location and function of chopper
- Disassemble thyristors
- Identify capacitor bank
- Inspect capacitor bank
- Inspect chokes/transformers
- Inspect thyristors
- Overhaul chopper
- Reassemble thyristors
- Replace capacitor bank
- Replace chokes/transformers
- Replace thyristors

Inspecting and maintaining cam control

- Adjust cams and switches
- Adjust contactors
- Clean cams and switches
- Clean pilot motor
- Explain difference between acknowledgement and actuator contacts
- Inspect cams and switches
- Inspect pilot motor
- Overhaul cam control
- Repair pilot motor
- Replace cams and switches
- Replace pilot motor
- Test pilot motor

Inspecting and maintaining master controller (for DC propulsion system)

- Check lever for free movement
- Demonstrate knowledge of pulse width modulation
- Inspect master controller for debris
- Locate and use repair manual
- Lubricate using proper lubricant
- Overhaul master controller
- Repair master controller
- Replace master controller
- Test master controller

Inspecting and maintaining electronic control unit

- Access faults
- Access history
- Calibrate after battery removal
- Change batteries
- Clean electronic control system
- Demonstrate knowledge of MVFB (multifunction vehicle bus)
- Identify cards by box number
- Inspect electronic control system
- Overhaul electronic control unit
- Interpret LEDs on propulsion container
- Replace cards
- Replace electronic control system
- Set time/date on TCU
- Test electronic control system
- Test individual modules
- Test input and output

Inspecting and maintaining ventilation system

- Adjust air flow sensor and timers
- Blow out sensors and blower fans
- Check airflow direction, unclog heat sink if needed
- Check all fasteners
- Check fans using reduced power test
- Check pipe routing
- Check TCU for blower faults
- Check ventilation system for debris

- Clean ventilation system
- Demonstrate knowledge of blower monitor circuit
- Identify intake and exhaust ends
- Lubricate ventilation system
- Overhaul ventilation system
- Perform air flow test on ventilation system using proper safety procedures
- Repair fan and motor assembly
- Repair sensors
- Replace fan and motor assembly
- Replace filter following proper safety procedures
- Replace sensors
- Use proper nozzle for blow out

Inspecting and maintaining high-speed circuit breaker

- Adjust high-speed circuit breaker
- Check fuse
- Check operation of main solenoid
- Clean high-speed circuit breaker
- Disassemble high-speed circuit breaker
- Inspect high-speed circuit breaker
- Overhauling high-speed circuit Breaker
- Test high-speed circuit breaker

Inspecting and maintaining contactor/arc chutes

- Adjust contactor/arc chutes
- Clean contactor/arc chutes with compressed air
- Identify different types of connectors
- Identify excessive arcing
- Inspect contactor/arc chutes
- Overhaul contactor/arc chutes
- Replace contactor/arc chutes
- Test contactor/arc chutes

Inspecting and maintaining resistance banks

- Check insulators and cage
- Check resistance
- Clean resistance banks
- Demonstrate knowledge of conditions that can make resistance banks implode
- Inspect resistance banks for cracks and damage
- Overhaul resistance banks
- Repair sections of resistance banks
- Replace resistance banks

Maintaining knife switch (DC link)

- Adjust knife switch
- Clean knife switch
- Inspect knife switch
- Lubricate knife switch
- Overhaul knife switch
- Replace knife switch
- Test knife switch

Inspecting and maintaining overcurrent protection

- Check operation of overcurrent protection

- Clean overcurrent protection
- Overhaul overcurrent protection
- Replace overcurrent protection

- **203.3 Tools**

NOTE: Can be integrated in other parts of module or taught separately.

Demonstrate ability to use bench test equipment (electric and hydraulic)
Demonstrate ability to use laptop and software
Demonstrate ability to use fluid cleaner/pump/oil analyzer
Demonstrate ability to use caliper/brake release tools
Demonstrate ability to use suspension spacer
Demonstrate ability to use caliper stands
Demonstrate ability to use brake force tester
Demonstrate ability to use quick disconnect adapters/fittings
Demonstrate ability to use signal generator to test sensors
Demonstrate ability to use digital multi meter
Demonstrate ability to use repin connectors
Demonstrate ability to use insulation blankets (cutting rotor)
Demonstrate ability to use acetylene torch
Demonstrate ability to use welding equipment (arc, MIG, TIG, plasma cutter)
Demonstrate ability to operate equipment mover
Demonstrate ability to use filter carts
Demonstrate ability to use breakout boxes
Demonstrate ability to use portable test equipment
Demonstrate ability to use oscilloscopes
Demonstrate ability to use voltage/current regulators
Demonstrate ability to use anti-static bags
Demonstrate ability to use torque wrenches
Demonstrate ability to use hand tools
Demonstrate ability to use crimping tools and use
Demonstrate ability to use soldering tools
Demonstrate ability to use heat shrink guns
Demonstrate ability to use wire labeler
Demonstrate ability to use vibration meter

RAIL VEHICLE LEVEL 200
SUBJECT OVERVIEW

Module: 204 – Auxiliary Inverters & Batteries

Note: All 200 level courses should be delivered only after completion of 100 level training

About the Author: Phil Lowe

Phil Lowe, who is currently a First Class Electrical/electronic maintainer at Southeastern Pennsylvania Transportation Authority (SEPTA), has 1 year of instruction at Camden community college and over 30 years of experience in rail car operations including work in a running car house and heavy maintenance repair shop. In these positions he has been responsible for troubleshooting and repairs for the outgoing line and electrical vehicle overhaul of light rail vehicles, respectively.

Having proven abilities in a wide range of technical skills on rail vehicles, Mr. Lowe is considered a Subject Matter Expert (SME) and shares his knowledge with the industry – locally and nationally. Locally he has mentored and instructing incumbent and new employees and worked on the rail work group for the Keystone Transit Career Ladder Partnership. In this capacity he Reviewed skill gap analyses, maintained minutes for rail work group, tracked promotions and new hires in the rail department, reviewed and updated mentoring procedures, evaluate trainees, review test material with test monitors, interfaced with production staff, developed and review curriculum and courseware, reviewed classification responsibility for TWU employees and job descriptions, reviewed budgets, recommended training aids and attended project steering committee meetings.

Nationally, Mr. Lowe currently serves on two groups whose main mission is to create a nationally recognized system of training and qualifications for rail vehicle maintenance technicians: The Joint National Transit Rail Vehicle Training Standards Committee and the Transportation Cooperative Research Project's E-7 Panel.

Overview/Purpose

This material provides a general overview of rail vehicle auxiliary inverters and batteries to give technicians a basic introduction to the subject and prepare them for national qualification testing. Material presented here is intended only as a primer to rail vehicle auxiliary inverters and batteries and follows the National Training Standards established jointly by representatives from both labor and management.

As a primer additional knowledge will be needed to become fully qualified on this subject. Material presented here does not address every possible aspect of every vehicles auxiliary inverter and battery systems because these aspects vary slightly between rail car designs and manufacturers. Supplemental courseware and other resources to help technicians become qualified on this subject are listed below.

Table of Contents

Suggested Tools/Training Aids:

- power point presentations
- transparencies
- manuals
- schematics
- mock-up/live-coupler
- video/animations
- Schematics
- lap top computer
- multi-meter
- clamp-on amp meter
- oscilloscope/o-scope
- tools listed in L.O.s

Topics Covered:

Topics listed below are covered in this introduction of Couplers. A full copy of the National Training Standards from which these topics were taken is attached.

- Batteries
- Motor Alternator
- Solid State Inverter
- Battery Charger/LVPS
- Tools

Definitions, Abbreviations and Acronyms

For the purposes of this lesson, the following glossary of terms, definitions, acronyms, and abbreviations shall apply. They are not all inclusive, and the reader is encouraged to explore the text, footnotes and bibliography sources for further information.

- **ATM:** Standard Atmosphere
- **AUX:** auxiliary
- **CFM:** Cubic Feet Per Minute
- **Com:** Commutator (DC motors)
- **DC:** Direct Current
- **DMM:** Digital Multi-meter
- **GTO:** Gate Turnoff Thyristor
- **IGBT:** Insulated Gate Bi-polar Transistor
- **NiCd:** Nickel Cadmium
- **OEM:** Original Equipment Manufacturer
- **LVPS:** Low voltage power supply
- **PM:** Preventative Maintenance
- **PPE:** Personal Protection Equipment
- **RMS:** Root Means Squared
- **RPM:** revolutions per minute
- **SCR:** Silicone Controlled Rectifier
- **SG:** Specific Gravity
- **VOM:** Voltage Ohm Meter

Introductory Text by Topic Area

i. Batteries

Introduction to Batteries
Batteries are a source of **DC** power which store energy through the interaction of **positively** and **negatively** charged **poles**. The area between these poles can either be made of liquid or gel – resulting in **wet** or **dry** cell batteries, respectively. This material is **caustic** and should be handled with care. Sufficient **PPE** should be worn while dealing with batteries and batteries should always be well **ventilated** as they do give off a dangerous gas.

For transit rail vehicle systems the two most commonly used batteries are **NiCd** and **Lead Acid** Batteries – explored more below. While connected to a running rail vehicle, these batteries are generally **charged** at 1.5 to 2 volts above operating voltage. For example if 10 volts are needed to run a system, the charge being transmitted will be 11.5 to12 volts.

Single cell battery connected to form block

Batteries in transit systems come in two different types:

1. **Block style** – 5 individual cells put together in a casing(ex: car battery)
2. **Individual cells** – looks like 1/5 of a block style battery. It has the same lay out but is a different size

NiCd Battery Introduction

While Nickel Cadmium batteries (NiCd) come as both a wet and gel cell battery, **wet** cells are used by transit agencies and will therefore be the focus of this material. One example of a gel battery is the sort that you would use in an everyday camera.

Individual cell transit battery in a battery tray

Wet Cell NiCd Batteries come in two types:

1. **Single/Individual cells** – These batteries carry **1.2 volts** of DC power. In order to minimize stocking needs, most transit agencies are starting to use single cell batteries to build the battery they need. Although transit agencies differ by the equipment they use, most systems are 12, 24 or 36 volts. The battery load needed is determined by the auxiliary running circuits (tracks brakes, sanders, etc.).
2. **Mono-block** – a mono-block battery is a series of 5 single cell batteries banded together

Inspecting and Maintaining NiCd Batteries

Check and verify battery specifications
Each individual rail vehicle will have different battery specifications having to do with physical size, voltage outputs and current outputs. The specifications can be found in the Heavy maintenance manual for the specific rail vehicle. Once these specifications are found they are tested in the following ways:

1. **Physical size** – Determine if batteries fit into the allotted space – usually known as the **battery tray**. This has more to do with the current storage capability needed for the operation of the rail vehicle.
2. **Voltage Outputs** – Use a DMM digital multi-meter (or Voltage Ohm Meter (VOM)) to verify voltage.
3. **Current Outputs** – To measure the current output. You can use a clamp-on amp meter on the system while it is running or you can break the circuit and put a DMM in line with the load.

Cleaning NiCd batteries and connections

NiCd batteries will generally be cleaned under two different circumstances:

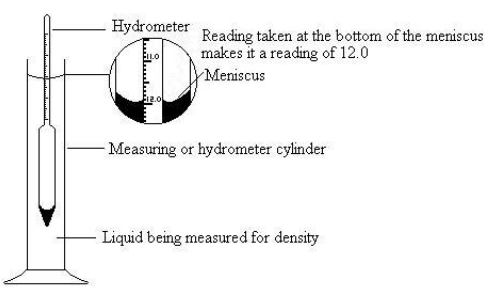
1. **Preventive Maintenance** – The system should be periodically inspected through preventative maintenance (PM). The frequency of PM examination will differ by location. During a PM examination, maintainers should inspect for **operation** and **cleanliness**. Operation is checked by making sure that all **connections** are tight. Cleanliness is determined by a **visual** inspection. Sometimes white powder will collect on the battery and battery terminals – this is a sign of **corrosion**. Corrosion is the disintegration of materials due to chemical reactions with its surroundings.

Corrosion on Batteries

2. **Service Failure/Dead Battery** - When there is a service failure and the rail vehicle will not start,(dead car) the battery circuit is the first thing that should be inspected. If there is a charge within the battery but it is not being relayed to the system the connection may be bad. In this case the connections should be checked and the terminals should be cleaned.

To clean a NiCd battery, simply use **water** and a clean dry **rag** or **dust brush**. DO NOT use a wire brush to clean a NiCd battery.

As batteries contain **electrolytes** which will **burn** your skin, take care to use sufficient **PPE** such as a **face shield** and **rubber gloves**. Also make sure the space you are working in is well ventilated and that there are no **flammable** substances nearby. Some agencies will have **designated areas** used to clean and maintain batteries.



Checking NiCd batteries specific gravities

Specific Gravity is not normally checked in the field – but upon initial manufacturing or filling in the field as the measurement changes as it is used. This is not checked on periodic inspection as it is difficult to do and can be misleading

Specific gravity (SG) is the **density** of the **electrolytes** within the wet cell of a battery as compared to the density of **water**. Optimal SG for a NiCd battery is **1.7**atm or 1.7 times as dense as water. As batteries age electrolytes **deteriorate** and the SG **decreases**. Since the electrolyte is the medium by which the two poles are separated, it is important to make sure that

SG stays at a sufficient level. If SG falls below a certain level, failure will occur and the battery will no longer hold a charge. Batteries may last over five years.

When specific gravity of a new battery cell is measured, a **hydrometer** is used. If the hydrometer shows a lower than optimal density the battery should be **returned**. Because of the **environmental risks** involved and because it is hard to determine that deficient electrolytes are the only problem with a given battery, it is much more common to just **replace** the battery entirely. A NiCd battery can be **repaired** by **replacing** the **electrolytes**. The deficient electrolytes can be dumped into a drum and replaced with new electrolytes either using a **battery fill tool/syringe** or by free hand (more on this later). This may not be the best course of action due to the fact that there may be more than just an electrolyte failure in the battery.

Checking NiCd battery voltages

Voltage within a NiCd battery may decrease either because the electrolytes within the battery are failing or because the charging circuit is failing. Use a DMM (or a Voltage Ohm Meter (VOM)) to verify voltage of each individual cell both while charging and while not charging. If a battery charges but does not hold a charge, the charging circuit is okay but there is an issue with the battery and it should be replaced. If the battery does not charge at all, there may be an issue with the charging circuit.

Checking liquid level of cells

The first step in checking liquid levels in the cells is to check the spe**c**ifications given by the Original Equipment Manufacturer (OEM). Once you have this number you can measure check the liquid levels by a **visual** inspection. Make sure that the liquid is over the plates. If the electrolyte is not at the proper level, **distilled** or **deionized water** should be added until it is. Water can be added either by free hand or by using a **battery fill tool**. Take special care to not overfill the battery cell as this will cause electrolytes to spill from the battery and enter the environment. If a spill does occur, work to contain it as well as possible using proper PPE.

Digital Multi-meter

Calibrating and verifying calibration

In order to calibrate a battery you first need to put all batteries **in series** with each other. You will then check the voltage across the entire battery using a **DMM**. If this reading does not equal the assumed sum of all of the batteries (for example a string of 25 1.2 volt batteries measure at 25 volts instead of 30 volts) the battery needs to be **calibrated**. Calibration simply means finding the bad cell and replacing it. This is done by measuring the voltage of each individual battery and replacing the cells which do not measure the correct voltage. Calibration should be verified. Verify calibration by measuring cumulative charge again.

Testing Charge and load battery conditions

Charge and load of batteries are measured under four certain conditions:

1. Charging with No Load
2. Charging with Load
3. Not Charging with Load
4. Not Charging with No Load

To measure these you want to perform the following steps:

1. Turn the car to not-charging and check battery output using a DMM – this will give you the Not Charging with No Load measure

2. Turn the car to charging and measure using a DMM – this will give you the Charging No Load measurement
3. Turn on loads which would be used during normal operation and measure using a DMM – this will give you the Charging with Load measurement
4. Turn the charging circuit off while maintaining the load and measure using a DMM – this will give you the Not Charging with Load measurement

Table 1 below shows what the readings for each measure should be. If these measures aren't correct, first check the battery charging circuits to make sure it is within specifications. If the charging circuit is operating correctly, check connections to the battery and cleanliness of the terminals. If this still does not fix the problem, the batteries should be replaced.
Test the battery under 4 certain conditions:

	Charging	**Not Charging**
Load	**Reading should be 1.5-3 volts above battery specifications**	**Voltage will walk down. The rate of discharge depends on size of battery and size of load.**
No Load	**Reading should be 1.5-3 volts above battery specifications**	**Battery should maintain a nominal drop in voltage over a 3-5 minute time frame**

Lead Acid Battery Introduction

Unlike NiCd Batteries, Lead Acid batteries use lead posts which are connected to the plates by liquid electrolyte. Generally Lead Acid Batteries have been phased out in the transit industry and replaced with NiCd batteries. This is because:

- Lead acid batteries require **more maintenance** than NiCd batteries
- Lead acid batteries are **less dependable**
- Older charging systems are not as dependable as electronic systems. Lead acid batteries are more easily **overcharged** which may cause **overheating** of the system or fire. Overheating creates a distinctive **odor** (rotten egg smell). Overcharging also **diminishes** the **life span** of the battery by boiling off electrolytes.

Lead Acid batteries are most commonly are found in block style.

Inspecting and maintaining lead acid batteries

Check and verify battery specifications
Each individual rail vehicle will have different battery specifications having to do with voltage outputs, specific gravity and current requirement of the rail vehicle. The specifications can be found in the Heavy maintenance manual for the specific rail vehicle. Once these specifications are found, they are tested in the following ways:

1. **Voltage outputs** – use a digital multi-meter (DMM) or Voltage Ohm Meter (VOM) – to verify voltage. If the voltage is note correct the system with either under or over charge.

2. **Specific gravity** – check specific gravity only if the battery is new or has been refilled. Specific gravity for lead acid batteries is determined the same way as it is for NiCd batteries (see above).
3. **Current Requirement** – measured with a clamp-on amp meter or breaking the circuit and putting a DMM in series with the load.

Cleaning Lead Acid batteries and connections
Lead Acid Batteries will generally be cleaned under the same circumstances as NiCd batteries:

1. Preventative Maintenance
2. Service Failure/Dead Battery

See above for more information.

When cleaning, make sure **ventilation caps** are clear. They should be on top of the cells and have nothing blocking the little holes in them. Sometimes a white film called **corrosion** can block these holes. To clean, use an abrasive pad on the terminals. On all other parts use a **paint brush.**

Checking lead acid battery specific gravities
The specific gravity of a battery should only be checked on a new battery after a battery is refilled as it is difficult to get a true reading and can be misleading. Specific gravity is checked the same way as with a NiCd battery. See Above.

Checking lead acid battery voltages
Use a DMM or VOM to verify voltage of each individual cell both while charging and while not charging. If a battery charges but does not hold a charge, the charging unit is okay but there is an issue with the battery and it should be replaced. If the battery does not charge at all, either the battery or the charging unit may be faulty.

Checking liquid level of cells
After finding the specifications given by the OEM, the liquid levels of a lead acid battery should be checked the same way as NiCd batteries - by a visual inspection. See above for more information.

Calibrating and verifying calibration
Lead Acid batteries are calibrated in the same way as NiCd batteries – by placing batteries **in series** with each other and then checking the voltage required using a DMM. See above for more information.

Testing Charge and Load Battery Condition
For Lead acid batteries, charging voltage is generally two to three volts above normal battery voltage – check manufacturer's requirements. Like NiCd batteries, charge should be measured under four certain conditions:

1. Charging with No Load
2. Charging with Load
3. Not Charging with Load
4. Not Charging with No Load

See above for more information.

Table 2 below shows what the readings for each measure should be. If these measures are not correct, first check the battery charging circuits. If the charging circuit is operating correctly, check connections on the battery for tightness of connections and cleanliness of the terminals. If this still does not fix the problem, batteries should be replaced.

	Charge	No Charge
Load	**Reading should 2-3 volts above battery voltage**	**Voltage will walk down. The rate of discharge depends on size of the battery and size of the load.**
No Load	**Reading should be 2-3 volts above battery specifications**	**Battery should maintain a nominal drop in voltage over a 3-5 minute time frame**

Maintaining low voltage sensor

There is a threshold sensor LED on the console that will light up to signal that the output voltage is low. In this case both the thermal switches and low voltage sensor should be inspected.

Inspecting and testing thermal switches
Use a milli-ohm meter to make sure the resistance across the thermal switch is within specifications. You can apply an outside heat or cold source to activate the circuit.

Inspecting and testing low voltage sensor
Decrease voltage output. If the low voltage sensor does not engage then there is a problem with the sensor and it should be replaced. In some cases the control board may also need to be replaced (see below).

Cleaning low voltage sensors
Low voltage sensors should either be blown out with dry clean air or vacuumed – whichever your manufacturer and/or authority recommends.

Replacing Thermal Switches and Low Voltage Sensors
To replace thermal switches and low voltage sensors follow the steps below:

1.) Shut down car
2.) Remove high and low voltage
3.) Disconnect electrical connections
4.) Remove mounting hardware
5.) Place the new device
6.) Put mounting hardware back
7.) Reconnect electrical connections

Sometimes the thermal switch or low voltage sensor is on a circuit board. In this case replace the entire circuit board.

Maintaining battery breaker disconnect
A battery breaker is a circuit breaker connected to the battery for protection. Battery Breaker Disconnect disconnects the battery from the rail vehicle.

Some rail vehicles use a knife switch to disconnect the batteries from the car. When the handle is up (and disconnected from either side of jaws) it is open. When there is a connection then it is closed.

Normally, a knife switch is employed only during maintenance to cut off all power to the rail vehicle. Generally it is in an electrical enclosure (ex: plastic or fiberglass) with a latch so that it isn't accidentally switched.

Inspecting battery breaker disconnect
Battery breaker disconnects should be inspected under two certain conditions:
1. **Preventative Maintenance** - Periodic inspections of total system either by mileage or time (ex: every 50,000 miles or every 60 days). Frequency of PM varies by location.
2. **System Failure** - when system is not charging correctly. If connections are not properly seated then the battery will fail to charge

To inspect, check wires for wear and connections tightness.

First the knife switch should be **visually inspected** to make sure that a thin film of **electro-conductive grease** is present on the jaws. This knife switch increases the connection between the switch and the jaws. Then test to make sure that knife switch **moves freely** by moving it with your hand. While moving switch, make sure to hold onto insulated handle.

Cleaning battery breaker disconnect
The battery breaker disconnects should also be cleaned during preventative maintenance or when the system is not charging correctly.

They are cleaned with a nonabrasive cleaner (ex: motor cleaner that evaporates quickly) and a rag. Make sure to wear appropriate PPE to prevent skin contact.

Testing battery breaker disconnect
A battery breaker disconnect is tested with a DMM. The DMM should read zero when the battery breaker connected in a closed position and infinity when it is open.

Replacing battery breaker disconnect
To replace a battery breaker disconnect first disconnect the charging circuit and the battery. Then simply unbolt and remove the old unit and bolt in the new one. Make sure to test the new unit after it is connected.

ii. Motor Alternator

Motor Alternators use electromagnetic induction to **convert mechanical energy** to **electrical energy**. This is done through a **DC Motor** (usually 600 volt) which is directly connected by a common shift to an alternator which puts out **AC Voltage** and **Current**. These are usually 230 AC, three phase output. In order to maintain the output from the motor alternator, there are a series of circuits for voltage output and frequency control.

In transit vehicles, the output side of the motor alternator handles the auxiliary motor circuits.

Technology in the transit industry is moving towards static inverters, which are more reliable, and away from motor alternators.

Maintaining the DC Motor Part of a Motor Alternator

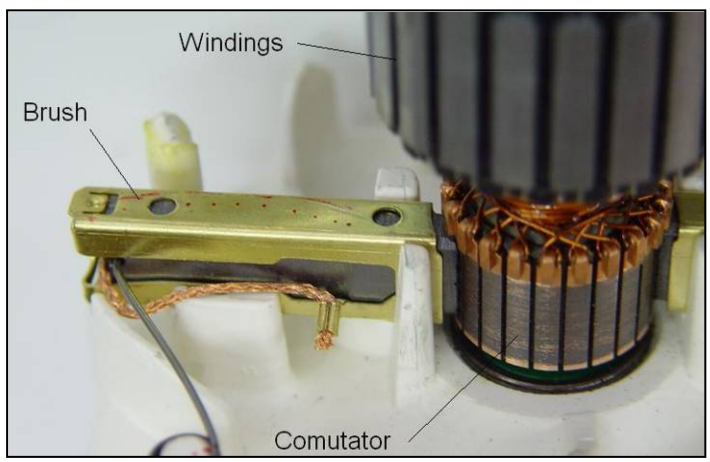
Cleaning DC motors
DC motors should be cleaned on an agency determined schedule of **preventative maintenance**. They are cleaned by blowing out the motor with **dry compressed air**.

Inspecting DC motors
The first step to inspecting a DC motor is to **clean** it, as described above. Then **visually inspect** associated **wiring** for **wear** and **cracked** insulation. Take special care in inspecting the face of the brushes, the brush holders and the commutator.

When inspecting a **commutator**, look for the following three conditions, which may indicate a problem:

1. **Streaking** – the commutator is lighter overall with dark streaks along the brush path. Thin lines of dark and light color alternate, close together. Streaking is not necessarily an immediate problem but is a sign of uneven brush wear.
2. **Tracking** – forms a thicker path around the commutator in shades of color, adjacent to the brush path. Tracking is a sign of a previous problem that led to abnormal wear.
3. **Banding** – resembles streaking but with thicker streaks. Banding is caused by an oily atmosphere.

Inspecting the face of the brushes and brush holders will be described in more detail below.



Checking and replacing DC motor brushes

Face of the Brush
To inspect the face of the brush, first **remove** the brushes by removing the springs. **Visually inspect** the **shunts** on the brushes. If brush wear is below the manufacturer's suggested wear level (or looks like it will be by the next inspection cycle) – replace the brush. It is important that brush grade match the commutator specifications. To **replace** the brushes, simply unscrew the shunt, remove brush, put new brush in and tighten the shunt screw.

Brush Holders
When inspecting the brush holders you are checking three main things:

1.) Movement - make sure that the brush track is free – that is that the brush can move freely in the track of the brush holder. If it does not move freely, replace the brush holder.
2.) Connections - make sure connections to the brush holder are tight and without corrosion
3.) Proper mounting

You should also make sure there are no shorts. This will be explored more below in the flash-over section.

Testing DC motors

DC motors are typically only tested in **failure** situations. When testing a DC motor you should check **insulation values** and **winding resistance.**

The **insulation** value indentifies how **isolated** the motor is from **ground** and is measured using a megger. The ideal installation value changes with each OEM, check the **heavy repair manual** for the minimum value. If the value reflects a "dead short" then there is a problem and the motor should needs trouble-shooting. It is important to note that readings will **change** depending on **atmospheric** conditions. In **higher humidity** conditions will cause **lower megger readings**.

Milli-ohm readings of **motor windings** should also be taken using a milli-ohm meter. Consult the heavy maintenance manual for acceptable values. If the value is too low there is an internal short within the windings.

Repairing DC motors

The most common problem in DC motors is **flashover** which can have multiple causes may include:

- A **short** from the **commutator** to the **motor case**
- A short from **bar to bar** on the commutator itself
- **Brush bounce** – brushes are not seated properly because of high **mica**. The air around the brush becomes positively charged and provides a path to ground causing a flashover.

A flashover is evidenced by black burn marks.

If the signs of flash over are visible. Megger the motor to determine if it is a **field short** or an **armature short**. If there is a main **field short**, the motor will need to be **replaced**. If it is an **armature short**, we can then try to correct the problem by **cleaning** the commutator by using different **grits** of **stones**, from roughest to most refined (cutting, finishing and polishing). After cleaning the commutator, **replace** all the **brushes** and **check** the **brush holders**.

Replacing DC motors

DC motors should be replaced when there is either a **main field** short or if the commutator is in **severe condition**. Steps on how to replace a DC motor **varies** greatly. See your heavy repair **manual** for more information.

Maintaining voltage regulators

The output side of the motor alternator supplies power for the operation of the auxiliary motor circuits and low voltage power supplies within a transit car. Most propulsion motor blowers are used to cool DC traction motors. These are usually 230 AC, three phase motors.

In order to **maintain** the **output** from the motor alternator, there are a series of circuits for **voltage** output and **frequency control**.

Voltage and Frequency Regulators
Please note that because of the **similarities** between voltage and frequency regulators track each other, the text of this section will be referring to both, unless otherwise noted.

Both Voltage and Frequency regulators are **printed circuit boards** that are usually found in the **motor alternator control box**. The two types of regulators have slightly **different components** which may differentiate them but the failsafe way of figuring out which is which is to look at the **schematic drawing** and **locate** them on the car. The boards and their sizes will also **vary** with each system.

Frequency and voltage sensor boards

Small adjustments to voltage and frequency can be made on the **car**; more **in-depth** adjustments will need to be made in a **lab** environment.

Adjusting Regulators
An **adjustment potentiometer** is located on each board to be used for **on-car adjustment**. Adjustments should be made while running but under **varying loads**. As you adjust one potentiometer the other output will change. Therefore, you will need to work back and forth between voltage and frequency until they are within range. Readings should be taken from leg to leg. In most cases, a 230 volt 3 phase AC at 60 Hz.

Testing Regulators
For **frequency regulators**, manufacturers specify recommended Revolutions Per Minute (RPM) for frequency output. RPM can be tested using a **strobe tachometer** (pictured below). There is a direct positive connection between DC voltage and the corresponding operating frequency.

For both regulators you must use a true **Root Means Squared (RMS) DMM** to check for 230 volts leg to leg in a three phase circuit.
If the inputs are within specifications and we have **lost outputs** there is probably a **board failure**. Check terminals to make sure that all screws and/or pins are tight.

Repairing Regulators
Repairs to printed circuit boards are best made under **lab** conditions.

Replacing Regulators
If by adjusting the frequency and voltage boards we cannot bring the car into specification, you may want to replace the frequency or voltage board. In most cases, replace the voltage regulator first. If this does not fix the problem, then also replace the frequency regulator, following the steps below:

1. Shut car down
2. Turn battery off
3. Remove the input and output wires from the voltage regulator board
4. Remove mounting screws
5. Visually inspect the board for the following. If any of these are present, the board must be replaced with a known good board:

    a. Raised traces
    b. Board discoloration/burnt
    c. Excessive heat on individual components
    d. Bad solder connects
6. Before replacing board, inspect wires going to it. If the wires are burnt, replace them.
7. Follow protocol of your agency on if the broken board is fixed in shop or sent out
8. Obtain rebuilt board and install it in the car by replacing mounting crews and input and output wires.
9. Turn the battery and power to the car back on
10. Once the board is replaced, test regulators as described above

NOTE: Before touching electronic circuits, take care to ground yourself.

Speed/frequency Control Components
There is a set ratio between speed and frequency which varies with each vehicle. Consult your heavy maintenance manual for a chart which illustrates this ratio.
There are two different devices present on transit rail vehicles which make sure that this ratio is maintained:

1. **Over-speed circuit** – if the frequency goes too high this protection circuit will shut down the alternator.
2. **Centrifugal over-speed Switch** – A speed sensor which will shut down the motor alternator if the speed goes too high. As the motor alternator starts to spin, it throws out a counterweight that hits a switch that turns off the motor alternator.

Maintaining speed/frequency control components
Speed/frequency control components should be cleaned on a regular preventative maintenance schedule by either blowing them off with dry compressed air or by using a vacuum.

Testing speed/frequency control
You can tell that there is a failure in the **over-speed circuit** when it is not tripping at the appropriate times – either too soon or not tripping at all. This will create a situation where output frequency cannot be maintained.

The **centrifugal over-speed switch** is also found to be faulty when it does not trip at the appropriate time. Refer to the heavy maintenance manual to find out at what RPM value the switch should trip and then test with a strobe tachometer.

Adjusting speed/frequency control
Over-speed circuits cannot be adjusted**.** If adjustments need to be made, replace the frequency regulator board (see above).
However, adjustments can be made to the **centrifugal over-speed switch** at the centrifugal counterweight. **Tighten** or **loosen** the **screw** depending on how sensitive you want the switch to be. Optimal sensitivity rating varies with each machine. Refer to heavy maintenance manual to find out at what RPM value the switch should trip.

Repairing speed/frequency control
The **over-speed circuit** or the **centrifugal over-speed switch** can be repaired in the field. Both should be replaced and the faulty part should be sent to the **shop** for repair

Replacing speed/frequency control

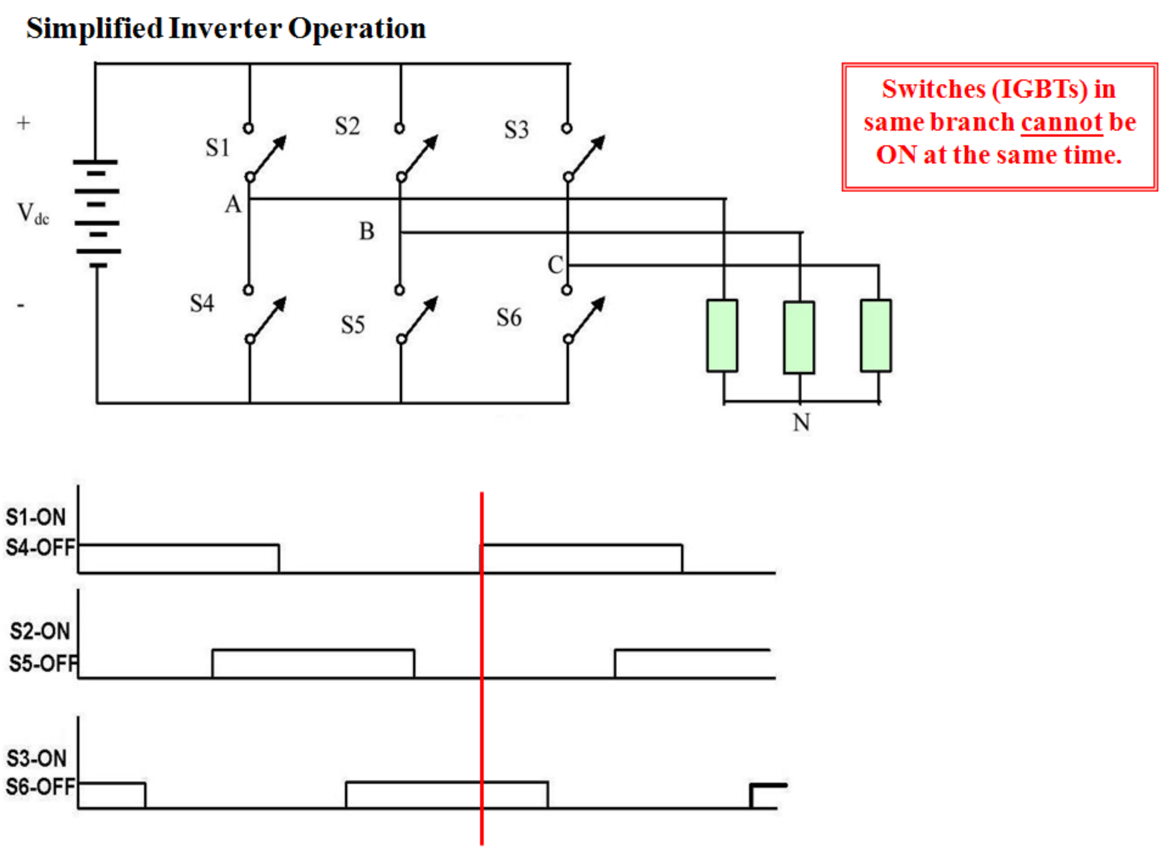
The **over-speed circuit** is made up of frequency regulator board and centrifugal switch. Normally you would just replace one of these. To replace the **centrifugal over-speed switch** simply disconnect by removing wires and unscrewing the switch itself, remove, replace with a new switch and reconnect. After it has been replaced, check the counterbalance to make sure it moves freely.

iii. Solid State Inverters

Solid State Inverters perform the same task as motor alternators, **converting** DC power to AC power, but use **electronics** as opposed to the rotating equipment.

1.) **Insulated Gate Bi-polar Transistor (IGBT):** These are very fast of the switches. Through the use of six IGBTs three high and three low. In controlling the pulse width or on time of the gates. We can create a simulated three phase 230 AC sine wave.

2.) **Gate Turnoff Thyristor (GTO):** a type of solid state thyristor. These a fast switches. GTOs did not need opposing current flow to turn them off. They can be turned on and off from their gates. They are not fast enough or reliable enough to use in the newer class of inverters



Maintaining Solid State inverters
Maintain these systems by **cleaning** and checking to make sure **connections** are **tight**. This should be done on the authority's preventative maintenance schedule.

Inspecting Solid State Inverters
Before working with solid state inverters, make sure to **discharge** them. Once they are discharged, physically check **connections** to make sure they are tight. If they are loose, **tighten** them. Then **visually inspect** the equipment, looking for signs of excessive heat such as **burn marks** and **discoloration**. **If these are present replace/repair the circuit board.**

Cleaning Solid State Inverters
Clean solid state inverters by blowing them out with **compressed air** or **vacuuming** them.

Testing Solid State Inverters
As technology changes **laptops** and **software** diagnostics become the primary tool. The technician's job now becomes translating a line in a fault log into a schematic to decide whether there is a high voltage or a low voltage problem and whether it is an input voltage to a sensor or a faulty sensor.

First **connect** the laptop. Then run the **simulation**. The simulation will run a low voltage test of the solid state inverter and detect firing errors

Replacing Solid State inverters
You would not replace the whole inverter but replace modules or boards. Repairs done to boards in solid state inverters will be done in the electronics department as a shop environment may not be the best place to do board level repairs. Technicians in a carhouse should be concerned with replacement of boards and not components. This is done by disconnecting electrical connections, removing mounting hardware, installing new device, replacing mounting hardware and reconnecting the electrical connections.

Maintaining Other Inverter Components

Maintain Capacitor Filters
To maintain capacitor filters check the following:
1. That all connections are tight
2. That there are no signs of leakage such as oil on the filter

Maintaining Electronic Controls
No maintenance is required most solid state components, unless there is a failure. For the compartment, periodically make sure that **connections** are **tight**. To maintain driver controls, inspect using a laptop by installing the **laptop** and running a simulation. The simulation will run a low voltage test and detect firing errors

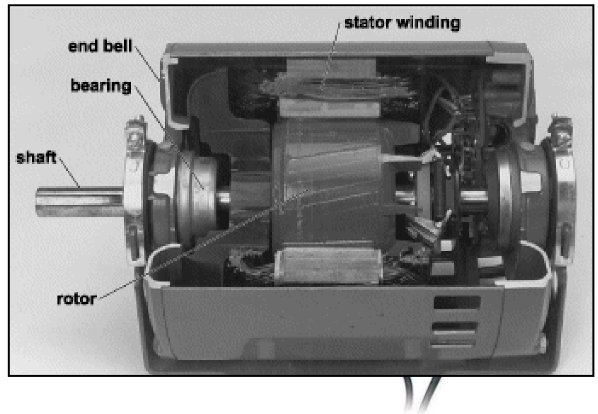
Maintaining Output Transformers
You will also use a laptop to check the input (primary) and output (secondary) sides of the transformer. Supply high voltage and connect the laptop to read the transducer to check that output voltage is correct. Make sure to also check the hall effect transducer.

Maintaining ventilation
If the component container has a ventilation fan, see that it is operating properly. If it has input and output filters the air filters should be changed at regular preventative maintenance intervals.

Maintaining AUX inverter ventilation system

There are multiple things that should be done to maintain an auxiliary inverter ventilation system including:

1.) **Replacing air Filters**: should be done regular intervals, as per manual
2.) **Testing Sensors:** using a laptop
3.) **Replacing Sensors**: if they are faulty. Replace sensors by disconnecting them, removing them by unscrewing/unbolting them, putting thermal compound on new unit and placing the new unit.
4.) **Testing blower fan**: Check air flow (measured in CFM) by using an air flow meter (annnameter). If air flow is limited check the duct work, replace the blower fan.
5.) **Replacing blower fan and fan unit:**



a. Disconnect the motor electrically
b. Disconnect mounting brackets
c. Remove blower motor and take it to back shop to be rebuilt
d. Mount the new blower
e. Connect it electrically

Maintaining AC motors

AC Motors are made of two different main parts:

1. **Stator** – static housing frame that has windings
2. **Rotor** – rotating section that induces electrical fields

Cleaning AC motors

AC motors should be cleaned using **dry compressed air** on a regular schedule of **preventative maintenance**.

Inspecting AC motors

AC motors should also be inspected for **wear** to the output **cables**. In addition, **bearings** should be checked for extensive **lateral movement**.

Testing AC motors

AC motors should also be checked for **insulation** and **winding resistance**. Consult heavy repair **manual** for equipment specifications.

Repairing AC motors

In AC motors, the most common problem is **bearing failure**. Make sure to check for lateral movement. When this movement exceeds manufacturer's specifications, tear down the motor and replace the bearings.

Replacing AC motors

AC motors **vary** greatly in how they are replaced. Consult heavy repair **manual**.

iv. Battery Charger/Low Voltage Power Supply

1.) While the rail vehicle is powered up, the Low Voltage Power Supply (LVPS) is not only supplying the car with operating voltage and current, it is also charging the battery. Some older systems use a full wave rectifier to respond to low current needs. Most systems use a silicone controlled rectifier

2.) **Silicone Controlled Rectifier (SCR):** Three phase AC is (rectified) changed to DC using SCRs to control the voltage out-put by advancing or retarding the negative firing angle. Through a bridge rectifier with mated diodes. This provides a controlled DC out-put at a car charging level.

Low Voltage Power Supply

Maintaining battery charger/LVPS

To maintain the LVPS, check out-put under load and no load to make sure that it is at manufacturer specifications.

Maintaining rectifier and filters

Rectifiers change an AC voltage into a DC voltage. Filters smooth the voltage by controlling the ripple and filter changes in voltage and current. Filters come in two types:
Two types: capacitors and inductors (aka choke).

Both should be maintained on a regular preventative maintenance schedule by blowing them out with compressed air or vacuuming them. Also check to make sure connections are tight.

Maintaining input capacitor

Make sure they are clean by blowing them out with compressed air or vacuum – whatever your system recommends. Check to make sure connections are tight. If they are electrolyte capacitors make sure they are not leaking by visual inspection. Look at screw connections

LV PS regulator board

Maintaining temperature sensor

It is important to maintain the temperature sensor as a failure will lead to a system shut down.

In some systems a laptop with a diagnostic program is used. Other systems use a DMM to test the temperature sensor.

Maintaining heater

In cold climates it may be necessary to have a heater in the LVPS so that it does start under low temperatures. To maintain the heater check that connections are clean and tight. If the heater fails check the input voltage and voltage drop across the resistor.

Maintaining electronic controls

Depending on diagnostic software or voltage inputs and outputs on boards, determine which boards are bad or approaching failure. Replace the failed boards. If under test situations the boards are not within specifications replace them before failure.

v. **Tools**

Demonstrate ability to use laptop to test and diagnose system (see above – pages 16-17)

Demonstrate ability to use bench test equipment to diagnose system (see sections on power supply and multimeters above – page 4)

Demonstrate ability to use digital multimeter (see above – page 4)

Demonstrate ability to use oscilloscopes
An oscilloscope (o-scope) is a test instrument that lets you look at varying signals in a graph form in real time. An o-scope will show wave forms, the time betweens signals as pulse width and rise times.

Demonstrate ability to use chart recorder
Calibrate chart recorder to specified directions according to manufacturer and graph the results. Recently, chart recorders have been replaced with laptops running diagnostic software in real time.

Demonstrate ability to use ohm wheel/speed sensor
Magnetic pick up sensors use gear teeth in motor operation to detect rotation speed. Hall effect speed sensors are a transducer. For more information see above (page 13)

Bibliography

SAFT, “Material Safety Data Sheet Product Name: Industrial Pocket Plate Nickel-Cadmium Storage Battery.”

National Brush Digest, National Electrical Carbon Corporation, Greenville, SC, 1957 and 1977 editions and the 12 reprinting

Relevant OEM Contact Information

OEM	Website	Contact Information
Hoppecke Batteries	http://www.hoppecke.com/	Contact Form
Saft	http://www.saftbatteries.com/	Contact Form
SEPSA	www.Albatross-sl.es	Sepsa North America, Albatros North America, Inc 445 Duane Avenue Schenectady, NY 12304-2626
Transtechnik	http://www.transtechnik.com/	Transtechnik GmbH & Co. KG Ohmstrasse 1 83607 Holzkirchen Germany Phone: +49-8024-990-0 Contact Form
Kiepe	http://www.kiepe.com/?lang=en	KIEPE DI TODESCHINI E CODEGA S.N.C. Via per Giabbio 23834 Premana (LC) tel: (+39) 0341 890271 e-mail: request@kiepe.com
Transrail	http://www.transrail.se/	Transrail Sweden AB Löfströms allé 6A SE-172 66 Sundbyberg Phone: +46 8 404 09 90 transrail@transrail.se
Toshiba	http://www3.toshiba.co.jp/sic/english/index2.htm	Contact Form
Faiveley	http://www.faiveley.com/uk/home.php	Contact Form
Turbo Power	http://www.turbopowersystems.com/	Contact Form

Supplemental Courseware Materials

Sub Module	Title	Source	Media	Cost	Notes
204.1 Batteries	Material Safety Data Sheet Product Name: Industrial Pocket Plate Nickel-Cadmium Storage Battery	SAFT	PDF	$0	
204.2 Motor Alternator	National Brush Digest	National Electrical Carbon Corporation	Book	Varies : $2-9 on amazon	"The Bible of Commutator Brushes"
204.3 Solid State Inverters	LRV 39kVA Converter Training Presentation	SEPTA	PowerPoint	$0	

204. Auxiliary Inverters and Batteries: Introduction and Preventive Maintenance

- **204.1 Batteries**

  Inspecting and Maintaining NiCd Batteries

  3. Check and verify battery specifications
  4. Clean NiCd batteries and connections
  5. Check NiCd battery specific gravities
  6. Check NiCd battery voltages
  7. Check liquid level of cells
  8. Calibrate and verify calibration
  9. Charge and load test battery condition

  Inspecting and maintaining lead acid batteries

  10. Check and verify battery specifications
  11. Clean lead acid batteries
  12. Check lead acid battery specific gravities
  13. Check lead acid battery voltages
  14. Check liquid level of cells
  15. Calibrate and verify calibration
  16. Charge and load test battery condition

  Maintaining low voltage sensor

  17. Inspect and test thermal switches
  18. Inspect and test low voltage sensor
  19. Clean low voltage sensor
  20. Replace thermal switch
  21. Replace low voltage sensor

  Maintaining battery breaker disconnect

  22. Inspect battery breaker disconnect
  23. Clean battery breaker disconnect
  24. Test battery breaker disconnect
  25. Replace battery breaker disconnect

- **204.2 Motor Alternator**

  Maintaining DC motors

  26. Clean DC motors
  27. Inspect DC motors
  28. Check and replace DC motor brushes
  29. Test DC motors
  30. Repair DC motors
  31. Replace DC motors

  Maintaining AC motors

  32. Clean AC motors
  33. Inspect AC motors
  34. Test AC motors
  35. Repair AC motors
  36. Replace AC motors

  Maintaining voltage regulators

  37. Adjust voltage regulators
  38. Test voltage regulators
  39. Repair voltage regulators

40. Replace voltage regulators

Maintaining frequency/speed control components

41. Test speed/frequency control
42. Adjust speed/frequency control
43. Repair speed/frequency control
44. Replace speed/frequency control

- **204.3 Solid State Inverter**

Maintaining GTOs

45. Inspect GTOs
46. Clean GTOs
47. Test GTOs
48. Replace GTOs

Maintaining IGBTs

49. Inspect IGBTs
50. Clean IGBTs
51. Test IGBTs
52. Replace IGBTs

Maintaining thyristors

53. Inspect thyristors
54. Clean thyristors
55. Test thyristors
56. Replace thyristors

Maintaining other inverter components

57. Maintain capacitor filters
58. Maintain electronic controls
59. Maintain output transformers
60. Maintain ventilation

- **204.4 Battery Charger/LVPS**

Maintaining battery charger and LVPS

61. Maintain rectifier and filters
62. Maintain input capacitor
63. Maintain temperature sensor
64. Maintain heater
65. Maintain electronic controls

Maintaining AUX inverter ventilation system

66. Replace filters
67. Test sensors
68. Replace sensors
69. Test blower fan
70. Replace blower fan

- **204.5 Tools**

NOTE: Can be integrated in other parts of module or taught separately.

Demonstrate ability to use laptop to test and diagnose system
Demonstrate ability to use bench test equipment to diagnose system
Demonstrate ability to use digital multimeter
Demonstrate ability to use oscilloscopes
Demonstrate ability to use chart recorder
Demonstrate ability to use ohm wheel/speed sensor

RAIL VEHICLE LEVEL 200
SUBJECT OVERVIEW

Module: 205 – Friction Brakes

Note: All 200 level courses should be delivered only after completion of 100 level training

About the Author: Eric Petersen

Eric Petersen has been associated with railcar maintenance for 21 years. He started his career with Los Angeles County Metro as a mechanical and electro-mechanical maintainer. Petersen is currently the Manager of Technical Training and Document Control at Washington Metropolitan Area Transportation Authority.

Overview / Purpose

This material provides a general overview of friction brakes to give technicians a basic introduction to the subject and prepare them for national qualification testing.

Material presented here is intended only as a primer to the subject, keeping in mind that rail systems have different characteristics. It follows the National Training Standards established jointly by representatives from both labor and management. As a primer additional knowledge will be needed to become fully qualified on this subject. Material presented here does not address every possible aspect because brake systems vary at each transit agency. Other resources to help technicians become qualified on this subject are listed below.

Table of Contents

Suggested Tools/Training Aids:

- o power point presentations
- o transparencies
- o manuals
- o schematics
- o mock-up/live-coupler
- o video/animations
- o volt-ohm/meter
- o pressure gauge

Topics Covered

Topics listed below are covered in this introduction of Friction Brakes. A full copy of the National Training Standards from which these topics were taken is attached.

- o Hydraulic Braking
- o Electrical Hydraulic Unit
- o Actuator Brake
- o Pneumatic Braking System
- o Common Brake Components
- o Tools

Definitions, Abbreviations and Acronyms

For the purposes of this lesson, the following glossary of terms, definitions, acronyms, and abbreviations shall apply. They are not all inclusive, and the reader is encouraged to explore the text, footnotes and bibliography sources for further information.

Definitions

- o **Brake cylinder:** A cylinder in which compressed air acts on a piston that transmits the force of the compressed air to the associated brake rigging.
- o **Brake control unit (BCU)**: A device that controls and transmits pressure to brake units in response to control commands received either from the electronic control unit or the railcar itself.
- o **Brake disc:** A circular solid or finned metal mass with a contact area that is rotating with respect to the disc brake pads that are brought into contact with it to provide the retarding friction force. Usually mounted to the wheel, hub, or axle. Also known as a **Rotor** or **Friction ring**.
- o **Brake head:** A holder which carries the detachable brake shoe or brake pad.
- o **Brake shoe key:** A key by which a brake shoe is fastened to a brake head.
- o **Caliper:** The assembly on disc brakes which hold the disc pads and straddles the disc.
- o **Disc brake pad:** A replaceable friction element secured to a brake head for the purpose of producing a retarding friction force onto the face of a brake disc.
- o **Disc brake unit:** A friction brake in which the brake pads create retarding force by rubbing on a separate disc or discs mounted on the wheel hub or the axle.
- o **Electronic control unit (ECU):** Electronic equipment designed to convert a railcar's electronic inputs into an electrical output useful to the braking system.

Definitions (continued)

- **Hydraulic pressure control unit (HPCU):** A device that controls and transmits hydraulic pressure to disc brake units in response to control commands. Also known as **Electronic hydraulic unit (EHU).**
- **Track brake:** An electro-magnet that when energized, comes in contact with the running rail and produces friction forces that stop the train.
- **Tread brake shoe:** A replaceable friction element secured to a brake head for the purpose of producing a retarding force onto the tread of the wheel.
- **Tread brake unit:** A friction brake in which the brake shoes create retarding force by rubbing on the wheel treads.
- **Truck control unit:** See brake control unit (BCU).

Acronyms

- **ANSI:** American National Standards Institute
- **OEM:** Original Equipment Manufacturer
- **MSDS** Material Safety Data Sheet
- **BCU:** Brake Control Unit
- **ECU:** Electronic Control Unit
- **HPCU:** Hydraulic Pressure Control Unit
- **PPE**: Personal Protective Equipment
- **PSI**: Pounds per Square Inch

Introductory Text by Topic Area

1.0 Pneumatic Braking System
2.0 Hydraulic Braking
3.0 Electrical Hydraulic Unit
4.0 Actuator Brake
5.0 Common Brake Components
6.0 Tools

I. Introduction

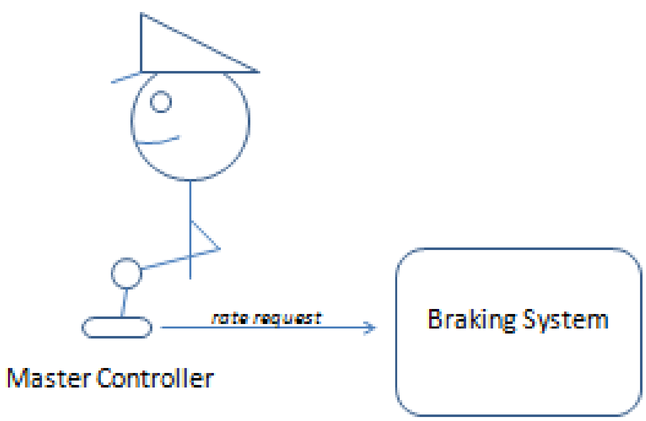
Brakes may be considered one of the most vital systems of the rail vehicle. The failure of this system would be catastrophic. As such, the inspection and maintenance of rail vehicle friction brakes is critical. The major topics that will be detailed in this primer include: pneumatic braking systems hydraulic braking systems, and common brake components. Because brake component names vary system to system, one particular set of names have been chosen and are defined below.

The preventive maintenance of friction brakes should be performed as per OEM recommendations and rail transit system testing, experience and procedures. Rail vehicle friction brakes and associated components should be inspected and maintained on a regular schedule as determined by the rail transit system. Minimally, inspection and maintenance tasks should comply with government regulations (Federal, state and local) and OEM recommended intervals. For ideal operation it is suggested that other items be considered when developing a preventative maintenance schedule such as industry experience, operating environment, historical data and failure analysis.

Note that since pneumatic braking systems are the most common across transit systems and both the pneumatic and hydraulic braking systems have several similar components this primer will detail pneumatic braking first, followed by hydraulic braking.

Typical Sequence of Braking Events

Typically the Braking System is responsive to the Train Operator's Master Controller request for braking effort.



II. Pneumatic Braking System

As the name would imply, air is the “heart” of the pneumatic friction braking system. High pressure air is used to create the friction forces necessary to slow or stop the rail vehicle. The pneumatic braking components are typically associated with one of the four functional groups depicted later.

- Air Supply Unit
- Electronic Control Unit
- Brake Control Unit
- Braking Devices

An overview of a typical electronic pneumatic braking system is detailed in Figure 1 below.

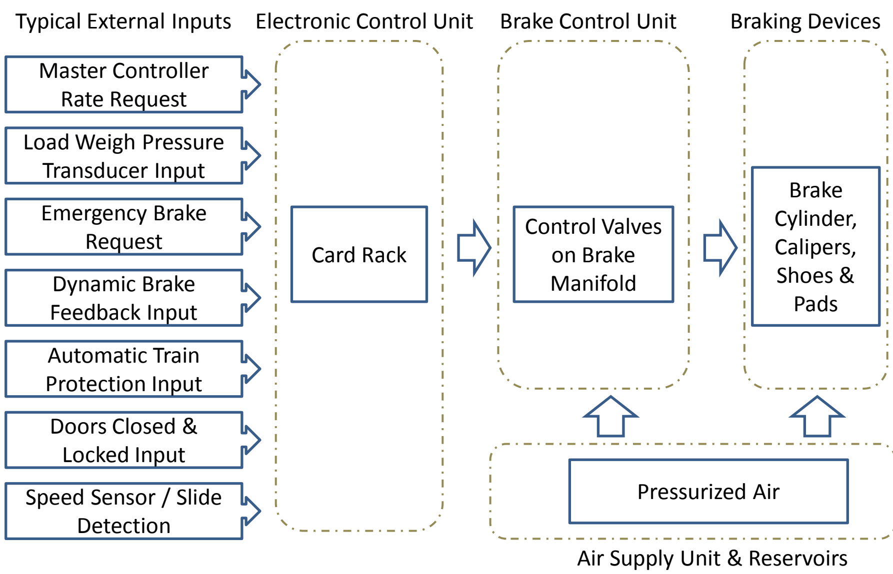


Figure: 1 Pneumatic Brake System Overview

Air supply unit – The air supply unit is the “power” of the pneumatic braking system. It provides pressurized air to the brake system by compressing atmospheric air using a series of cylinders, and then routing this compressed air, which is at a higher pressure, into an air tank such that this compressed air can be used to do work at a later time.

Electronic control unit – The electronic control unit is the “brains” of the pneumatic braking system. The ECU takes in external signals from the vehicle, buffers these signals and then uses them to provide a calculation of the required braking effort, which is output as a controlled volume pressure to control the brake cylinder pressure.

Brake control unit (also called **truck control unit**) – The brake control unit (BCU) is the “controlling” portion of the pneumatic braking system. The BCU is typically made up of groups of controlling valves whose purpose is to respond to the electrical inputs for the ECU and pneumatic inputs from the vehicle’s air springs (secondary load weigh input). The output of the BCU is a dynamic brake cylinder pressure, responsive to the ECU input.

Brake cylinder, calipers, shoes and pads – The brake cylinder, calipers, shoes and pads are the "muscle" of the pneumatic brake system. They take the output of the BCU's relay valve which controls the brake cylinder's pressure, and create proportional mechanical friction forces designed to resist the rotation of the vehicle's axle, thereby slowing or stopping the vehicle.

Common Components of the Pneumatic System

The following are common components found in the pneumatic system:

1. Air Compressor - The compressor pressurizes the air to do the work in the friction brake system
2. Filter/Dryer – Removes moisture from the system to keep moisture out of the system.
3. Pressure Switches – Are used to turn on and off different pieces of equipment in association with pre-defined pressures.
4. Air Valves – Represent a broad category of valves designed to manipulate the various air pressures in a myriad of different ways.
5. Brake Manifold – Typically large ported piece of aluminum that holds and connects each of the various air valves.
6. Brake Cylinder – Here is where the pneumatic pressure generated by the friction brake system is converted into a mechanical force that will be used to clamp the friction brake pads against the friction brake disc or wheel tread.
7. Brake Calipers – Mechanical device used to retain the brake heads and allow for the clamping force to be translated to the brake heads and friction brake pads.
8. Friction Disc – An axle mounted piece of equipment that the brake pads press against producing friction forces which slow the rate of the axle's rotation.
9. Electronic Control Unit (ECU) – An electronic piece of equipment which takes the vehicle's electrical inputs (brake request, load, etc.) and translates them into an electronic signal or signals used to control the brake control unit's (BCU) many valves.
10. Brake Control Unit (BCU) –This unit is typically a group of air valves, mounted on the Brake Manifold, tasked with the job of taking the electrical signal from the EBCU, and using it to control the BCU's Air Valves such that the desired brake cylinder pressure is produced, resulting in the appropriate friction brake pad force and the appropriate rate of vehicle deceleration.

Air Supply Unit

The air supply unit provides the "power" to the brake system by compressing atmospheric air using a series of cylinders, and then routing this compressed air, which is at a higher pressure, into an air tank, such that this compressed air can be used to do work at a later time. A simplified configuration of this process is depicted in Figure 2.

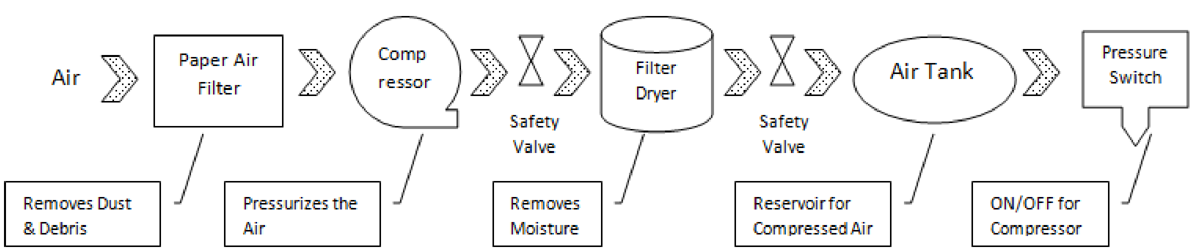


Figure 2: Air System Air Flow Simplified

Air is drawn into the air compressor through a paper air filter which removes dirt and contamination from the air. The air compressor then runs the air through a series of pistons which are used to pressurize the air by forcing the same amount of air molecules into a smaller space. The compressed air is then routed into the filter-dryer system which removes moisture from the air. After passing through the filter-dryer system, the air is then routed into an air tank/reservoir where the air is held. Overpressure safety valves are used between certain stages and will vent the air to atmosphere if the system's normal operating parameters are exceeded. They are installed for safety purposes only. A pressure switch which monitors the reservoir's air pressure is used to turn the compressor on when the air tank's lower pressure set point is reached, and off when the air tank's upper pressure set point is achieved. By doing this, adequate air pressure can be maintained for the braking system's use.

The **air compressor** is the pneumatic friction brake system's source for the high pressure air. An air compressor takes in air at atmospheric pressure and increases the pressure of that air by running it through cylinders which increase the pressure of that air, usually in multiple stages of cylinders, until it is compressed and at a pressure suitable to do the friction brake system's work. This pressure is typically between 90 and 150 pounds per square inch (psi).

Pneumatic brake systems employ a **filter-dryer** stage just after the compressor to remove moisture from the air system. The moisture that they remove would cause component degradation, and could rust air tanks, and lead to the system's failure.

Pressure switches are electro-pneumatic devices that have contacts which are moved by pneumatic pressures, and which electrically open and close when the associated pressures are achieved. Their electrical contacts are typically used in series circuits designed to provide an input when, for example, all of the friction brakes have been released or applied. These inputs are then fed to other systems on the vehicle. In the example of the Friction Brakes Released signal, this information is typically fed to the propulsion system as a requirement prior to the train applying power to its motors. These switches often have a rubber diaphragm which expands and contracts depending on the pressure of the air being applied as an input. When the air pressure gets within a given range, the movement of the diaphragm causes a change in the position of the electrical contacts which can either be used to open or close the contacts depending on the configuration of the pressure switch being used.

Air Valves and Associated Equipment

Types of Air Valves:

1. Check Valves – Limit air flow to one direction only.
2. Overflow Valves – Limit air from flowing beyond a particular point until a pre-set pressure is reached.
3. Pressure Regulator Valves – Maintain air pressure at a pre-set pressure.
4. Safety Valves (pop-off valves) – Vent air pressure to atmosphere once their pre-set pressure is reached. They are typically used to protect against exceeding a system's maximum safe pressures.

5. Air Tanks – Are air reservoirs which are typically used to hold pressurized air for later use.
6. Cut-Out Cocks – Are used to allow or block (and sometimes vent) air pressures from moving from one part of the system to another. They are manually operated.
7. Mesh Filters – Keep debris from moving through the system, and allow it to be eliminated from the system.

The valves associated with the air supply portion of the pneumatic friction braking system are typically in place to control the flow of the air through the system.

Check valves are valves designed to limit air flow such that air is only allowed to flow in one direction. This lends them to applications in which they are used to protect air supplies from venting to atmosphere should a break in the piping occur. Additionally, they are used to protect air supply sources from backflow.

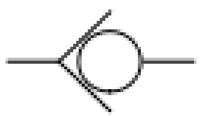


Figure 3: Symbol for Check Valve

Check Valves limit air flow to one direction and are typically used to protect air supplies against venting in the event of a pipe breaking. Below as shown in Figure 4 is how a check valve could be used to protect a downstream reservoir from venting if there was a break in the Upstream Reservoir's Piping or Tank.

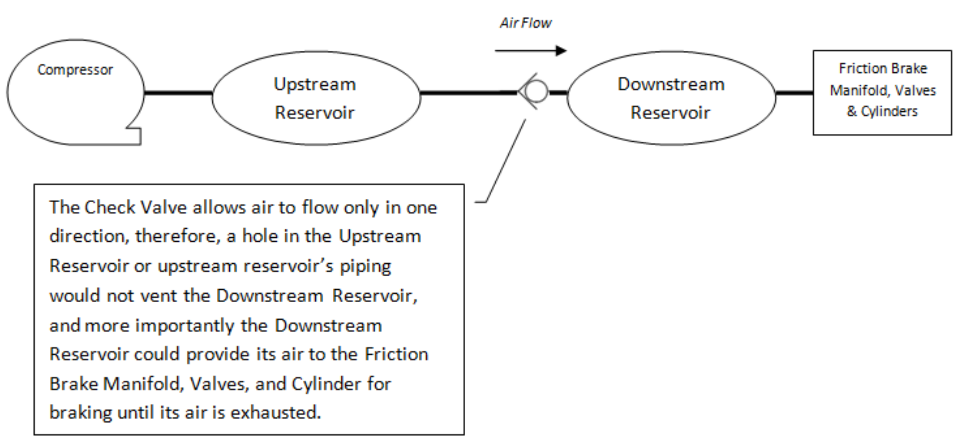


Figure 4: Illustration of air flow, using a check valve

Pressure overflow valves restrict the flow of air from one section of the system's tubing to another section until the set air pressure has been achieved. In doing this they can be used to make sure that sufficient air pressure has been built-up within the system to perform the work required by that section's function within the system.

Pressure regulator valves are designed to keep a section of the system's brake piping at a set pressure. The regulator valve will do this by venting excess pressures to atmosphere, and by allowing air pressure from a higher pressure source to flow into the system when the air pressure goes below the set value.

Safety valves are valves that vent the system's pressure to atmosphere when the pressures exceed normal operating pressures. They are used to provide protection when the system malfunctions and regular system parameters are not maintained. Air tanks are used to store a specific volume of pressurized air. They are typically isolated from other parts of the system by check valves which protect them from being completely vented in the event of a downstream air leak.

Cut-out cocks are air flow valves with manually operated handles that either allows the flow of air, when the handle is in one position, or completely cut-off the flow of air when the handle is rotated 90 degrees. In conjunction with cutting out the air, some cutout cocks also vent downstream air pressure when put into the cut-out position. Cut-out cocks are manually operated valves that simply isolate one section of the air system from another. Traditional transit cut-out cock valve has a handle that is usually configured to allow air flow when the handle is put at a right angle (at 90 degrees) to the piping, and which blocks air flow when put in line with the piping. This configuration can be reversed on some properties

Various filters are typically employed throughout an air system to eliminate debris from the air in a system. The debris would be associated with an upstream component's failure, and is not typical to a braking system.

Electronic Control Unit

The electronic control unit is the "brains" of the pneumatic braking system. As shown in Figure 5, the ECU takes in external signals from the vehicle, buffers these signals and then uses them to provide a calculation of the required braking effort, which is output as an electrical signal used by the BCU to determine the controlled volume pressure which controls the brake cylinder pressure.

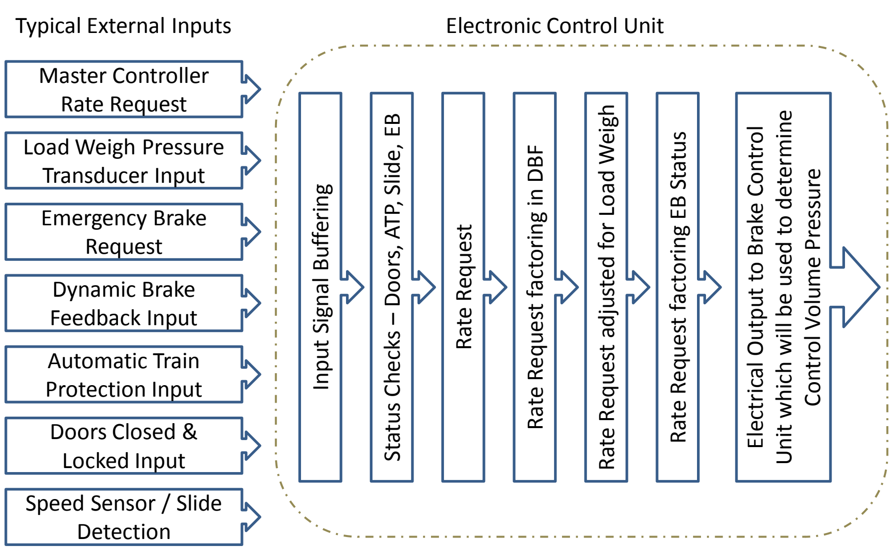


Figure 5: Electronic Control Unit Functionality

Brake Control Unit

The brake control unit, also known as truck control unit, is the “controlling” portion of the pneumatic braking system. The BCU is typically made up of groups of controlling valves, mounted on a drilled and ported manifold, whose purpose is to respond to the electrical inputs from the ECU and pneumatic inputs from the vehicle’s air springs (secondary load weigh input). The output of the BCU is a responsive brake cylinder pressure tied to the ECU’s electrical input to the BCU. See Figure 6 below.

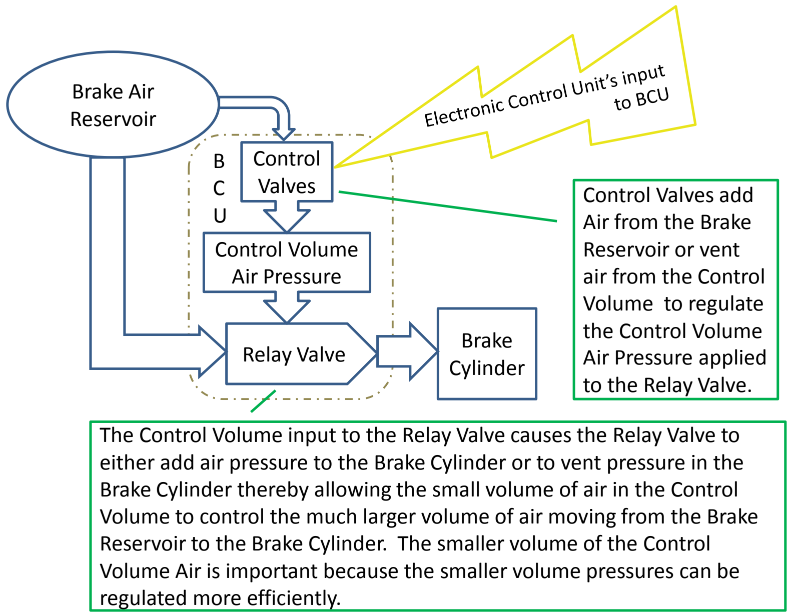


Figure 6: Brake Control Unit Block Diagram

Brake Manifold and Valves

The brake manifold is a used to support and route air to the different brake valves (figure 7) associated with the pneumatic brake system:

1. Control Valves – Add or remove air pressure to the control volume portion.
2. Emergency Brake Valve – Used to vent the system, thereby causing a pre-set pressure to be used as the control volume pressure.
3. Load Weigh Valve – Can mechanically adjust the control volume pressure to compensate for a vehicle’s loaded weight. It is used as a mechanical back-up to the electronic load weigh compensation accomplished by the ECU’s response to pressure transducer inputs from the vehicle’s air bags.
4. Pressure Transducer – A device that converts a mechanical pressure input into a corresponding electrical output.
5. Dump Valve – Momentarily vents the Brake Cylinder Pressure to atmosphere when energized to remedy a slide condition.
6. Test Fittings – Are points where pressure can be measured.
7. Relay Valve – Allows a small control volume air pressure to be used to control the pressure of a much larger volume of air. In the system described, the relay valve allows control volume pressure to control the friction brake cylinder’s pressure.

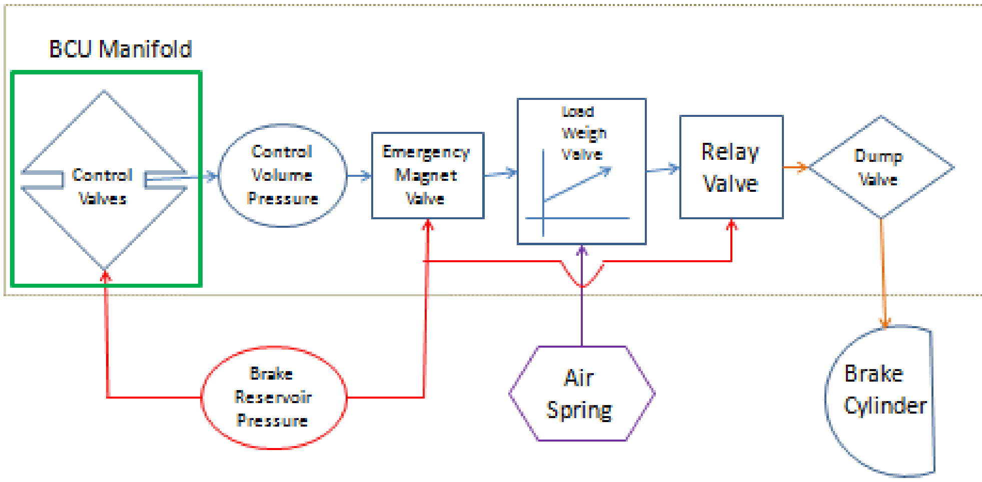


Figure 7: Brake Manifold and Control Valves Block Diagram

Control valve(s) are manipulated via the electronic input from the Electronic Control Unit (ECU). The ECU's signal will cause the control valves to either charge (increase air pressure) or vent (decrease air pressure) in the control volume. Under normal operating conditions this will have a direct effect on Brake Cylinder Pressure, and Braking Force.

The **control volume** of air is a small amount of air whose pressure under normal, non-emergency, operating conditions is used to control the Brake Cylinder Pressure.
The **emergency magnet valve** routes air in a "normal" path from the control volume to the Load Weigh Valve when energized (normal condition). When an "emergency" condition exists (loss of power to the unit, emergency mushroom depressed, etc.) the emergency magnet valve is de-energized and air from the Brake Reservoir is routed to the Load Weigh Valve in place of the control volume air.

The **load weigh valve** is in place to perform a secondary, all mechanical, load weigh calculation, and clamps the control volume pressure at a maximum based on this mechanical calculation. Under normal conditions, this clamping is not needed because the Electronic Control Unit performs the primary load weigh calculation electronically and adjusts the control volume pressure, which results in the Load Weigh Valve's output pressure being equal to its input. However, in an emergency condition, when the Emergency Magnet Valve is de-energized, the load weigh valve, clamps the brake reservoir pressure (now substituted for control volume pressure) at a pre-adjusted level that factors in the air spring load weigh input and outputs this level.

The **relay valve** allows the small control volume air pressure to control the Brake Cylinder pressure by regulating the air input to the Brake Cylinder from the Brake Reservoir.

The **dump valve** is energized is response to a slide condition, detected by the ECU when the input from speed sensors is different. When energized, the Dump Valve momentarily vents the air from the line going to the Brake Cylinder from the Brake

Reservoir and from the Brake Cylinder itself, which causes a momentary loss of pressure, thereby allowing the wheels to turn freely for a brief moment.

Air spring (figure 8) is a rubber element inserted between the truck frame and the bolster to level the vehicle and act as a form of suspension. The pressure inside of the air spring is typically used to estimate vehicle load as it pertains to propulsion and braking acceleration calculations.

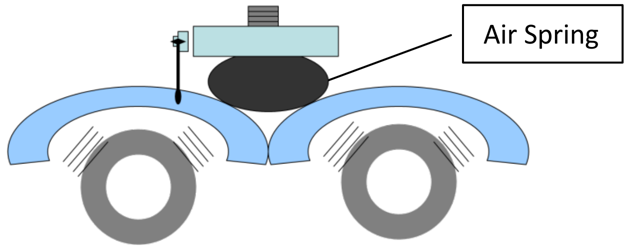


Figure 8: Air Spring

Pressure transducers are electro-mechanical devices that are used to produce an increased voltage or current flow in response to an increased pressure input. The input provided by the pressure transducer to the ECU allows for the ECU's Load Weigh calculation which is incorporated into the electrical signal sent to determine the Control Volume pressure.

Test fitting are often installed on brake system manifolds and throughout the brake system's piping such that the system's brake pressures can be read at various stages and used to determine if the various valves within the system are performing their designed function properly.

Brake Cylinder, Calipers, Shoes and Pads – The brake cylinder, calipers, shoes and pads are the "muscle" of the pneumatic brake system. They take the output of the BCU's relay valve which controls the brake cylinder's pressure, and create proportional mechanical friction forces designed to resist the rotation of the vehicle's axle, thereby slowing or stopping the vehicle. Figure 9 shows the location of the major brake system components.

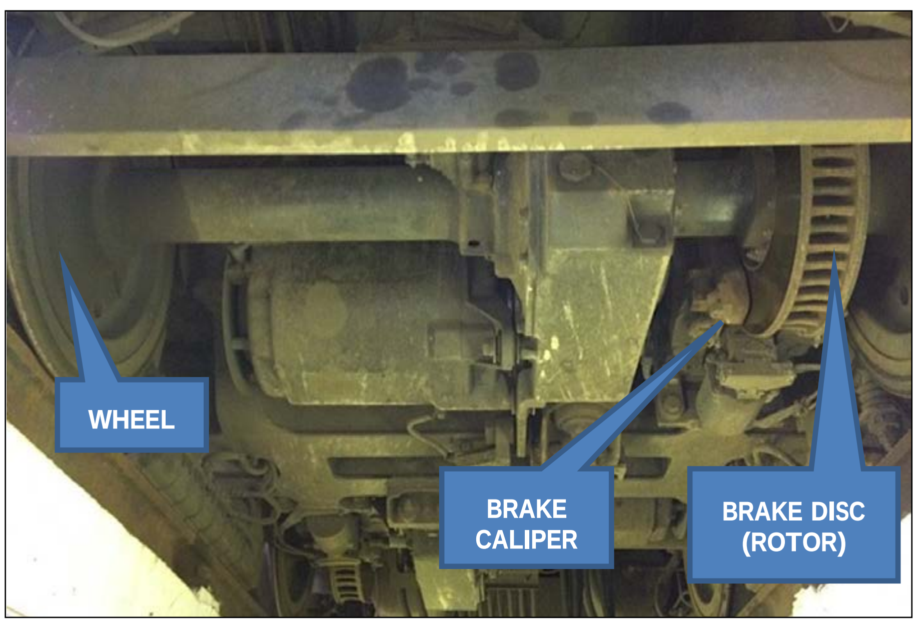


Figure 9: Disc Brake Equipment – Courtesy of PATransit

The cylinder is typically a piston which applies the input brake cylinder pressure to a lever arm, the brake calipers, in such a way so as to apply force via the lever arm and brake pads against the friction brake disc.

Safety Concerns of Friction Brakes Operation and Maintenance

When performing any operation, inspection or maintenance tasks take care to wear the appropriate personal protective equipment (PPE) – and minimally follow ANSI standards. Below are some safety requirements. Others will be dispersed throughout the text of this primer.

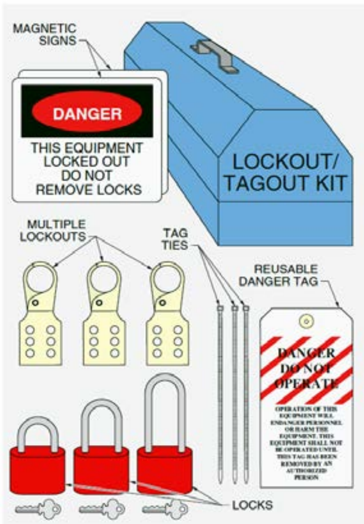


Figure10: Lockout/Tagout Kit

Voltage: Energy Supply

- To avoid possible injury ensure that the equipment is secured against uncontrolled movement in accordance with rail transit system safety procedures before starting inspection and maintenance procedures. During inspection and preventative maintenance brakes may be cycled ON and OFF.

Lockout/Tagout

- If any corrective or preventative procedures are required, ensure brakes are cut-out before performing any work. Follow lockout/tagout procedures as per your authority (figure 10).
- Verify that electrical power is removed by checking with reliable equipment.
- To avoid possible injury, notify all concerned that equipment is about to be energized before restoring power. If vehicles are coupled and controls are trainline, assure that it is safe for equipment in coupled cars to become operational before energizing any high voltage or battery circuits.

Pinch Points

To avoid possible injury while inspecting friction brakes, keep hands and tools away from pinch points (figure 11).

Figure 11: Pinch Points

Cleaning

- To avoid possible injury while using compressed air for dislodging dirt and debris, wear appropriate eye, face, and respiratory protection meeting minimum ANSI or other applicable national industry standards. Keep air pressure at the blowgun nozzle below 30 pounds per square inch (PSI).
- Use only those cleaning products and lubricants proven safe and authorized for use by the rail transit system. Consult OEM and MSDS references for suitability for each application to prevent personal injury and damage to the equipment.

Visual/Audible and Operation Inspection of the Disc Brake Equipment

It is important to do both a visual/audible and operation inspection of the disc brake equipment (figures 12).

First, inspect disc brake units for damaged, loose or missing components. The disc brake unit is composed of an actuator and caliper, which creates retarding force on a disc attached to the wheel or axle of the transit vehicle. The retarding force on the disc is transferred to the rail to slow the vehicle. Correct any damage found and secure loose and replace missing components. Refer to OEM.

Also, check for leaks and repair as required. Be sure to visually inspect brake lines and hoses for leaks, mounting and chafing; repair if necessary.

Apply and release the brakes and verify operation for: proper operation of the disc brake unit per OEM; proper piston travel per the OEM; and no indication of binding or fouling of the disc brake unit's levers and/or pins.

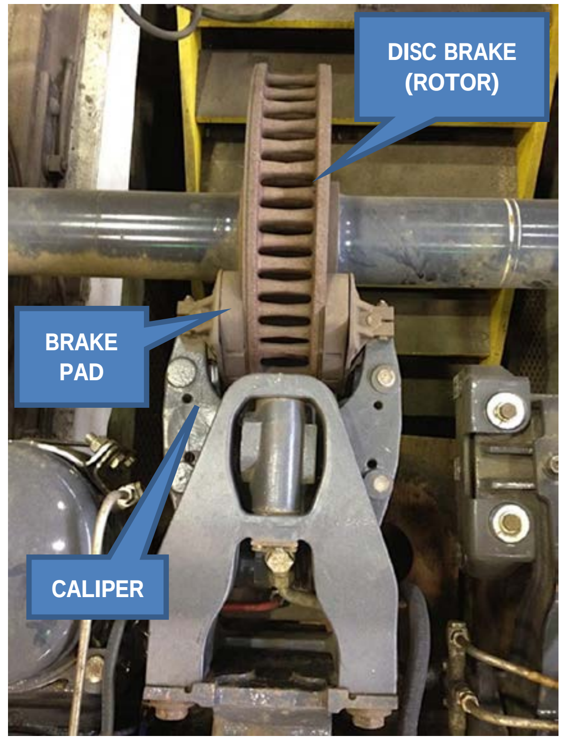


Figure 12: Friction/Disc Brake Components – Courtesy of PATransit (top view)

Lubricate the disc brake unit as recommended by the OEM and in accordance with rail transit system procedures. Examine the brake disc faces for damage, cracks or nicks along the outer periphery of the brake disc. Some radial checks and thermal checks are normal during operation. Also, inspect the hub for lateral movement on axle seat, cracks, broken or missing tangs, or damage. Be sure to check brake disc mounting hardware, such as bolts, nuts, washers and retaining mechanisms, for proper attachment.

Measure the disc brake at the greatest wear locations for proper thickness and improper wear patterns such as scoring or excessive dishing. And, inspect the disc brake for any fin obstructions or damage. Refer to the OEM for condemning and inspection recommendations.

Inspect for missing disc brake pads. Replace missing disc brake pads and ensure that the disc brake pad is properly secured. Also, check the thickness of the disc brake pads. Renew the disc brake pad if remaining wear material is less than the condemning limit set by the rail transit system to ensure that there will be useful life to the next inspection interval.

Ensure that the disc brake pad is properly latched and/or secured. Note that because of taper wear, care must be taken to ensure that the inspection is performed at the thinnest point of the disc brake pad.

Also, inspect disc brake pad for broken or missing friction braking material. If the disc brake pad is found condemnable, renew the disc brake pad. Make sure that the brake pad is properly secured. During disc brake pad renewal, check the disc brake pad securing mechanism by doing a visual inspected and replaced if broken, worn, or damaged. Be sure to the check disc brake unit for worn bushings and pins.

As always refer to the OEM for condemning and inspection recommendations and in accordance with rail transit system procedures.

Visual/audible and Operation Inspection of the Brake Cylinder Equipment

During preventative maintenance of the **brake cylinder equipment** be sure to do both a visual/audible and operation inspection. Inspect brake cylinder or tread brake units for damaged, loose or missing components and mounting hardware. Correct any damage found; secure loose and replace missing components. Refer to OEM. Make sure to inspect brake lines and hoses for leaks, mounting and chafing. Repair/replace as required.

Friction Brake Equipment Inspection

Friction brakes systems differ railcar to railcar, however, it is recommended that during periodic inspections the following equipment, described below, is looked at:

- **Disc Brake** – Disc Brake, also known as a rotor, should be checked for thickness, to make sure that they have enough mass to dissipate the heat load that is generated during braking. Checked for thermal cracking, loose hardware, and excessive disc concavity
- **Disc Brake Pads** - Should be checked to verify that they are thick enough to make it the next inspection, and that there are no signs on the disc face that there is debris lodged on the pad's contact face.
- **Disc Brake Unit** - A friction brake in which the brake pads create retarding force by rubbing on a separate disc or discs mounted on the wheel hub or the axle.
- **Track Brake** - A magnetic friction brake that compresses against the running rail and is activated by an electrical signal.
- **Tread Brake Shoes** - A replaceable friction element secured to a brake head for the purpose of producing a retarding force onto the tread of the wheel.
- **Tread Brake Unit** - A friction brake in which the brake shoes create retarding force by rubbing on the wheel treads.

Be sure to check for missing tread brake shoes and renew all missing tread brake shoes. Inspect the thickness of the tread brake shoes. Renew the tread brake shoe if remaining wear material is less than the condemning limit established by the rail transit system to ensure that there will be useful life to the next inspection interval.

Make sure that the brake shoe key is fully inserted through the brake shoe key slot. **(**Note that because of taper of the wheel tread, care must be taken to ensure that the inspection is performed at the thinnest point of the brake shoe.)

Inspect tread brake shoes for broken or missing friction braking material. If the tread brake shoe is found condemnable, renew. During tread brake shoe renewal, the brake shoe key is to be inspected and replaced if broken, worn or damaged. Ensure that any brake shoe keys replaced are secured in place.

Be sure to apply and release the brakes and verify operation for: proper operation of the brake cylinders or tread brake units per the OEM; proper piston travel per the OEM; and no indication of binding or fouling of the tread brake equipment levers and/or pins.

Lubricate the brake cylinder levers or linkages as recommended by the OEM and in accordance with rail transit system procedures.

III. Hydraulic Braking

Hydraulic braking in vehicles is a braking mechanism which uses hydraulic fluid to transfer pressure from the controlling mechanism to the braking mechanism. Generally, hydraulic braking systems are reliable and quite powerful. These systems involves a master cylinder, hydraulic fluid, hydraulic lines and one or more often called “slave” cylinders, which actuate each individual brake. The basic principles of hydraulics include: 1) Fluids cannot be compressed; 2) Fluids can transmit movement. In other words, they act like a steel rod in a closed container and master cylinder transmits fluid to wheel cylinder or caliper piston; and 3) Fluids can transmit and increase force

A simplified configuration of this process is depicted in Figure 13.

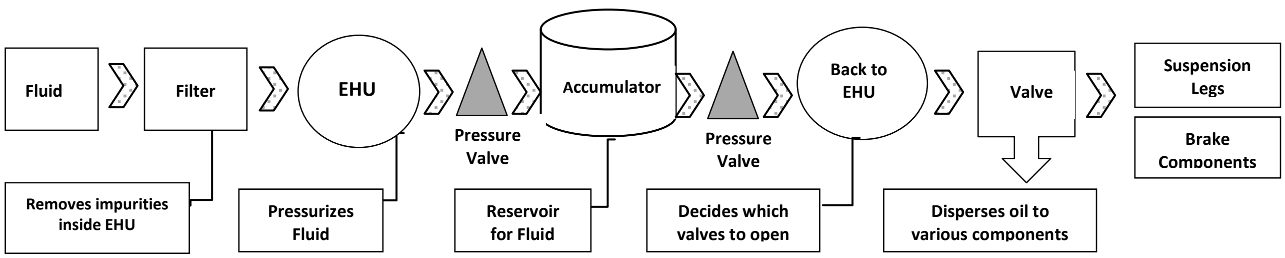


Figure 13: Hydraulic System Fluid Flow Simplified

The hydraulic braking system is designed as a closed system: unless there is a leak in the system, none of the brake fluid enters or leaves it, nor does the fluid get consumed through use.

The hydraulic braking system operates much the same of the pneumatic braking system, which was explained in detail in the text above. Instead of a compressor, there is an electric hydraulic unit (EHU) that pressurizes fluid instead of air. Secondly, the accumulator functions as an air tank would in the pneumatic braking system.

A hydraulic brake system for vehicles, particularly light rail vehicles, includes at least one brake actuator for engaging the brake by means of a group of springs and disengaging the brake by hydraulic pressure.

The system is comprised of an electric drive motor and pump for supplying pressurized hydraulic fluid to the actuator, and a safety valve and solenoid valves for controlling the pressure of the hydraulic fluid in the actuator. An accumulator is connected to the electric drive motor and pump for delivering the pressurized hydraulic fluid via valves and restriction for adjusting the pressure in the accumulator to a value substantially inversely proportional to the load of the vehicle. It is connected to the actuator by shuttle valves controlled by the pressure of the accumulator when the control safety valve and solenoid valves are actuated to relieve hydraulic fluid from the actuator.

Common Components of the Hydraulic System

The following are common components found in a hydraulic braking system as shown in Figure 13 above:

1. Electric Hydraulic Unit (EHU)
2. Filter (inside EHU)
3. Brake Manifold (in EHU)
4. Pressure Valves
5. Pressure Switches
6. Control Valves
7. Brake Actuator
8. Electronic Brake Control Unit (EBCU)
9. Brake Calipers
10. Friction Disc/Rotor

Note that these components, except for the electronic hydraulic unit (EHU) and brake actuator, are components also used in a pneumatic braking system and were described in detail above.

IV. Electrical Hydraulic Unit and Brake Actuator

Brake actuators and hydraulic units are, can be considered the ‘arm’ and ‘muscle’ of a brake while the electronic components form the ‘brains’ of the brake system controlling the arm and muscle.

Electronic Hydraulic Unit (EHU)

The electronic hydraulic unit (EHU) (figure 14), is also known as the electronic hydraulic control unit. It takes input signals and uses these inputs to correctly create an electronic response(s) which will cause the mechanical portion, such as the valves, brake manifold and brake actuator, to create appropriate braking.

Figure 14: Electronic hydraulic unit– Courtesy of Hiawatha Light Rail

Brake Actuator

The brake actuator is a relay device that is part of the brake assembly that stores energy. It fires a burst of air into the brake assembly when the EHU sends an electronic signal to stop the rail vehicle. Its sole purpose is to ensure that the brakes are applied at the same instance to all of the rail vehicle wheels.

Here’s how the brake actuator system works. The brake actuator is enabled after the air, hydraulic and electrical lines from the front of the rail vehicle are attached to the correct connectors to each brake assembly on the rail car. On activation, the front brakes act almost instantly, while there would be a bit of lag time to the rear and other brake assembly, the brake actuator eliminates this lag time.

Spring-applied actuators provide the “fail-safe elements” of the safety system in rail vehicles. If the energy supply fails, the braking force is provided with the force of a mechanical spring.

Visual/audible and Operation Inspection of the Brake Control Equipment

It is important to perform the following visual, audible and operation inspections of the brake control equipment, starting first with the cab brake control equipment. As always refer to and follow OEM and rail transit system procedures.

Cab Brake Equipment

Inspect cab brake equipment for damaged or loose components. Correct any damage found and secure any loose components. Refer to OEM. Verify that cab gauges are within their calibration period. And, inspect for leaks; repair as required.

Figure 15: Master Controller – Courtesy of Hiawatha Light Rail

Inspect the master controller (figure 15). Be sure to apply and release the brakes and verify operation for: proper operation of the master controller or brake valve; no binding of the handle; proper brake cylinder gage indication; and proper function of brake status indicating lights.

Note that the master controller serves as the primary operational interface between the vehicle and the operator. It monitors trainline inputs and generates trainline commands for propulsion and braking. The master controller is customized to handle the vehicle level electronic input/output signals. Master controller equipment is installed wherever a motorman’s cab is present on the vehicle. Safety features are designed into the unit such as the “dead man” automatic brake application, and only one controller is allowed to be active on the train consist at any given time.

Apply both a ‘service brake’ and an ‘emergency brake’ application and verify proper brake cylinder pressure or indication.

Lubricate the brake valve or master controller as recommended by the OEM and in accordance with rail transit system procedures.

Complete the cab inspection by operating all of the cab’s emergency and penalty brake initiating devices and verifying proper operation.

Other Brake Control Components

Be sure to inspect air brake operating control equipment for damaged or loose components. Repair and secure as needed. Verify proper position of all cut-out valves and seals as required. Check the brake control unit of all damaged or loose components and air leaks. As necessary, repair any damage and secure loose components.

Inspect hydraulic brake control unit for damaged or loose components, hydraulic leaks and fluid level. Fix any damage found, secure loose components, and refill and bleed as required. Be sure to inspect mounting hardware, torque stripes and safety/tamper proof seals. Repair or replace as required.

Examine the accumulator for damaged or loose components. Be sure to pressure-test the accumulator as recommended by the OEM.

Make sure to check for leaks and repair as required. Be sure to clean or replace filters. Also, verify operation of trip valve/trip switch, and lubricate as recommended by the OEM. Using a test gauge in all modes of brake and release conditions, verify proper pressure.

Finally, be sure to perform self-tests and verify proper brake operation. Also, review on-board recording equipment for recorded faults.

V. Common Brake Components

The majority of the common brake components found in rail vehicles have been covered in the text above:

- Electronic Control Unit (pp. 5,6,9 &11)
- Brake Calipers (pp.6, 12,18 &19)
- Rotors (Disc Brake) (p.2, 11,13 &14)
- Brake Pads / Brake shoes (pp.2,5, 6, and11-16)
- Brake Transducers (pp.11)
- Filters (pp.7, 8 & 19)
- Hoses (pp. 13 &14)
- Piping (pp.7, 8 & 11)

The other common brake components that technicians should be familiar with and include in preventive maintenance checks are:

Parking brake equipment
Inspect the parking brake (hand brake) equipment for damaged or loose components. Correct any damage found and secure any loose components in accordance with OEM. Check for leaks; repair as required. Next, apply and release the parking brake equipment and verify proper operation. Make sure to inspect for interference and damage. If recommended by OEM, lubricate the parking brake equipment. Verify that the manual quick-release mechanism is functioning properly.

Track brake equipment
During the inspection and maintenance of the track brake equipment, inspect for slag buildup on the contact surface. Remove slag buildup if found. Check the components for proper attachment, signs of damage or corrosion, or missing parts. Correct any damage found, and secure loose and replace missing parts in accordance with OEM.

Inspect magnet contact surface height with approved gauge, and adjust suspension as necessary and refer to the OEM. Also, examine electrical cable connections for cracks, kinks and abrasions. Repair and replace as required.

Check pole shoes for wear. If wear is beyond condemning limits, replace pole shoe as specified by the OEM and your rail transit system procedures. Inspect the condition of suspension and related components. Replace as required.

Examine track brake stops for looseness or damage. Inspect buffer pads for wear, and replace as required. Also, inspect condition of compression spring. Replace as required. Refer to OEM. Also, check attaching bolts and ensure that locking wire, if used, is securely attached. Replace as required.

Be sure to verify proper operation of track brakes and suspension by energizing and de-energizing the track brake.

VI. Tools

The majority of tools during the inspection and maintenance of rail vehicle friction brakes have been covered in this and other rail vehicle primers. And in accordance with the APTA recommended vehicle inspection and maintenance the standard tools carried by maintenance personnel are sufficient to perform required inspection and maintenance of rail vehicle friction brakes described in this primer.

The only other tools that are recommended that technicians be familiar include the following:

Breakout Box (figure 16) – Lets the technician establish electrical connection to individual lines on a connector without interrupting the connection between the equipment and the diagnostic tool. This allows for simultaneous execution of testing and monitoring the test. It enables users to switch, cross and tie interface leads.

Figure 16: Breakout Box

Volt Ohm/meter (VOM) (figure 17) – An electronic measuring instrument that combines several measurement functions in one unit. A typical multi-meter would include basic features such as the ability to measure voltage, current, and resistance.

Figure 17: Volt-Ohm/Meter

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APTA Rail Transit Standards, Vehicle Inspection and Maintenance APTA RT-RP-VIM-007-02 “Recommended Practice for Friction Brake Equipment Periodic Inspection and Maintenance, 7/26/04

How Hydraulics Work – Basic
http://science.howstuffworks.com/hydraulic1.htm

Hanning-Kahl
http://www.hanning-kahl.com/products-service/light-rail-technology/vehicle-technology/hydraulic-brake-systems/hydraulic-power-unit.html

Relevant OEM Contact Information

OEM	Website	Contact Information
Wabtec	http://www.wabtec.com	1001 Air Brake Avenue Wilmerding, PA 15148 Phone: (412) 825-1000 Fax: (412) 825-1019
Knorr/New York Air Brake Corp	http://www.progressiverailroading.com/	748 Starbuck Ave. Watertown, NY13601 Phone: 315-786-5431 Fax: 315-786-5676
TechTran	www.techtrans.com	Corporate Headquarters Dallas / Fort Worth, Texas 1701 West Northwest Hwy Suite 100 Grapevine, TX 76051 800-852-8726 tel 817-488-0306 fax

Attachment: Industry Training Standard

205. Friction Brakes: Introduction and Preventive Maintenance

- **205.1 Hydraulic Braking**

  Inspecting and maintaining hydraulic braking
  - Analyze fluid
  - Bleed system
  - Check fluids
  - Check system pressure
  - Depressurize system
  - Explain cause of low and high fluid readings
  - Explain causes of fluid breakdown
  - Explain fluid flash point and related safety precautions
  - Fill fluids
  - Flush fluids
  - Identify braking system check points/sight glass location
  - Identify contaminants and their effect on fluid appearance
  - Identify different fluids and their uses
  - Measure vehicle weight to set brake effort
  - Recycle fluids
  - Set up flush cart with proper piping

  Inspecting and maintaining flush cart
  - Change filters
  - Reset pump pressure
  - Clean flush cart
  - Explain meaning of different fault codes
  - Describe load cells

- **205.2 Electrical Hydraulic Unit**

  Inspecting and maintaining electrical unit
  - Blow out and clean commutators
  - Check electrical unit for chafing and vibration
  - Check for leaks and damage
  - Check LORD mounts
  - Check tightness of ground shunts
  - Clean valves
  - Disassemble electrical unit
  - Identify correct hose size and type
  - Inspect electrical carbon brushes
  - Reassemble electrical unit
  - Replace breathers
  - Replace cannon plugs
  - Replace damaged fittings
  - Replace damaged hoses
  - Replace electrical carbon brushes
  - Replace filters
  - Replace fluid
  - Replace transducers and seals
  - Replace valves
  - Replace wiring
  - Test electrical unit

- **205.2 Electrical Hydraulic Unit (continued)**

Inspecting and maintaining varistors/pressure transducers

- Check transducer output
- Choose proper filter
- Compare demand and actual readings
- Demonstrate ability read hydraulic schematics
- Demonstrate ability to diagnose transducer problems
- Replace varistors/transducer
- Test varistors/transducer

Inspecting and maintaining motor assembly

- Cycle motor
- Inspect electrical carbon brushes
- Measure startup timing
- Repair bearings
- Repair electrical carbon brushes
- Replace bearings
- Replace electrical carbon brushes
- Replace motor assembly
- Test motor assembly

Inspecting and maintaining control valves

- Verify valve position
- Describe control valve operation
- Test control valves
- Repair control valves
- Replace control valves

Inspecting and maintaining pump-off circuit

- Test release cable
- Check for leaks
- Inspect emergency brake hand pump
- Fill emergency brake hand pump
- Test emergency brake hand pump
- Describe purpose of a witness tag
- Test pump-off circuit
- Repair leaks in hoses or hard lines
- Test emergency brake hand pump
- Repair emergency brake hand pump
- Replace emergency brake hand pump
- Lock out emergency brake hand pump system
- Bleed pressure

Maintaining cut-off switch

- Replace cut-off switch

Inspecting and maintaining accumulators

- Check nitrogen levels
- Fill accumulators
- Follow high-pressure safety procedures
- Identify Schrader valve
- Check accumulator and mounting for damage and missing components
- Fill accumulators
- Replace accumulators
- Repair accumulators
- Change mounts
- Change rock shields

- **205.2 Electrical Hydraulic Unit (continued)**
    - Change hardlines
    - Change Schraeder valves

- **205.3 Actuator Brake**

  Maintaining spring
    - Check spring
    - Adjust spring
    - Replace spring

  Maintaining electric motor
    - Replace electric motor
    - Test electric motor

- **205.4 Pneumatic Braking System**

  Inspecting and maintaining check valves
    - Inspect check valves
    - Test check valves
    - Replace check valves

  Inspecting and maintaining air reservoir
    - Inspect air reservoir
    - Drain air reservoir

  Inspecting and maintaining pneumatic control unit
    - Inspect pneumatic control unit
    - Test pneumatic control unit
    - Repair pneumatic control unit
    - Replace pneumatic control unit

  Performing preventive maintenance on brake valves
    - Inspect brake valves
    - Test brake valves
    - Repair brake valves
    - Replace brake valves

  Inspecting and maintaining air gauges
    - Test air gauges
    - Replace air gauges

  Inspecting and maintaining air cocks
    - Test air cocks
    - Replace air cocks

  Inspecting and maintaining hydraulic/pneumatic unit
    - Test hydraulic/pneumatic unit
    - Check oil level
    - Fill hydraulic/pneumatic unit
    - Replace hydraulic/pneumatic unit

  Inspecting and maintaining air compressor
    - Test air compressor
    - Check oil level
    - Fill air compressor
    - Inspect filter-drier
    - Replace filter-drier
    - Adjust pressure switches
    - Replace air compressor
    - Test filter-dryer
    - Test pressure switches

- **205.4 Pneumatic Braking System (continued)**
  - Replace pressure switches
  - Replace air compressor
  - Adjust pressure switches
  - Replace pressure switches

- **205.5 Common Brake Components**

  Inspecting and maintaining parking brake
  - Test parking brake
  - Test failsafe operation
  - Replace parking brake
  - Repair parking brake

  Inspecting and maintaining electronic control unit
  - Clean electronic control unit
  - Vacuum electronic control unit
  - Check connectors
  - Clear fault codes
  - Explain function of reset button
  - Replace electronic control unit
  - Test cards
  - Repair cards
  - Replace cards

  Inspecting and maintaining brake calipers
  - Check pivots
  - Lubricate pivots
  - Check brake calipers for leaks
  - Check mountings and seals
  - Identify uneven wear patters and explain causes
  - Align caliper to rotor of train
  - Replace brake calipers
  - Repair brake calipers
  - Test brake calipers

  Inspecting and maintaining rotors
  - Inspect rotors for cracks, FOD damage, wear lines, concaveness/convexness and rust
  - Torque bolts to proper specifications
  - Replace rotors
  - Torque bolts to proper specifications
  - Turn rotors

  Inspecting and maintaining brake pads/shoes
  - Inspect brake pads/shoes
  - Replace brake pads/shoes
  - Inspect clips
  - Explain wear indicator
  - Explain wear patterns and causes
  - Remove clips/pins
  - Replace clips/pins in correct orientation

- **205.5 Common Brake Components (continued)**

  Inspecting and maintaining brake transducers
  - Inspect brake transducers
  - Clean brake transducers
  - Repair brake transducers
  - Replace brake transducers
  - Test brake transducers

  Inspecting and maintaining manual brake release
  - Inspect manual brake release
  - Replace manual brake release
  - Test manual brake release

  Inspecting and maintaining brake bypass switch (electric cutout)
  - Test brake bypass switch
  - Repair brake bypass switch
  - Replace brake bypass switch

  Inspecting and maintaining track brake
  - Measure track brake
  - Test track brake
  - Replace track brake
  - Check suspension clearance and height
  - Check for corrosion on wear plate
  - Explain isolation
  - Clean debris
  - Replace rusty components

  Inspecting and maintaining sanding system
  - Test sanding system
  - Fill sanding system
  - Clean sanding system
  - Check sand level
  - Inspect tubes for obstructions
  - Inspect nozzle
  - Inspect heaters
  - Inspect compressor
  - Inspect level filters
  - Clean seal
  - Repair sanding system
  - Replace sanding system
  - Replace valve
  - Replace drop tube

  Inspecting and maintaining electrical cabling
  - Inspect cabling
  - Check for corrosion on hangers
  - Verify cables slide smoothly
  - Inspect wiring harnesses for damage
  - Identify when rerouting is necessary
  - Repair electrical cabling
  - Replace electrical cabling
  - Repair connectors

- **205.5 Common Brake Components (continued)**

  Inspecting and maintaining piping and hoses
  - Inspect piping and hoses
  - Verify piping and hoses slide smoothly
  - Inspect wiring harnesses for damage
  - Identify when rerouting is necessary
  - Repair piping and hoses
  - Replace piping and hoses
  - Identify correct hose size and type

  Inspecting and maintaining caliper support rod
  - Lubricate caliper support rod
  - Replace caliper support rod
  - Adjust caliper support rod

  Inspecting and maintaining caliper support
  - Lubricate caliper support
  - Replace caliper support

  Inspecting and maintaining filters
  - Clean filters
  - Replace filters
  - Inspect intake filter for motors and electrical boxes
  - Locate correct filter type and part number
  - Replace filters

  Inspecting and maintaining anti-spinslide circuits
  - Test anti-spinslide circuits
  - Clean speed sensors
  - Locate sensors on axles, motor and gearbox
  - Test anti-spinslide circuit
  - Repair anti-spinslide circuit
  - Replace anti-spinslide circuits

- **205.6 Tools**

  NOTE: Can be integrated in other parts of module or taught separately.

  Demonstrate ability to use bench test equipment (electric and hydraulic)
  Demonstrate ability to use laptop and software
  Demonstrate ability to use fluid cleaner/pump/oil analyzer and filter cart
  Demonstrate ability to use caliper/brake release tools
  Demonstrate ability to use caliper stands
  Demonstrate ability to use brake force tester
  Demonstrate ability to use signal generator to test sensors
  Demonstrate ability to use digital multi meter
  Demonstrate ability to use oscilloscope
  Demonstrate ability to use breakout boxes
  Demonstrate ability to use voltage/current regulators
  Demonstrate ability to use portable test unit
  Demonstrate ability to use megger/HiPot
  Demonstrate ability to use a wheel lathe

RAIL VEHICLE LEVEL 200
SUBJECT OVERVIEW

Module: 206 – HVAC: Heating, Ventilation and Air Conditioning

Note: All 200 level courses should be delivered only after completion of 100 level training

About the Author: Bertrand Alexander

Bertrand Alexander is a member of IBEW Local 1245 and is employed as a Light Rail Vehicle Technician by Sacramento Regional Transit District in Sacramento California. Bertrand has enjoyed a long career in the transit industry having previously worked as a senior product specialist for Luminator Corporation the East and West Coast offices. He was also a supervisor in the West Coast office. While at Luminator Bertrand worked independently and was responsible for warranty repair, software support, and communication system modernization for Luminator's transit customer's bus and light rail fleets. Bertrand earned an Associate in Occupational Studies in Electronic and Circuit Systems from TCI Technical Career institutes in New York, NY.

Overview/Purpose

This material provides technicians with an overview of heating, ventilation and air conditioning (HVAC) on rail vehicles in order to give technicians a basic introduction to the subject and prepare them for national qualification testing.

Material presented here is intended only as a primer to the subject, keeping in mind that rail systems have different characteristics. It follows the National Training Standards established jointly by representatives from both labor and management. As a primer, additional knowledge will be needed to become fully qualified on this subject. Material presented here does not address every possible aspect because HVAC systems vary at each transit agency. Other resources to help technicians become qualified on this subject are listed below.

This module focuses on HVAC and associated Federal regulations and their application. It provides technicians with a theoretical foundation for further study and practical application.

Table of Contents

Suggested Tools/Training Aids

- power point presentations
- transparencies
- manuals
- schematics
- gauges
- basic hand tools
- lap top computer (optional)

Topics Covered

Topics listed below are covered in this introduction of Heating, Ventilation and Air Conditioning (HVAC). A full copy of the National Training Standards from which these topics were taken is attached.

- Background Knowledge
- Compressor/Motor
- Evaporators and Condensers
- Refrigeration Components
- Heaters
- HVAC Controls
- Electrical Circuits and Electronic Controls
- Tools

Definitions, Abbreviations and Acronyms

For the purposes of this lesson, the following glossary of terms, definitions, acronyms, and abbreviations shall apply. They are not all inclusive, and the reader is encouraged to explore the text, footnotes and bibliography sources for further information.

Definitions

- **Ammeter:** An instrument that measures electric current, especially in amperes.
- **Compressor:** A large electric pump that pressurizes refrigerant, turning it from a gas back into a liquid, and causes the continuous flow of refrigerant through the system.
- **Evaporator:** A heat exchanger that absorbs heat and allows vaporization (i.e. converting liquid refrigerant to a vapor refrigerant).
- **Condenser:** Facilitates heat transfer
- **Expansion valve:** Regulates refrigerant flow into the evaporator
- **Evacuate**: Remove air and moisture from a refrigerant system.
- **HVAC Controller:** A sensing device that compares the actual state (e.g., temperature) with a target state, then draws a conclusion and electronically signals the action to be taken (e.g., start the blower).
- **Heat:** A form of energy contained in matter.
- **Heat Transfer:** A process during which heat moves from a warmer substance to a cooler substance resulting in the warmer substance becoming cooler and the cool substance becoming warmer.
- **Hygrometer:** Any of several instruments that measures the humidity of the atmosphere.
- **Manometer:** An instrument (as a pressure gauge) that measures the pressure of gases and vapors.
- **Manifold gauge:** Common used tool for inspecting and diagnosing refrigeration systems.
- **Micron:** Unit used for stating low pressure. One micrometer, which is one millionth have a meter or approximately 1/25,000 of an inch.
- **Psychrometer:** A hygrometer consisting essentially of two similar thermometers with the bulb of one being kept wet so that the cooling that results from evaporation makes it register a lower temperature than the dry one and with the difference between the readings constituting a measure of the dryness of the atmosphere.
- **Refrigerant:** A chemical substance used in air conditioner unit that absorbs heat and changes from a liquid to a gaseous state during the refrigeration process.
- **Refrigeration:** The process of cooling or lowering the temperature of a space or a substance to a level below that of the surrounding area.
- **Recover:** To capture the refrigerant in the system, not allowing it to escape into the atmosphere.
- **Schrader Valve:** Service valve that requires a depressor fitting.
- **Thermometer:** An instrument for determining temperature, that consists of a glass bulb attached to a fine tube of glass with a numbered scale, containing either mercury or colored alcohol that rises and falls with changes of temperature.

Definitions (continued)

- **Thermostat:** An automatic device for regulating temperature that controls the supply of gas or electricity to a heating apparatus.
- **Wattmeter:** A calibrated instrument used for measuring electric power in watts.

Abbreviations and acronyms

- **ANSI:** American National Standards Institute
- **CFR**: Code of Federal Regulations
- **HVAC:** Heating, Ventilation and Air Conditioning
- **MSDS:** material safety data sheet
- **OEM:** original equipment manufacturer
- **PPE**: Personal Protective Equipment

Introductory Text by Topic Area

1.0 Background Knowledge
2.0 Compressor/Motor
3.0 Evaporators and Condensers
4.0 Refrigeration Components
5.0 Heaters
6.0 HVAC Controls
7.0 Electrical Circuits and Electronic Controls
8.0 Tools

I. Introduction

The proper functioning of Heating, Ventilation and Air Conditioning (HVAC) Systems ensures rail transit passengers' comfort, and for some passengers it may be needed for health reasons. The periodic inspection and maintenance of rail vehicles HVAC systems is determined by the individual rail transit systems. Minimally, inspection and maintenance tasks should comply with government regulations (Federal, state and local) and OEM recommended intervals. For ideal operation it is suggested that other items be considered when developing a preventative maintenance schedule such as industry experience, operating environment, historical data and failure analysis.

The term "air-conditioning" includes heating, cooling, humidity control and filtering for environmental comfort. For the purposes of this introduction to rail vehicle maintenance, air conditioning will be used to specifically address the act of "cooling"– moving heat away from an area where it is not wanted to an area where it is of no consequence – and "heating" as it is traditionally used in HVAC systems. The basic components of a typical HVAC unit (figure 1) are outline in the diagram below.

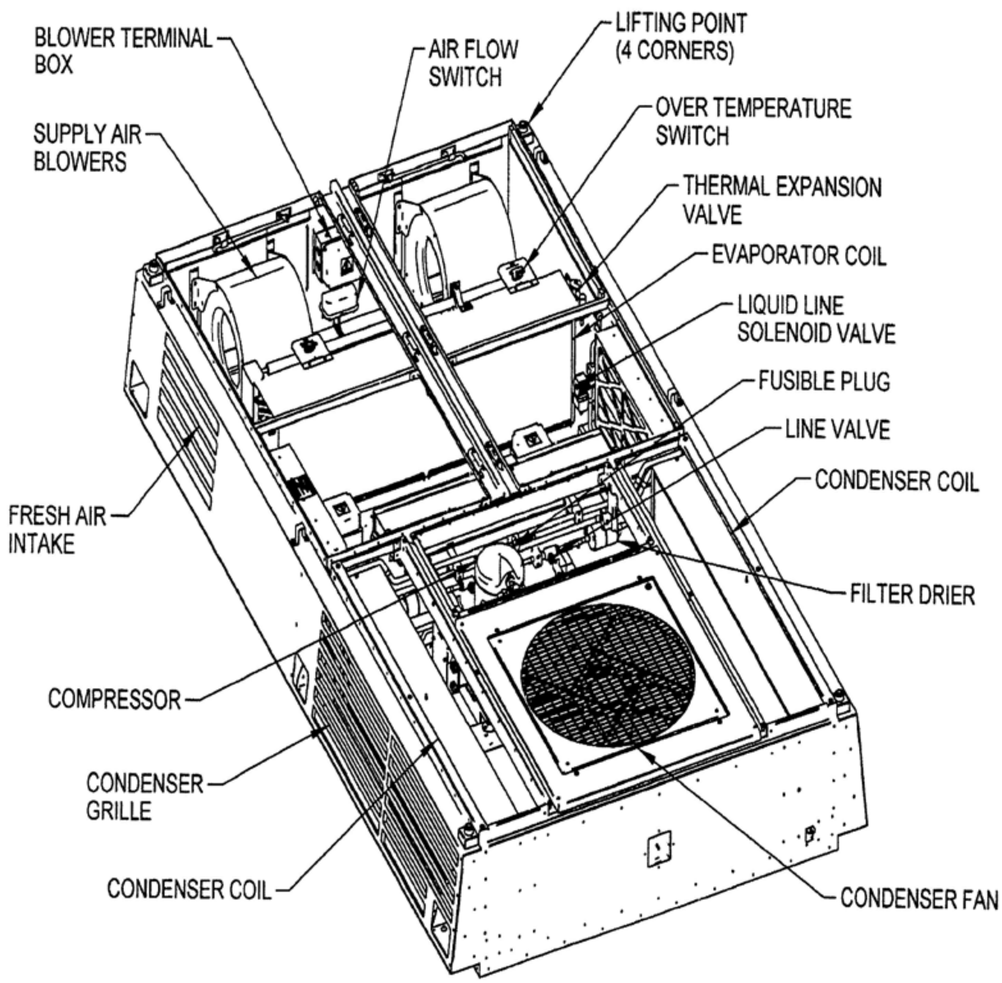


Figure 1: Generic HVAC Unit

II. Background Knowledge

Air conditioning (AC) on a rail vehicle works the same way it does in an office, a car or a house. Some components of AC systems vary in the way they do their work, but the basic systems are all the same as is the theory.

Air conditioners use refrigeration to cool indoor air. Refrigeration is the process of cooling or lowering the temperature of a space or a substance to a level below that of the surrounding area. You might also think of refrigeration as the process of removing heat. There are two basic methods of lowering temperature: heat transfer and change of state. Both play a role in traditional cooling systems and will be explained in detail in the theory section below.

Here are basic concepts about refrigeration and AC. First, air conditioners use one of basic laws of thermodynamics which is that when a liquid converts to gas it absorbs heat. This process is called phase conversion.

Second, here's how phase conversion works in AC units. In the unit's closed system of coils special chemical compounds, called refrigerants, evaporate and condense over and over again. The AC unit fans move warm interior air over these cold, refrigerant-filled coils. When hot air flows over the cold coils, the refrigerant insides absorbs heat as it changes from a liquid to a gaseous state.

The third concept involves pressure. The AC unit converts the refrigerant gas back to a liquid again. This occurs when the unit's compressor puts the gas under high pressure which creates unwanted heat. That heat gets evacuated to the outdoors with the help of a second set of coils called condenser coils and a second fan.

In summary, to keep cooling efficiently, this cycling process must be continuous – liquid refrigerant, phase conversion to a gas/heat absorption, compression and phase transition back to a liquid again.

All air conditioner units must have five basic components to work:

1. Compressor
2. Condenser
3. Expansion value (also called metering device)
4. Evaporator
5. Copper refrigerant tube (a tube that connects these air conditioner parts)

Refrigeration Components

A diagram of the AC refrigeration cycle (figure 2) shows the refrigeration process and key AC unit components. There are four (4) major AC components which are split into two (2) sections:

- Indoors - indicated in blue and includes AC parts numbered one (1) and two (2)
- Outdoors - indicated in red and includes AC parts numbered three (3) and four (4).

These four components are divided into two different pressures: high pressure and low pressure. The high-pressure side is the condenser unit (outdoor/red) and the low-pressure side is the air conditioning evaporator (indoor/blue).

It's important to note that the dividing point between high and low pressure cuts through the compressor and the expansion valve.

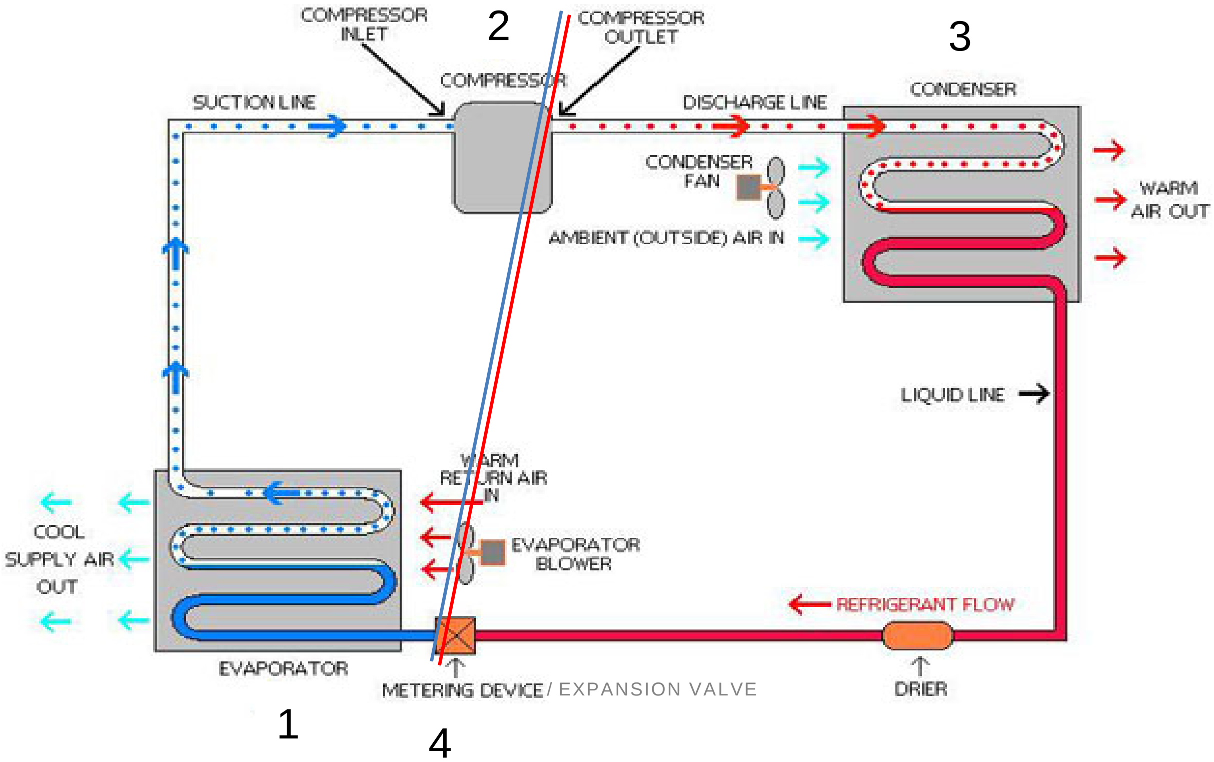


Figure 2: AC Refrigeration Cycle

Refrigeration Process

The refrigeration cycle is a process that removes heat from the indoor evaporator to outdoor condenser units. Let's start the process with the AC evaporator (#1 in figure 2) which is a heat exchanger that uses the refrigerant to absorb heat into the air conditioner system. Specifically, the liquid refrigerant flows through the evaporator where it absorbs indoor heat causing the liquid refrigerant in the evaporator to boil and become vapor. Note that the refrigerant usually flows from the bottom of the evaporator coils and boils as it moves to the top in the evaporator. A primary function of the evaporator is to boil the liquid refrigerant so that it becomes vapor.

The temperature of the refrigerant will always try to equalize. The 75°F heat will flow to 40°F refrigerant and it will increase the 40°F temperature and boils it. After the liquid refrigerant travels across the evaporator coils, the entire liquid refrigerant then boils. This point is known as the saturated vapor point.

The AC evaporator has three important tasks. First it heats, secondly it boils the refrigerant to vapor (saturated vapor), and finally creates superheat.

It is important to note the liquid refrigerant is usually fed from the bottom because if fed from the top, it would easily drop to the bottom of the coils before it could boil the refrigerant to absorb enough heat. Also, if an AC evaporator were to feed liquid refrigerant into an air conditioner compressor, it would shorten the AC compressor life by creating too much pressure because liquids do not compress.

The second step of the refrigeration cycle involves the compressor (#2 in figure 2) which is often called the heart of the AC unit. As stated earlier, it's one of the dividing points between the high and low pressure sides. The compressor produces the pressure differential and causes the refrigerant to flow.

As depicted in Figure 2, the compressor has a refrigerant inlet line and refrigerant outlet line. The inlet lines (blue) are known as: suction pressure; back pressure, or low side pressure. And outlet lines (red) are known as: discharge pressure; head pressure or high side.

The compressor absorbs vapor refrigerant from the suction line and compresses that vapor to high superheat vapor. As the refrigerant flows across the compressor, it also removes the heat of compression, motor winding heat, mechanical friction, and other heat absorbs in the suction line.

The next step in the refrigeration cycle involves the AC condenser (#3 in figure 2) where the air is cooled. It functions the same way as the evaporator, but it does the opposite. The condenser units are located outdoors with the compressor. Its purpose is to reject both sensible and latent heat of vapor absorbed by the AC units. It receives high temperature, high pressure, superheated vapor from the compressor, and rejects that heat to the low temperature air. After rejecting all the vapor heat, the refrigerant state is condensed back from a vapor to liquid refrigerant.

The condenser has three important steps: first, remove the sensible heat (de-superheat); second, remove latent heat (condense); and third, remove more sensible heat (sub-cooled). The terms sensible heat and latent heat are defined in the next section on heat and cooling theory.

During final step in the refrigeration cycle as depicted in Figure 2, the refrigerant flows through the metering device/expansion value at specified levels, and thus beginning the continuous cycle of refrigeration.

Servicing AC Units
Common tools for serving AC units include portable service gauges mounted on a bar-like instrument. Air-conditioning gauges are used to measure air conditioner unit's pressure within closed-system to evaluate or troubleshoot the AC units. The compound gauge (blue) is attached to the low side of the system. It reads system pressures both above and below atmospheric pressure. The high-side gauge (red) is attached to the high side of the system. It only reads pressure above atmospheric, and has a higher range than the compound gauge.

Manifold Gauge – The AC manifold gauge (figure 3) set is the most frequently used tool for inspecting and diagnosing refrigeration systems. The air conditioning gauge set allows the HVAC technician to check the AC unit's operating pressures, transfer AC refrigerant, pressure test the system, purge the system with nitrogen, and perform other necessary tasks. The gauge manifold set includes hoses, manifold, gauges and valves.

The AC manifold gauge set has three chambers: the low-pressure chamber (left side); utility chamber (middle); and the high-pressure chamber (right side). The blue HVAC manifold gauge is connected to the low-pressure side of air conditioner unit. To read the pressure in the discharge line the red high pressure gauge hose is connected to the air conditioner high-pressure side. The utility port (the middle chamber) can be used with a vacuum pump, a recovery unit or to add and remove refrigerant from AC units.

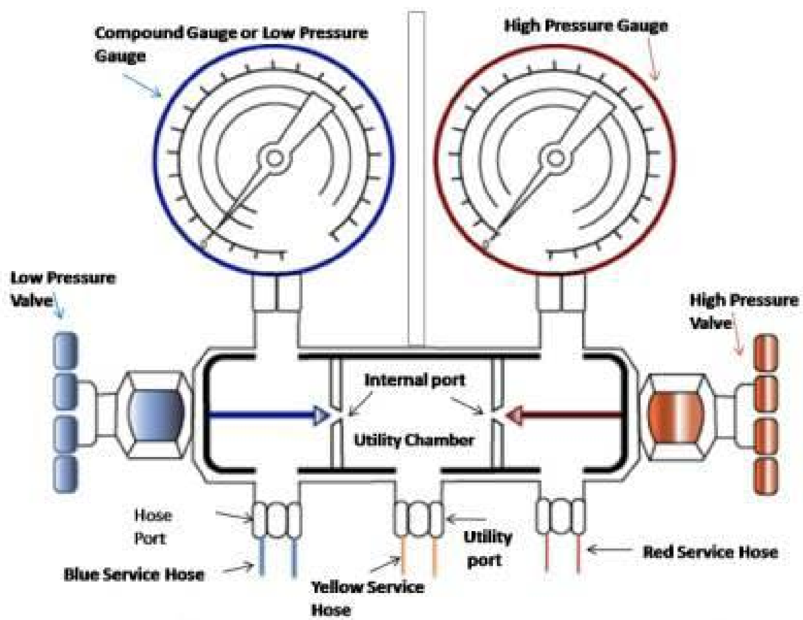


Figure 3: Manifold Gauge—Source: www.central-air-conditioner-and-refrigeration.com

III. Background Theory

The following terms and concepts provide a basic understanding of the theory of heat, cooling and temperature.

Heat

Heat is a form of energy contained in matter. This form of energy is also called thermal energy. All forms of matter in all three physical states (solids, liquids, and gas) contain thermal energy. The amount of heat contained in any substance depends on many things. The amount of heat can change because thermal energy can be transferred from one substance to another.

Temperature

Heat and temperature have a direct relationship, but they are not the same. Heat is the amount of energy contained in the material. Temperature is a measurement of the intensity of the heat in the material.

Heat Transfer

Heat transfer is a basic method of lowering temperature. When heat moves from one substance to another, it always goes from the warmer substance to the cooler substance. As it does, the warmer substance becomes cooler and the cool substance becomes warmer. This process is called heat transfer. For example, you place an ice cube a glass of water to cool the water. Or, if you place a block of ice in front of a fan, when the fan blows air over the ice, the ice cools the air.

Change of State

Change of state is another basic method of lowering temperature. It occurs when water or some other liquid changes state by evaporating. While evaporating, its temperature drops. The principle of changing states can be used for cooling purposes. Consider the way in which a breeze cools you off when you perspire on a hot summer day. As the perspiration on your body evaporates into the air, it absorbs heat from your body and transfers it to the surrounding air. Heat transfer combined with the change of state is used in refrigeration applications.

Latent Heat

All pure substances in nature are able to change their state. Solids can become liquids (ice to water) and liquids can become gases (water to vapor), but changes such as these require the addition or removal of heat. The heat that causes these changes is called latent heat.

Latent heat however, does not affect the temperature of a substance - for example, water remains at 212ºF/100°C while boiling. The steam, at the point of boil will be hotter, but note that as it cools it returns to a liquid. The heat added to keep the water boiling is latent heat. In other words, heat that causes a change of state with no change in temperature is called latent heat. As an ice cube changes from a solid to a liquid, the temperature of the ice remains 32º.

Thermal Kinetic Energy and Sensible Heat

Thermal energy is a condition of the molecules or atoms in a substance. It exists in two forms: thermal kinetic and thermal potential energy. Thermal kinetic energy is the energy due to the motion of the molecules and atoms. The molecules or atoms of any substance are always in motion; their speed of motion is a measure of the thermal kinetic energy they possess. This kind of heat energy is directly related to temperature. In other words it can be sensed or felt through physical contact. In refrigerant systems, it is called sensible heat for this reason. When an object is heated, its temperature rises as heat is added. The increase in heat is called sensible heat. Similarly, when heat is removed from an object and its temperature falls, the heat removed is called sensible heat.

Super-Heat

Superheat refers to the number of degrees a vapor is above its saturation temperature (boiling point) at a particular pressure. Saturation temperature is the point at which a substance has absorbed all the heat it can take without changing state. You measure superheat by taking the low side pressure gauge reading, converting that pressure to temperature using a pressure-temperature (PT) chart, and then subtracting that temperature from the actual temperature measured using an accurate thermometer or thermocouple at the same point the pressure was taken.

It's important to know the superheat of a system because it gives an indication of the amount of refrigerant flowing into the evaporator is appropriate for the load. If the superheat is too high, then not enough refrigerant is being fed resulting in poor refrigeration and excess energy use. If the superheat is too low, then too much refrigerant is being fed possibly resulting in liquid getting back to the compressor and causing compressor damage.

Sub-Cooling

Sub-cooling is the condition where the liquid refrigerant is colder than the minimum temperature (saturation temperature) required keeping it from boiling, thus changing from the liquid to a gas phase. The amount of sub-cooling, at a given condition, is the difference between its saturation temperature and the actual liquid refrigerant temperature.

Sub-cooling is desirable for several reasons. It increases the efficiency of the system since the amount of heat being removed per pound of refrigerant circulated is greater. In other words, you pump less-refrigerant through the system to maintain the refrigerated temperature you want. This reduces the amount of time that the compressor must run to maintain the temperature. The amount of capacity boost, which you get with each degree of sub-cooling varies with the refrigerant being used. Sub-cooling is also beneficial because it prevents the liquid refrigerant from changing to a gas before it gets to the evaporator. Pressure drops in the liquid piping and vertical risers can reduce the refrigerant pressure to the point where it will boil or "flash" in the liquid line. This change of phase causes the refrigerant to absorb heat before it reaches the evaporator. Inadequate sub-cooling prevents the expansion valve from properly metering liquid refrigerant into the evaporator, resulting in poor system performance.

IV. Compressor/Motor

Introduction to Compressor/Motor Inspection and Maintenance

As noted previously, the compressor is commonly called the heart of the HVAC system. Provided below are the basic inspection and maintenance techniques used for most HVAC systems found on rail transit vehicles.

In addition to your rail transit system manuals and the OEM, the following materials are normally used during an inspection and maintenance of the HVAC system: cleaning solutions, lubricants, refrigerant, and compressed air, as well as, filters and filter dryers.

Safety concerns of HVAC Systems Operation and Maintenance

When performing any operation, inspection or maintenance tasks take care to wear the appropriate personal protective equipment (PPE) – and minimally follow ANSI standards.

Be sure to follow these basic safety requirements. Others will be dispersed throughout the text of this primer.

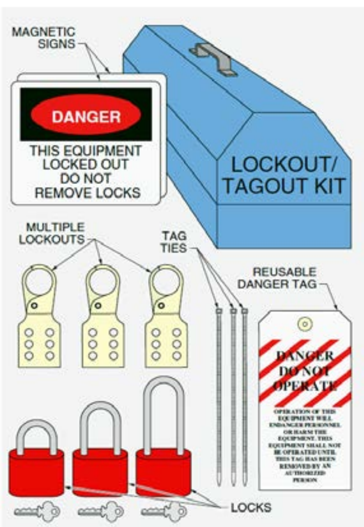


Figure 4: Lockout/Tagout Kit

Lockout/Tagout

- o If any corrective or preventative procedures are required on the HVAC system, ensure that **power** to the HVAC unit is **shut off and remains off** until personnel are safely clear of moving parts. Always follow lockout/tagout procedures as per your authority (figure 4).
- o Verify that electrical power is removed by checking with reliable equipment.
- o To avoid possible injury if the HVAC equipment operates unexpectedly, notify all concerned that equipment is about to be energized before restoring power. If vehicles are coupled and controls are trainline, make sure that it is safe for equipment in coupled cars to become operational before energizing any high voltage or battery circuits.

Pinch Points

To avoid possible injury when performing inspection of maintenance on HVAC systems, keep hands and tools away from pinch points (figure 5).

Figure 5: Pinch Points

Cleaning

- o To avoid possible injury while using compressed air for dislodging dirt and debris, wear appropriate eye, face, and respiratory protection meeting minimum ANSI or other applicable national industry standards. Keep air pressure at the blowgun nozzle below 30 pounds per square inch.

- Use only those cleaning products and lubricants proven safe and authorized for use by the rail transit system. Consult OEM and MSDS references for suitability for each application to prevent personal injury and damage to the equipment.

General Mechanical Inspection

It is recommended that a general mechanical inspection be performed before focusing on the major individual HVAC components. Be sure to inspect housing latches and fasteners for damage and security. Replace or repair if necessary. Check the housing seals for integrity and air bypass. And, check housing, panels and structure for corrosion. Inspect the fresh air and return air filters, louvers and grills. Clean or replace in accordance with OEM or the transit agency requirement. Make sure that all mechanical mounting components for damage and security. Finally, review microprocessor fault data logs and vehicle maintenance history files. This information will specify which components have had repeated problems and as such should receive a more detailed inspection and operational check.

HVAC Operational Inspection

During an HVAC operational inspection, the following tasks must be performed to verify the system is functioning properly. First, monitor the gauge pressures versus the vehicle temperature to determine acceptable operation. This procedure is done by cycling the HVAC unit through its various cooling modes by simulating ambient and in car temperatures through the use of a computer or other control box.

Next, be sure to verify that airflow is sufficient. Check the refrigerant level in receiver sight glass, if unit is so equipped. Verify proper condensate flow. On reciprocating compressor systems verify that the pump is down. If the HVAC system is equipped with adjustable thermal expansion valve, check that there is superheat at evaporator suction line. Also, check proper pressure switch operation, as required. Be sure to inspect for icing along suction lines, thermal expansion valves and at the evaporator.

Make sure no flash gases (bubbles) are in the liquid line sight glass, if unit is so equipped. Flash gases may be indicative of a low refrigerant charge or piping restriction. Further details regarding the operational checks will be proved in the text below.

Always follow your authority's preventive maintenance schedule and procedures. Also, if any deficiencies are found and repairs or replacement of components are made, be sure to document in accordance with your rail transit system procedures and OEM recommendations.

Inspection and Maintenance: HVAC Compressors

Perform the following checks during the periodic inspection and maintenance of an HVAC compressor (figure 6).

- On an open-drive compressor, check the drive/motor coupling for security and excess wear and play.
- Examine the compressor shaft seal for refrigerant leakage. Either repair or replace the seal when leakage exceeds OEM recommendations.

- Check for refrigerant leakage on compressor fittings, gaskets and seals.
- Be sure to check the oil level and verify it complies with OEM procedures.
- Inspect oil by extracting an oil sample, where possible, and test for proper color and acid content.

Figure 6: Typical compressor inside an HVAC unit

When inspecting and performing maintenance checks on HVAC systems there are several tools technicians can use to assist the technician, among them are:

Refrigerant recovery/recycle machine – Can remove refrigerant from an AC system, test for leaks, measure oil content, purge the system and replace refrigerant and oil. Newer machines can do all this automatically.

Pressure and vacuum micron gauge – Used by the technician to confirm that the system is leak free and non-condensable. A micron is a unit of measurement starting from a perfect vacuum (no pressure) that is expressed in linear increments; one inch = 25,400 microns thus one micron = 1/25,400 of an inch.

Sight Glass
The sight glass (figure 7), is used as a diagnostic tool for checking the health of the HVAC system. It is normally located in the head of the receiver/drier. However, it may be located in one of the metal lines leading from the top of the receiver/drier.

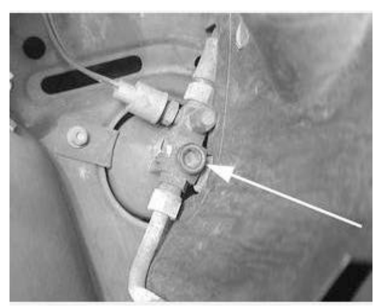


Figure 7: Sight Glass

Be sure to wipe the sight glass clean and proceed with the following steps. First, with the engine and the air conditioning system running, look for the flow of refrigerant through the sight glass. If the air conditioner is working properly, you'll be able to see a continuous flow of clear refrigerant through the sight glass, with perhaps an occasional bubble at very high temperatures.

Next, cycle the air conditioner on and off to make sure what you are seeing is clear refrigerant. Since the refrigerant is clear, it is possible to mistake a completely discharged system for one that is fully charged. Then turn the system off and watch the sight glass. If there is refrigerant in the system, you'll see bubbles (figure 8) during the off cycle. If you do not observe any bubbles when the system is running, and the airflow from the unit in the vehicle is delivering cold air, everything is okay.

While the system is operating if you observe oils streaks (A), constant bubbles (B) or foam (C) as in Figure 8 that indicates the system is low on refrigerant. Oil in the sight glass, normally appears as a series of streaks, but occasionally it may be a solid stream of oil. In either case, it means that part of the charge has been lost.

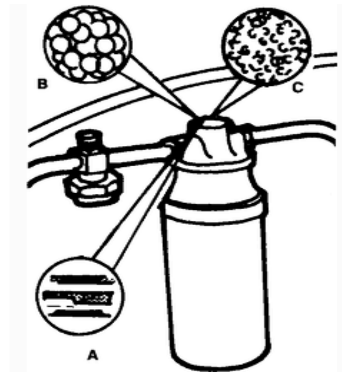


Figure 8: Sight glass problems

Compressor Components

Compressor Assembly
When inspecting the compressor assembly, be sure to perform an oil analysis. An oil test kit can be used to test ac unit oil for acidity. Acid will damage internal components. Be sure to check that the level of the oil meets OEM requirements. In addition, inspect the compressor seals. Test the crank case heater. Also, test and adjust the unloader valve operation. Replace any of the components – seals, crank case heater or unloader valve – that are defective, in according with your authority's guidelines.

Motor Coupling / AC and DC Motors
Be sure to inspect motor coupling and replace if needed. Also, check for froze bearings. Check the AC motor and if necessary replace it or worn bearings. Examine the DC motor and determine if it needs to be replaced. Be sure to check the commutator for wear or damage. Clean or change brushes. Check the brush assembly and adjust or replace as needed.

Compressor Mountings
Inspect the compressor mountings. Change cushions on mountings or replace compressor mountings.

Service Valves, Pressure Limit Switches and Motor Overload Device
Inspect the compressor service valves and replace as needed. Be sure to inspect the protection devices. Test pressure limit switches and replace if necessary, and inspect the motor overload device.

Piping and Fittings
Check piping and fittings for leaks. Examine the braided line for fraying or damage, and if necessary, repair piping and fittings. Inspect piping for dirty or oily areas. Clean those areas and then use a leak detector to check for leaks. Repair as required. Note that a refrigerant leak detector is tool designed to pinpoint the location of refrigerant leaks in air conditioning and refrigerant systems, chillers, or cold storage units. The sensor is passed over piping, connectors etc. Typically a visual and an audio alarm will alert the technician to a leak. Check the condition of vibration-eliminator piping. Also, insure that expansion valve sensing bulbs are in correct location and in firm contact with evaporator discharge line, where possible without removing insulation. And finally, check for integrity and proper installation of piping insulation.

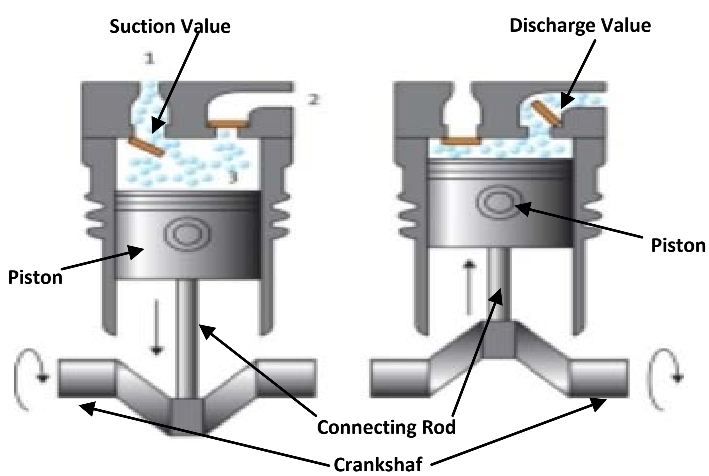
Filter/Dryer
Check indicator on filter/dryer and replace dryer if it indicates moisture in the system. Be sure to clean all drip trays, drain pipes and nozzles. Inspect for leaks and repair as necessary and insure all drains are free-running.

Types of Refrigeration System Compressors
There are five basic types of refrigeration system compressors:

- Reciprocating
- Rotary
- Helical (or screw)
- Scroll
- Centrifugal

Reciprocating Compressor
A reciprocating compressor is much like a gasoline engine, but requires a power source. Generally this is an electrical motor which turns a crankshaft in the compressor that moves the piston up and down. Suction and discharge valves control the flow of refrigerant vapor into and out of the cylinder. Reciprocating compressors can have one to 16 cylinders, depending upon the size of the system. Reciprocating compressors are a piston-cylinder type of pump. The main parts include a cylinder, piston, connecting rod, crankshaft, cylinder head and valves. The operating cycle of a reciprocating compressor (figure 9) is shown below.

The piston on the down stroke (left in figure 9) results in a low pressure area is created between the top of the piston, the cylinder head and the suction line of the air conditioning evaporator. Cold refrigerant vapor rushes through the suction valve inlet and into the low-pressure area. On the up stroke, (right in figure 9) the suction valve closes and the exhaust (discharge) valve is forced open with the increasing pressure. The vapor is compressed and forced into the discharge (high) side of the refrigeration system. When the piston reaches the top of the cylinder, the discharge valve closes, and the suction valve opens as the piston starts down again drawing in cold refrigerant vapor to complete the cycle.



1. Intake valve 2 Exhaust valve 3. Refrigerant

Figure 9: Operating Cycle of Reciprocating Compressor

Rotary Compressor

In a rotary compressor (figure 10) the refrigerant is compressed by the rotating action of a roller inside a cylinder. The roller rotates eccentrically (off-center) around a shaft so that part of the roller is always in contact with the inside wall of the cylinder.

A spring-mounted blade is always rubbing against the roller. The two points of contact create two sealed areas of continuously variable volume inside the cylinder. At a certain point in the rotation of the roller, the intake port is exposed and a quantity of refrigerant is sucked into the cylinder, filling one of the sealed areas. As the roller continues to rotate the volume of the area the refrigerant occupies is reduced and the refrigerant is compressed. When the exhaust valve is exposed, the high-pressure refrigerant forces the exhaust valve to open and the refrigerant is released.

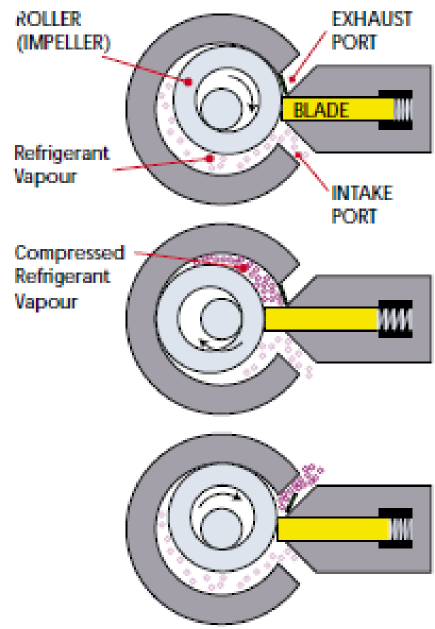


Figure 10: Rotary Compressor

Rotary compressors are very efficient because the actions of taking in refrigerant and compressing refrigerant occur simultaneously.

Helical Compressor

The helical compressor, also known as a screw compressor, compresses the vapor between mating, screw-shaped rotors. One rotor has lobes and the other has mating grooves. As the rotors turn, the lobes and grooves come together to compress the vapor.

Screw compressors are rotary positive displacement machines. Note that a positive displacement pump causes a fluid to move by trapping a fixed amount of it and then forcing (displacing) that trapped volume into the discharge pipe. Some positive displacement pumps work using an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pump as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. The volume is constant given each cycle of operation.

Two helical rotors are rotated by a series of timing gears as shown in diagram below (figure 11) so that gas trapped in the space between them is transported from the suction to the discharge piping.

In low-pressure air service, non-lubricated screw compressors can deliver a clean, oil-free air. In hydrocarbon service most screw compressors require that liquid be injected to help provide a seal. After-coolers and separators are required to separate the seal oil and recirculate it to suction.

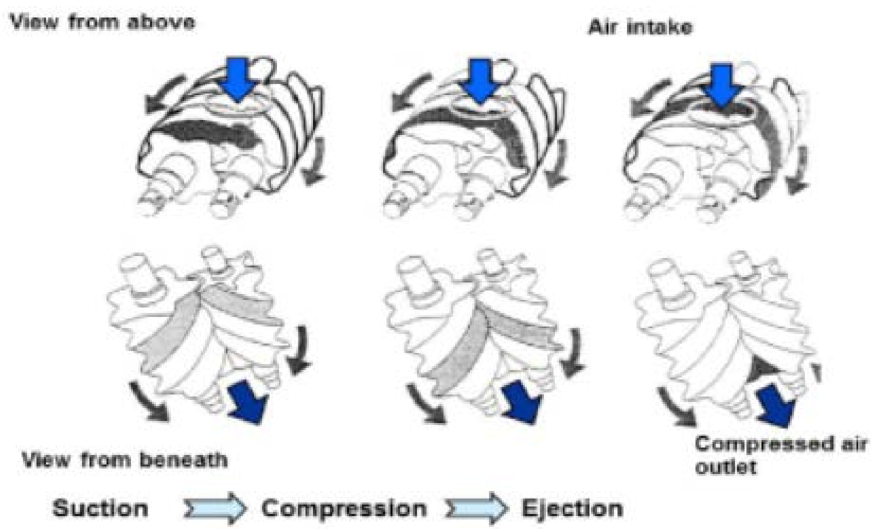


Figure 11: Helical Compressor, also known as a Rotary Screw Compressor

Scroll Compressors

In a scroll compressor the compressed refrigerant is done by two offset spiral disks that are nested together. The upper disk is stationary while the lower disk moves in orbital fashion. The orbiting action of the lower disk inside the stationary disk creates sealed spaces of varying volume. Refrigerant is sucked in through inlet ports at the perimeter of the scroll. A quantity of refrigerant becomes trapped in one of the sealed spaces. As the disk orbits the enclosed space containing the refrigerant is transferred toward the center of the disk and its volume decreases. As the volume decreases, the refrigerant is compressed. The compressed refrigerant is discharged through a port at the center of the upper disk.

Scroll compressors are quiet, smooth-operating units with the highest efficiency ratio of all compressor types. They are commonly used in automobile air conditioning systems and commercial chillers.

The visual path of refrigerant inside a scroll compressor is demonstrated in six steps shown in this diagram (figure 12).

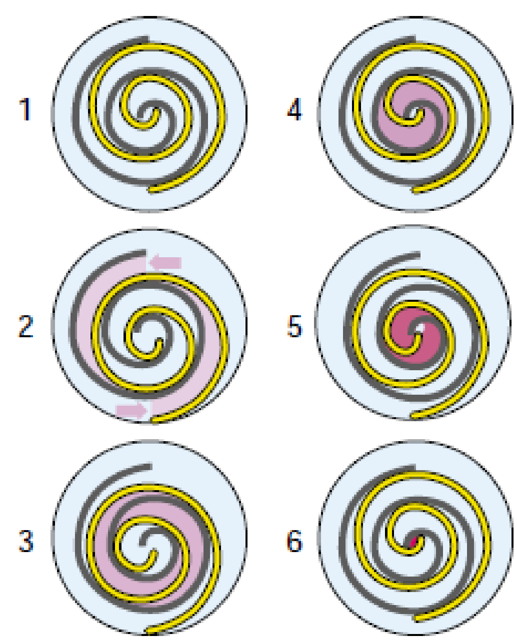


Figure 12: Compression process inside a Scroll Compressor

Centrifugal Compressors

The centrifugal compressor (figure 13) uses a high-speed impeller to compress the refrigerant vapor. Centrifugal compressors can have one or several impellers. If they have more than one, the first impellers compress the vapor, and then discharge the vapor to the next impeller for further compression, and so on. This process is called staging.

The impellers force the refrigerant outward, exerting centrifugal force on the refrigerant. The refrigerant is pressurized as it is forced against the sides of the container (volute).

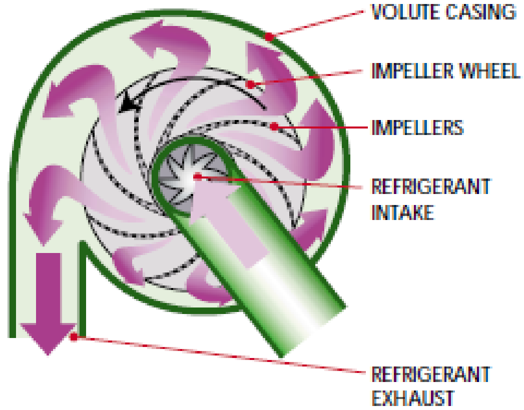


Figure 13: Centrifugal Compressors

Centrifugal compressors are well suited to compressing large volumes of refrigerant to relatively low pressures. They are desirable for their simplistic design and few moving parts.

V. Evaporators and Condensers

Inspection and Maintenance: HVAC Evaporators and Condensers
The following tasks are recommended during the inspection and maintenance of HVAC condensers and evaporators.

Clean the condenser and evaporator coils and fins with compressed air according to 29 CFR 1910.242b, or use an appropriate cleaning solution. If desired, the effectiveness of cleaning can be measured as a function of pressure drop across the condenser; rail transit system experience and OEM recommendations can establish the appropriate level. Always inspect for damage to fins and coils, and evidence of leaking. Repair per OEM instructions. In addition, clean and inspect all fan blades. Check that fans rotate freely and without obvious bearing noise. Finally, be sure to clean evaporator drain pans and drain lines.

SAFETY WARNING

- To avoid possible injury while using compressed air for dislodging dirt and debris, wear appropriate eye, face, and respiratory protection meeting minimum ANSI or other applicable national industry standards. Keep air pressure at the blowgun nozzle below 30 pounds per square inch.
- Use only those cleaning products and lubricants proven safe and authorized for use by the rail transit system. Consult OEM and MSDS references for suitability for each application to prevent personal injury and damage to the equipment.

Evaporators
Evaporators are classified as either refrigerant-to-air evaporators or refrigerant-to-liquid evaporators based on what they cool.

Refrigerant-to-Air Evaporators
The refrigerant-to-air evaporator (figure 14) is a tube coil. The tubes usually have fins to expose more surfaces to the air passing through the evaporator.

Fine tube evaporators are also called extended-surface evaporators, plain tube evaporator are called prime-surface evaporator.

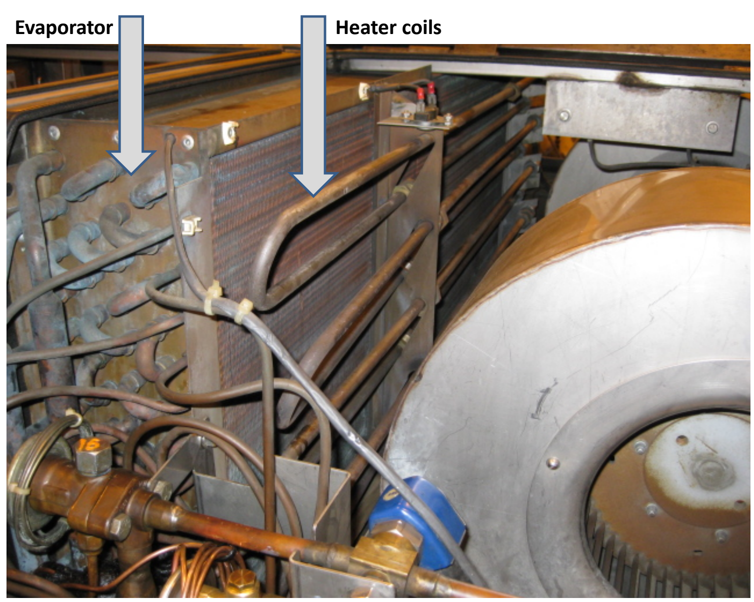


Figure 14: Refrigerant-to-Air Evaporators

Refrigerant-to-Liquid Evaporator
Refrigerant-to-liquid evaporator is a shell containing tubes. One type is basically a plain tube evaporator submerged in the liquid in the shell. In other type, the liquid being cooled runs through the tubes in a shell with refrigerant.

Condensers
Condensers usually use water or air to remove heat from the refrigerant. Thus condensers are classified as air-cooled or water-cooled condensers. A third type, the evaporator condenser, uses both air and water. Condensers used in transportation vehicles will use air to remove heat from refrigerant.

Air-Cooled Condenser
An air-cooled condenser is usually a fins-and-tube coil. It looks much like and evaporator. The refrigerant transfers heat to the tube and condenser inside the tube. Then the heat transfers to the fins; from the fins the air passing over the fins.

Water-Cooled Condenser
Water-cooled condensers is either shell-and-coil or tube type. Hot refrigerant vapor enters the top of the condenser and flows over the water tubes as it condenses. The liquid refrigerant falls to the bottom of the condenser. A water-regulating valve controls the flow of water through the water tube. The valve opens and closes in response to compressor discharger pressure the valve opens to let more water flow when the pressure rises above a set point. A drop in pressure causes the valve to slow down the water flow. When the water compressor stops operating, it stops building up pressure in the condenser and the water-regulating valve closes completely.

Most systems use water-cooled condensers, so that the water can be reused by circulating the warm water from the condenser to the cooling tower. The water enters the top of the tower and sprays down over baffles inside the tower. The spraying action causes a small amount of water to evaporate. The evaporating water absorbs heat from the remaining water. A fan forces air through the tower, and increases the rate of evaporation. The cool water collects in the sump at the bottom of the tower, and returns to the condenser for reuse.

VI. Refrigeration Components

Inspection and Maintenance: HVAC Refrigeration Components
The three major refrigeration components – compressor/motor, evaporators and condensers – were discussed in detail in prior sections above. The fourth major refrigeration component is the metering device (expansion valve) which is described below.

Metering Devices
There are six common types of metering devices used in commercial and industrial refrigeration systems:

- Fixed orifice tube
- Expansion valves
- Automatic expansion valve
- Hand-operated expansion valve
- Thermostatic expansion valve (TXV)
- Thermal-electric expansion valve

Fixed Orifice Tube
The expansion tube, better known as a fixed orifice tube (FOT), is a nonadjustable device that has a fixed orifice metering element and a fine-mesh strainer. Unlike the expansion valve, the FOT has no remote bulb, no moving parts, and will not vary the amount of refrigerant entering the evaporator in the same manner as an expansion valve. The FOT varies the amount of refrigerant between high side and low side based on a pressure differential. The liquid refrigerant flow across the valve is purely dependent upon the difference between the entering pressure (high pressure from the condenser/receiver) and the pressure at the outlet of the valve (low pressure within the evaporator), coupled with the degree of needle/orifice opening. This type of valve is unable to provide any real degree of variation in refrigerant liquid flow to suit variations in evaporator load and cannot automatically protect the compressor against excessive liquid flooding.

Expansion Valves
An expansion valve can be compared to a simple water faucet. The faucet can be fully open, fully close, or position at any point in between. How a particular expansion valve adjusts the flow through it depends on its design.

Automatic Expansion Valve
The automatic expansion valve (figure 15), maintains constant pressure in the evaporator. The evaporator pressure acts on the lower side of the diaphragm. Atmospheric pressure plus the force from a spring act on the upper side of the diaphragm. When evaporator pressure drops;

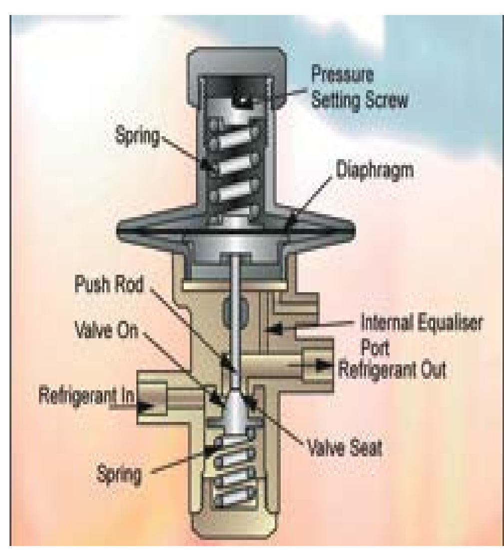


Figure 15: Automatic Expansion Valve
Source: ACR-news.com with permission

the pressure on the lower side of the diaphragm drops.
The atmospheric pressure and the spring then push the diaphragm down. This action opens the needle valve (device that connects to the automatic expansion) wider allowing more refrigerant to enter the evaporator. The additional refrigerant increases evaporator pressure; increasing evaporator pressure pushes up on the diaphragm and partly closes the needle valve slowing down the refrigerant flow. Thus the valve maintains a constant pressure in the evaporator.

Hand-operated Expansion Valve

The hand-operated expansion valve is the simplest type of expansion valve. It requires a human operator to regulate refrigerant flow to the evaporator. Its use is limited to systems operating under nearly constant loads for long periods of time, or on bypass lines and bleed off connections. The valves are normally dedicated to large capacity systems with a fixed or very stable thermal load since any change required in refrigerant flow must be achieved by manually adjusting the valve setting. This clearly requires constant attendance by an engineer. The hand-operated expansion valve must also be closed when the compressor is stopped to prevent liquid from flooding the compressor since liquid refrigerant will continue to flow through the evaporator until system pressures have equalized**.**

Thermostatic Expansion Valve (TXV)

The thermostatic expansion valve (figure 16) needs a capillary tube and thermal element (bulb) to work. The capillary tube connects the element to the top of TXV figure. The element (sensing bulb or thermal bulb) is partly filled with a liquid refrigerant (usually the same refrigerant used in the system) and maintains some liquid under all conditions of temperature and load.

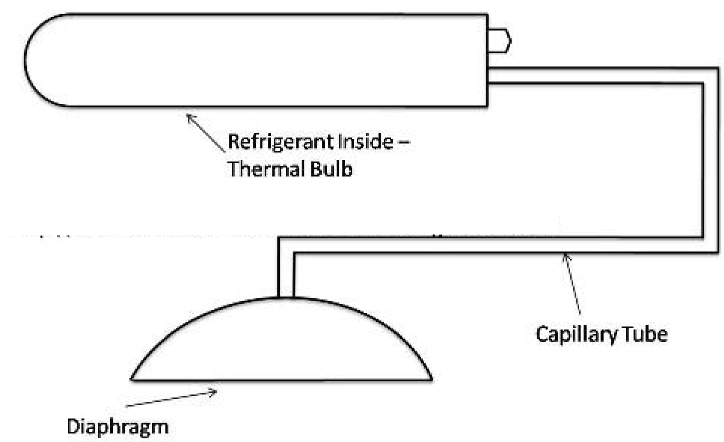


Figure 16: Thermostatic Expansion Valve –Source: central air conditioner and refrigeration.com

A cross section of a thermostatic expansion valve components (figure 17), and the operation principle are shown here. The numbered TXV components are:

1. Temperature sensing bulb
2. Thermostatic head
3. Diaphragm
4. Internal equalizer
5. Temperature adjustment

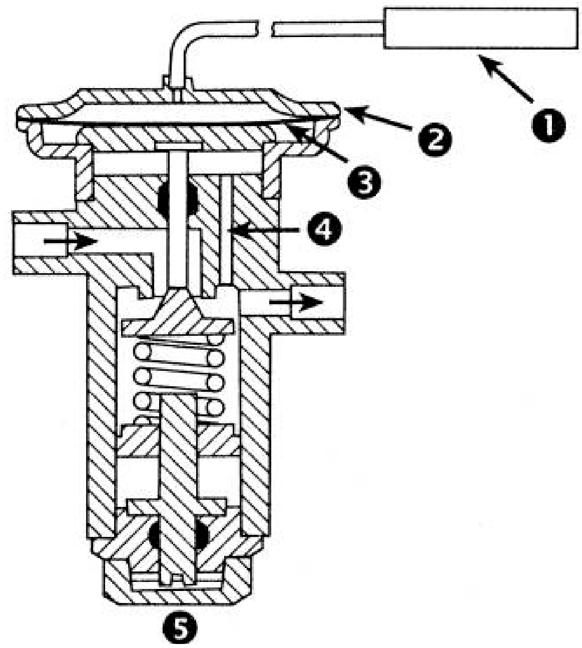


Figure 17: Cross section of a typical TXV

The bulb temperature at which the valve opens is determined by the refrigerant pressure at the valve's output and the force exerted by the internal spring. Changing spring tension changes the temperature of opening.

There are three forces that control the operation of the thermal expansion valve:

- Pressure 1 – The vapor pressure of the thermostatic element (a reaction to the bulb temperature), which acts to open the valve.
- Pressure 2 – The evaporator pressure, which acts in a closing direction below the diaphragm.
- Pressure 3 – The pressure equivalent of the superheat spring force, which is also applied underneath the diaphragm in a closing force.

At any constant operating condition, these forces are balanced. Therefore, P1=P2+P3. When a change in temperature in the suction line occurs, the pressure in the thermal bulb also changes similarly. With an increased heat load, the refrigerant in the evaporator coil boils faster. This results in a rise in temperature at the thermal bulb because of superheating.

The higher temperature produces an increase in pressure within the thermal bulb due to superheating. The higher temperature produces an increase in pressure within the thermal bulb, which increases the pressure at P1. The pressure in the evaporator at P2, and the spring pressure in the TXV at P3 remain constant. Therefore, with the increased pressure at P1, the bellows (diaphragm) expands to force a wider valve opening.

As a result, more refrigerant is allowed to enter the evaporator to compensate for the increased heat load. The increase in flow rate increases to evaporator pressure P2, which establishes a balance control once again. With a decreased load the reverse cycle takes place.

Thermal Electric Expansion Valve

The electronic expansion valve (EEV) (figure 18) operates with a much more sophisticated design. EEVs control the flow of refrigerant entering a direct expansion evaporator. They do this in response to signals sent to them by an electronic controller.

A small motor is used to open and close the valve port. The motor is called a step or stepper motor. Step motors do not rotate continuously. They are controlled electronically and rotate a fraction of a revolution for each signal sent to them by the electronic controller.

The step motor is driven by a gear train, which positions a pin in a port in which refrigerant flows. Step motors can run at 200 steps per second and can return to their exact position very quickly. The controller memory remembers the number of step signals sent by the controller. This makes it possible for the controller to return the valve to any previous position at any time. This also gives the valve very accurate control of refrigerant that flows through it. Most of these EEVs have 1,596 steps of control and each step is 0.0000783 inches.

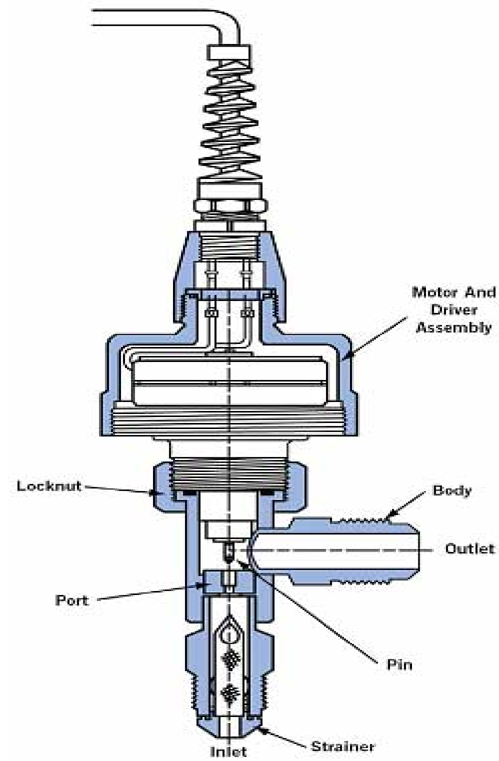


Figure 18: Electronic expansion valve (EEV)

VII. Heaters

Inspection and Maintenance: HVAC Heaters

When performing a period maintenance check of heaters, it is important to:

- o Verify all heaters are operational and heating the air as required. This may be done by checking heater resistance when not in operation, by checking power consumption in operation, or by checking the temperature near the heater.
- o Be sure to examine the resistance to ground.
- o Inspect and verify the heater contactor operation.
- o Make sure that the air flow switch device is operating properly.

Rail Vehicle Heater

A heater is an object that emits heat causing another body to achieve a higher temperature. In a household or domestic setting, heaters are usually appliances whose purpose is to generate heating (i.e. warmth).

Heaters exist for all states of matter, including solids, liquids and gases. Heaters in trains are often incorporated in the design of the HVAC unit.

Both heating and air conditioning work on the principle that heat always moves from a warm object to a cooler one, just as water flows from a higher to a lower level. Furnaces and heaters put heat into the air to make living space warmer while air conditioners remove heat to make living space cooler.

Rail vehicles typically have two methods by which heat is introduced into the passenger compartment. Train HVAC units have coils near the evaporator (see figures 14 and 19) that generate heat electrically in the same way a home space heater works. The warm air is then distributed throughout the car body by way of the plenum or duct work that otherwise carries cooled air from the HVAC unit.

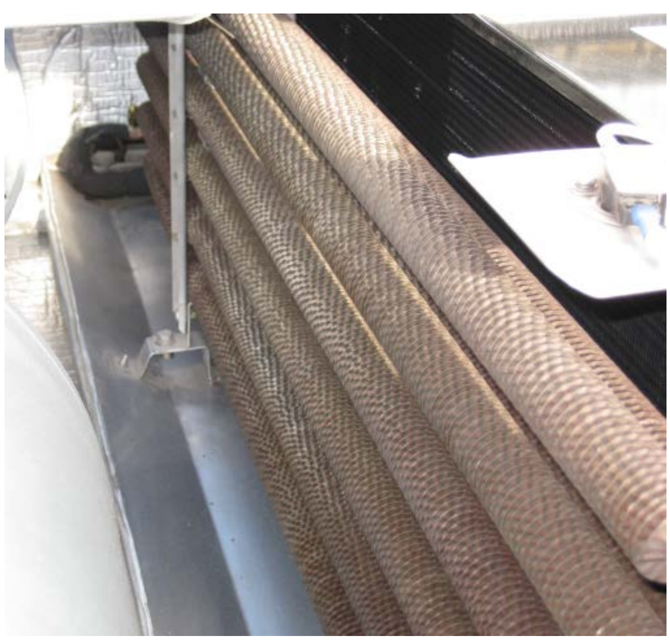


Figure 19: Heater Coils - Source: Sacramento Regional Transit

Some rail vehicles have dedicated heating units under the seats or along the baseboards (figure 20). These too create heat by passing electricity through a series of wires or wire coils.

Figure 20: Baseboard Heater - Source: Sacramento Regional Transit

Most under-the-seat units (A) are self-contained and have a squirrel cage blower fan within the casing (B) as well as heater coils (C). See figure 21 below.

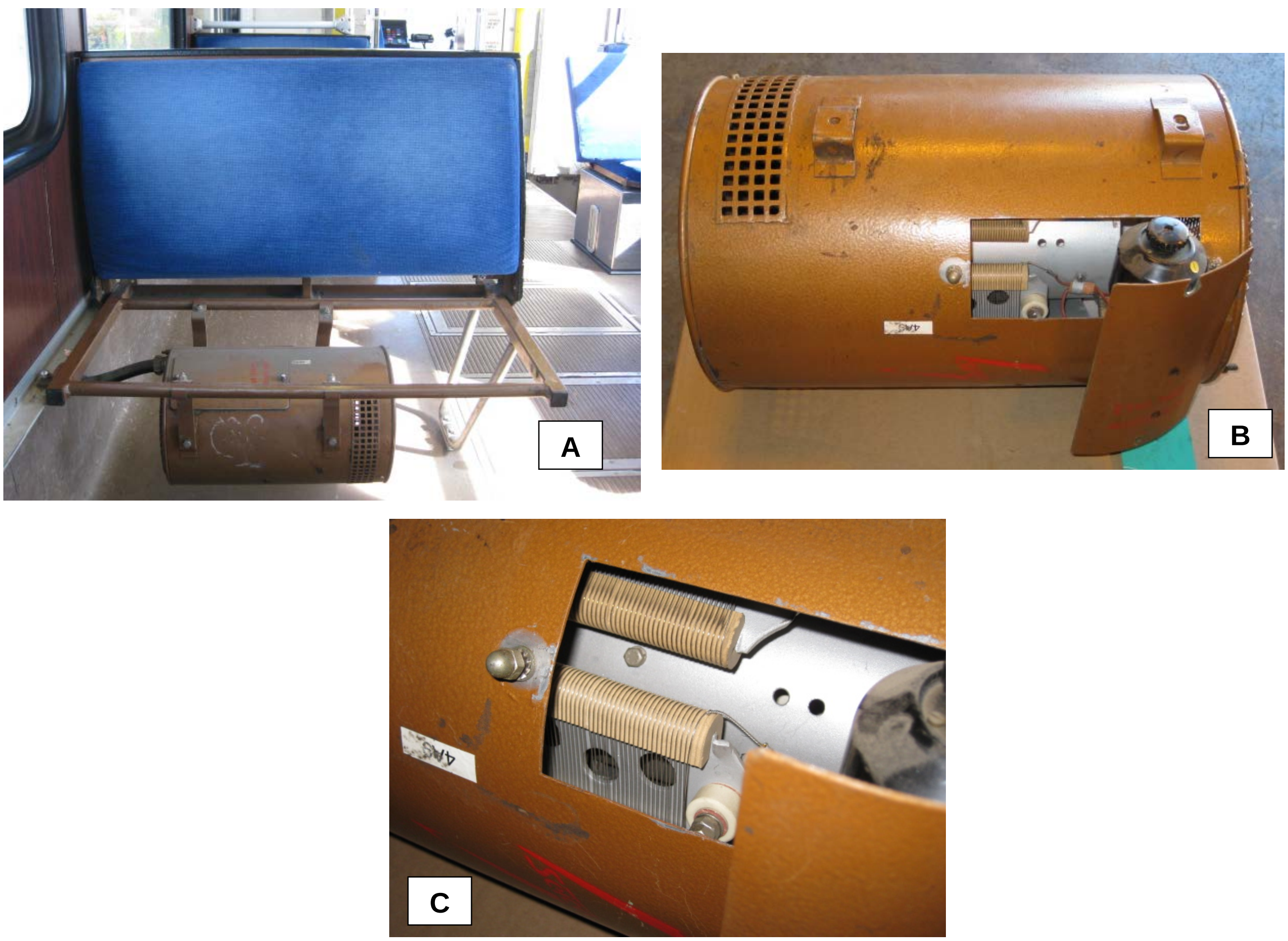


Figure 21: Under-the-seat heater (A), heater cage (B), and(heater coils (C) - Source: Sacramento Regional Transit

Rail vehicles generally have a self-contained HVAC unit mounted either on top of the car (figure 22) or underneath.

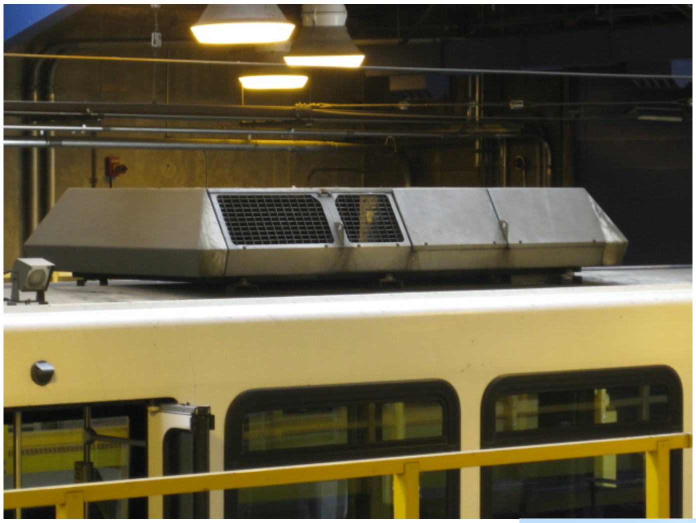


Figure 22: Two typical rooftop HVAC Units - Source: Sacramento Regional Transit

The HVAC integrated unit, often called a rooftop unit, is a complete system within a single enclosure. Some rooftop units circulate air pulled through the ceiling access, filters and cools the air, then re-circulates it into the car using the integrated blower system.

Controls may be located within the unit that are accessible through the ceiling (figure 23) or mounted inside the car itself. These types of systems may be designed to function on either R22 or 134A Freon types. Heater coils can also be incorporated for the colder climate areas. The cooling capacity can range from 10 to 14 tons.

Figure 23: Ceiling access to rooftop HVAC Units - Source: Sacramento Regional Transit

VIII. HVAC Controls

HVAC Control System

Control in an HVAC system is defined as the starting, stopping or regulation of heating, ventilation or cooling. Controlling an HVAC system involves three distinct steps:

- Measure a variable (e.g. temperature) and collect data.
- Process the data with other information.
- Cause a control action.

These functions are met through a sensor, controller and controlled device.

Elements of a Control System

Any HVAC control system has four basic elements:

- Sensor measures actual value of controlled variable such as temperature, humidity or flow and provides information to the controller.
- Controller receives input from sensor, processes the input and then produces intelligent output signal for controlled device.
- Controlled device acts to modify controlled variable as directed by controller.
- Source of energy is needed to power the control system. Control systems use either gas or electric power supply.

Control Systems Components

Sensors

Generally, sensors measure the controlled medium, such as air temperature, and provide a controller with information concerning changing conditions in an accurate and repeatable manner. The common HVAC variables are temperature, pressure, flow rate and relative humidity. Some electronic sensors commonly use wire resistance to provide a signal and can be directly connected to the electronic controller. Some sensors can measure a number variable that affect the controller logic, including time of day or electrical demand condition. Sensors are an extremely important part of the control system and can be a weak link in the chain of control.

Controllers

The controller’s function is to compare its input instructions – signals such as setpoint (i.e. desired temperature) – from the sensor and then produce an output signal. The output signal may be either to the controlled device or to other logical control functions.

Type of signals from the controllers can be electric, electronic, pneumatic (i.e. gas, air, wind) or digital. All controllers have an action. They are either ‘direct acting’ which means its output increases as the sensor’s input increases or ‘reverse acting’ which would mean for example, if the temperature increases the controller’s output decreases.

Controlled Devices

HVAC control takes place through control valves which are used to maintain space temperature. There are several different physical types of valves used in the HVAC industry. Controlled devices have a part called actuators which drive the valves and dampers to open or closed positions. They respond to a signal from a controller.

There are three main types of actuators commonly used in HVAC control:

- solenoids
- electric motors
- pneumatic

Inspection and Maintenance: HVAC Control System

During the inspection and maintenance of HVAC controls perform the following tasks. Be sure to check and adjust thermostats. Replace as needed. Examine the low-pressure and high-pressure switches. Also, test the flow switch and replace, if necessary. Make sure the temperature controls/sensors are functioning properly. Test and replace as needed. As always inspect and replace components in accordance with your transit system's guidelines and OEM recommendations.

IX. Electrical Circuits and Electronic Controls

HVAC systems are controlled and protected by electrical and electronic circuits like the HVAC controller below (figure 24). These HVAC control systems are fed information by a thermostat (figure 25) and other sensors.

Figure 24: HVAC Controller- Source: Sacramento Regional Transit

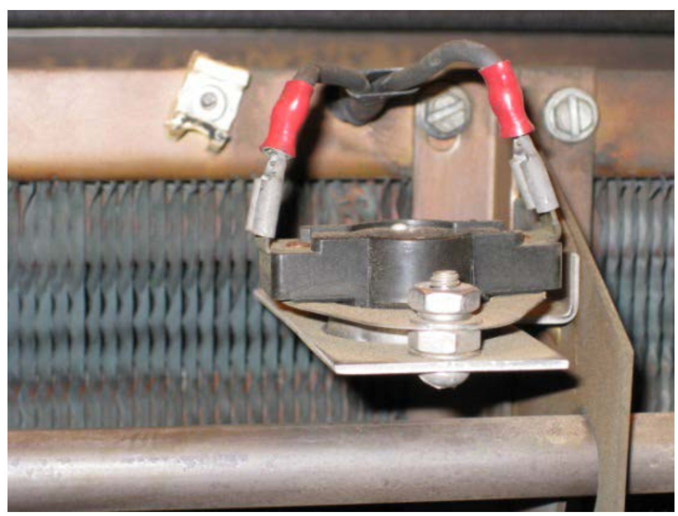


Figure 25: Thermostat- Source: Sacramento Regional Transit

As part of the inspection and maintenance check of controller, it is recommended that the technician perform the following checks. Verify the correct controller software is installed. Make sure that the controller is functioning correctly by using an operational test that verifies appropriate control modes. If hard logic is used, check contactor operation. Be sure to examine relays and connectors. Test to see if relays and connectors can hold load. Replace is necessary. Also, test the control boards and perform function tests with portable test equipment. Determine if the control boards need to be replaced and follow your transit system guidelines. Examine the current protection and replace, as needed. Check and test the ground fault interrupter (GFI) protection. Replace if necessary. Remember to always inspect and replace components in accordance with your agency's guidelines and OEM recommendations.

X. Tools

The majority of tools used in HVAC maintenance have been covered in the text above:

- Manifold gauge (p. 8)
- Pressure and vacuum micron gauge (p.13)
- Refrigerant recovery/recycle machine (p.13)
- Sight glass (pp.12-14)
- Oil test kit (p.14)
- Refrigerant leak detector (p.14)

The other tools that technicians may use include the following:

Vibration meter – A commonly used tool that allows the technician to find vibrations on motors or other rotating components caused by bearing failure, misalignment of parts, imbalances, looseness and other causes.

Vacuum pumps (figure 26) – Removes gas molecules from a sealed volume in order to leave behind a partial vacuum. There are many different types of vacuum pumps, but the main function of a vacuum pump is to pull air or gases out of a container. The air or gas is sucked or pumped out, leaving the container devoid of any or most air or gas molecules. Forms of vacuum pumps are used in household and commercial vacuum cleaners, for vacuum sealing food, or vacuum packing other objects you wish to save from the elements.

Figure 26: Vacuum Pump

Laser sensor – Used to determine the carbon dioxide level in an environment. A level that is too high will send the HVAC unit a command to allow more fresh air into the area being monitored.

Breakout Box (figure 27) – Lets the technician establish electrical connection to individual lines on a connector without interrupting the connection between the equipment and the diagnostic tool. This allows for simultaneous execution of testing and monitoring the test. It enables users to switch, cross and tie interface leads.

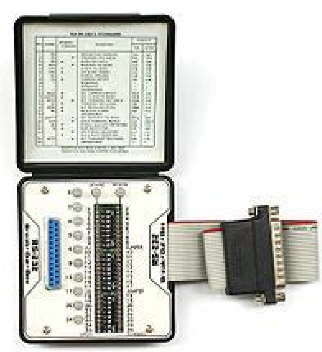
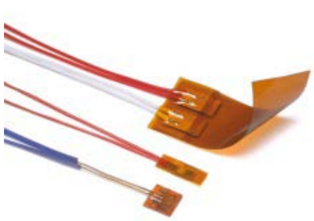


Figure27: Breakout Box



Thermometers, temperature bulb and ribbon (figure 28) – Devices for measuring the temperature of a component or area. Used for diagnostic purposes.

Figure 28: Ribbon Thermometer

Clean Air Act of 1990

The Clean Air Act of 1990 regulates the use, handling and disposal of refrigerants. It also defines the means by which technicians must be certified to handle refrigerants and to work on cooling equipment.

The purpose of Section 608 of the Clean Air Act is to: reduce emissions to the lowest level achievable; maximize recovery and reclaiming of refrigerants; recover refrigerant before disposing of appliances; and prohibit venting (releasing to the atmosphere) while installing or servicing air conditioning/refrigeration equipment

Definitions

- **Recover –** To capture the refrigerant in the system, not allowing it to escape into the atmosphere. The same owner may only use recovered refrigerant in the system from which it was removed, or another system owned. It may not be sold.
- **Recycle –** To clean the refrigerant, by the use of a filter or other apparatus, to remove contaminants, moisture, and oil. The same owner may only use recycled refrigerant in the system from which it was removed, or another system owned. It may not be sold.
- **Reclaim –** To process the refrigerant by returning it to the ARI 700 standard *(Air Conditioning and Refrigeration Institute, Standard 700-1993)* for new, virgin refrigerant. This service must be performed by facilities licensed by the EPA to process, analyze, and certify the used refrigerant. Reclaimed refrigerant can be sold and used for any legal purpose.

EPA-608 Certification Requirements for Service Technicians

In order to work on Transportation HVAC systems, service technicians must have passed an EPA-608 exam and be certified. Here are the types of certification:

- **Type I**: Certification covers the installation, servicing, and repair of small appliances, which are defined as those machines that contain less than 5 pounds of refrigerant, and are sealed at the factory.
- **Type II**: Certification covers the installation, servicing, and repair of high-pressure appliances other than small appliances.
- **Type III:** Certification covers the installation, servicing, and repair of low-pressure appliances.
- **Universal**: Certification is the designation for technicians certified in all three categories:
  Type II, III, and I.

Clean Air Act Compliance

Recovery

The basics of refrigerant recovery begin with having the proper equipment. You will need manifold gauges, safety glasses, gloves, a refrigerant recovery cylinder, scale, approved refrigerant recovery unit, and the proper hoses (including hoses with low-loss fittings) to connect to the discharge side of your recovery equipment.

Safety is always a concern when recovering refrigerant. Always wear safety glasses and gloves to keep debris from getting into your eyes and to prevent frostbite. Never recover refrigerant near an open flame, because it will decompose into phosgene gas.

Breathing phosgene gas can be fatal when recovering refrigerant, always use a scale to prevent overfilling the recovery tank. Overfilling the recovery tank can cause it to rupture and severely damage equipment — a potentially fatal situation for service technicians and others in the area.

Some recovery equipment is available with an 80% overfill sensor or tank overfill sensor (TOS). A TOS is a cable that will interface with a liquid level switch on the recovery cylinder and shut off the power supply to the unit if the tank reaches 80% of its capacity. Working with high-pressure refrigerants has unique safety issues. R-410A probably is the most commonly used high-pressure refrigerant today. Recovering it requires the use of different tanks, hoses, manifolds, and recovery equipment.

A standard 350 Department of Transportation (DOT) recovery cylinder will not work for high-pressure refrigerants. Instead, you must use a 400 DOT recovery cylinder. Unfortunately, there are no distinct markings indicating a 350 from a 400 DOT cylinder. Both are yellow on top and gray on the bottom. Always make sure to check the top of the cylinder to confirm that the cylinder is a 400 DOT.

The gauges used on a traditional manifold set do not read the level of pressures you will encounter with the high-pressure refrigerants. When working with high-pressure refrigerants, make sure you use a manifold set with a low-side gauge that reads pressures up to at least 500 psig, and a high-side gauge that reads up to at least 800 psig. Also, make sure that you use hose assemblies that are rated by UL for high-pressure. When purchasing new recovery equipment, look for recovery equipment that can be used on high-pressure refrigerants. They're the wave of the future, and if you're not working with them now, you soon will be.

Refrigerant Recovery Methods

Always use a filter-dryer or particulate filter on your refrigerant recovery unit. It is also important to use an acid core dryer when recovering from a burned out system. Acid and particulate matter will cause damage to your refrigerant recovery system. If you use the appropriate filter on every job, your refrigerant recovery equipment should give you many years of trouble-free service. The three different recovery methods are: vapor recovery, which is the most common; the push-pull method; and the liquid recovery method, which is gaining in popularity.

Recovery Method Steps

The following provides the steps related to each recovery method. Remember, your system configuration may vary. Check your operation manual to find the proper configuration for your unit.

Vapor Recovery Method

The following are the steps for proper use of the vapor recovery method:

- Connect a hose with a low-loss fitting on both ends to the discharge side of the recovery equipment.
- Connect the other end of the hose to the tank liquid port on the recovery cylinder.
- Place the recovery cylinder on a scale.
- Connect a hose from the low-side service port of the HVAC system.

- Connect the other end of this hose to the center (charging) port of your manifold set.
- Connect a hose to the low side of your manifold set.
- Connect the other end of this hose to the suction side of the recovery equipment.
- Connect a hose from the tank vapor port to the high gauge on the manifold set. This will allow you to monitor the tank pressure.
- Close valves on manifold set.
- Open vapor and liquid valves on the recovery cylinder.
- Start the recovery system.
- Allow unit to pull into the appropriate vacuum based on refrigerant type.
- Close all valves and disconnect from the HVAC system, or begin purge cycle.

Liquid Recovery Method
Until recently, it was unheard of to recover direct liquid. But with the use of oil-less compressors and constant pressure regulator valves, it's become the preferred method of recovery by most recovery equipment manufacturers. Oil-less recovery equipment has an internal device to flash off the refrigerant. Oil-less compressors will tolerate liquid only if metered through a device like a CPR valve. Don't attempt to use the liquid recovery method unless your unit is designed to recover liquid.

Liquid recovery is performed the same way as standard vapor recovery. The only difference is that you will connect to the high side of the system. Recovering liquid is ideal for recovering large amounts of refrigerant, such as refrigerant transfer, or if the system you're servicing will allow you to recover liquid.

Push-pull Recovery Method
Use the push-pull method only after you have first checked the configuration of the system being serviced. Here are the questions to ask first:

- Are less than 10 pounds of refrigerant in the system?
- Is the system a heat pump, or one with a reversing valve?
- Will the system allow a solid column of liquid to form?
- Does the system have an accumulator?

If the answer to any of these questions is yes, refer to the vapor or liquid recovery methods. Otherwise, here are ten steps to using the *push-pull recovery method*:

1. Connect a hose from the tank vapor port to the center port of the manifold set.
2. Connect a hose from the low side of the manifold set to the suction side of the refrigerant recovery unit.
3. Connect a low-loss hose from the discharge side of the recovery unit to the low-side service port
4. Connect the low-loss hose from the high-side service port to the tank liquid valve.
5. Place the tank on a scale.
6. Open valves on recovery cylinder
7. Start refrigerant recovery machine.
8. Open the low-side valve on the manifold set.
9. Monitor the scale.
10. Switch the unit over to vapor recovery once the scale stops picking up weight.

Importance of Deep Vacuum
The purpose of a vacuum pump is to remove moisture and air from an A/C-R system. Modern systems are built tighter and charges are more critical. That means these systems have a greater sensitivity to moisture and other contaminants, making thorough evacuation critically important.

Moisture in a refrigeration system, directly or indirectly, is the cause of most problems and complaints. First, moisture can cause freeze-up in a system. Moisture is picked up by the refrigerant and transported through the refrigerant line in a fine mist, with ice crystals forming at the point of expansion.

“Freeze-up” is not the only problem caused by moisture. It can also result in corrosion, the effects of which are not apparent until the real damage has occurred. Moisture alone is bad enough, but combined with refrigerants containing chlorine, hydrochloric acids can form. These greatly increase the corrosion of metals.

Also, refrigerant oil rapidly absorbs moisture. Water-formed acids combine with the refrigerant, forming a closely bonded mixture of fine globules. The effect is called slugging and it greatly reduces the lubricating ability of the oil.

A vacuum pump removes troublesome moisture by lowering the pressure within the system and vaporizing (or boiling off) the moisture, then exhausting it along with air.

Proper Refrigerant Disposal
In the natural course of your job, you’re bound to end up with refrigerant for which you have no need. Both state and government regulations are very strict on what you can and can’t do with used refrigerant. The guidelines are set up to avoid the damaging effects refrigerants can have on the atmosphere. Amendments to the Environmental Protection Agency’s Clean Air Act in the 1990s specified that is unlawful to knowing dispose of, vent or release in any manner any substance used as a refrigerant into the environment. Service and technicians were specifically cited as persons whose jobs involve maintaining, servicing, repairing or disposing of an appliance or industrial process refrigeration. The term “appliance” refers to air conditioners, refrigerators, chillers, or freezers used for commercial or residential purposes.

In general, if the refrigerant is not contaminated it can be recycled and reused. You can typically take the non-contaminated refrigerant back to the wholesaler for exchange. If the refrigerant is contaminated, you’ll need to send it to a reclamation facility. At the reclamation facility they’ll separate the refrigerant into the individual component refrigerants or incinerate it in accordance with EPA guidelines. To locate the reclamation facility nearest you, visit this EPA Web site: http://www.epa.gov/Ozone/title6/608/reclamation/reclist.html.

As always follow your rail system’s procedures for the proper recovery methods and disposal of refrigerant.

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Compressors, How They Work, www.fscc-online.com

Schnubel, Mark, Automotive Heating and Air Conditioning, 2009 Delmar Cengage Learning

Super Heat: visit www.emersonclimatecontractor.com
Recovery: Ralph A. Vergara, Ritchie Engineering technical sales manager, 800/769-8370 ext. 404, e-mail him at rvergara@ritchieengineering.com

Environmental Protection Agency (EPA) – Stationary Refrigeration and Air-Conditioning, Section 608 of the Clean Air Act, www.epa.gov/ozone/title6/608

Relevant OEM Contact Information

OEM	Website	Contact Information
Air International Thermal Systems	www.aithermalsystems.com	80 Turner Street Port Melbourne, Victoria 3207 Australia Phone: 61 3 9644 4281 Fax: 61 3 9645 3292
ThermoKing	http://www.thermoking.com/tk/index.asp	314 W 90th St Minneapolis, MN 55420 (952) 887-2200
Northwest Rail Electric	http://www.nwrail.com/	2630 SE Steele Street Portland Oregon 97202 (503) 231-4808, fax (503) 230-0572
Merak North America	http://www.merak-hvac.com/en/	861 Baltimore Blvd Westminster, MD 21157
Faiveley	http://www.ellconnational.com/	(Faiveley) Ellcon-National, Inc. 50 Beechtree Boulevard Greenville, SC 29604
Air International	http://www.aithermalsystems.com	1265 Harmon Road Auburn Hills, MI, 48326
Wabtec	http://www.wabtec.com	1001 Air Brake Avenue Wilmerding, PA 15148 Phone: (412) 825-1000 Fax: (412) 825-1019

Attachment: Industry Training Standard

206. HVAC: Introduction and Preventive Maintenance

- **206.1 Background Knowledge**
  Demonstrate ability to read schematics
  Demonstrate knowledge of what three phases is and how it works
  Explain the concept of a thermal fuse
  Identify different refrigerants and types of oil
  Identify correct seals for different refrigerants and types of oil
  Attain 608 Certification if required, or understand the requirements
- **206.2 Compressor/Motor**
  Inspecting and maintaining compressor assembly
    - Adjust unloader valve
    - Change oil and sight glass
    - Check for air bubbles
    - Check for moisture in sight glass
    - Check oil level and sight glass
    - Demonstrate knowledge of difference between scroll compressor and piston compressor
    - Describe failure symptoms
    - Identify smell of burning oil
    - Inspect compressor seals
    - Perform oil analysis
    - Repair crank case heater
    - Replace compressor assembly
    - Replace compressor seals
    - Replace crank case heater
    - Replace unloader valve
    - Test crank case heater
    - Test unloader valve operation

  Inspecting and maintaining motor coupling
    - Inspect motor coupling
    - Replace motor coupling

  Inspecting and maintaining AC motor
    - Inspect AC motor
    - Check for frozen bearings
    - Replace AC motor or worn bearings

  Inspecting and maintaining DC motor
    - Inspect DC motor
    - Check commutator for wear or damage
    - Clean brushes
    - Change brushes
    - Repair brush assembly
    - Replace and adjust brush assembly
    - Replace DC motor

  Inspecting and maintaining compressor mountings
    - Inspect compressor mountings
    - Change cushions on mountings
    - Replace compressor mountings

  Inspecting and maintaining piping and fittings
    - Check piping and fittings for leaks
    - Check braided line for fraying or damage
    - Repair piping and fittings

- **206.2 Compressor/Motor (continued)**

Inspecting and maintaining compressor service valves
- Inspect compressor service valves
- Replace compressor service valves

Inspecting and maintaining protection devices
- Test pressure limit switches
- Inspect motor overload device
- Replace pressure limit switches

- **206.3 Evaporators and Condensers**

Inspecting and maintaining condenser assembly
- Inspect condenser assembly
- Clean coils with compressed air or water
- Replace condenser assembly

Inspecting and maintaining fan assembly
- Inspect AC motor
- Inspect DC motor
- Clean brushes
- Change brushes
- Inspect grill
- Replace grill
- Repair grill
- Replace AC motor
- Replace DC motor

Inspecting and maintaining condenser fins
- Inspect fins for bends and other damage
- Clean fins
- Straighten fins
- Check for leaks

Inspecting and maintaining evaporator fins
- Inspect fins for bends and other damage
- Clean fins
- Straighten fins
- Check for leaks

- **206.4 Refrigeration Components**

Inspecting and maintaining liquid receiver tank
- Inspect liquid receiver tank
- Replace liquid receiver tank

Maintaining filter dryer
- Inspect filter dryer
- Replace filter dryer

Inspecting and maintaining heater core elements
- Inspect thermal switches
- Test heater core elements for opens
- Inspect heater core elements
- Replace heater core elements

Inspecting and maintaining piping
- Inspect piping for leaks and chafing
- Inspect relief plugs
- Inspect piping
- Repair piping

- **206.4 Refrigeration Components (continued)**

  Inspecting and maintaining air filters
  - Replace air filter
  - Inspecting and maintaining condensation pan/drain
  - Inspect condensation pan/drain
  - Clean condensation pan/drain
  - Blow out drain lines with compressed air
  - Inspecting and maintaining sight glass
  - Inspect sight glass for moisture
  - Replace sight glass
  - Inspecting and maintaining expansion valve
  - Inspect expansion valve
  - Test expansion valve using super heat check
  - Replace or adjust expansion valve
  - Inspecting and maintaining solenoid valve
  - Check solenoid valve operation
  - Inspect solenoid valve
  - Replace solenoid valve

- **206.5 Heaters**

  Inspecting and maintaining cab heaters/defrosters
  - Inspect can heaters/defrosters
  - Test cab heaters/defrosters
  - Clean cab heaters/defrosters
  - Replace cab heaters/defrosters (teach in level 250 if this is backshop work)
  - Repair cab heaters/defrosters (teach in level 250 if this is backshop work)
  - Rebuild cab heaters/defrosters (teach in level 250 if this is backshop work)

  Inspecting and maintaining sidewall/floor heaters
  - Test sidewall/floor heaters
  - Clean sidewall/floor heaters
  - Repair sidewall/floor heaters
  - Replace sidewall/floor heaters

  Inspecting and maintaining overhead heat
  - Inspect overhead heat
  - Test overhead heat
  - Repair overhead heat
  - Replace overhead heat

- **206.6 HVAC Controls**

  Inspecting and maintaining thermostats
  - Adjust thermostats
  - Replace thermostats

  Inspecting and maintaining low-pressure switch

  Inspecting and maintaining high-pressure switch

  Inspecting and maintaining flow switch
  - Test flow switch
  - Replace flow switch

  Inspecting and maintaining temperature controls/sensors
  - Test temperature controls/sensors
  - Replace temperature controls/sensors

- **206.7 Electrical Circuits and Electronic Controls**

  Inspecting and maintaining relays and connectors
    - Test if relays and connectors can hold load
    - Inspect relays and connectors
    - Replace relays and connectors

  Inspecting and maintaining control boards
    - Test control boards
    - Perform function tests with portable test equipment
    - Replace control boards

  Inspecting and maintaining over current protection
    - Test over current protection
    - Replace over current protection

  Inspecting and maintaining GFI protection
    - Test GFI protection
    - Replace GFI protection

- **206.8 Tools**

  Demonstrate ability to use oil test kit
  Demonstrate ability to use refrigerant recovery/recycle machine
  Demonstrate ability to use two-stage vacuum pumps
  Demonstrate ability to use pressure and vacuum micron gauge
  Demonstrate ability to use refrigerant leak detectors
  Demonstrate ability to use laptop, software and portable test unit
  Demonstrate ability to use breakout box
  Demonstrate ability to use thermometers
  Demonstrate ability to use manifold gauge set
  Demonstrate ability to use temp bulb/ribbon
  Demonstrate ability to use laser sensor
  Demonstrate ability to use vibration meter

RAIL VEHICLE LEVEL 200
SUBJECT OVERVIEW

Module: 207 - Current Collection and Distribution

Note: All 200 level courses should be delivered only after completion of 100 level training

About the Author: Jack Shaw

Jack Shaw, a member of the Joint National Transit Rail Vehicle Training Standards Committee, has worked at Metro Transit since 1985. The agency serves the twin cities of Minneapolis/St. Paul Minnesota. Jack began as a helper and progressed to an Electrical Mechanic Foreman. He joined Metro Transit after a four year tour in the U.S Army as a Calvary Scout. He also served in Balad Iraq in 2004 while serving in the Minnesota Air National Guard.

Overview/Purpose

This material provides a general overview of rail current collection and distribution systems to give technicians a basic introduction to the subject and prepare them for national qualification testing. Current collectors, consisting of pantograph, third rail and trolley pole applications, are electrically conductive devices that allow current to be distributed through to the train.

Material presented here is intended only as a primer to the subject, keeping in mind that rail systems have different characteristics. It follows the National Training Standards established jointly by representatives from both labor and management. As a primer additional knowledge will be needed to become fully qualified on this subject. Material presented here does not address every possible aspect because current collection and distribution vary at each transit agency. Supplemental courseware and other resources to help technicians become qualified on this subject are listed below.

Table of Contents

Suggested Tools/Training Aids:

- power point presentations
- transparencies
- manuals
- Recommended Practice for Standard for Third Rail Current Collection Equipment Periodic Inspection and Maintenance, APTA RT-S-VIM-001-02
- Standard for Pantograph Current Collection Equipment Periodic Inspection and Maintenance, APTA RT-S-VIM-002-02
- Volt-ohm/meter
- Pressure gauge

Topics Covered:

Topics listed below are covered in this introduction of current collection and distribution. A full copy of the National Training Standards from which these topics were taken is attached.

- Background
- Safety
- Pantograph
- Third Rail
- Trolley Pole
- Common Components
- Tools

Definitions, Abbreviations and Acronyms

For the purposes of this lesson, the following glossary of terms, definitions, acronyms, and abbreviations shall apply. They are not all inclusive, and the reader is encouraged to explore the text, footnotes and bibliography sources for further information.

Definitions

With a diversity of manufacturers and rail transit agencies, it is necessary to establish a common vocabulary to describe components that are identical or similar in nature and function. For the purposes of clarity the following terms and definitions will be used in this document: (as taken from APTA)

- **Carbon Strip:** The current collector strip mounted to the top of the pantograph, which slides along the contact wire.
- **Pantograph:** (pantograph current collection equipment) The current collector apparatus, typically consisting of a linked framework, mounted on top of a rail transit vehicle.
- **Third Rail:** An electrical conductor (also called contact rail) located alongside the track designed to carry energy for the propulsion and auxiliary systems of trains.
- **Third Rail Current Collection Equipment:** A mechanical assembly commonly mounted to a rail transit vehicle truck frame (usually four assemblies per car, electrically linked together). Its design provides a continuous pressure applied sliding shoe connection to the third rail for the purpose of transferring power from the third rail to the rail transit vehicle.
- **Original equipment manufacturer (OEM):** Enterprise that designs and builds equipment initially.

Abbreviations and Acronyms

- **ANSI:** American National Standards Institute
- **CFR:** Code of Federal Regulations
- **MSDS:** Material Safety Data Sheet
- **OEM:** Original Equipment Manufacturer
- **OSHA:** Occupational Safety and Health Administration
- **PPE**: Personal Protective Equipment

Introductory Text by Topic Area

1.0 Background
2.0 Safety
3.0 Pantograph
4.0 Third Rail
5.0 Trolley Pole
6.0 Common Components
7.0 Tools

I. Introduction

The current collection and distribution systems for rail vehicles will vary between rail transit systems. The inspection and maintenance of the components and the entire current collection and distribution system should be performed on a regular schedule as determined by the individual rail transit system.

Minimally, inspection and maintenance tasks should comply with government regulations (Federal, state and local) and OEM recommended intervals. For ideal operation it is suggested that other items be considered when developing a preventative maintenance schedule such as industry experience, operating environment, historical data and failure analysis.

II. Background

Current Collection and Distribution Overview

The electric transmission system for modern electric rail systems consists of three major components:

- Catenary
- Pantograph
- Trolley pole

Pantographs and trolley poles are mounted atop rail cars and obtain electrical current through the overhead catenary power supply as shown in Figure 1. Catenary applications provide high speed, high power capacity and long spans, but with the trade off of high visual impact.

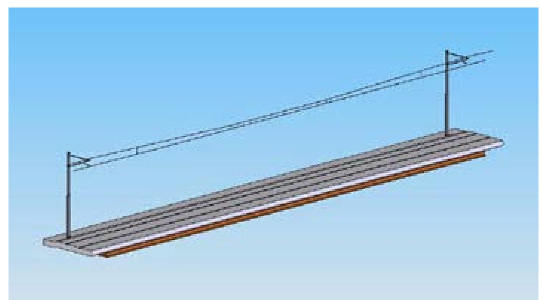


Figure 1: Overhead catenary power supply – Source: Atlas Rail Components Ltd

High voltage from the overhead catenary feeds the rail car by means of a pantograph shown in Figure 2, or via a trolley pole shown in Figure 3.

Figure 2: Pantograph mounted atop rail car receives current through overhead catenary wire

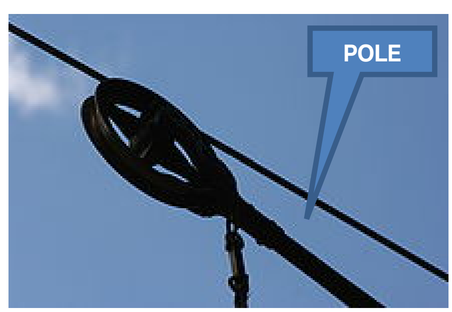


Figure 3: Trolley pole extends upward atop rail vehicle to collect current from overhead catenary

Unlike overhead catenary, the third rail is typically placed alongside a railway track as shown in Figure 4.

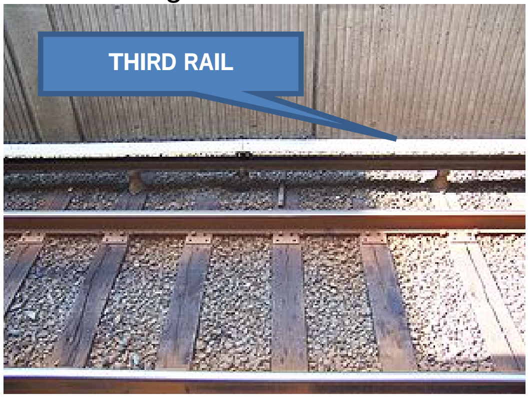


Figure 4: Fixed third rail alongside tracks

In summary, the electric transmission system for modern electric rail systems consists of an upper weight carrying wire known as a catenary from which is suspended a contact wire as shown in Figure 5 along with other transmission components. (Note: The "dropper" is also known as a hanger.)

There are two ways that the rail vehicle is connected to this line of power: a pantograph or trolley pole. These three major components, catenary, pantograph and trolley pole, as well as their functions, will be described in detail in subsequent sections.

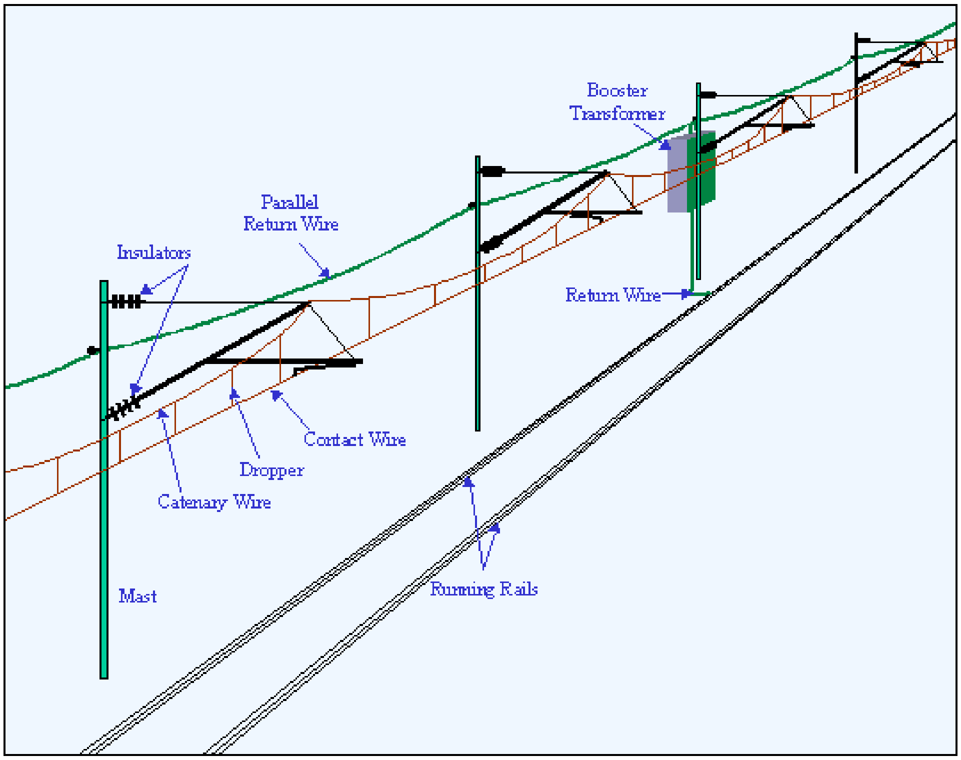


Figure 5: Catenary wire application in rail electrical transmission system

II. Safety Concerns

When performing any operation, inspection or maintenance tasks take care to wear the appropriate personal protective equipment (PPE) – and minimally follow ANSI standards. Below are some safety requirements. Others will be dispersed throughout the text of this primer.

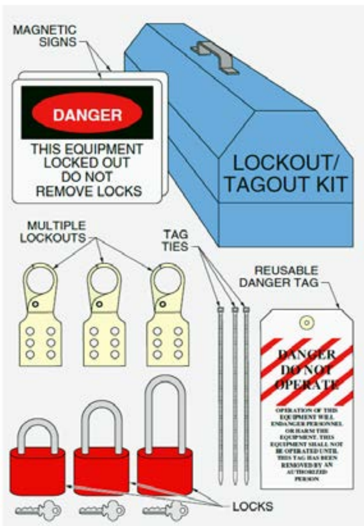


Figure 6: Lockout/Tagout Kit

Voltage: Energy Supply

- To avoid possible injury make sure that the control power is **shut off and remains off** until personnel are safely clear of moving parts. Follow lockout/tagout procedures as per your authority (Figure 6).
- Verify that electrical power is removed by checking with reliable equipment.
- To avoid possible injury, notify all concerned that equipment is about to be energized before restoring power. If vehicles are coupled and controls are trainline, assure that it is safe for equipment in coupled cars to become operational before energizing any high voltage or battery circuits.
- Potential electrical hazards may include: electric shock, fires, explosion and electrocution.

Pinch Points

To avoid possible injury while moving doors manually for inspection purposes, keep hands and tools away from pinch points (Figure 7).

Figure 7: Pinch Points

Cleaning

- To avoid possible injury while using compressed air for dislodging dirt and debris, wear appropriate eye, face, and respiratory protection meeting minimum ANSI or other applicable national industry standards. Keep air pressure at the blowgun nozzle below 30 pounds per square inch.
- Use only those cleaning products and lubricants proven safe and authorized for use by the rail transit system. Consult OEM and MSDS references for suitability for each application to prevent personal injury and damage to the equipment.

III. Pantograph

The pantograph, as shown in Figure 8 below, is mounted on the roof of the car. It is the device that forms the electrical link between the overhead catenary wire and vehicle power system. The pantograph is spring loaded and pushes a carbon strip up against the contact wire to draw the electricity needed to run the train. The steel rails on the tracks act as the electrical return. As the train moves, the carbon strip slides along the wire and can set up acoustical standing waves in the wires which break the contact and degrade current collection. This means that on some systems adjacent pantographs are not permitted.

Figure 8: Pantograph atop rail vehicle

Pantographs are the successor technology to trolley poles, which were widely used on early streetcar systems. Trolley pole are still used by trolleybuses, whose freedom of movement and need for a two-wire circuit makes pantographs impractical, and some streetcar networks, which have frequent turns sharp enough to require additional freedom of movement in their current collection to ensure unbroken contact.

Pantographs with overhead wires are now the dominant form of current collection for modern electric trains because, although more expensive and fragile than a third-rail system, they allow the use of higher voltages.

Pantographs (Figure 9) are typically operated by compressed air from the vehicle's braking system or electrically. It can either raise the unit and hold it against the conductor or when springs are used to affect the extension, it can lower it. As a precaution against loss of pressure in the second case, the arm is held in the down position by a catch.

For high-voltage systems, the same air supply is used to "blow out" the electric arc when roof-mounted circuit breakers are used.


Figure 9: Pantograph

Inspection and Maintenance of Pantograph

SAFETY WARNING: Before beginning an inspection or maintenance of the pantograph make sure: • Pantograph lowered • Catenary power removed and isolated • Roof accessed • Safety pin installed

The following components as show in (Figure 10) are to be included when doing a periodic inspection and maintenance checks of the pantograph. As always, follow your authority's and OEM procedures and guidelines.

- **Springs** – Look for corrosion, whether on car one or two. Be sure to test pantograph tension. This can be done by hanging weights, using a fishscale, spring tension gauge or also known as contact balance. Specific tension requirements can be found in the manufacturer's manual. If the tension is out of adjustment, adjust the spring using a spanner wrench. Tension should be checked in three stages: (heights)–when the header is in the upper position (where carbon strip touches line); middle (pivot); and lower.
- **Carbon strips** (Figure 11) – Visually inspect, look for chips as this will wear down quickly over time. Carbon strips must be replaced if cracks are detected. Make sure that there is the proper thickness. In some cases there is a wear line. In others, manually measure the thickness and be sure to refer to manufacturer's manual for specifications which is generally 1/8 to ¼ inch. Make sure the carbon strip is perpendicular with catenary using a straight edge, level or square and parallel with each other. Use turn buckles until this state is achieved.
- **Carbon strip heater** – If not functioning properly, "ohm it out." Be sure to measure the electrical resistance – against manufacturer's specifications.
- **Head bushings** – Make sure it operates properly and head moves freely. Replace it, if this is not the case. Note that these can also be tested with a heat gun.
- **Horns** – Look for worn paint, repaint as necessary. Worn paint indicates that the catenary is out of alignment.
- **Shunt** – Activates when part of a circuit diverts (shorts). It forces the electrical current to move around the dead spot and hit a point where it can continue on, unbroken. The bearings, installed at the pantograph pivoting joints are protected by shunts from voltage. Visually inspect all shunts for frayed, broken, cut, burnt or otherwise defective conditions. If any of these conditions exist, replace the shunt. When replacing shunts, make sure the contact surfaces are clean and free from dirt or corrosion. Be sure to check for loose connections and tighten as required.
- **Pivot** – If not sealed, lubricate as required. If it is a sealed unit, then only lubricate the pin.

- **Bearings** – Inspect the bearings for freedom of movement and excessive play. Replace as required. Be sure to clean the exterior of the bearing assembly and lubricate with approved lubricants.
- **Insulator** – Visually inspect for carbon buildup from carbon strip. Be sure to look for cracks as it may be made of ceramic. Also, check for torque stripe. Clean with an approved, non-conductive carbon-dissolving solvent.
- **Manual Lowering Device** – This fiberglass crank manually activates the electrical lowering device (ELD). Cut off power and crank it to see if it works. In some cases you'll count how many cranks it takes to reach the upper and lower limits – as per manufacturer specifications.
- **Electrical Lowering Device** – Perform an operational test by running it and down. There are two limit switches that are adjusted to set the upper and lower limit. To test upper limit, first remove catenary cable. Visually inspect the cable on ELD for fraying and or damage and replace if necessary. If not operating correctly, reposition the limit switch.
- **Control Box** – Usually not inspected under normal preventative maintenance check, but maybe inspected for troubleshooting purposes.
- **Coupling Rods** – Inspect to make sure the rods are straight and not damaged. Be sure to lubricate pivot points.
- **Autodrop** – Visually inspect to make sure it's there and that it shears the pin and allows the pantograph to drop without getting struck.

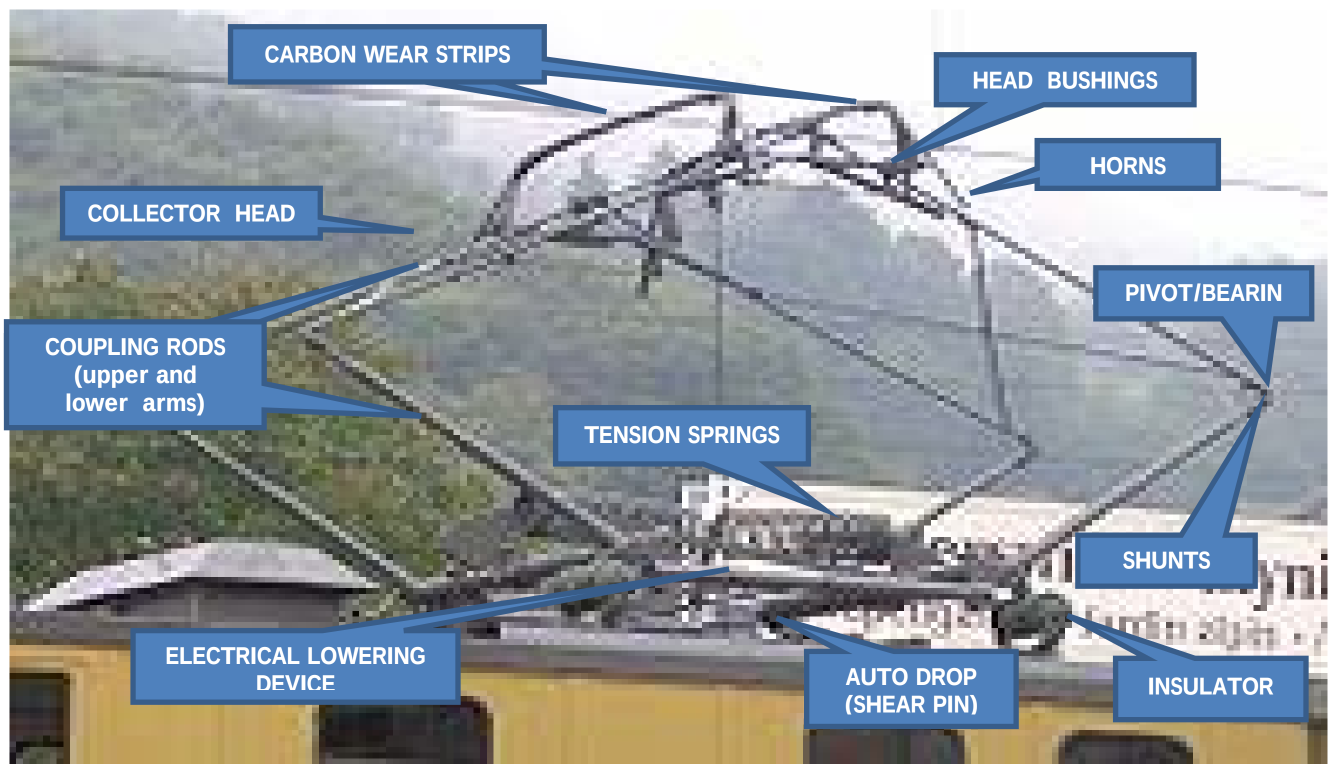


Figure 10: Pantograph Components

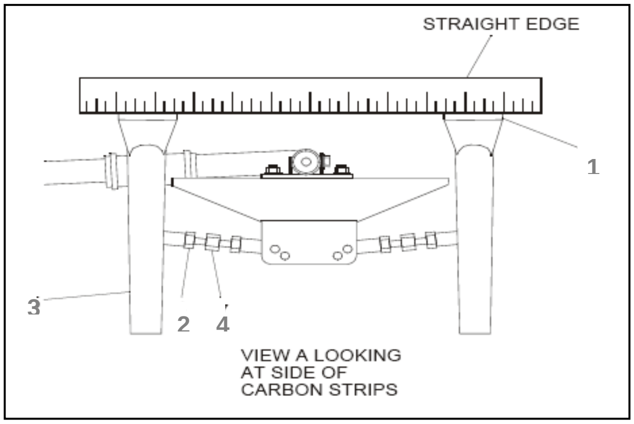


Figure 11: Straight edge tool and components: Carbon strips (1), Hex nuts (2), Pan head (3), and Turnbuckles (4)

Safety Precautions for Specific Tasks

When conducting specific tasks during the inspection and maintenance of the pantograph, the following safety procedures must be followed. First, work on the pantograph must be performed under overhead wire that is voltage free and in an area where no overhead wire is present.

During the lowering and raising operation, remain clear of the pantograph to avoid being struck. Be sure to pay particular attention to rotating equipment and energy stored in the springs. When detaching equipment from the pantograph assembly, ensure all components are adequately supported to prevent uncontrolled movement

IV. Third Rail

Third rail systems are a means of providing electric traction power to railway trains by using an additional rail, called a conductor rail, for that purpose. On most systems, the conductor rail is placed on the sleeper ends outside the running rails (see Figure 4), but in some cases a central conductor rail is used as shown in Figure 12. The conductor rail is supported on ceramic insulators or insulated brackets, typically at intervals of ten feet (three meters) or so.

Figure 12: Central Conductor Rail application

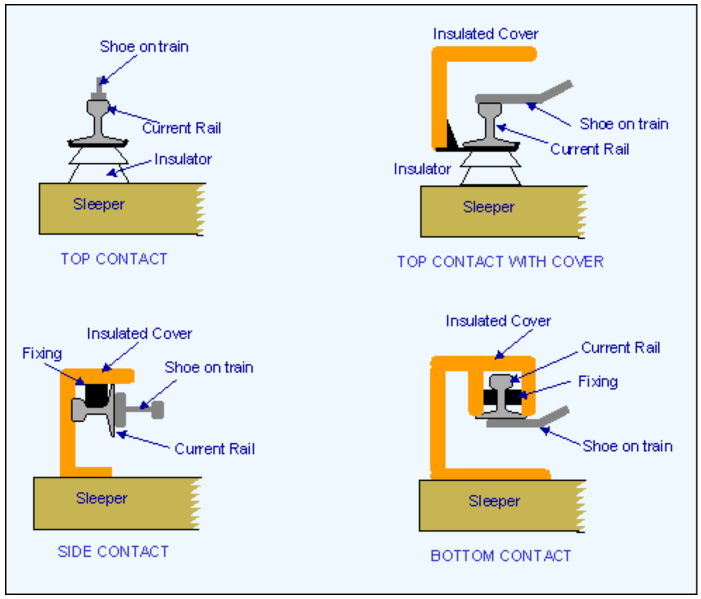


Figure 13: Train Shoe, Sleeper Block Diagram

The trains have metal contact blocks called "shoes" (Figure 13) which make contact with the conductor rail. The traction current is returned to the generating station through the running rails. The conductor rail is usually made of high conductivity steel, and the running rails have to be electrically connected using wire bonds or other devices, to minimize resistance in the electric circuit.

The conductor rails have to be interrupted at level crossings and at crossovers, and ramps are provided at the ends of the sections to give a smooth transition to the train shoes.

There is considerable diversity about the contact position between the train and the rail; some of the earliest systems used top contact, but developments used side or bottom contact, which enabled the conductor rail to be covered (Figure 14), protecting track workers from accidental contact and protecting the conductor rail from snow and leaf fall.

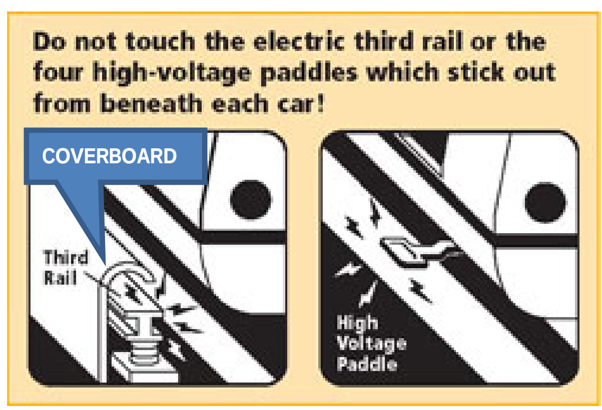


Figure 14: Coverboard – Source: BART

Inspection and Maintenance of Third Rail

SAFETY WARNING: Before beginning any inspection or maintenance of the third rail, be sure to disconnect traction power.

When inspecting and maintaining the third rail, perform the following checks of the following components in accordance with your rail transit system and OEM procedures:

- **Paddle assembly** – Check for wear and that it is at the right height for the assembly using a gauge with a collector height measuring stick from the base of the track.
- **Tension spring** – Check torsion with a spring tension gauge. Look for deformities and/or damage. Incorrect torsion may cause uneven wear on the shoe and therefore it may not be level.
- **Shoe** – Check that contact shoe (Figure 15) has proper thickness. Make sure there are no holes. Current collector shoes must be replaced if the pad wear limit hole is exposed or the shoe is worn down to the condemning limit. Use a shoe pad wear gauge, if applicable. A braided copper band connects the power from each paddle to the high voltage power distribution network.
- **Shoe Pad** – Check for correct contact to the third rail. Excessive burning of pad area generally indicates improper shoe height, alignment or improper spring tension. Adjust or replace in accordance with rail transit system procedures.
- **Shoe Beam Gibs** – Visually inspect for wear and damage as they are made of rubber and insulate the truck from the current collector. (Figure 15)

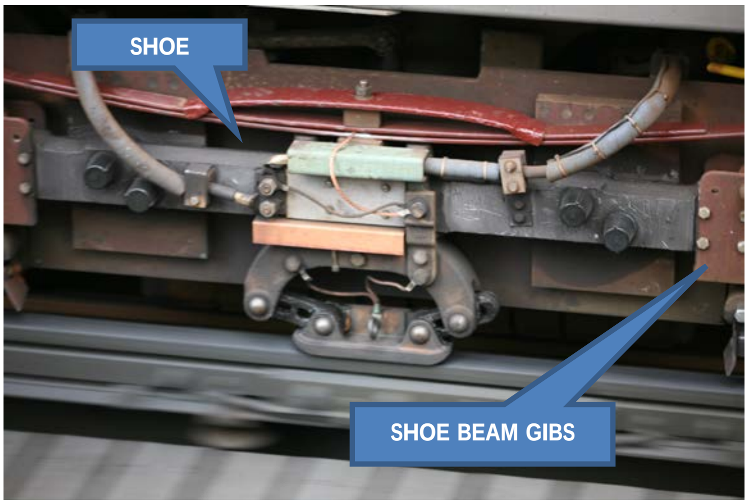


Figure 15: Train Shoe and Shoe Beam Gibs – Source: CTA

- **Arc Shield** – Visually inspect this insulator from a truck frame for cracks. Note that it also functions as a secondary insulator. Clean with pressure washer. If faulty or damaged, replace the entire unit. Note that reports of a jerky car may be an indication that the arc shield is faulty.
- **Bus Bar** – Make sure all hardware is tight to appropriate torque as per manufacturer specs. Look for cracks, breaks, signs of arcing. Repair or replace as necessary. Also, check for blown fuses since the bus bar connects power from the collector paddle to the fuse.
- **Fuses** – Perform circuit continuity test on all cartridge type fuses and replace all fuses that exhibit an "open" condition. Inspect all ribbon type fuses for security and signs of damage or overheating. Replace all damaged or blown fuses.
- **Insulation Test** – Perform an insulation test using a megger set at 500 or 1000 Vdc. Ensure the knife switch (Figure 16) or main breaker is in the open position. Connect the megger negative lead to carbody ground and the positive lead to the line side of the main knife switch or circuit breaker. An insulation level sufficient to ensure freedom of tracking, arcing, fire and other electrical hazards shall be achieved and maintained. A minimum level of five (5) megohms is desired for the equipment.

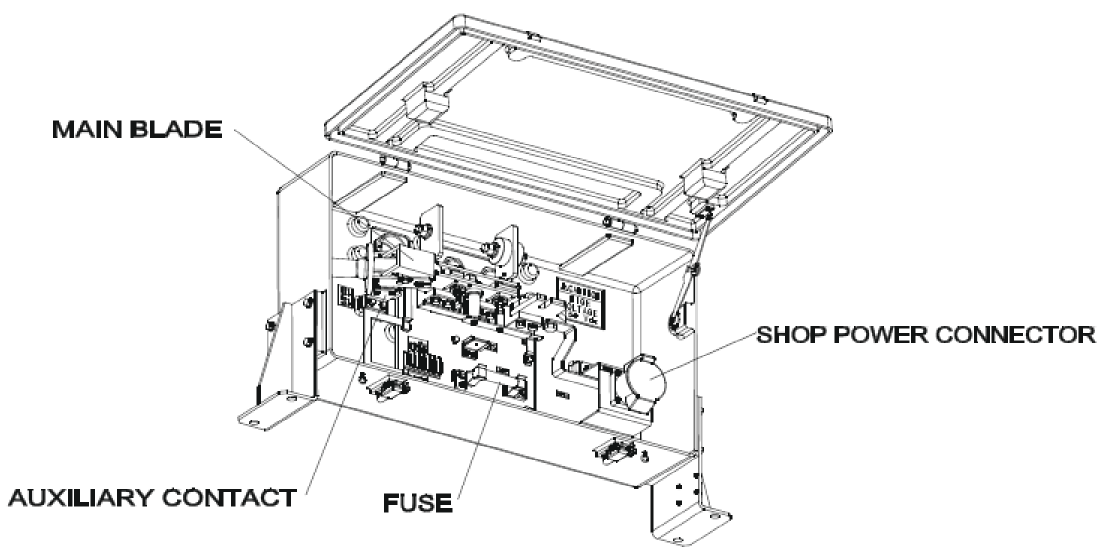


Figure 16: Main Knife Switch

V. Trolley Pole

A trolley pole is a tapered cylindrical pole of wood or metal, used to transfer electricity from a "live" overhead wire to the control and propulsion equipment of a light rail vehicle or trolley bus.

A trolley pole is *not* "attached" to the overhead wire. As shown in Figure 17, the pole sits atop a sprung base on the roof of the trolley vehicle, the springs maintaining the tension to keep the trolley wheel or shoe in contact with the wire.

If the pole is made of wood, a cable brings the electrical current down to the vehicle. A metal pole may use such a cable, or may itself be electrically "live", requiring the base to be insulated from the vehicle body.

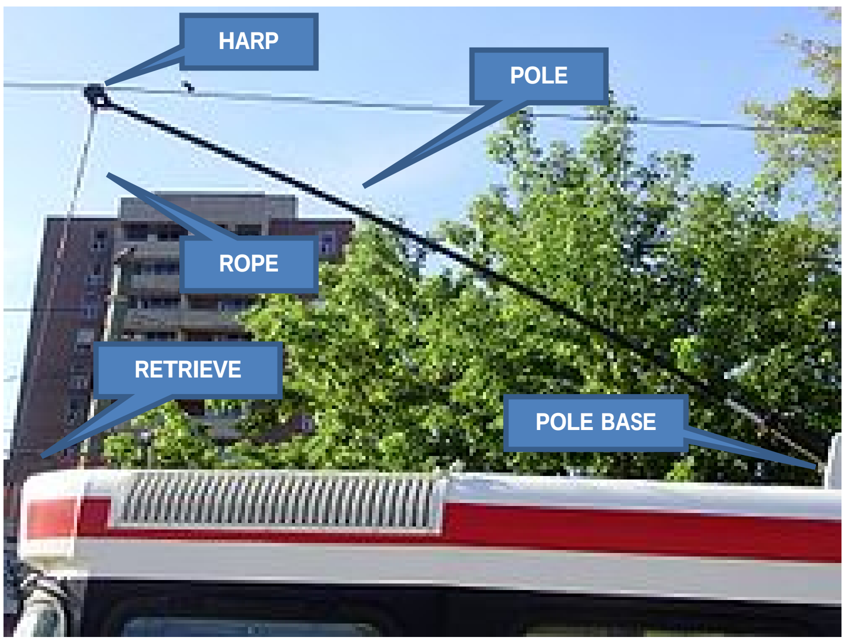


Figure 17: Trolley Pole application

On systems with double-ended railway cars capable of running in both directions, the trolley pole must always be pulled behind the car and not pushed, or de-wiring is very likely, and it can also cause damage to the overhead wires.

At terminus points therefore, the conductor must turn the trolley pole around to face the correct direction, pulling it off the wire either with a rope or a pole and walking it around to the other end. In many cases, two trolley poles are provided, one for each direction, so in this case it is just a matter of raising one and lowering the other. Since the operator could raise the pole at one end whilst the conductor lowered the other, this saved time and was much easier for the conductor.

Care must be taken to raise the downed pole first, to eliminate the damage caused by arcing between the pole and wire. In the United States, the dual-pole system was the most common arrangement on double-ended vehicles. However, pushing of the pole (termed "back-poling" in the US or "spear-poling" in Australia), was quite common where the trams were moving at slow speeds, such as at wye terminals (also known as reversers) and whilst backing into the sheds.

Trolley poles are usually raised and lowered manually by a rope from the back of the vehicle. The rope feeds into a spring reel mechanism, called a *trolley catcher* or "trolley retriever." The trolley catcher contains a detent, like that in an automotive shoulder safety belt, which "catches" the rope to prevent the trolley pole from flying upward if the pole is “de-wired.” The similar looking retriever adds a spring mechanism that yanks the pole downward if it should leave the wire, pulling it away from all overhead wire fittings. Catchers are commonly used on trams operating at lower speeds, as in a city, whilst retrievers are used on suburban and interurban properties to limit damage to the overhead at speed.

On some older systems, the poles were raised and lowered using a long pole with a metal hook. Where available, these may have been made of bamboo due to its length, natural straightness and strength, combined with its relative light weight and the fact that it is an insulator. Trolleybuses usually carried one with the vehicle, for use in the event of dewirement, but tram systems usually had them placed along the route at locations where the trolley pole would need reversing.

The poles used on trolleybuses (Figure 18) are typically longer than those used on trams, so as to allow the bus to take fuller advantage of its not being restricted to a fixed path in the street (the rails), by giving a degree of lateral steer ability that enables the trolleybus to load passengers at curbside, as do all buses.

Figure 18: Longer Trolleybuses Poles

Inspection and Maintenance of Trolley Poles

SAFETY WARNING:
Before beginning any inspection or maintenance of rail vehicle trolley poles and related components make sure to LOTO.

During the inspection and maintenance of trolley poles, be sure to perform the following checks of the listed trolley pole components in accordance with your authority's and OEM procedures.

- **Pole Base** – Visually inspect for damage. Check tension on the (compression) spring. Check ability of the pole base to pivot. Lubricate as necessary. Check insulators for damage. It's a socket that the pole sticks in.
- **Pole** – Inspect the pole for damage.
- **Rope** – On the rope, look for fraying or fatigue.
- **Retriever** – The retriever is a reel that removes slack from the rope. Be sure that there's no slack.
- **Harp** – The trolley pole will connect with the catenary in one of two ways: by a wheel (Figure 19) or by a harp and slider, also known as a shoe. The harp holds the slider which connects to the line. Be sure to inspect the slider for wear and either measure it or look at wear lines.

Figure 19: Wheel

VI. Common Components

The three forms of current collection and distribution – pantograph, third rail and trolley – discussed above, share common components that include surge arrestor (protect electronic equipment against overvoltage transients; main breaker; cables; shunts (a device which allows electric current to pass around another point in the circuit); and tension springs.

Main Breaker (High Speed Circuit Breaker)
The main breaker, also known a high speed circuit breaker, is a single contact breaker, thermally rated for the design current. It is designed to protect the equipment and prevents damage from over current. When the systems experiences over current caused by short circuit, inverter failure, etc., the high speed circuit breaker (HSCB) disconnects the main DC line circuit.

Surge arrestor (**surge suppressor**)
The surge arrestor is an appliance designed to protect electrical devices from voltage spikes. A surge protector attempts to limit the voltage supplied to an electric device by either blocking or by shorting to ground any unwanted voltages above a safe threshold.

Other majority of the common components specified by the APTA standards have been covered in the text above:

1. Fuse (p.15)
2. Cables (pp. 16 & 19)
3. Shunts (p. 10 & 19)
4. Tension spring (p.14 & 16)

VII. Tools

In addition to the standard tools carried by maintenance personnel, the following tools are normally required for pantograph current collection equipment inspection and maintenance:

1. Force gauge (spring scale or digital)
2. 500 or 1000 Vdc Megohm-meter (commonly referred to as a Megger)
3. Stopwatch
4. Third rail shoe height gauge

Note that the megger and multi-meter require periodic calibration as specified by the rail transit system practices.

The majority of tools used while performing periodic inspection and maintenance of rail vehicle electrical components were covered throughout this primer. A common tool used by technicians, the volt-o-meter, is described below.

Volt Ohm/meter (VOM) (Figure 20) **-** An electronic measuring instrument that combines several measurement functions in one unit. A typical multi-meter would include basic features such as the ability to measure voltage, current, and resistance.

Figure 20: A Volt-Ohm/Meter

Bibliography

APTA Rail Transit Standards, Vehicle Inspection and Maintenance APTA RT-S-VIM-001-02 “Standard for Third Rail Current Collection”

APTA Rail Transit Standards, Vehicle Inspection and Maintenance APTA RT-RP-VIM-S-002-02 “Standard for Pantograph Current Equipment Periodic Inspection and Maintenance”

APTA Rail Transit Standards, Vehicle Inspection and Maintenance APTA RP-E-004-98, “Recommended Practice for Gap and Creepage Distance”

APTA Rail Transit Standards, Vehicle Inspection and Maintenance APTA RP-E-009-98, “Recommended Practice for Wire Used On Passenger Equipment”

Relevant OEM Contact Information

OEM	Website	Contact Information
Wabtec	http://www.wabtec.com/home.asp	Wabtec 1001 Air Brake Avenue, Wilmerding, PA Phone: 412-825-1000
Schunk, W.		146 N Held Drive Menomonee Falls WI, Phone: 262-253-8720
Faiveley	http://www.faiveleytransport.com	Faiveley Transport 50 Beechtree Boulevard Greenville, SC Phone: 864- 277-5000

Attachment: Industry Training Standard

207. Current Collection and Distribution: Introduction and Preventive Maintenance

- **207.1 Background Knowledge**
  Demonstrate understanding of basic AC/DC electricity

- **207.2 Safety**
  Follow safety procedures

- **207.3 Pantograph**
  Inspecting and maintaining pantograph collector
    - Inspect carbon strips condition and thickness
    - Adjust carbon strips
    - Inspect head bushings
    - Replace head bushings
    - Inspect horns
    - Paint horns
    - Inspect carbon strip heater
    - Test carbon strip heater
    - Measure head for proper leveling and carbon strips parallelism
    - Replace carbon strips
    - Replace horns
    - Replace carbon strip heater

  Inspecting and maintaining pantograph collector head
    - Test electrical lowering device
    - Adjust electrical lowering device
    - Repair electrical lowering device
    - Replace electrical lowering device

  Inspecting and maintaining manual lowering device
    - Test manual lowering device
    - Repair or replace manual lowering device

  Inspecting and maintaining insulator
    - Clean all insulators
    - Inspect frame and insulated mounts
    - Replace insulators

  Inspecting and maintaining raising mechanism (springs)
    - Inspect shear pin
    - Adjust raising mechanism
    - Check spring tension
    - Replace raising mechanism

  Inspecting and maintaining control box
    - Test control box
    - Adjust control box
    - Adjust pole controls
    - Replace control box

- **207.3 Pantograph (continued)**
  Inspecting and maintaining coupling rod
    - Inspect coupling rod
    - Lubricate coupling rod
    - Replace and adjust coupling rod

  Inspecting and maintaining auto drop
    - Inspect auto drop
    - Replace auto drop

- **207.4 Third Rail**
  Describe safety considerations for working with high voltage third rail
  Inspecting and maintaining collector paddle assembly
    - Inspect collector paddle assembly
    - Adjust paddle assembly
    - Clean paddle assembly
    - Replace paddle assembly
    - Inspect arc shield
    - Clean arc shield
    - Inspect height adjustor
    - Adjust height adjustor
    - Inspect paddle
    - Adjust paddle angle
    - Replace paddle
    - Replace arc shield
    - Replace height adjustor
    - Replace arc shield

  Inspecting and maintaining bus bar
    - Inspect bus bar
    - Clean bus bar
    - Replace bus bar

  Inspecting and maintaining shoe beams/gibs
    - Inspect shoe beams/gibs
    - Adjust shoe beams/gibs
    - Clean shoe beams/gibs
    - Replace shoe beams/gibs

- **207.5 Trolley Pole**
  Inspecting and maintaining pole base
    - Test pole base
    - Inspect pole base
    - Replace pole base

  Inspecting and maintaining pole
    - Test pole
    - Replace pole

  Inspecting and maintaining harp
    - Test harp
    - Replace harp

  Inspecting and maintaining slider
    - Replace slider

- **207.5 Trolley Pole (continued)**
  Inspecting and maintaining rope and retriever

- Inspect rope and retriever
- Replace rope and retriever

- **207.6 Common Components**

  Inspecting and maintaining surge arrestor (lightning arrestor)
    - Inspect surge arrestor
    - Clean surge arrestor
    - Replace surge arrestor

  Inspecting and maintaining main breaker (high-speed circuit breaker, line contactor)
    - Inspect main breaker
    - Test main breaker
    - Lubricate main breaker
    - Shim main breaker
    - Replace contacts on main breaker

  Inspecting and maintaining fuse
    - Inspect fuse
    - Test fuse
    - Replace fuse

  Inspecting and maintaining cables
    - Inspect cables
    - Replace cables

  Inspecting and maintaining shunts
    - Inspect shunts for looseness and fraying
    - Replace shunts

  Inspecting and maintaining tension spring
    - Inspect tension spring
    - Adjust tension spring
    -

- **207.7 Tools**

  Demonstrate ability to use a spring tension gauge
  Demonstrate ability to use gauges/collector stick
  Demonstrate ability to use a level or square
  Demonstrate ability to use a test stand
  Demonstrate ability to use a torque wrench
  Demonstrate ability to use a spanner wrench
  Demonstrate ability to use a chart recorder
  Demonstrate ability to use calipers
  Demonstrate ability to use contact balance
  Demonstrate ability to use a volt/Ohm meter
  Demonstrate ability to use a megger

RAIL VEHICLE LEVEL 200
SUBJECT OVERVIEW

MODULE: 208 – CAR BODY

Note: All 200 level courses should be delivered only after completion of 100 level training

About the Author

Jack Shaw, a member of the Joint National Transit Rail Vehicle Training Standards Committee, has worked at Metro Transit since 1985. The agency serves the twin cities of Minneapolis/St. Paul Minnesota. Jack began as a helper and progressed to an Electrical Mechanic Foreman. He joined Metro Transit after a four year tour in the U.S Army as a Calvary Scout. He also served in Balad Iraq in 2004 while serving in the Minnesota Air National Guard.

Overview / Purpose

This material provides a general overview of rail vehicle bodies to give technicians a basic introduction to the subject and prepare them for national qualification testing. Material presented here is intended only as a primer to rail vehicle bodies and follows the National Training Standards established jointly by representatives from both labor and management. It reflects light rail car vehicle bodies, keeping in mind that heavy-rail and commuter rail vehicles have different characteristics.

As a primer additional knowledge will be needed to become fully qualified on this subject. Material presented here does not address every possible part of every vehicle make or model because rail car designs and materials vary with each manufacturer. Supplemental courseware and other resources to help technicians become qualified on this subject are listed below.

Note that all 200 level courses should be delivered only after completion of 100 level training.

Table of Contents

Suggested Tools/Training Aids:

- power point presentations
- transparencies
- manuals
- schematics
- railcar

Topics Covered:

Material presented here follows the National Training Standards developed for Car Body under Section 208. Subsections include:

208.1 Articulation
208.2 Interior
208.3 Exterior
208.4 Lighting Systems
208.5 Cab

A full copy of the National Training Standards from which these topics were taken is attached.

Definitions, Abbreviations and Acronyms

For the purposes of this lesson, the following glossary of terms, definitions, acronyms, and abbreviations shall apply. They are not all inclusive, and the reader is encouraged to explore the text, footnotes and bibliography sources for further information.

- **CRV:** Commuter Rail Vehicles
- **LRV:** Light Rail Vehicles
- **HRV:** Heavy Rail Vehicles

Introductory Text by Topic Area

Note: those providing text should review the complete training standard (attached) to ensure all learning objectives are addressed.

1.0 Types of Rail Vehicles

There are three basic types of rail vehicles used in public transportation service: Light Rail Vehicles (LRVs), Heavy Rail Vehicles (HRVs), and Commuter Rail Vehicles (CRVs). The equipment for each is very different.

Light Rail refers to an electric railway with a "light volume" traffic capacity compared to heavy rail. Light rail may use shared or exclusive rights-of-way, high or low platform loading and multi-car trains or single cars. Light Rail is also known as "streetcar," "trolley car" and "tramway."

Heavy rail is defined as an electric railway with the capacity for a "heavy volume" of traffic and is characterized by exclusive rights-of-way, multi-car trains, high speed and rapid acceleration, sophisticated signaling and high platform loading. Heavy Rail is also called "rapid rail," "subway," "elevated (railway)" or "metropolitan railway (metro)."

Commuter rail is typically a railroad operating local and regional passenger trains between a central city, its suburbs, and/or another central city. It may be either locomotive-hauled or self-propelled, and is characterized by multi-trip tickets, specific station-to-station fares, practices that follow existing railroad employment and usually has only one or two stations in the central business district. Commuter Rail is also known as "suburban rail." Commuter railroads typically operate over tracks owned by freight rail companies or Amtrak. [1]

The information covered in this basic guide centers around LRVs and can also be applied to HRVs. However, the guideline does not include information for Commuter Rail Vehicles because unlike light and heavy rail, CRVs are regulated by the Federal Railroad Administration and therefore is outside the scope of this overview.

Light Rail

Heavy Rail

Commuter Rail

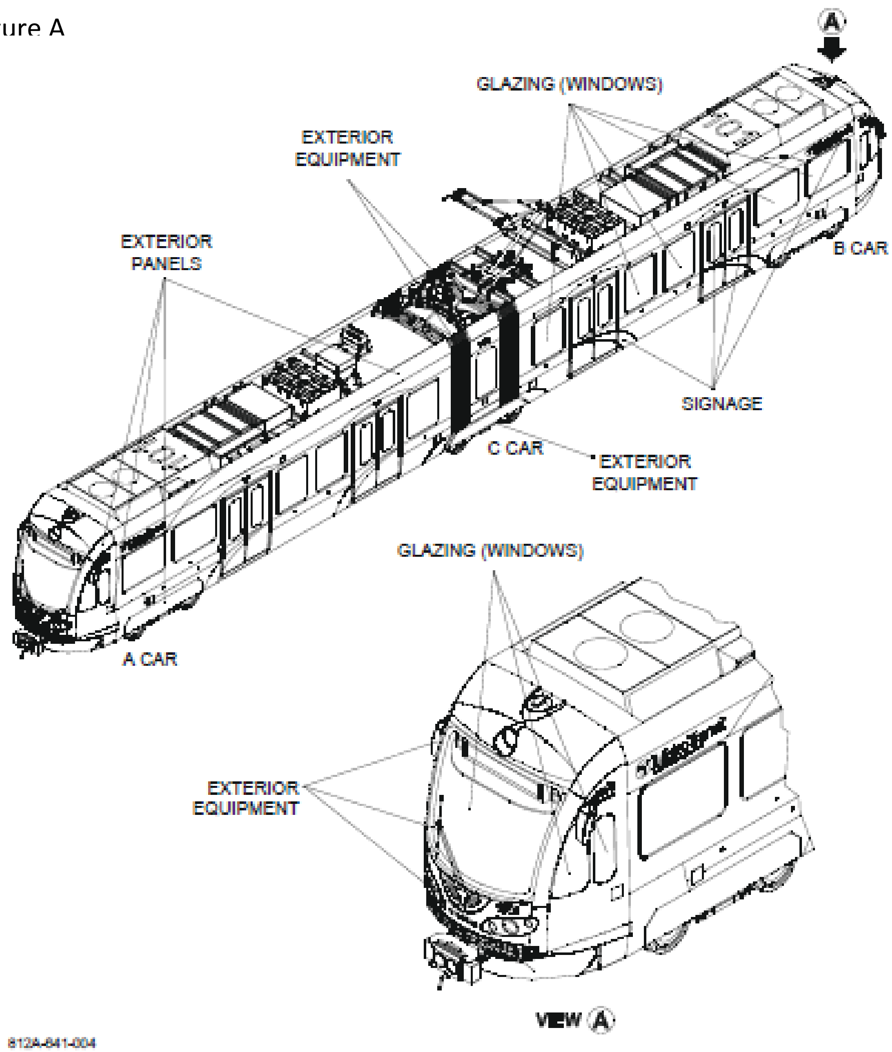
[1] ^ "Glossary of Transit Terminology". *Online Publications and Databases*. American Public Transportation Authority. 2008. Archived from the original on September 27, 2007. Retrieved 12.22.2010. Also see http://en.wikipedia.org/wiki/Passenger_rail_terminology for more information.

2.0 Car Body Overview

2.1 System Diagram

While systems differ between LRV and HRV designs, a typical rail car will look something like Figure A below:

Figure A



2.2 Car Body Basics

Rail Vehicles typically consist of two cars, the A Car and the B Car where the car bodies are very similar. In a LRV, the C Car as shown in Fig A above joins the A Car and the B Car and serves as a small linking car body also known as the articulation section.

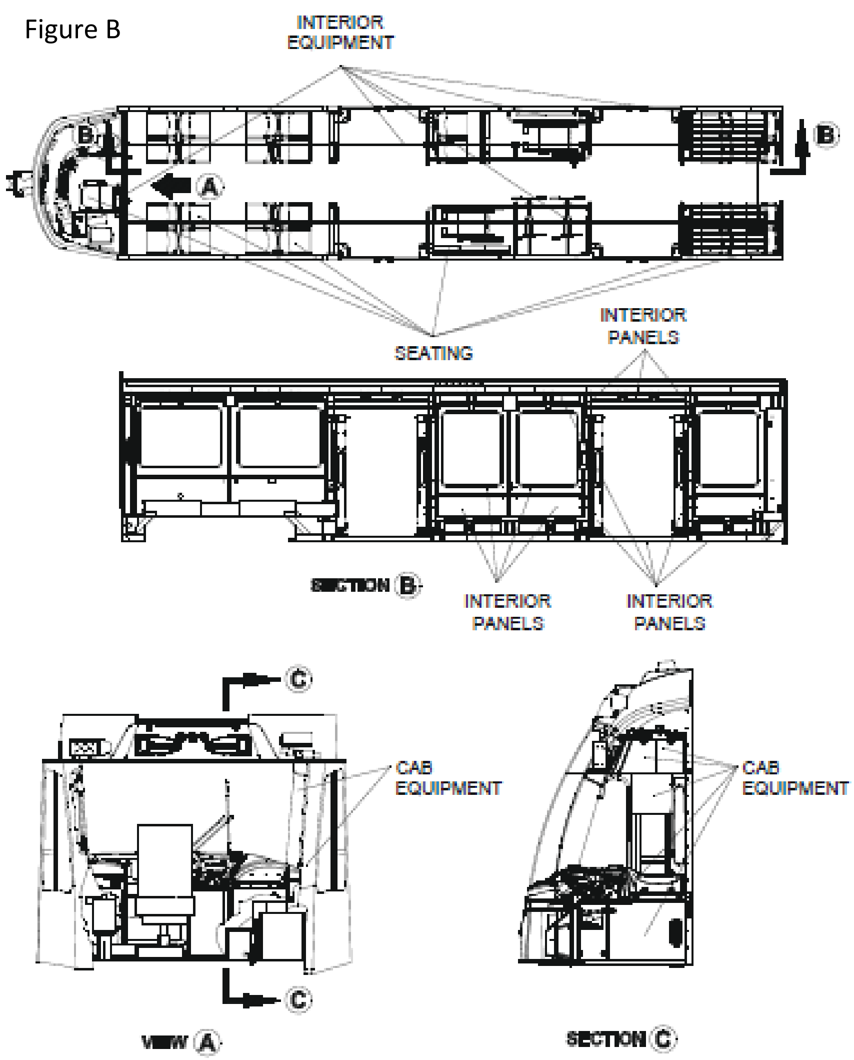
Each car body consists of a welded steel frame with attached exterior and interior equipment and panels. The frame is an assembly of the side frames, roof frame, end frames, and floor frame, all welded to the under-floor chassis. Glazing (windows) and seats are included in car body structures.

Maintainable components of the car body are as follows:

- Exterior Panels
- Exterior Equipment
- Interior Panels
- Interior Equipment
- Cab Equipment
- Glazing
- Seating
- Signage

The subassemblies that comprise each section listed above are described below and illustrated in the following figures. See Figure B below.

Figure B

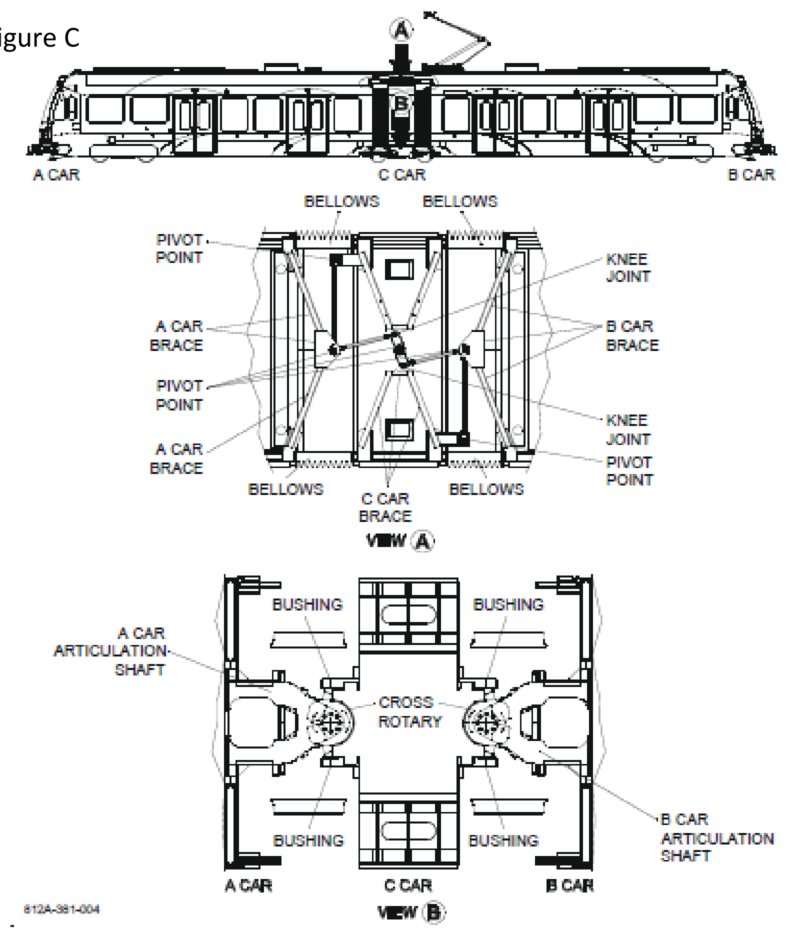


3.0 Articulation

3.1 Articulation Overview

LRVs are generally run as pairs (A and B Cars) and have between them articulation components and weather repelling shields called bellows (sometimes called the C Car). The other main parts of the articulation element include the link, dampener, bearings, rollers, slides, removable panels and articulation joint. Again there may be equipment described here that is not applicable to an agency's local equipment. The articulation joint and its component parts allow the vehicle to bend horizontally for curves and vertically for track irregularities. There is an upper (roof) and a lower (under-frame) articulation assembly at each end of the C Car. See the Functional Operation section for details. See Figure C.

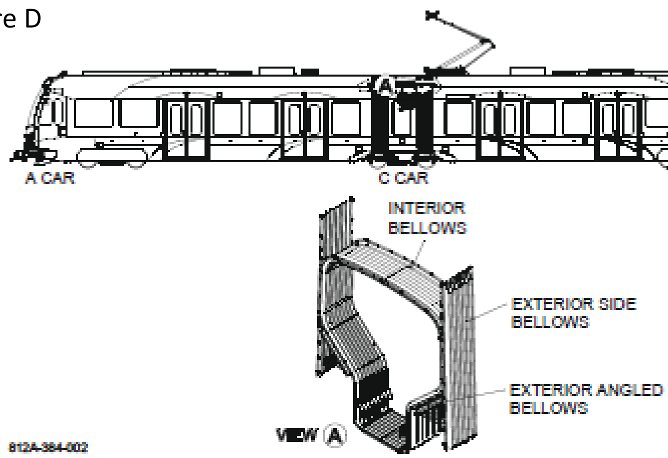
Figure C



3.2 Bellows

There are two bellows on the vehicle. There is a bellows between the end of the C Car and the non-cab end of the A Car and a second bellows between the other end of the C Car and the non-cab end of the B Car. A protective outer bellows partially surrounds the inner bellows. See Figure D.

Figure D



The bellows has an interior bellows, an exterior bellows, and an angled exterior bellows as described below:

- Interior Bellows Assembly: A pleated reinforced rubber bellows surrounds the carbody frame completely at each end of the C Car. An aluminum frame on each bellows end is encased in a rubber gasket. The aluminum frames attach to matching brackets on the end frames of the C Car and the end frames of the A Car and the B Car.
- Exterior Side Bellows Assembly: Protective bellows of reinforced rubber cloth attach to the sides of the end frames between the C Car and the A Car and between the C Car and the B Car. Each inner pleat attaches to a pleat of the interior bellows described above. These straight protective bellows are reinforced with aluminum ribs on every outside fold. Aluminum strips on each edge of the exterior bellows screw onto the outer edge of the car body ends. The top of the aluminum strips attaches to brackets that project above the roof frame. Structural adhesive is applied between strips and car body.
- Exterior Angled Bellows Assembly: The angled bellows is fitted to the angle of the C Car body frame. The upper edge of each angled bellows pleat attaches to a pleat of the straight exterior side bellows. The angled bellows is also outside the interior bellows. The angled bellows protects the lower part of the interior bellows from dirt, moisture, and abrasion from objects on the track. Aluminum ribs protect the outer folds of the angled bellows. The ribs then bend out from the inner edge of the angled bellows on a horizontal plane to continue to the exterior bellows. These ribs provide an attachment point for the lower edge of the angled bellows to the exterior bellows.

4.0 Interior

4.1 Interior Overview

Generic interior components include flooring, stairs, windows, seats, stanchions, modesty panels, signage, exit path marking, fire extinguishers, doors, interior panels, threshold heaters, passenger hand rails, luggage racks and wheelchair restraints. The materials used for these components can vary widely. Lighting is dealt with as a separate topic later in this introductory guide.

Technicians will need to be familiar with repair and fabrication of the many materials used as well as the electrical and mechanical skills necessary to maintain the various components.

4.2 Interior Panels

Removable interior panels that line the passenger rooms of the A Car, the B Car, and the C Car include the following:

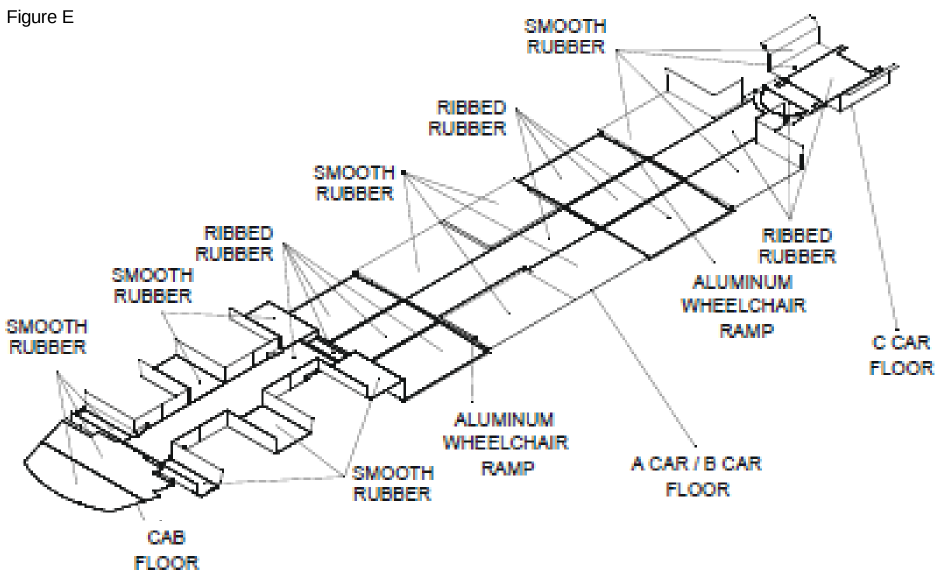
- Floor Covering
- Composite Floor Panels
- Wall Lining Passenger Room
- Windscreens
- Ceiling Panels.

The subassemblies that comprise each section listed above are described below.

4.2.1 Floor Covering

The floor covering of the LRV consists of smooth and ribbed rubber panels glued down with epoxy to the composite floor panels listed in subsection 4.2.2 below. Included with the floor panels are rubber panels covering the sides of the seat mounting boxes. See Figure E below.

Figure E



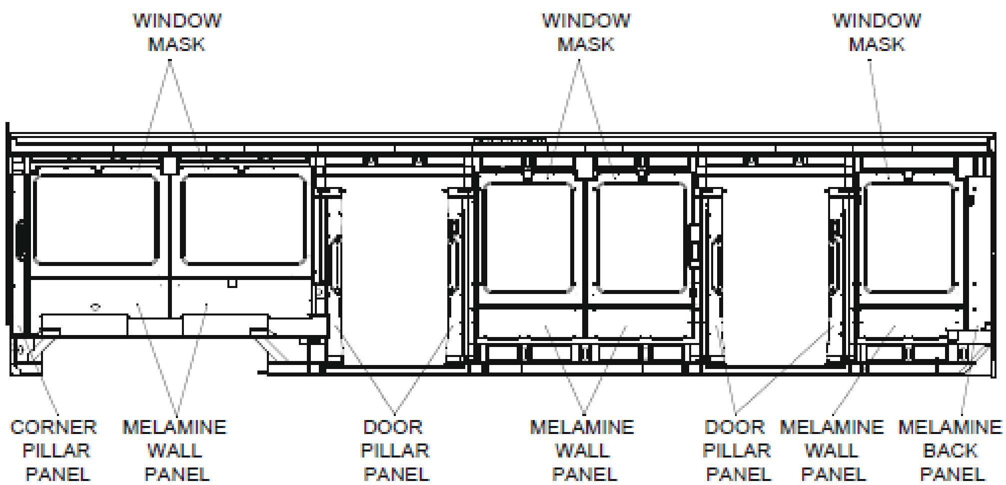
4.2.2 Composite Floor Panels

Floor sub-panels are typically screwed to the car body under-frame. Various panels made of a composite material comprise the car floor in the cab and passenger areas. Composite panels also cover the articulation joints and the C Car.

4.2.3 Wall Lining Passenger Room

The wall linings on the right side and left side of the passenger rooms consist of corner pillar panels, door pillar panels, window masks, and melamine wall panels. See Figure F below.

Figure F

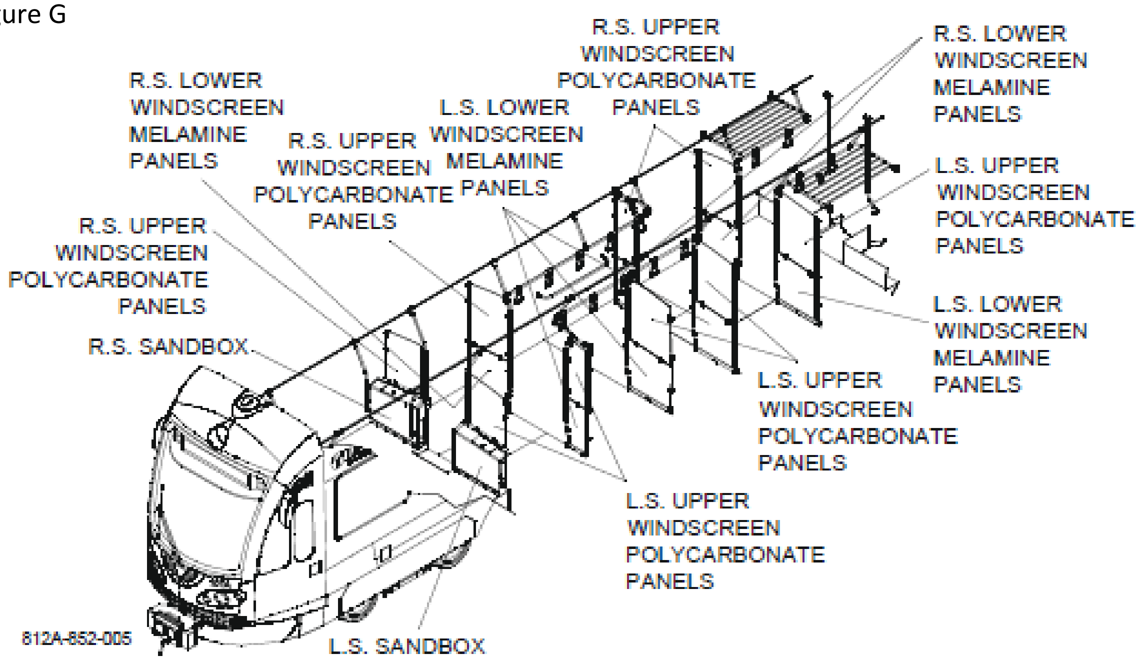


4.2.4 Windscreens

Windscreens are transverse panels that cut the wind when the doors are open. There are typically nine windscreens in all in each car, four on the right side and five on the left side. Windscreens are found on each side of each door. The windscreens are attached by clamps (mounting brackets) to the floor, the wall, and to upright stanchions that are part of the handrail system.

Some windscreens between doors are narrower than the others. This arrangement allows a wheelchair to fit between the narrower windscreen and the windscreen on the opposite side of the car. See Figure G below.

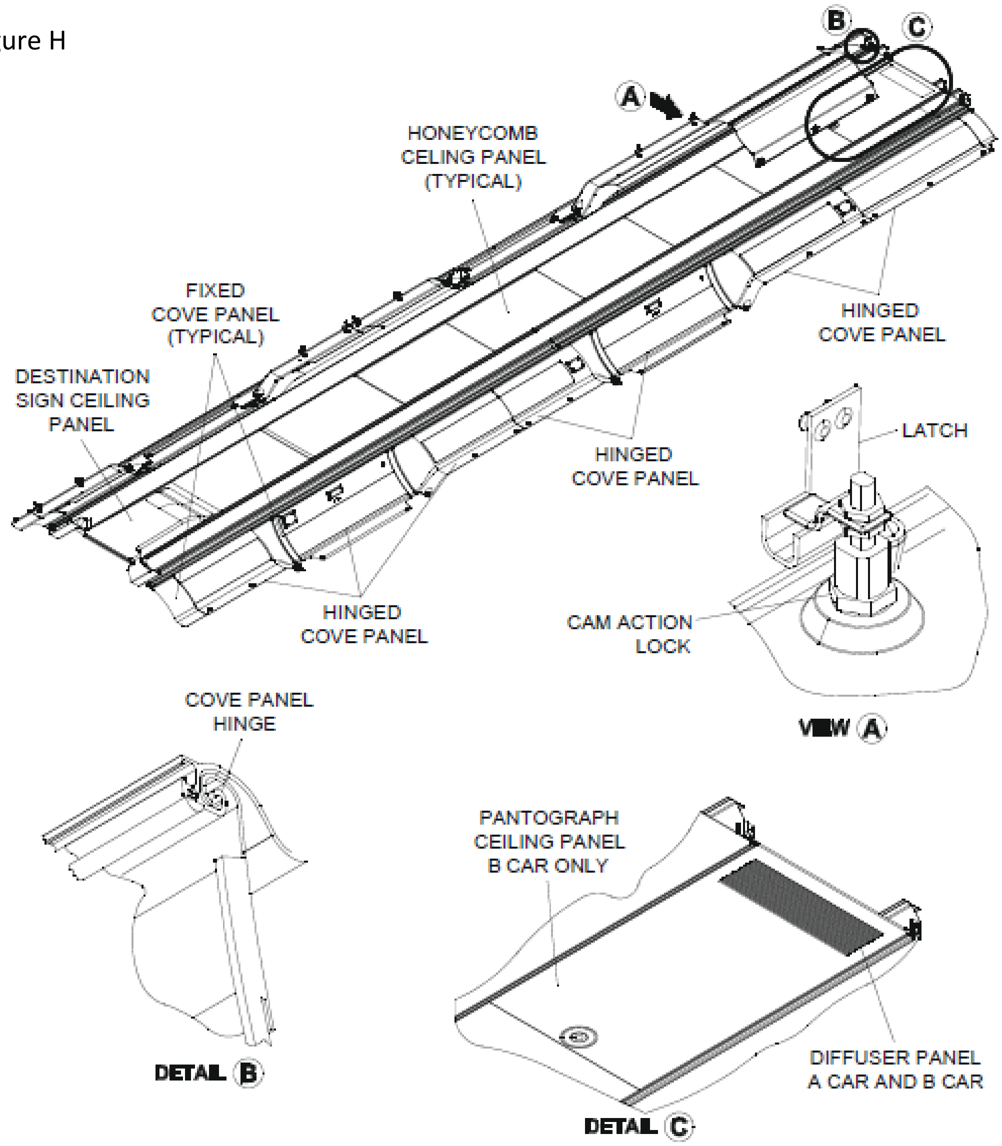
Figure G



4.2.5 Ceiling Panels

The side ceilings of the LRV are lined with contoured panels. The cove panels run the length of all three cars on each side of the center ceiling panels. The larger cove panels are hinged. Between the hinged panels are smaller fixed cove panels. Above the cove panels, the center ceiling consists of honeycomb panels which also extend the length of the vehicle. See Figure H below.

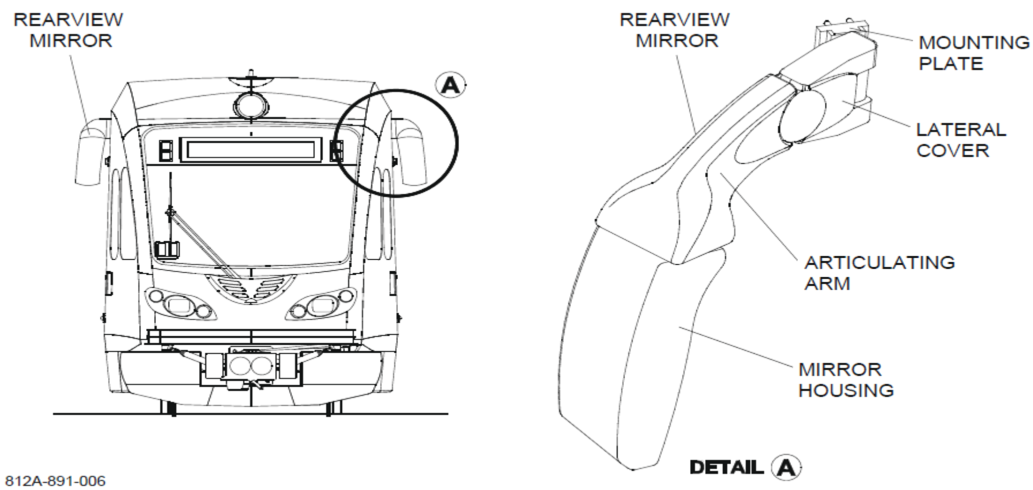
Figure H



5.0 Exterior
5.1 Exterior Overview

Rail vehicle exteriors also vary widely but all have similar components that can be addressed in a general text such as this. There are body panels, skirts and struts, mirrors, grab rails, wipers, horns, various equipment boxes, under-frame brackets, ADA ramps and wheelchair lifts, ducts, grills, barriers between cars (rods, chains etc.), sanders and sometimes even snow plows. Many of these features can be seen in the Figure I below.

Figure I



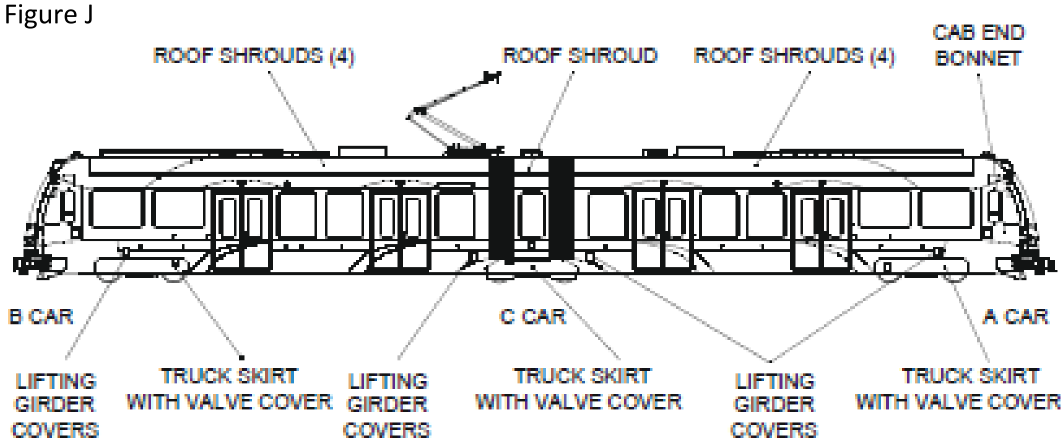
5.2 Removable Exterior Panels

Removable exterior panels include the following:

- Cab end bonnet
- Lifting girder covers
- Truck skirts
- Roof shrouds.

The above items are described below in Figure J.

Figure J



5.2.1 Cab End Bonnet

The cab end bonnet covers the cab end of the car back to the cab partition. The cab end bonnet is a fiberglass-reinforced plastic molded panel. It has a streamlined contour whose design complements the rest of the vehicle exterior. The panel is mounted to the car end bracketing with rivets. A neoprene gasket is installed between the cab end bonnet and the exterior panels to which it attaches to prevent rattling.

5.2.2 Lifting Girder Cover

In both the A Car and the B Car, two transverse hollow girders are welded to the car body frame on each side of the car. These girders provide attachment points for lifting straps on an overhead crane. The end of each hollow girder is covered by a locking hinged cover.

5.2.3 Truck Skirt

The truck skirts cover the wheels of all cars. Motor trucks skirts are hinged panels attached to the car body exterior shell. Each skirt is fastened down with two cam-action locks, one in each lower corner. The skirts swing up to open and each is held up with a gas spring. The C Car skirts are held in place by four brackets.

5.2.4 Roof Shroud

Roof shrouds are typically attached to brackets welded to the roof frame on each side of the A Car and the B Car, and another shroud attached to the roof brackets on the side of the C Car. The shrouds are fastened with screws to the brackets, with a neoprene strip between the shroud and the bracket. The brackets project above the roof platform. Many components are mounted on the roof, such as battery boxes and propulsion units. The roof shrouds protect and hide the roof-mounted components.

5.3 Exterior Equipment

Removable exterior equipment includes the following:

- Windshield Wiper and Washer System
- Rearview Mirrors
- Snowplow
- Drainage
- Articulation/Bellows

The above items are described below except for articulation/bellows, which were already described above.

5.3.1 Windshield Wiper and Washer System

The windshield wiper and washer system maintains a clean windshield, providing a clear view for the car operator in bad weather.

5.3.2 Rearview Mirrors

There are typically two exterior rearview mirrors, one attached to the exterior shell above the opening cab side window on each side of the cab. The mirrors are articulated and must be adjusted so that the operator has an optimum view of passengers getting on and off the vehicle. Sometimes mirrors are adjusted automatically via electric motors and controllers. There are also heaters installed in the mirrors to keep them frost-free.

5.3.3 Snowplow

The snowplow is a V-shaped welded steel plate assembly that attaches to brackets on the cab under-frame behind and below the coupler. The snowplow must be adjusted so that it clears the rails of snow even when the car is at maximum load.

5.3.4 Drainage

Drainage is provided from the battery box and other units mounted on the roof of the vehicle. Water is carried down from the roof by hoses that drain onto the roadway from the under-frame. Strainers on the roof keep debris out of drainage hoses.

6.0 Lighting Systems

There are numerous lights on the car body both interior and exterior. Some lights are actuated by an event such as a door opening or brakes being applied. Other lights actuate when an event does not take place as intended such as a "door open" indicator. Other lighting applications are headlights, interior passenger convenience lighting, emergency flashers, exterior marker lights (can be found on the roof, and sides of the car), emergency lights, destination signs and in some cases stop request lights.

The Washington Metro photos below shows destination signs, door indicator lights, headlights and marker lights.

7.0 Cab

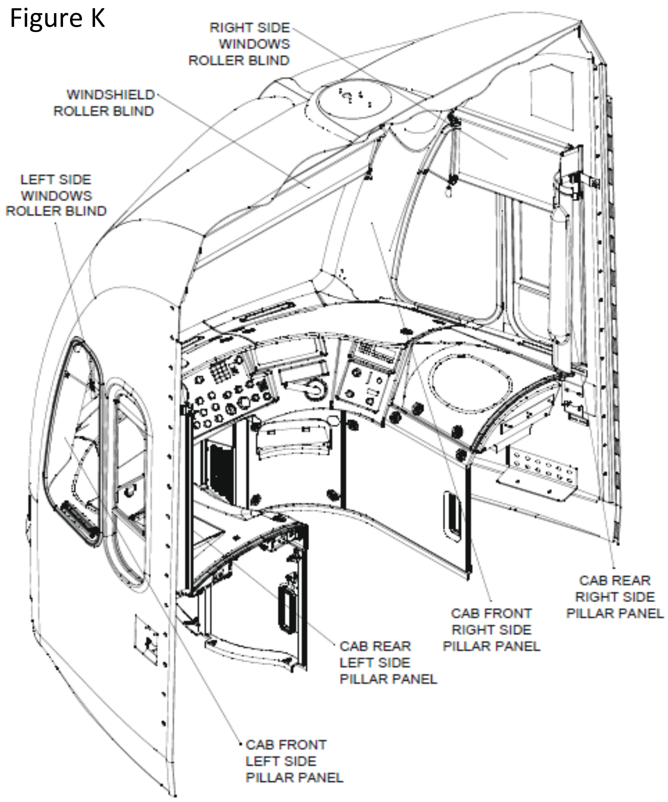
Cab equipment typically includes the following:

- Cab Door
- Roller Blinds
- Cab Wall Lining

- Cab Console Lining
- Upper Cab Panels.

The equipment listed above is described in the subsections that follow. An illustration of the cab is shown in Figure K below.

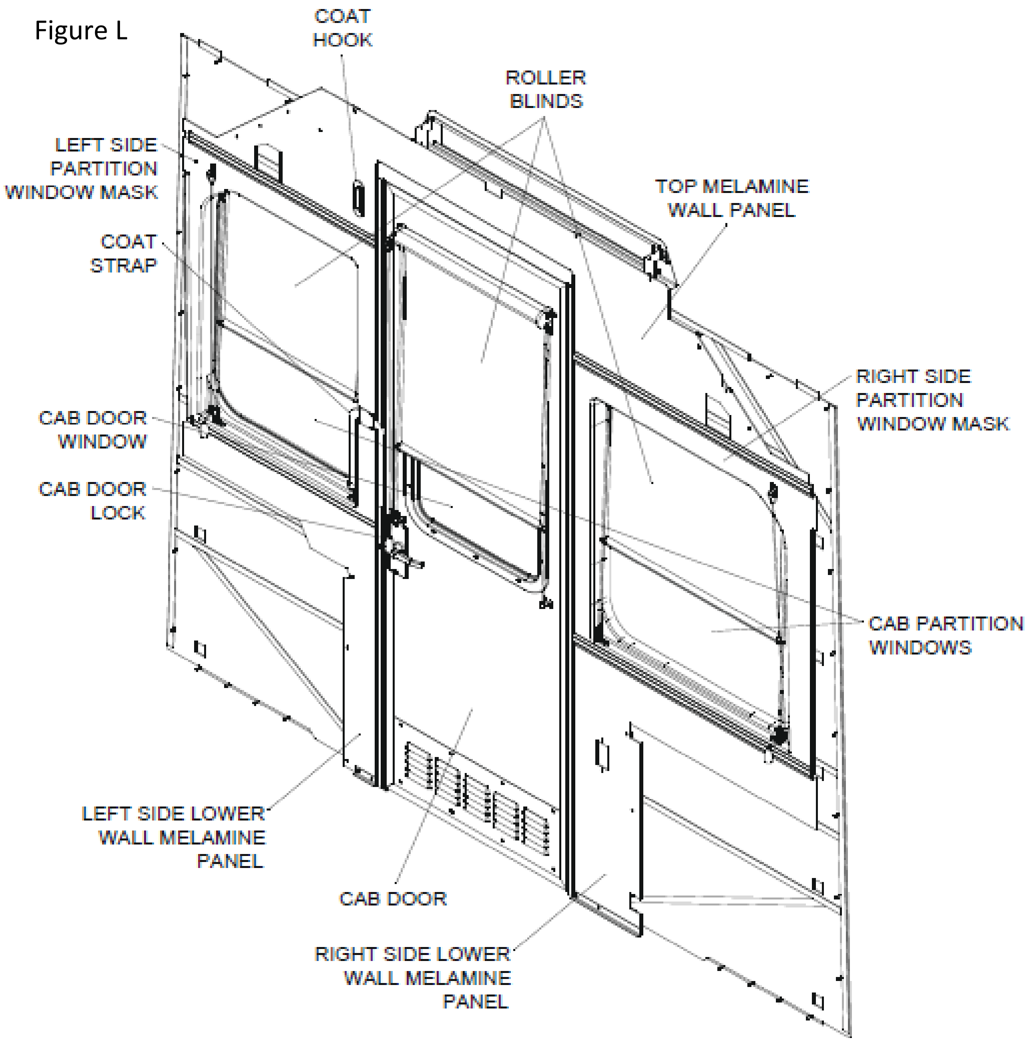
Figure K



7.1 Cab Door

The cab door separates the cab from the passenger room. The door is typically paneled in melamine. The quarter-turn door latch locks from the cab side. There is an opening window in the door with a roller blind installed on the cab side. See Figure L below.

Figure L



7.2 Roller Blinds

There are three roller blinds shading the cab, and three roller blinds in the cab partition wall. Roller blinds are illustrated in Figures K and L.

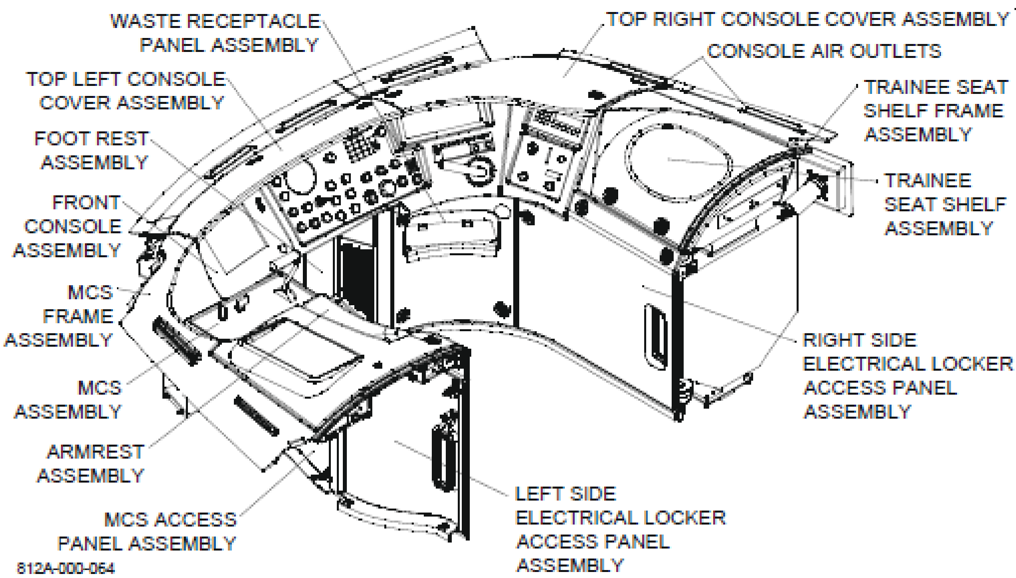
7.3 Cab Wall Lining

The cab wall lining consists of composite panels that cover the corner pillars and melamine panels that cover the partition wall.

7.4 Cab Console Lining

The cab console lining consists of several fiberglass panels. Some are contoured and locked in place with cam-action locks. These panels open to allow access to equipment behind them. Others are fastened down to the car body frame with rivets and have holes molded into them to accept other cab equipment. See Figure M below.

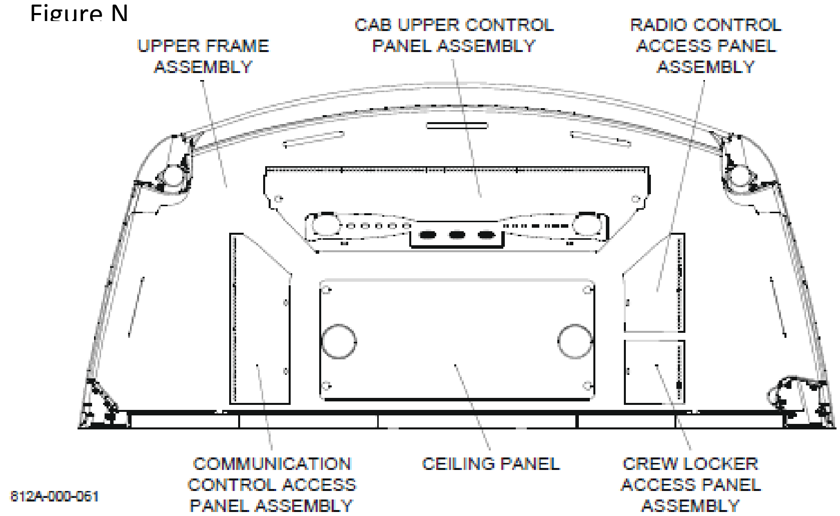
Figure M



7.5 Upper Cab Panels

The upper cab panels are hinged or removable and are locked into place with cam-action locks. See Figure N below.

Figure N



Bibliography

"Glossary of Transit Terminology". *Online Publications and Databases*. American Public Transportation Authority. 2008. Archived from the original on September 27, 2007. Retrieved 12.22.2010.

http://en.wikipedia.org/wiki/Passenger_rail_terminology

Relevant OEM Contact Information

OEM	Website	Contact Information
Alstom		
Bombardier		
Breda		
CAF		
Kawasaki		
Kinkisharyo		
Nippon Sharyo		
Siemens		
Stadler		
Sumitomo		

208. Car Body: Introduction and Preventive Maintenance

- **208.1 Articulation**

  Inspecting and maintaining Link
  - Inspect link
  - Lubricate link
  - Adjust link
  - Replace link

  Inspecting and maintaining bearings, rollers and slides
  - Inspect bearings, rollers and slides
  - Lubricate bearings, rollers and slides
  - Replace bearings, rollers and slides

  Inspecting and maintaining dampener
  - Inspect dampener
  - Lubricate dampener
  - Replace dampener

  Inspecting and maintaining bellows
  - Inspect bellows
  - Replace bellows

  Inspecting and maintaining removable panels
  - Inspect removable panels
  - Replace removable panels

  Inspecting and maintaining articulation joint
  - Inspect articulation joint
  - Lubricate articulation joint
  - Repair articulation joint
  - Replace articulation joint

- **208.2 Interior**

  Inspecting and maintaining flooring
  - Inspect flooring
  - Clean flooring
  - Test threshold heaters
  - Repair flooring
  - Repair threshold heaters
  - Replace threshold heaters

  Inspecting and maintaining stairs
  - Inspect stairs
  - Clean stairs
  - Test step heaters
  - Repair stairs
  - Repair step heaters
  - Replace step heaters

  Inspecting and maintaining windows
  - Inspect windows
  - Clean windows
  - Inspect vandal guard
  - Clean vandal guard

- Repair windows
- Replace windows
- Replace vandal guard

Inspecting and maintaining seats

- Inspect seats
- Clean seats
- Repair seats
- Replace seats

Inspecting and maintaining sanding system

- Test sanding system
- Clean sanding system
- Fill sanding system
- Repair sanding system

Inspecting and maintaining stanchions/modesty panel

- Inspect stanchions/modesty panel
- Clean stanchions/modesty panel
- Repair stanchions/modesty panel
- Replace stanchions/modesty panel

Inspecting and maintaining interior panels

- Inspect interior panels
- Clean interior panels
- Repair interior panels
- Replace interior panels

Inspecting and maintaining signage

- Inspect signage
- Replace signage

Inspecting and maintaining low-level exit path marking

- Inspect low-level path exit marking
- Replace low-level path exit marking

Inspecting and maintaining fire extinguisher

- Inspect fire extinguisher
- Replace fire extinguisher

Inspecting and maintaining first aid kit

- Inspect first aid kit
- Replace first aid kit

Inspecting and maintaining end doors

- Inspect end doors
- Adjust end doors
- Repair end doors
- Replace end doors

- **208.3 Exterior**

Inspecting and maintaining body panels

- Inspect body panels
- Repair body panels
- Replace body panels

Inspecting and maintaining skirts/struts

- Inspect skirts/struts
- Repair skirts/struts
- Replace skirts/struts

Inspecting and maintaining mirrors

- Inspect mirrors

- Clean mirrors
- Test mirror heaters
- Repair mirrors
- Replace mirrors
- Repair mirror heaters
- Replace mirror heaters

Inspecting and maintaining grab rails
- Inspect grab rails
- Replace grab rails

Inspecting and maintaining wipers
- Test wipers
- Inspect wipers
- Replace wipers
- Inspect or replace wiper linkage

Inspecting and maintaining horn/gong/whistle
- Test horn/gong/whistle and horn mount
- Inspect horn/gong/whistle and horn mount
- Replace horn/gong/whistle

Inspecting and maintaining windows/frames
- Inspect windows/frames
- Replace windows/frames

Inspecting and maintaining under-frame and brackets
- Measure under-frame and brackets
- Inspect under-frame and brackets
- Repair under-frame and brackets
- Replace under-frame and brackets

Inspecting and maintaining equipment boxes (mounts and covers)
- Inspect equipment boxes
- Repair equipment boxes
- Replace equipment boxes

Inspecting and maintaining snow plow/pilot
- Measure snow plow/pilot
- Inspect snow plow/pilot
- Repair snow plow/pilot
- Replace snow plow/pilot

Inspecting and maintaining ADA ramps/tread plate
- Inspect ADA ramps/tread plate
- Repair ADA ramps/tread plate
- Replace ADA ramps/tread plate

Inspecting and maintaining wheelchair lifts
- Test wheel chair lifts
- Inspect wheel chair lifts
- Repair wheel chair lifts
- Replace wheel chair lifts

Inspecting and maintaining ducts and grills
- Inspect ducts and grills
- Clean ducts and grills
- Repair ducts and grills
- Replace ducts and grills

Inspecting and maintaining safety boards
- Measure safety boards

- Inspect safety boards
- Repair safety boards
- Replace safety boards

Inspecting and maintaining between car barriers/chains
- Inspect between car barriers/chains
- Replace between car barriers/chains

- **208.4 Lighting Systems**

Inspecting and maintaining door buttons
- Test door buttons
- Inspect door buttons
- Replace door buttons

Inspecting and maintaining emergency flashers
- Test emergency flashers
- Inspect emergency flashers
- Replace emergency flashers

Inspecting and maintaining door indicator lights
- Test door indicator lights
- Inspect door indicator lights
- Replace door indicator lights

Inspecting and maintaining headlights
- Test headlights
- Inspect headlights
- Replace headlights
- Align headlights
- Clean headlights

Inspecting and maintaining stop/tail lights
- Test stop/tail lights
- Inspect stop/tail lights
- Replace stop/tail lights

Inspecting and maintaining brake indicator lights
- Test brake indicator lights
- Inspect brake indicator lights
- Replace brake indicator lights

Inspecting and maintaining roof/rail lights
- Test roof/rail lights
- Inspect roof/rail lights
- Replace roof/rail lights
- Align roof/rail lights
- Clean roof/rail lights

Inspecting and maintaining marker lights
- Test marker lights
- Inspect marker lights
- Replace marker lights

Inspecting and maintaining interior lights
- Test interior lights
- Inspect interior lights
- Replace interior lights

Inspecting and maintaining car fault indicator
- Test car fault indicator
- Inspect car fault indicator
- Replace car fault indicator

Inspecting and maintaining passenger emergency lights
- Test passenger emergency lights
- Inspect passenger emergency lights
- Replace passenger emergency lights

Performing preventive stop request lights
- Test stop request lights
- Inspect stop request lights
- Replace stop request lights

- **208.5 Cab**

Inspecting and maintaining cab door
- Inspect cab door
- Repair cab door
- Replace cab door

Inspecting and maintaining windshield/frame
- Inspect windshield/frame
- Repair windshield/frame
- Replace windshield/frame

Performing preventative maintenance on operator seat
- Test operator seat
- Inspect operator seat
- Repair operator seat
- Replace operator seat

Inspecting and maintaining operator controls/indicators
- Test operator controls/indicators
- Inspect controls/indicators
- Clean controls/indicators
- Replace controls/indicators
- Repair controls/indicators

Inspecting and maintaining breakers/cut-out switches
- Inspect breakers/cut-out switches
- Repair breakers/cut-out switches
- Replace breakers/cut-out switches

Inspecting and maintaining wiper motors/regulator
- Test wiper motors/regulator
- Inspect wiper motors/regulator
- Repair wiper motors/regulator
- Replace wiper motors/regulator

Inspecting and maintaining cab ceiling lighting
- Test cab ceiling lighting
- Inspect cab ceiling lighting
- Replace cab ceiling lighting
- Repair cab ceiling lighting

Inspecting and maintaining dash lights
- Test dash lights
- Inspect dash lights
- Repair dash lights
- Replace dash lights

Inspecting and maintaining first aid kit
- Inspect first aid kit
- Replace first aid kit

Inspecting and maintaining fire extinguisher

- Inspect fire extinguisher
- Replace fire extinguisher

Inspecting and maintaining sun visors

- Test sun visors
- Inspect sun visors
- Repair sun visors
- Replace sun visors

RAIL VEHICLE LEVEL 200
SUBJECT OVERVIEW

Module: 209 - Doors

Note: All 200 level courses should be delivered only after completion of 100 level training

About the Author: Jay Shah

Jay Shah has functioned as the co-chair of the Transportation Learning Center's Joint National Rail Vehicle Training Standards Committee since 2008. Mr. Shah has over 28 years of transit rail experience - 24 of which as a manager of maintenance and overhaul shops with operating budgets up to $70 million. In this position Mr. Shah acquired vast experiences in the areas of training, mentoring, development and succession planning. He also has a background in engineering and PE liscense and has authored articles which have been used by other Transportation Authorities to address their MDBF problems

Reflective of these accomplishments, Mr. Shah has been the recipient of several transportation awards, including the NYCT President' Circle Award and the Managerial Achievement Award.

Overview/Purpose

This material provides a general overview of door systems on transit rail vehicles in order to give technicians a basic introduction to the subject and prepare them for national qualification testing.

Material presented here is intended only as a primer to the subject, keeping in mind that rail systems have different characteristics. It follows the National Training Standards established jointly by representatives from both labor and management. As a primer additional knowledge will be needed to become fully qualified on this subject. Material presented here does not address every possible aspect because door systems vary at each transit agency. Supplemental courseware and other resources to help technicians become qualified on this subject are listed below.

Table of Contents

Suggested Tools/Training Aids:

- power point presentations
- transparencies
- manuals
- schematics
- mock-up
- on board self-test feature
- PTU
- Volt-o-meter
- Pressure gauge

Topics Covered:

Topics listed below are covered in this introduction of Rail Vehicle Doors. A full copy of the National Training Standards from which these topics were taken is attached.

- Door Controls
- Door Panel and Track
- Tools

Definitions, Abbreviations and Acronyms

For the purposes of this lesson, the following glossary of terms, definitions, acronyms, and abbreviations shall apply. They are not all inclusive, and the reader is encouraged to explore the text, footnotes and bibliography sources for further information.

Definitions

- **Access equipment:** Any vehicle entryway accessory that may be deployed to aid the boarding of passengers including steps that deploy when doors are operated.
- **Blinker door:** Door panel pairs that rotate into the entryway or stepwell when opened.
- **Check sheets:** Forms with provision for acknowledging completion of outlined inspection and maintenance tasks.
- **De-energized**: Automatic door equipment that is disconnected from its power source and will not operate automatically.
- **Door guide:** Tracks or other restraints that constrain the motion of door panels.
- **Door operator:** The drive mechanism that operates door panels.
- **Door panel:** The moveable barrier element of a vehicle entryway.
- **Energized:** Automatic door equipment that is poised to operate when a command signal is received.
- **Lost motion:** Motion and force that is not transmitted to the door panel due to cumulative clearances in the door operator mechanical components.
- **Operating agency:** Purchaser, lessee or contractor that utilizes equipment for the carriage of people.
- **Original equipment manufacturer (OEM):** Enterprise that designs and builds equipment initially.
- **Plug door:** Rigid door panels that are rotated from outside the car shell when open, and into the entryway portal when closed.

Definitions (continued)

- **Pocket:** Cavity formed by the car shell outer wall and inner liner that receives door panels when open.

Abbreviations and acronyms

- **ANSI** American National Standards Institute
- **MSDS** material safety data sheet
- **OEM** original equipment manufacturer
- **PPE**: Personal Protective Equipment
- **DMCU**: Door monitoring and control unit

Introductory Text by Topic Area

1.0 Door Controls
2.0 Door Panel and Track
3.0 Tools

I. Introduction

There are multiple types of Door System configurations for Rail Vehicles which differ by the manner in which the doors move in order to open and close and what powers their operation – either air or electricity.

To open, a door can slide, fold or swing. Sliding doors come as either pocket types or exterior exposed types. Folding doors normally have a bi-fold and either fold inward or outward. Swinging doors also either swing inward (blinker doors) or outward (plug doors).

Rail Vehicle doors and their components should be inspected and maintained on a regular schedule as determined by the individual rail transit system. Minimally, inspection and maintenance tasks should comply with government regulations (Federal, state and local) and OEM recommended intervals. For ideal operation it is suggested that other items be considered when developing a preventative maintenance schedule such as industry experience, operating environment, historical data and failure analysis.

Door System

Doors are part of a larger system which consists of the following parts:

Operator and Non-operator cars (A and B)

1.) Door monitoring and control unit
2.) Interior guard light
3.) crew switch – Exterior and interior
4.) guard light – exterior and interior
5.) fault light assembly
6.) Door closing warning light
7.) Door panels
8.) Door Control Relay panel
9.) Door Operators (including limit switches) – type varies with system
    a. Overhead
    b. Side panel
    c. Or underseat

Operator Car only (A)

1.) Master Door Controller
2.) Buzzer

Preventive Maintenance of these systems should be performed as per OEM recommendations and Rail Transit System's Testing and Experience.

II. Door Controls

Introduction to Door Control Inspection and Maintenance

As outlined above there are many parts that make up the door system of a transit rail vehicle. The sections below cover the inspection and maintenance techniques for the most common door parts. These parts are ordered in the same way that they would be inspected:

1.) On car door control units - Door monitoring and control unit (DMCU) and Door Control Relay panel (DCRP)
2.) On car stand alone components – Door cut-out and guard lights
3.) Door Operator Components

In operator's cab door control units – Master Door Controller

Safety concerns of Door Operation and Maintenance

When performing any operation, inspection or maintenance tasks take care to wear the appropriate personal protective equipment (PPE) – and minimally follow ANSI standards. Below are some safety requirements. Others will be dispersed throughout the text of this primer.

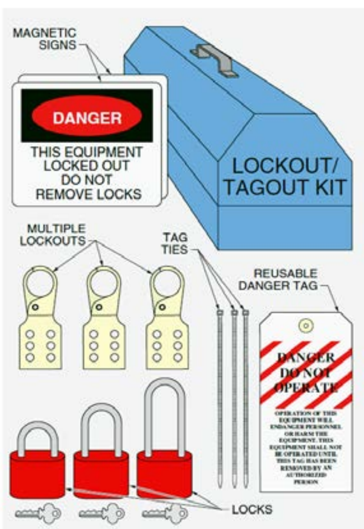


Figure 1: Lockout/Tagout Kit

Voltage: Energy Supply

- To avoid possible injury if door equipment operates unexpectedly, assure that **power** to the door operator and control power is **shut off and remains off** until personnel are safely clear of moving parts. Follow lockout/tagout procedures as per your authority (figure 1).
- Verify that electrical power is removed by checking with reliable equipment.
- To avoid possible injury, notify all concerned that equipment is about to be energized before restoring power. If vehicles are coupled and controls are trainline, assure that it is safe for equipment in coupled cars to become operational before energizing any high voltage or battery circuits.

Pinch Points

To avoid possible injury while moving doors manually for inspection purposes, keep hands and tools away from pinch points (figure 2).

Figure 2: Pinch Points

Cleaning

- To avoid possible injury while using compressed air for dislodging dirt and debris, wear appropriate eye, face, and respiratory protection meeting minimum ANSI or other applicable national industry standards. Keep air pressure at the blowgun nozzle below 30 pounds per square inch.
- Use only those cleaning products and lubricants proven safe and authorized for use by the rail transit system. Consult OEM and MSDS references for suitability for each application to prevent personal injury and damage to the equipment.

Inspection and Maintenance: On Car Door Control Units

There are basically 3 types of Door Controls:

- Door monitoring and control unit (DMCU)
- Door Control Relay panel (DCRP)
- Master Door Controller (MDC)

Of these three, the DMCU and DCRP are located in the car itself. The MDC is located in the operator’s cab of the car. The in car door control units will be covered here and the MDC will be covered later on as this is the order in which they should be inspected.

Although door controls can be controlled through relay logic, it is becoming more and more common for them to be controlled by microprocessors which utilize programmable logic for non-safety critical functions that use redundancy and/or speed cycle checking for safety functions. In addition to door operation, door control units that use Micro-processors are able to log faults and vehicle maintenance history files. These files should be available and reviewed before work begins. Diagnostic information may pinpoint components that are repeatedly failing, perhaps intermittently. Troublesome components can be identified and receive more detailed inspection and function checks.

Generally data from this system, also known as the Monitoring and Diagnostics System (MDS), and any other log is downloaded and printed the previous night so that the maintenance personnel can have a hard copy as a reference during the inspection. Note that if there is an error message on the print out there may be a problem with either the DMCU, DCRP or the Door Control Unit (DCU) located in the operator’s cab. The DCU is the “brain” that collects information for the entire train from the DMCU/DCRPs which are the “brains” on each individual car. The compiled data from the DCU is communicated to the MDS so that it can be viewable to maintenance personnel. In the case of an error message, the DMCU/DCRPs, DCU and their associated connections should be inspected and repaired/replaced.

In older systems where relays are used, data faults are not logged into the control unit. Before doing any work on the unit, the maintenance personnel should consult the car maintenance log at their authority.

Door Monitoring and Control Unit (DMCU)

The DMCU should be inspected on every inspection cycle but there is no routine maintenance is required on this unit. Maintenance only occurs when a fault is found. However, the unit is cleaned after the inspection as grease/dirt may be put on the unit during inspection.

It is located in the overhead panel near each door opening. DMCU controls one door opening, consisting of two door operators. Therefore a fault could indicate a fault in one or both of the door operators.

1.) Open the DMCU panel and inspect for the fault light on the DMCU.
2.) Ensure that all connectors are properly installed.
3.) If any fault light is detected then analyze by either downloading the data using portable test equipment (PTE) and consult the manufacturers guide.
4.) If the unit itself is faulty, it should be removed and replaced. In order to remove, disconnect cable connectors, loosen hardware and slide the unit to remove it. To replace the unit, slide new unit in place, tighten hardware according to manufacturers' procedure including torque the hardware and connect cable connectors. The faulty unit should be sent out for investigation and repair by the electrical department/lab or repaired as per the Transit Authority procedures.
5.) If it is an issue with anything other than the DMCU such as the door panel, relays etc., repair as per the OEM/transit authority procedures.

Door Control Relay Panel (DCRP)

Each rail vehicle has two DCRPs. Each controls all door operators on one side of the car – either left or right. They are commonly referred to as either the left DCRP or right DCRP. It is located in the overhead panels in the passenger area.

The DMCU should be inspected on every inspection cycle but there is no routine maintenance is required on this unit. Maintenance only occurs when a fault is found. However, the unit is cleaned after the inspection as grease/dirt may be put on the unit during inspection.

1.) Open the DCRP panel and inspect for the fault light on the DCRP.
2.) Ensure that all connectors are properly installed.
3.) If any fault light is detected then analyze by either downloading the data using portable test equipment (PTE) and consult the manufacturers guide.
4.) If the unit itself is faulty, it should be removed and replaced. In order to remove, disconnect cable connectors, loosen hardware and slide the unit to remove it. To replace the unit slide new unit in place, tighten hardware according to OEM/transit authority procedures including torque the hardware and connect cable connectors. The faulty unit should be sent out for repair and investigation by the electrical department/lab or repaired as per the Transit Authority procedures. .
5.) If it is an issue with anything other than the DCRP such as the door panel, relays etc., repair as per the OEM/transit authority procedures.

Inspection and Maintenance: On Car Stand Alone Components

There are two door system components which are located remotely but should still be inspected and maintained: door switch and indicator lights.

Door Cut-Out Switch

The door cut-out switch (figure 3) is located on the bottom half of the door post for each panel. There are two positions: normal and cut-out. The function of the switch should be inspected on every inspection cycle. Ensure that latch goes behind the door panel when it is closed.

The switch should be in normal position if everything is okay with the door operator. When there is a problem with the door operator and it cannot be repaired then the door cut-out switch will be moved to the cut-out position. This will electrically disconnect the power to the individual door operator and also will mechanically lock the door panel in the closed position. The guard light and the fault light (below) will be off.

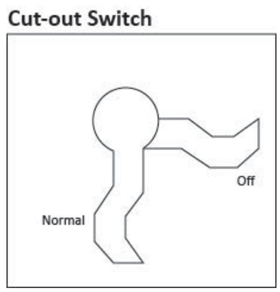


Figure 3: Door Cut-Out Switch

Guard Lights

On any rail vehicle, there are four guard lights: two exterior and two interior (figure 5). The interior lights are located near the ceiling at opposite ends of the car, caddy corner from each other (figure 4). The interior lights have only one bulb each. The exterior lights are located one each on the left and right side of the car. Each of the exterior light has two bulbs – this is in case one burns out, there is another bulb as a back-up.

Figure 4: Guard Light

Whenever inspecting and maintaining lights it is important to:

- Make sure that the bulbs are operational
- Clean any dirt and grease from the lens
- Inspect the lens for any damage including chips or cracks
- Make sure that all connections are tight
- Replace or repair any damaged parts as required

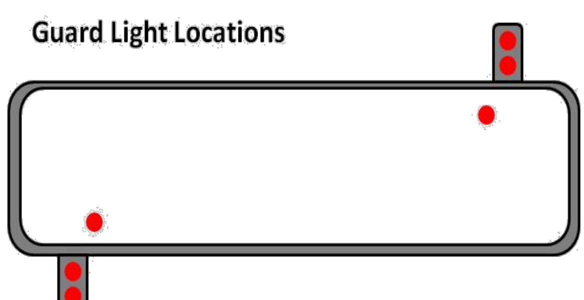


Figure 5: Example Guard Light Locations

Inspection and Maintenance: Door Operator Components

There are several inter-related parts that can all be found in the vicinity of the door operator. The door operator can be located either above the door opening, on the side of the car next to the panel (figure 6) or under a seat. These items should all be cleaned, lubricated, inspected and maintained following your authority's preventive maintenance schedule and procedure:

1.) Relays and Solenoids
2.) Motors and Drive Mechanisms
3.) Limit, Proximity and micro switches
4.) Sensors
5.) Sensitive Edges
6.) ADA warning Light
7.) Fault Light
8.) Crew Switch
9.) Emergency Release Mechanism

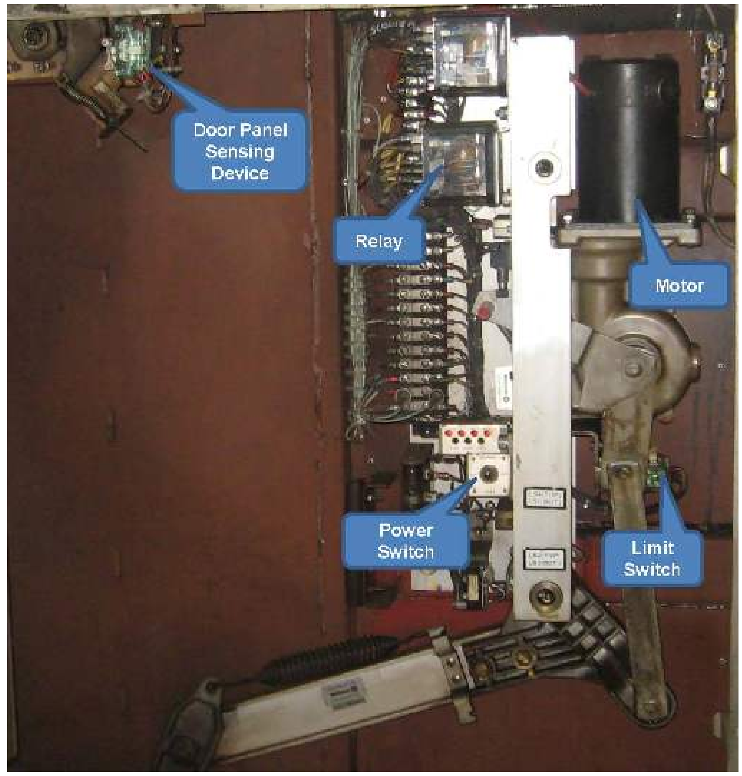


Figure 6: Door Operator Components

SAFETY WARNING:
Before beginning any inspection or maintenance on door operator and components make sure to cut the power by putting the door operator switch to the OFF position.

Relays and Solenoids – Check the attaching hardware and physical condition of relays and solenoids. When practical, operate relays manually, checking for binding or inconsistent operation. Check for bent or burnt contacts. When recommended, measure resistance and perform continuity checks across the contacts and coils of de-energized relays and solenoids. When required, replace relays only – do not attempt to adjust. Adjust the solenoid as required.


Figure 7: Relay
Source: Vapor (http://www.vapordoors.com/images/relays_image.jpg)

Check all wires going to the solenoid and relay board to make sure the connections are tight and no wires are broken or damaged. Repair or replace as required.

Motors and Drive Mechanisms – Check commutator (figure 8) for burns and discoloration. Check for worn or broken commutator brushes. If these conditions exist, clean the commutator (note that if any excessive dust or dirt exists, it may cause arcing) and replace any worn or broken brushes. Test the motor. Replace the motor if there is still evidence of excessive arcing. Check brush length, caps and springs. Replace unserviceable components where necessary.

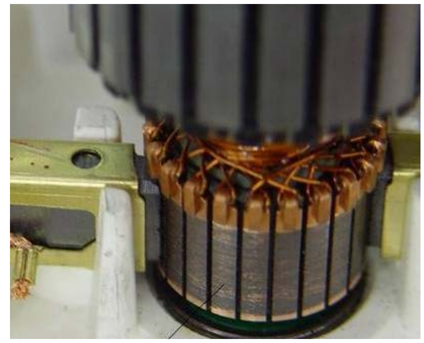


Figure 8: Commutator

Switches – In addition to limit, proximity and micro switches also check the door panel sensing switch (PSS). The PSS is a secondary safety device that checks the position of the door panel. It is connected in series with the door operator circuit.

Check the attaching hardware and physical condition of limit switches. When practical, operate switches manually, checking for binding or inconsistent operation. When recommended, measure resistance and perform continuity checks across the contacts and coils of de-energized switches. Gauge the switches and if required, adjust door operator switches using limit gauges (also known as a go/no-go gauges). A go/no-go gauge has ends with two sizes (thicknesses) – one that is the acceptable size (go gauge) and one is unacceptable (no-go gauge). These are used to check and adjust the position of the limit switches as required per your OEM/Transit authority procedure.

If any relay is found not operating as intended it must be replaced. Check all wires going to the switches to make sure the connections are tight and no wires are broken or damaged. Repair or replace as required.

Sensitive Edges – The function of sensitive edges is to detect any obstruction in the door way. When this obstruction is detected the door automatically recycles – generally 3 or 4 times. After multiple recycles the door will attempt to close and stay open at the point of obstruction.

Obstructions can be detected in two ways:

1.) Current through the motor – the motor controlling door movement will only push so hard. If there is more resistance than allowably designed, the current going to the motor will cease. When the conductor recycles the door, the door will open completely and attempt to close. If the obstruction is gone, the door will close and lock. If the obstruction is still there, the door will recycle automatically. Note that in newer systems it is sometimes an option to use local recycling (as opposed to global recycling) where only the obstructed door panel recycles. This feature should be tested and inspected for deformation and damage during the regularly scheduled preventive maintenance. If the feature does not work or is damaged, repair or replace as per OEM/Transit authority requirements. There is no additional maintenance required for this feature.
2.) Depressing sensitive edge – Depressing sensitive edges work much like the contact switches found on the stop requested tape on a bus. When the rubber

edge of the door panel is depressed by an obstruction a relay is sent to the door operator to automatically opens the door. This feature should be tested and inspected for deformation and damage during the regularly scheduled preventive maintenance. The sensitive edge tool is used to verify proper operation of the sensitive edge and pressure switch. One example of a sensitive edge tool is used in Sacramento on the Siemens U2-A LRV for the bifold doors. Holding a device (wooden tool) with the dimensions of 10mm X 90mm between the sensitive edges as the door closes, the doors should close without opening. Holding a device (wooden tool) with the dimensions of 22mm X 35mm between the sensitive edges as the door closes; the door must reverse direction and return to the open position. The sensitive edge tool insures the door will open if a small object like a child's hand should be caught between the closing door leafs. If the feature does not work or is damaged, repair or replace as per OEM/Transit authority requirements. There is no additional maintenance required for this feature.

On both of these types of edges, use silicon lubricant to prevent dry rot and damage to exposed rubber. The frequency will vary depending on weather conditions at the given authority. Please follow OEM/Transit Authority procedures.

Sensors

In some systems, rail vehicle doors are equipped with edges which can sense an obstruction without touching it. This equipment is called a sensor and can come in multiple forms including a light barrier and a LED safety curtain.

Light Barrier

The function of the light barrier (figure 9) is to monitor the entry and exit areas of streetcars, subway, LRV's and railway cars. The light barrier operates on the reflected light principle. A light beam is streamed across a door opening and reflected back to the photo receiver. When the light beam is interrupted the Door Control Unit is notified, if the door is open the timer is interrupted and the door remains open, the close door timer begins timing when the beam is restored. If the light beam is interrupted during the door close evolution the DCU is notified and it reverses the door direction opening the door. [i]

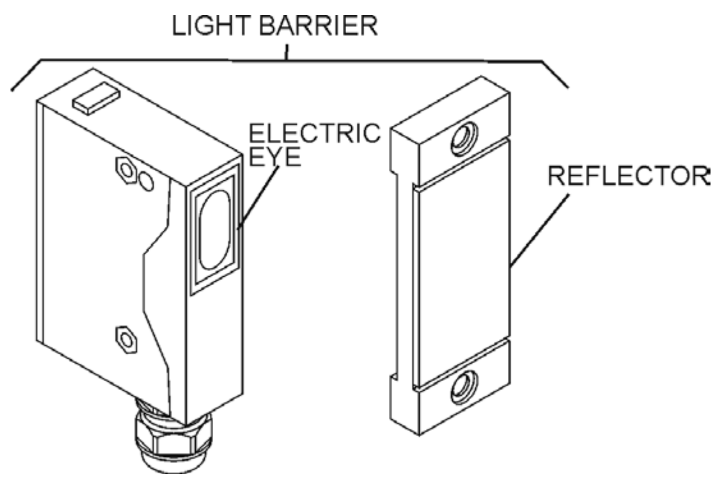


Figure 9: Light Barrier
Source: Sacramento Regional Transit District

LED Safety Curtain

Safety light curtains are easy to understand. A photoelectric transmitter projects an array of synchronized, parallel infrared light beams to a receiver unit. When an opaque object interrupts one or more beams the control logic of the light curtain sends a stop signal to the DCU. The transmitter unit contains light emitting diodes (LEDs) which emit pulses of invisible infrared light when energized by the light curtains timing and logic circuitry. The light pulses are both sequenced – one LED is energized after another – and modulated - pulsed at a specific frequency. Corresponding photo-transistors and supporting circuitry in the receiving unit are designed to detect only the specific pulse and frequency designated for it. These techniques offer enhanced safety and rejection of external light sources. The control logic, user controls and diagnostic indicators may be contained in a separate enclosure or be enclosed in the same housing as the receiver electronics.[ii]

Fault Lights

Figure 10: Fault Light

The fault light is found near the door in the passenger area (figure 10). It lights both when there is a fault and whenever the door is open.

Whenever inspecting and maintaining lights it is important to:

- Make sure that the bulb is operational
- Clean any dirt and grease from the exterior of the lens
- Inspect the lens for any damage including chips or cracks
- Make sure that all connections are tight and undamaged
- Replace any damaged parts

ADA warning Light – Besides the audio warning chimes, ADA warning lights are also required on all new vehicles but may not be found on older vehicles. This light is located directly in the center of the door opening. This light must come on when the door is activated as to warn deaf passengers of the movement. Just as fault lights above – ADA warning lights should be inspected and maintained in the following ways:

- Make sure that the bulb is operational
- Check that the light activates before the door opens and closes
- Clean any dirt and grease from the lens
- Inspect the lens for any damage including chips or cracks
- Make sure that all connections are tight and undamaged
- Replace any damaged parts

Crew Switch - The crew switch (figure 11) is designed to allow any crew member/employee access or exit to a car. This key activated switch opens the single panel on which the key is used. Generally, a crew switch is located inside the passenger area of the car and on the outside of the vehicle – usually near the ceiling and at the front and/or the back of the vehicle. Both interior and exterior crew switches should be cleaned, inspected and tested. When cleaning a crew switch clean the exterior and the interior of the switch cover (faceplate).

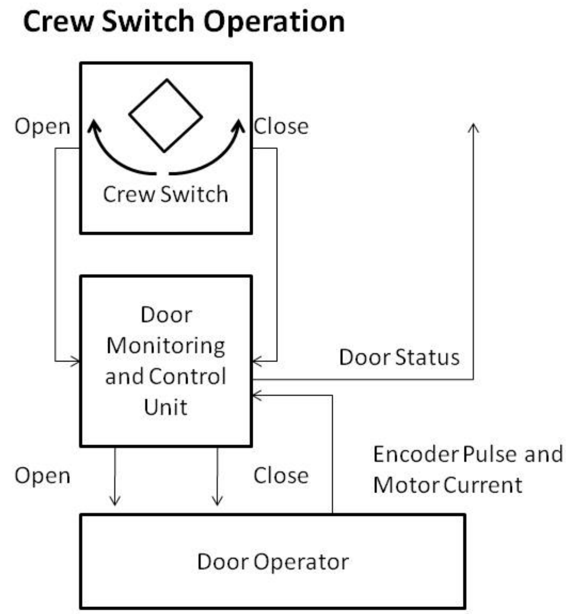


Figure 11: Crew Switch

Inspect the switch cover and seals to make sure it is weather tight, tighten any loose hardware and replace any damaged components. Test the functionality of all the switches.

Emergency Release Mechanism – This device allows crew members to open the doors in an emergency situation where the crew switch is not accessible. To activate this mechanism:

- Shut the power off to the door operator
- Move the red emergency release lever to the release position
- Slide the door panel into the pocket manually

The emergency release mechanism should be inspected on the Authority's preventive maintenance schedule. Check that the fault light activates and that the door is able to slide open. Make sure that the mechanism is working and that it is lubricated as required as per OEM/Transit Authority procedures.

Inspection and Maintenance: Master Door Controller (MDC)

Located in the operator's cab of the rail vehicle, the master door controller opens and closes the door in the train by transmitting the operator door commands to the trainlines and to the door control relay panels. The MDC can only be operated by the conductor who possesses the special key which must be in place in the Master Key Switch (MKS) when switching the default positioning of the door – either open and unlocked or closed and locked. See Figure 12 below for an example layout of the MDC panel.

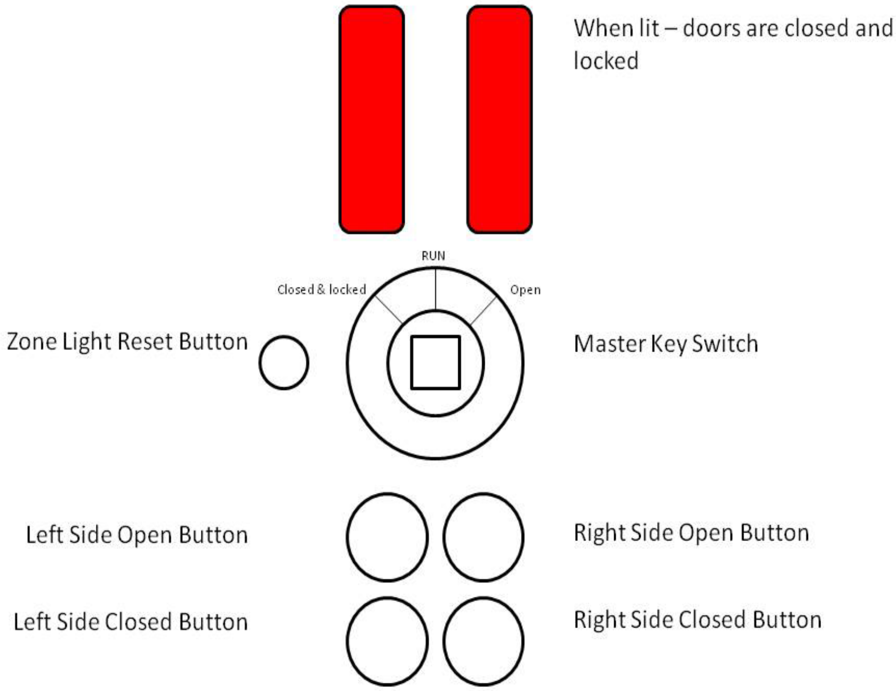


Figure 12: Master Door Controller

The *main commands* initiated by the Master Key Switch (MKS) on the MDC and transmitted to the trainlines are:

- Door unlock and open
- Door close and lock
- Buzzer

Some other commands that *may* be initiated by the MDC in new vehicles include:

- Partial door close
- Local door cycling
- Shuttle service
- Door Chime
- Zone and Dezone

When the MDC is not zoned-in, the doors in that zone/section will not operate. Therefore when performing inspection on the MDC make sure that the section you are working on is zoned-in.

SAFETY WARNING:

- Before operating the MDC ensure that nobody is working on or around the doors on the entire unit/train.
- Before opening or closing the doors, make an announcement on the train public announcement system.

The MDC should be inspected and tested on every inspection cycle to make sure:

- All buttons (zone and open/close) can be depressed
- All switches are operational
- The keys fits into the MKS and can be turned to and functions in all positions. The key should not be able to be removed in “Run” position
- All wires and connections are tightly secured and undamaged
- All mechanical connections for mounting are tight
- All lights are functional and in a good state of repair
- Buzzer works

There is no maintenance required on this unit unless a fault is found.

Inspection and Maintenance: Final Test

After completing the inspection on all door systems, the door system must be tested with the door cycler for at least 30 minutes. It is designed to be connected on one end of the electric portion on the train. This will test all components in the door system on each car including the trainline wiring.

If any fault is found during this testing, the door cycler will stop working. Troubleshoot the defect using the MDS, repair and cycle again. Repeat this step until the system works correctly.

III. Door Panel and Track

Introduction to Door Panel and Track Inspection and Maintenance

There are four main types of doors in rail vehicles – illustrated in Figures 13-16 below.

Figure 13: Side Door

Figure 14: End Door

Figure 15: Cab Door

Figure 16: Storm Door

The locations of these doors vary from car to car but Figure 17 below gives you an example of where these doors may be located.

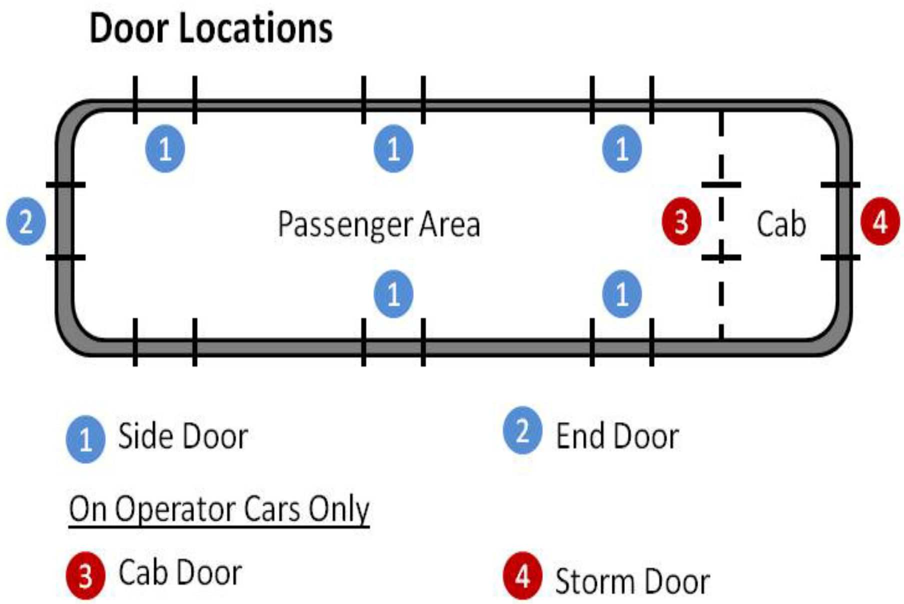


Figure 17: Example of rail vehicle with doors marked
Note these locations vary from car to car.

The text in this section will outline items that need to be inspected and maintained on rail vehicle doors:

- Door Glass – All doors
- Gaskets and Finger Guards – All doors
- Roller/Hangers and Linkage – Side and end doors only
- Locks – Operator's Cab, End and Storm doors
- Hinges – Operator's Cab and Storm doors
- Heated Thresholds – Side doors only
- Passenger Safety Features – Side doors only

Door Glass

All doors on a transit rail vehicle have glass which needs to be cleaned, inspected and replaced where applicable.

Door glass can be held in place either by metal or rubber. Door glass can be installed either with a metal frame or rubber gasket. Where a metal frame is used, the glass is secured in the frame with shims (flat metal retainer bars). A minimum of three shims are used to secure the glass. The last shim to complete the installation is secured with an allen screw. To remove the glass, use an allen key, pin punch and rubber mallet. First remove the allen screw with the allen key. Then using the pin punch and the rubber mallet, remove the bar with the allen key on it. Continue this procedure until all shims are removed.

Where a rubber gasket is used, first the rubber gasket is installed in the door panel. Then the glass is placed inside the gasket and secured with the appropriate lacing. The glass is installed with the glass installation tool and the lacing is installed with the lacing tool which holds the rubber lacing in a hole that runs through the length of the handle. To remove the glass, first remove the lacing using the installation tool and then pull it out by hand. Once the lacing is removed, the installation tool is used to remove the glass from the rubber gasket.

No routine maintenance is required on door glass but it should be cleaned with glass cleaner and a soft cloth as per the OEM/Transit Authority procedures. If there are any cracks, chips, scratches or unremovable marks are found, replace glass as necessary per the OEM/Transit Authority procedures.

There are various ways that glass is secured in the door:

- Locking rubber ring (lacing)
- Retaining metal clips

SAFETY WARNING

- To avoid possible injury while using compressed air for dislodging dirt and debris, wear appropriate eye, face, and respiratory protection meeting minimum ANSI or other applicable national industry standards. Keep air pressure at the blowgun nozzle below 30 pounds per square inch.
- Use only those cleaning products and lubricants proven safe and authorized for use by the rail transit system. Consult OEM and MSDS references for suitability for each application to prevent personal injury and damage to the equipment.

Gaskets and Finger Guards

Gaskets and finger guards are found on all doors on a rail vehicle. This includes side, end, operator cab and storm doors. Inspect to make sure that they are installed properly. If loose or missing hardware, tighten and replace hardware accordingly. Procedures may vary – make sure to follow your authority's procedures.

Insure that there are no cuts, cracks or missing pieces. If cuts, cracks or missing pieces are present, replace the gasket and/or finger guard. When replacing gaskets or finger guards follow your authority's procedures.

As gaskets and finger guards are exposed to the weather, they may dry out. Therefore lubrication is required during preventive maintenance. Acquire silicon and apply directly to all exposed rubber surfaces with a rag and then wipe it off with a dry rag. Lubrication procedures may vary – make sure to follow your authority's procedures.

Roller/Hangers and Linkage

Roller/Hangers and linkages are only found on side and end doors as operator's cab and storm doors have hinges instead.

The hanger and associated hardware should be cleaned to remove dirt, dust, oil and grease using rayon or polyester wipes and approved solvent. Service specified lubrication points with approved lubricants. Make sure to wipe off extra lubricant.

The following inspections should be made to avoid possible failures:

- Check that hanger hardware is tight and undamaged
- Check that all fasteners are tight
- Check that the door hanger hardware and doors are properly aligned
- Inspect rollers for binding, skidding or excessive looseness

Procedures may vary – make sure to follow your authority's procedures.

Hinges

Some cab doors have hinges. If hinges are present, inspect that they are functionally working and that the door can open and close easily. If there is some issue with the hinges, repair or replace as per your authorities procedures. Also, clean and lubricate during preventative maintenance as per your authorities procedures as to prevent rust and excessive wear.

Heated Thresholds

Heated thresholds are found on side doors only and are most common in Northern climates as warmer climates do not have as much of a need for heat. They are mounted under the threshold plates at the entry to the rail vehicle so that the floor stays warm, melting any ice that may cause a passenger to slip.

The heat is automatically controlled by thermostat. Once the temperature sensor is switched, the heat comes on. During inspection electrically and mechanically test the temperature sensor with a digital multimeter to make sure that it s functioning properly. If it is not functioning properly, repair or replace as per your authority's procedures.

Passenger Safety Devices

The following devices are located only on side doors for detecting and/or extricating obstructions providing safety for passengers:

1. A large, soft, floppy, leading door edge that permits extraction of a trapped limb.
2. Panel pushback to permit extraction of a trapped limb with panel position sensing for safety interlock.
3. Mated (tongue and groove) semi-rigid door edges to enhance panel position sensing capability.
4. Monitoring door-closing force or current for obstruction sensing with recycle to release.
5. Monitoring door closing time for obstruction sensing with recycle to release.
6. Sensitive door edges that detect when deformed by an obstruction can be configured to remove power, apply brakes or recycle the doors to release the obstruction.[1]

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[1] APTA Standard

During preventative maintenance all present features should be tested with the appropriate gauge (ex: door obstruction gauge, force measuring gauge, push-back gauge).

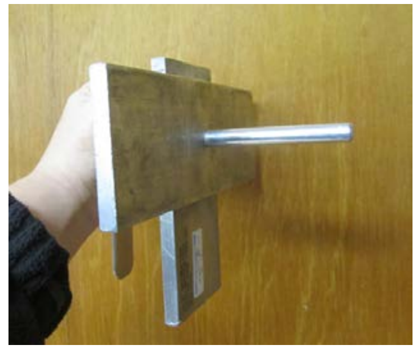

Figure 18: Obstruction Gauge

To use the door obstruction gauge (figure 18), first engage the automatic door cycler. Then stand either on the outside or inside of the car and put the round bar between the door panels while holding the handle. The door panel will not close and therefore not lock. The train operator will not get the door closed and locked indication and the fault light will remain on. Push the device in/out of the panel until one of the doors closes and locks – turning off the fault light. Repeat the same procedure for the other panel. This test should be performed at three different positions – at the top, middle and bottom of the door. If at any point the lights do not clear, adjust the limit switches according.

A common force measuring gauge is the rag-gauge (figure 19). To use this device, one technician should stand inside the car holding the rag. Another stands outside, holding the pressure gauge. Once the door is closed, with the rag in it, the technician on the outside of the vehicle will pull until doors are disengaged. The pressure measured at this point should be consistent with OEM/transit authority procedures. A common measurement is 15 psi. If the devices do not pass the test adjust, repair or replace as per authority's procedures.

Figure 19: Rag-Gauge

Door Locks

There are three common approaches to door locking:

1.) **Mechanical** - Mechanism inherent locking (over-center) with drive motor unlocking. This type of lock is locked/unlocked using a conventional key.
2.) **Electrical** - Separate lock mechanism (solenoid lock) independent of the drive mechanism. This type of lock is locked/unlocked using the push button switch located on the console in the operator cab.

3.) **Hybrid** - A combination use of inherent primary locking and solenoid secondary locking. This type of lock can be locked/unlocked using either a conventional key or the push button switch located on the console in the operator cab.

To test all three types of locks verify that locking devices fully engage and lock.

Cab door locks

Cab door locks can be mechanical, electrical or hybrid. During preventative maintenance, insure that the lock is operating properly and that it can be engaged and disengaged both manually and electrically. Also, lubricate locks as per authority's procedures.

End Door Locks

In some authorities the end door locks stay locked under normal operation so that passengers cannot move from one car to the next. End door locks may be either electrical or hybrid. In case of emergency, the end door locks can only be unlocked by the operating crew manually and/or electrically (trainline).

During preventative maintenance, insure that the lock is operating properly and that it can be engaged and disengaged both manually and electrically. Also, lubricate locks as per authority's procedures.

If the lock does not function as required, repair or replace the lock. Specific procedures vary – make sure to follow your authority's procedures.

Storm Door Locks

Storm doors have locks very similar to end door locks. Inspect and maintain the same as above. In addition, storm doors also have safety latches, located at the top and bottom of the door as to keep the door more tightly closed (figure 20). This tight closure prevents air and/or precipitation from being able to enter the storm door.

During preventative maintenance, make sure that the latches can be moved freely. If they are broken, repair or replace as per your authorities procedures. Also, clean and lubricate latches as required.

Figure 20: Safety Latches on Storm Door

IV. Tools

The majority of tools used in maintenance of rail vehicle doors have been covered in the text above:

1. Go/no-go gauges (p. 10)
2. Sensitive edge tester (p. 11)
3. Window installation tools (p. 15)
4. Door obstruction gauges (p. 19)
5. Pressure gauges (p.19)

The only other tool that is recommended that technicians be familiar with is the portable test unit, covered below.

Laptop/Portable Test Unit

On newer vehicles a laptop can be connected to analyze operation at two different places:

1. Train line - tests the overall functioning of the doors system. This will show you if there are any problems in the trainline wiring such as a high resistance (voltage drop). This will also show you if there are any problems with any of the door panels or the DMCU/DCRPs.
2. DMCU/DCRP – If the trainline test shows a problem at a specific DMCU/DCRP of a vehicle, the technician should connect the laptop to that individual unit to analyze the reason for failure of that door panel or door opening.

   An alternative to using a laptop is to look at the train operator display (TOD) screen which is located in the operator cab. This approach only displays trainline problems but will not give you the specifics of a DMCU/DCRP fault. Another advantage to using a laptop is that the technician has the ability to download the data and bring it into a workstation for analysis. When using the TOD screen, the technician must do any analysis in the cab.

Bibliography

Siemens-Duewag Sacramento LRV Corrective Maintenance Manual, Photoelectric Guard, 01/03/86

http://www.lightcurtain.com/light_curtain-operation.html

Relevant OEM Contact Information

OEM	Website	Contact Information
Example: OEM Name	www.oemwebsite.com	2222 Random Rd #220 Tampa, FL 2222 Phone: (222)222.2222 info@oemwebsite.com
Vapor Stone Rail Systems (Wabtec subsidiary)	http://www.wabtec.com/home.asp	http://www.wabtec.com/subsidiaries/contact.aspx?id=21
IFE	http://www.ife-doors.com	Knorr-Bremse GmbH Division IFE Automatic Door Systems 33.a Straße 1 A-3331 Kematen/Ybbs Phone: +43 (0) 7448 9000 Fax: +43 (0) 7448 9000 65110
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Faiveley	http://www.faiveleytransport.com	Le Delage Building Hall Parc - Bâtiment 6A 6ème étage 3, rue du 19 mars 1962 92230 Gennevilliers CEDEX - France Tél : +33 1 48 13 65 00 Fax : +33 1 48 13 65 54 info@faiveleytransport.com
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Attachment: Industry Training Standard

209. Doors: Introduction and Preventive Maintenance

- **209.1 Door Controls**

  Explain safety concerns of door operation and maintenance (pinching, motors, voltage)
  Inspecting and maintaining control unit
  Inspect control unit
  - Test control unit with portable test equipment
  - Download software, reprogram door controller and check for faults
  - Replace control unit

  Inspecting and maintaining door cut-out
  - Test door cut-out
  - Test individual doors and door interlocks
  - Adjust and/or repair door cut-out
  - Replace door cut-out

  Inspecting and maintaining out-of-service and door open indicator lights
  - Test out-of-service light
  - Replace out-of-service light
  - Test door open indicator light
  - Replace door open indicator light

  Inspecting and maintaining relays/solenoids
  - Test relays/solenoids
  - Replace relays/solenoids

  Inspecting and maintaining motors/drive mechanisms
  - Test motors/engines
  - Repair motors/engines
  - Replace motors/engines
  - Adjust motors/engines

  Inspecting and maintaining limit, proximity and micro switches
  - Test switches
  - Adjust switches
  - Replace switches

  Inspecting and maintaining sensors
  - Test sensors
  - Adjust sensors
  - Replace sensors

  Inspecting and maintaining sensitive edges
  - Test sensitive edges
  - Adjust sensitive edges
  - Replace sensitive edges

  Inspecting and maintaining ADA warnings
  - Test ADA warnings
  - Replace ADA warnings

  Inspecting and maintaining crew switch
  - Test crew switch
  - Repair crew switch
  - Replace crew switch

- **209.1 Door Controls (continued)**
  Inspecting and maintaining emergency release mechanism
    - Test emergency release mechanism
    - Lubricate emergency release mechanism
    - Adjust emergency release mechanism
    - Repair emergency release mechanism
    - Replace emergency release mechanism

- **209.2 Door Panel and Track**
  Inspecting and maintaining roller/hangers and linkage
    - Inspect roller/hangers
    - Lubricate roller/hangers
    - Adjust roller/hangers
    - Repair roller/hangers
    - Replace roller/hangers
    - Inspect door guide
    - Adjust door guide
    - Replace door guide

  Inspecting and maintaining door glass
    - Clean door glass
    - Inspect door glass
    - Replace door glass

  Inspecting and maintaining gaskets/seals
    - Inspect gaskets/seals
    - Lubricate gaskets/seals
    - Adjust gaskets/seals
    - Replace gaskets/seals

  Inspecting and maintaining cab door locks
    - Test door locks
    - Replace door locks

  Inspecting and maintaining cab doors
    - Test cab doors
    - Lubricate cab doors
    - Adjust cab doors
    - Replace cab doors

  Inspecting and maintaining heated thresholds (Northern climates only)
    - Inspect heated thresholds
    - Test heated thresholds
    - Repair heated thresholds

- **209.3 Tools**
  Demonstrate ability to use a laptop/portable test unit
  Demonstrate ability to use gauges
  Demonstrate ability to use a sensitive edge tester
  Demonstrate ability to use a window installation tool

PART II (in separate document)

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[i] Siemens-Duewag Sacramento LRV Corrective Maintenance Manual, Photoelectric Guard, 01/03/86

[ii] http://www.lightcurtain.com/light_curtain-operation.html

RAIL VEHICLE LEVEL 200
SUBJECT OVERVIEW

Module: 210 – Communications Systems

Note: All 200 level courses should be delivered only after completion of 100 level training

About the Author

Frank Grassi has worked as a Car Inspector in the Department of Subways for MTA-New York City Transit for the past nine years. He is a member of TWU Local 100 in New York. His experience includes troubleshooting and diagnostic work on Bombardier R-142, and Kawasaki R-142A, R-143 and R-160 subway equipment. Prior to his transit career he was a television cameraman at an ABC affiliate station in upstate NY. He later worked as a recording and video engineer for a major record label and for an advertising agency in Manhattan. As an independent businessman he designed, maintained, owned and operated his own audio recording studio (begun in the 1960's), which later morphed into a video production facility specializing in industrial and commercial projects (in 1980). Much of his electronic expertise came from his father, Ralph, who repaired radios and televisions in and around their Brooklyn home. Frank has a B.A. Degree, majoring in radio and television production, from Brooklyn College. He is a licensed radio amateur (KC2LJE) and a past member of the NY Chapters of the Audio Engineering Society (AES) and Society of Motion Picture and Television Engineers (SMPTE).

Overview / Purpose

Rail Communications Systems are perhaps the most easily understood but most often misunderstood in the spectrum of onboard systems, which a train crew must monitor and use in its daily work. There are many types of hardware in current use, and “New Technology” or computer based trains only add to the misunderstandings of how they operate. Essentially, most on-board communication systems are similar in nature to any conventional public address system, with a radio transmitter and some automatic switching thrown into the mix. If you've ever seen a public speaker pick up a microphone to address an audience and suddenly find himself surrounded by loud squeals and horrific ear piercing howls, you've just discovered how a seemingly simple system can go wrong. But, perhaps, it wasn't the system gone wrong, but rather the operator. This material covers the basic equipment and proper operation of so-called “New Technology” (computer based) Train Communication Systems in simple language, bearing in mind that because of the equipment used on individual systems, only general architecture can be given. It will be up to trainers at each location to detail the specific design of the *equipment actually in use*, which may vary substantially from the examples presented here.

Table of Contents

Suggested Tools/Training Aids:

- o New York City Transit New Train Procurement for NYCT Division B, System Functional Diagram, Panasonic Document SFD-R160-Com, Revision E
- o (See Bibliography)

Topics Covered:

Topics listed below are covered in this introduction of Rail Car Communication Systems. A full copy of the National Training Standards from which these topics were taken is attached.

- o Basic Rail Communications Types
- o Onboard Communications
- o Over-the-Air Radio & Communications Control Panel (CCP) (also called Communications Control Unit)
- o Signs
- o ”Background” Communications
- o LONWORKS
- o Closed Circuit TV *(note: Material will be added later)*

Definitions, Abbreviations and Acronyms

For the purposes of this lesson, the following glossary of terms, definitions, acronyms, and abbreviations shall apply. They are not all inclusive, and the reader is encouraged to explore the text, footnotes and bibliography sources for further information.

- **A/D - Analog to Digital:** The process of converting analog information, such as physical sound waves, into more easily processed and distributed numerical "words" or codes. These numerical "bits" do not deteriorate over long distances or through most electronic circuits. Digital representations of audio signals, for example, do not generally suffer from distortions generally associated with analog signals. The reverse process is called D/A, where digital information is converted into analog information.
- **Antenna:** An electromechanical device usually fashioned from aluminum or other metal. Antennas are usually mounted in an electrically unenclosed, unshielded area of a train. It converts electrical energy into radio frequency (R.F.) energy used for the reception and/or transmission of radio signals.
- **Antenna match:** An electrical device or circuit designed to match the impedance (a kind of A.C. resistance) of the antenna to the transmitter/receiver. Some matching devices can be simple coils, transformers or other passive electrical components, while others may use active circuitry to best transfer R.F. signal power between the antenna and the radio with minimum loss. In train communications systems, matching is usually not field adjustable and is set at the factory.
- **Audio:** The perceived analog output or sound made by a communications device or system. Audio may be considered "intelligible", where coherent spoken words or signals are received by a listener, or "unintelligible" (hash or static) where only random noise, squeals, garbled words or non-coherent signals are received by the listener.
- **AAS: Automatic Announcement System.** A feature on many rail and subway systems, whereby a menu of digitally recorded and stored recordings may be played over the train's public address system and synchronized to physical locations on the train's route in addition to verbal announcements spoken by the train crew. Such announcements may relate to safety or special conditions en-route. AAS systems have the ability to receive data from the train network to make automatic announcements regarding current stops, next station stops, transfer points, current time, and to display such data on LED and LCD screens and signs onboard the train.
- **CCP: Communications Control Panel.** The main communications interface between the system and the operator. In some fleets there is also a **CP or Conductor's Panel** which may be regarded as an auxiliary or backup interface between a second crew member and the system.
- **CBTC: Communication Based Train Control.** A method of Automatic Train Operation (ATO) which allows for operation of a train with limited human interaction. Propulsion, braking, door system and other operations are programmed by a tower operator. Using wayside signals and transmitter/receiver modules placed between the rails, the tower operator may communicate instructions to the train's computers which actually operate the on-board systems.
- **Communications Master Control (CMC). Also referred to as Communications Control Unit (CCU).** The "brains" of New Technology or computerized trains. The CMC contains needed electronics for the switching and interfacing of signs, public address, crew intercom**,** passenger intercom, some radio functions, route information, current time and the automatic announcement system (AAS). What was traditionally handled with relays and switches on older fleets can now be accessed using a keypad or touch sensitive screen in an operating cab. Information regarding operational conditions and faults of the CMC are downloadable using standard laptop computers also known as PTE, (Portable Test Equipment) running proprietary manufacturer's software.

Definitions, Abbreviations and Acronyms (continued)

- **CNC: Car Network Controller:** An *electronic unit* installed on each car, which can send and receive status data, under control of the Train Network Controller (TNC), *to activate or deactivate and monitor specific devices in the car - such as doors, signs, lights, speaker systems, etc*. The CNC also manages the *sequence of data transmission between the Car Network and the Train Network*.
- **Circuit: a)** an *electrical path* through which electrons flow to achieve a result. **b)** a term used to identify *types of transmission systems*, for example: *closed circuits* are usually private telephone-type loop systems where messages travel from a sender to selected receiver(s). Transmissions where communications may be received by a large number of receivers simultaneously, or over the air by radio, are considered *broadcasts. Open circuits* are generally defined as an interrupted electrical signal path – a circuit failure.
- **Clock:** An internal reference frequency to which equipment is synchronized. The clock allows digital data to be transmitted and received synchronously by equipment sharing a common network or "bus", that is, all such equipment is operating in step with one another.
- **F.C.C. Federal Communications Commission:** The Federal agency that assigns radio frequencies, call letters, regulates radio rules of operation, and monitors the airwaves. The FCC can impose stiff fines and revoke operating authority for unauthorized radio transmissions and systems not in compliance with U.S. laws.
- **ICM/ICS: Intercom System:** A closed circuit, two-way, audio path between crew members on a train. A private line usually connecting a train operator and a conductor for operational messages.
- **LED: Light Emitting Diode.** A semi-conductor component used as a lighting device. When used in displays, LEDs illuminate when a specific voltage is applied to them. Arrays of LEDs of different wavelengths and colors are often used in signs found in modern transit rail cars to present information to passengers and crew. An example of LEDs would be the displays one would see on large illuminated outdoor signs and signs frequently used in convenience store advertising messages. Unlike incandescent lights, LEDs have extremely long lifecycles on the order of 100,000 hours and rarely need to be replaced.
- **LCD: Liquid Crystal Display:** A type of electroluminescent display where alphanumeric characters are "backlit" on a lighter grey or green background. By using low control voltages, generated by a microcomputer, LCD characters can be made to either block or transmit that background light on a nearly invisible wire grid. For this reason, LCD characters are characteristically "blocky" in shape, having few rounded corners. Examples of LCD displays are those used on a calculator or in digital wristwatches.
- **MIC, Mike, (Microphone):** Electromechanical device which converts sound pressure into electrical signals for use by the public address amplifier, intercom, passenger emergency intercom or radio systems on a train. Classified by type (dynamic, condenser, etc.) and "polarity" or directionality.
- **OEM: Original Equipment Manufacturer:** The vendor or contractor which designs, builds and delivers equipment, and often provides training materials and service documents to the purchaser or agency.
- **P.A.: Public Address System:** The audio system in use in all current transportation vehicles to address passengers. ,
- **PEI: Passenger Emergency Intercom:** A two way, closed circuit communication path whereby *passengers* can initiate an "attention signal" or ring tone to call and verbally communicate with the train crew in the event of an emergency. Not to be confused with ICM/ICS above (a private line for operational messages).

Definitions, Abbreviations and Acronyms (continued)

- **PTT: Push to Talk:** A button or switch pressed to activate radio or onboard communications.
- **Radio:** Any wireless device for the transmission and reception of voice or data communications on radio frequencies assigned by the Federal Communication Commission (FCC).
- **Radio to P.A.:** A function on many CCPs (Communications Control Panels**)** that allows radio transmissions from a command center or tower to be broadcast over speakers in all cars of a train. In emergencies or evacuations from a train this feature could be a valuable life and time saver by allowing all passengers to hear the same information from authorities at the same time.
- **Receiver** (Dual meaning): 1. *Persons and Listener*s to any audio transmission. 2. Electromechanical *device* capable of receiving over the air radio transmissions.
- **RFI, Radio Frequency Interference:** Electrical noise or radiation from any source which creates noise or prevents good quality radio communications. Common causes of RFI might be onboard computers, transformers, inverters, transceivers or lighting devices**.** Other radio transmissions on the same or nearby radio frequencies can also create RFI conditions, as can atmospheric conditions such as unstable weather and sunspots.
- **Sender:** The initiator of a radio or public address communication. Generally, the person sending a message over a communications system. (Note: Do not confuse with “speaker” below).
- **SPKR., Speaker, Loudspeakers:** Electromechanical *device* which converts amplified electrical signals into sound waves. Loudspeakers produce amplified audio to address a single recipient such as a train operator, or a group of people at one time, such as passengers on railcars or buses.
- **Transceiver:** A handheld or portable radio (Transmitter/Receiver) used by the train crew to send and receive transmissions. Also used to describe the OEM's radio, which is typically built into, and a permanent part of, the cab of a train.
- **Tx/Rx:** Radio abbreviation for “Transmit/Receive” (an action) or “Transmitter/Receiver” (electronic device).
- **Transducer:** The *primary device* used to *convert one type of energy to another.* Examples include: microphones (acoustical energy to electrical), loudspeakers (electrical energy to acoustical), speed or rotation sensors (mechanical energy to electrical), and thermostats (heat energy to mechanical and electrical).
- **TNC:** Train Network Controller – the main *digital management device* which provides timing information and data transfer with various car control circuits including the Master Controller, the inter unit network (IUN) and Car Network Controllers (CNC) for door and sign systems, and door bypass circuit which allows powering with open doors in special situations. *The TNC provides necessary synchronizing information for powering and brakes, to ensure that all cars in a consist accelerate, and decelerate together smoothly.* The TNC works with the trainline Multiplexer system (TMX) and may be considered “trainline” with origins in the active operating cab. The TNC also interfaces with the Communication System (CMC).
- **TMX:** The multiplexer/demultiplexer (see below). Also: TMS, MUX/DEMUX, and MPX.

Introductory Text by Topic Area

Note: those providing text should review the complete training standard (attached) to ensure all learning objectives are addressed.

1.0 Basic Rail Communications Types

In considering all communications on railway systems, there are basically three types:

1. On Board
2. Over the Air
3. "Background" or "Housekeeping" Communications

Onboard

Systems typically used onboard a train include:

Audio: Public Address (P.A.), Automatic Announcement (AAS) Systems, Intercoms between crew members (ICM/ICS) and Passenger Emergency Intercoms (PEI).
Video: Recorded visual images of activity onboard the train that may be recorded for later review, or previously recorded messages, such as safety videos which might be played on screens inside the train for passengers.
Signage: Visual messages and informational texts displayed by LEDs, LCDs or Plasma Screens and used for passenger information.

Over the Air

Over the air **communications consist of r**adio (voice) and Digital Data such as maintenance information sent wirelessly to a central computer. Some systems may also include Video Data, which may also be wirelessly transmitted to a remote receiver or remote recorder.

"Background" or "Housekeeping" Communications

Background communications **consist of d**ata information networks and systems that are not usually apparent to train occupants, but run silently in the background between units. Their task is to keep the train running smoothly and to record operating conditions, faults and failures for later downloads or analysis. Included are the:

Event Recorder Unit (ERU),
Monitoring and Diagnostic System/Logic (MDSS or MDL),
Door Monitoring and Control Logic Unit (DMCU),
Inter Car Unit Networks (ICU),
Propulsion and Braking Networks,
Train Line and Train Network Controllers, and the
Multiplexer (TMX, TMS, multiplexer/demultiplexer or "Mux/Demux"), a digital time sharing system responsible for passing trainline status communications between two or more consists or sections of a train unit.

There are multiple digital background networks on today's New Technology (computer based) trains. They are also sometimes referred to as "housekeeping" signals.

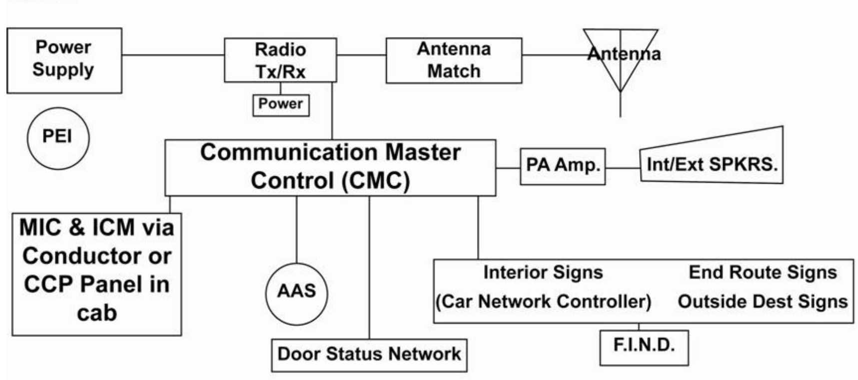
For the purposes of providing introductory material, the focus will be on primary communications systems - On Board and Over the Air. However, the student should understand that Background Communications briefly described above also play a vital role in safe and efficient operations of New Technology trains. Students should make an effort to become more familiar with them. More in-depth discussion on Background Communications will be forthcoming in Level 300 instruction materials being developed.

2.0 Onboard Communications

Onboard System Block Diagram
While all systems may differ slightly, on many New Technology trains the communications system will look something like this (Fig. 1)

General

Figure 1



Looking at communications Systems, as shown in Figure 1, the CMC is the central operating unit of the system. It is fed from a D.C. Power Supply which should be electrically separated and shielded from other power supplies on the train, for the lowest interaction between other units and for minimum Radio Frequency Interference (RFI). Typically, there are redundant power supplies for on-board communications systems; especially for radios. One is built into the CMC-A (or Master Communications Unit); the other is often part of the train's Low Voltage Power Supply (LVPS), and kicks in when there is a CMC power failure of predetermined time. Power supplies are well regulated and filtered to produce a steady D.C. current and voltage regardless of the demand for power of other units. There are also power converters in such systems. For example, a train may use 37.5 volts D.C. (LVPS) to operate the P.A. System amplifier, blowers, lights and perhaps signs; but the radio may require only 12 volts D.C.

Inputs to the CMC
The CMC receives a multitude of digital signals from the various train networks, such as doors, signs, lighting, and train control network, and processes it into usable information which may appear on the operating crew's computer screen display or be downloaded to an external diagnostic computer. There are built-in switching networks inside the CMC which use both digital switching and analog type relays.

The switching systems allow the CMC to send and receive status information with regard to signs, intercoms, public address and pre-recorded automatic announcements system (AAS) stored on a memory chip inside the Master (A Car) CMC-A. In “non operating” cars, (ones which have neither a train operator nor conductor cab) there may be resident CMC-B's which are used to “slave” messages and sign information from the main unit and also provide amplification for loudspeakers in those cars. Audio from the Amplifier may also be fed back to the CMC as part of its built in diagnostic test function.

Master CCU
In most train communication systems one and only one CCU is designated as the “Master” – all others are considered “slaves”. Master CCUs are most often selected by internal logic software as the car in which the Train Operator works. But another “A” car, usually the conductor's car, may be selected automatically as the communication Master car in the event of CCU failure in the primary car. The Master CCU may also be selected manually by physically turning off the

Communications circuit breakers in other selected “A” cars until the Master “jumps” to an A car with a working CCU-A restoring operation. The Maintenance Screen of the Train Operator's Display (TOD) will generally report where the Master CCU resides.

Outputs from the CMC

In addition to communicating with other CMC's in other cars and converting digital voice announcements into analog sound there may be a separate P.A. Amplifier or it may be inbuilt within the CMC chassis. The amp. powers both Internal Loudspeakers inside the car, and possibly External Loudspeakers, affixed and recessed on the outside of car body, if so equipped. These allow passengers on a platform to hear messages when doors are opened at a station or terminal. This function may be selected by the train crew from a switch or button labeled “Int/Ext” on the cab's Communication Control Panel (CCP).

NOTE: *The TOD Screen (the crewmembers' main computer display), is under command of the Monitoring and Diagnostic Logic System – often referred to as “MDS, MDSS, MDL or Logic” depending on the train system and local custom. In normal operation, the TOD might display routinely needed information such as routes, stations, train speed, special pre-recorded announcements (AAS - stored on compact flash (CF) media in the CMC), and possible equipment troubles. On most systems, a special Maintenance Key, Switch or Software Code allows technicians and maintainers access to important status, trouble and historical information affecting systems on the train. More detailed information, in the form of Fault and Historical Logs, may be downloaded using a laptop computer. In order to avoid unnecessary concern or worry by the crew, diagnostic and maintenance information, not critical to normal train operation, is generally not available without access to the Maintenance Key, Switch or Code.*

Signs

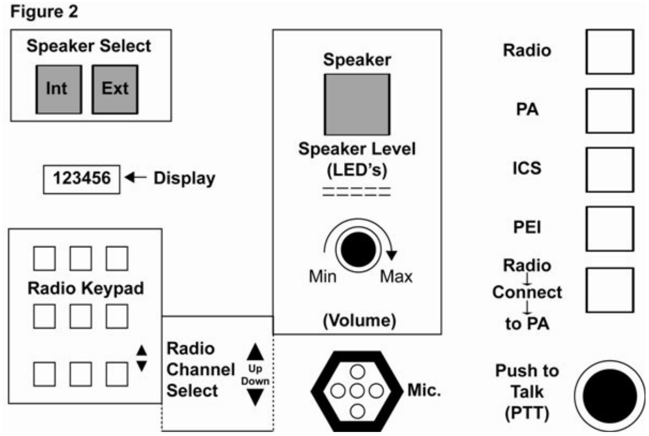
End Route Signs (end cars), Interior Message Display, and Outside Destination Signs are also networked and communicate with the CMC-A. The train's route is selected from the touch screen on the TOD, fed to the TNC - Train Network Control, through the Car Network Control, and then to the CMC. Once the system is “synchronized” as to its present position based on the train's crew input, the Automatic Announcement System and interior signs might flash a series of information displays such as the train's final destination, current station, time of day and route number or letter. Additionally, pre-recorded and stored audio messages played from the train's AAS system will also appear on interior ceiling signs (also called Interior Message Displays-IMD's).

3.0 Over-the-Air Radio & Communications Control Panel (CCP) (also called Communications Control Unit)

Radio

The train's over-the-air radio, usually located in the cab on a console or wall facing the train operator, has a separate power supply for minimum RFI and maximum reliability should the CCU's power fail. It interfaces with the CCU so that internal messages being played over the AAS simultaneously will not interfere with the radio's transmitting ability. When transmitting and the PTT (push to talk) button is depressed, the radio communications get top priority and mutes P.A., intercom and PEI communications within the cab. In fact, many train models use two separate speaker systems in the cab. One, on the CCP, is for radio reception only, while additional speakers on a back wall may be used for crew intercom, AAS and PEI communications. On a typical New Technology train the console CCP panel might look as in Fig. 2.

Figure 2



Some additional notes while speaking about train radios are:

a) The Volume Control on the CCP is used for Speaker Volume only.

b) The Volume Control cannot completely turn off incoming audio from the radio. This is a safety feature designed so that reception of important radio messages cannot be missed by accidentally turning the speaker completely off. There should always be audio from the radio speaker unless the channel of the receiver is turned to the incorrect frequency.

c) Radio microphone and transmitter volume level is pre-adjusted by the manufacturer and has an Automatic Gain Control. ***No adjustments are permitted to a transmitter without F.C.C. Authorization.***

d) Train crewmembers often carry a portable *transceiver* (combination transmitter/receiver) on their person, sometimes referred to as a “walkie-talkie”. Some use the unit's speaker as a microphone, and some have a separate detachable microphone and speaker. Often referred to generically as simply “a radio”, portable transceivers are capable of communicating with rail control towers and command centers in train yards and, when within range of a communications tower, on the road. Some transceivers feature a lower power P/L (private line) frequency for on-board crew communications. These reserved frequencies are often used as an alternative to the train crew's onboard intercom system (ICM or ICS) sometimes found on the CCP or back wall's Auxiliary Communication Panel (CP). But, be aware that the so-called radio P/L frequencies are actually *broadcasting over the air* for anyone within range to hear. Communications of a sensitive or personal nature, those intended for crewmembers' ears only, are best transmitted face-to face or over the train's internal intercom rather than on any radio. Users should always be aware of language and content, anytime he/she presses a PTT radio button. Radio broadcasts may be intercepted at any time by any radio buff with a scanning receiver or by the F.C.C., which may issue a citation and fine for unauthorized or indecent language as defined in the Communications Law.

e) Rail Communications are assigned power and frequencies by the F.C.C. under a Master License made out to the system operator or agency. All radios within the system are covered under that license. Frequencies for railroads generally fall into 158 – 161 MHz (megahertz or millions of cycles per second) (VHF), or 452 – 475 MHz (UHF) radio bands in which there are literally hundreds of thousands of choices of transmit/receive combinations and methods of transmission including both analog and digital, trunk systems and duplex schemes.

f) When the sender and receiver are communicating on the same frequency and one must wait for the other person's transmission to end before they can talk – that's “simplex” operation; when they are simultaneously transmitting on one frequency while receiving on another – that's “duplex”. A telephone, for example, allows you to hear and speak simultaneously and is therefore considered duplex. Often, railroad police and emergency units share these same frequencies or are assigned nearby ones under a blanket authorization of the F.C.C. There are also scores of equipment choices capable of serving the needs of railways.

g) Original Equipment Manufacturer (OEM) train radios are factory adjusted for maximum performance and usually have few or no user adjustable controls on their chassis. Power is generally limited to 10-15 watts Effective Radiated Power (ERP). Antennas are often hidden beneath the fiberglass trim of the train's bonnet and preferably close to the roof line in an area where weather will not corrode them and where radio signal will not become overly attenuated by the metal in the car's body. Antenna radiation may also be “polarized” horizontally or vertically for more effective communications on a given system and to reduce interference from other users operating on nearby frequencies.

Microphones

General

All *Microphones* are *Primary Transducers*. That is, they convert one type of energy into another. In this case it is the conversion of sound energy into electrical energy. Since the microphone is a *main communication interface* with which both crewmembers and technicians will interact, it seems fitting to devote a detailed discussion to this ubiquitous device.

Microphone Types

There are four different microphone types based on their electrical operation:

1. Pressure Gradient Microphones: Carbon
2. Piezoelectric Microphones: Crystal/Ceramic
3. Magnetic Microphones: Dynamic and Ribbon.
4. Capacitive Microphones: Capacitor/Condenser microphones).

Each microphone type will be briefly described with an emphasis on the ones most commonly encountered on train communications systems.

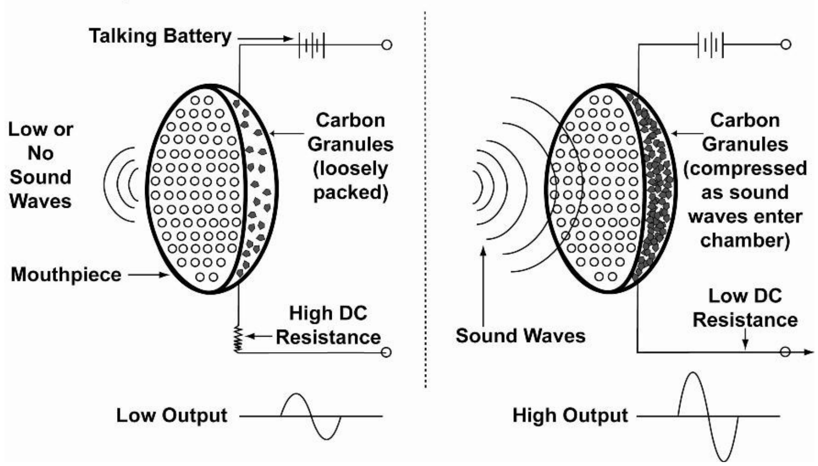
Pressure Gradient Microphones (or Pressure Microphones)

Pressure gradient microphones work on the principle of compressing and releasing pressure on granules of carbon encased in a semi-closed container or capsule, usually an inch or two in diameter. Sound waves enter the microphone (transmitter) by means of small holes or slots on one side of the capsule allowing air molecules to enter and create pressures on the carbon granules located inside. This is the same type of microphone first used in 1876 by Alexander Graham Bell on his prototype electric telephone.

Think of an old fashioned (black, rotary dial) telephone's mouthpiece. When the speaker talks, the pressures and “rarefactions” (release of air molecule pressure) generated by the voice pressure are translated into an analogous pressure that compress and release carbon granules located inside the mouthpiece. When carbon is compressed or released, a change in *electrical resistance to a current generated in the circuit by a "talking" battery* (9-48 volts,) is sent down attached wires, through balancing and filtering transformers or coils, into the telephone network and finally arrives at a magnetic "receiver" (earpiece or amplifier) where these variations in resistance are reproduced as sound. A simplified illustration of how a carbon microphone functions is found in figure 3.

Carbon microphones have the advantage of being inexpensive to produce , are relatively immune to shock and moisture from one's breath and the environment, and are low impedance – meaning their electrical signals can travel long distances before electrical resistance lowers their effectiveness and creates hum and loss of whatever high frequencies exist in the circuit. Their main disadvantage is frequency response. The quality of sound might be described as "telephone sounding" mainly because the range of sound that carbon sets deliver is somewhere between 300-3000 Hz which, coincidentally, is just about right for speech intelligibility, making them "just passable" for the earlier train communication systems of the 1930s-1950s. Some carbon sets are still in use on our tracks. If you've ever heard anyone complain about "garbled announcements" on a train, the carbon microphone may be the leading cause.

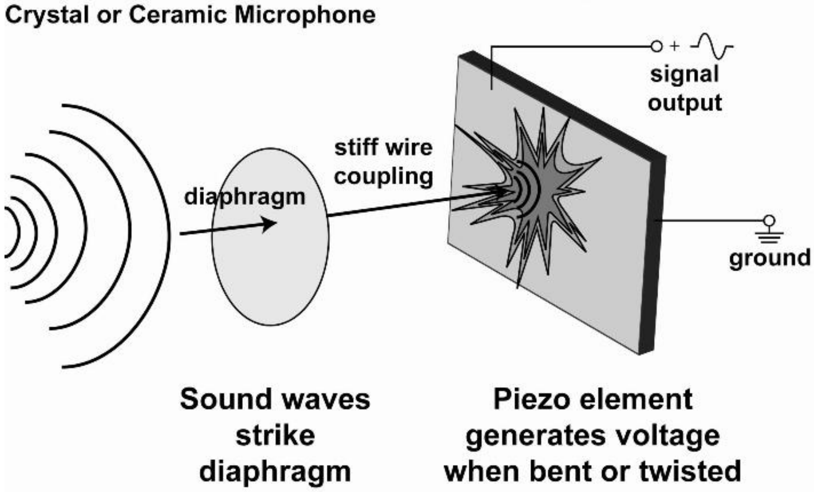
Figure 3. Simplified Carbon Microphone Operation Used in Telephones 1876-1990s



Piezoelectric: Crystal/Ceramic Microphones

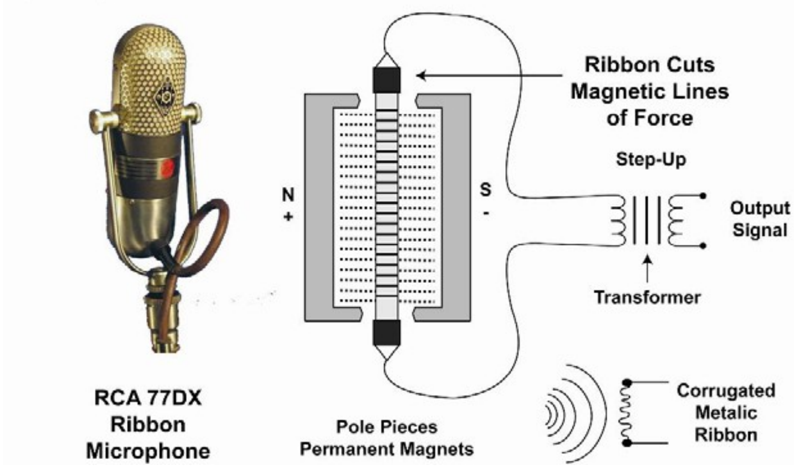
Piezoelectric microphones are usually found packed with tape recorders of the 1950s and 1960s. Piezoelectric elements have the property of producing a voltage when bent or twisted. Rochelle Salt Crystals, a commonly used piezo element, can generate electrical voltages when deformed and are the basic transducer used in these microphones. Usually a metallic "diaphragm" is attached with a stiff coupling wire to the piezoelectric element. When a person talks into the diaphragm, the minute motion of the sound waves from his voice bends the element slightly generating a voltage which is an analog in frequency and amplitude to the original sound. A simplified illustration of the operation of a Piezo-Electric Microphone can be seen in figure 4.

Figure 4. Simplified Piezo-Electric Microphone Operation Crystal or Ceramic Microphone



The advantages of piezoelectric microphones are that they are relatively inexpensive to build and have a very high output signal level approaching the “line levels” generated by pre-amplifiers and electronic musical instruments. These microphones have a noticeable “peak” in their response at around 5,000 Hz making voices slightly clearer, but “tinny” sounding. The disadvantages of piezoelectric microphones are limited frequency response (100-6,000 Hz nominally), severe treble loss beyond 7,000 Hz, and limited bass response below 100 Hz. Crystals types also can be damaged by high temperatures. Excessively dry or humid conditions could also shorten their life or cause them to fail; however, ceramic elements will withstand more variations in temperature extremes than will crystal types.

Figure 5. RCA 77DX Ribbon Microphone



The nature of these microphones requires them to be fed into an amplifier with high input resistances of 3-5 million ohms (megohms) to maintain bass response. This high impedance also limits cable length to no more than about 10 feet before hum and radio frequency interference (RFI) becomes a problem. Most piezo microphones are omni directional*;* that is, they pickup sound and unwanted background noises equally from all directions. Because they may use R.F sensitive crystals as an electrical pickup element, nearby radio stations have been known to be heard on some P.A. Systems using such microphones; not unlike the crystal detector diode used in early crystal radio receivers of the 1900s. Those sets often brought in multiple stations at one time. Piezo pickups do not discriminate!

Magnetic Microphones can be subdivided into two types: ribbon and dynamic.

Ribbon Microphones

Ribbon microphones**,** due to internal sensitivity to shock, are not commonly used in train based communication systems; however their operating principal should be recognized as a type of device one might encounter in a dispatcher's office or recording set-up. Ribbons are commonly used in recording studios and broadcast stations. They are characterized by a typically wide and smooth frequency response (40 – 12,000 Hz) with an enhanced low end making them favored as drum, horn and announcer microphones. (The oval shaped desk microphone that sat on Johnny Carson's desk on the old “Tonight” TV show, had tiny holes all around its circumference and became a trademark for this type of microphone)

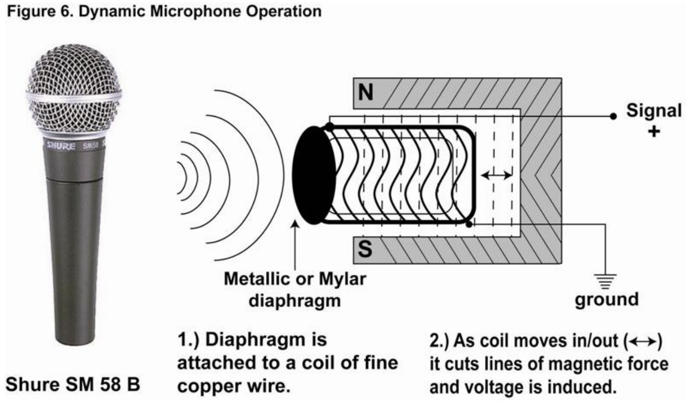
Ribbon microphones use a corrugated metallic ribbon suspended within a magnetic field. The ribbon moves in response to external sound waves and cuts lines of magnetic force in the field. The output of the ribbon is a low voltage which is sent to an amplifier for high fidelity amplification. The fragility of the ribbon, easily damaged by excessive wind and breath gusts, and the high pre-amplification needed for most audio mixers, preclude its efficient use on train systems. Ribbon microphones generally are bi-directional; that is they pick up only from the front and back and ignore sound from their sides making them excellent for studio use in controlled environments. A simplified illustration of a ribbon microphone can be found in figure 5.

Dynamic Microphones
Dynamics are perhaps the most widely used, rugged and popular general purpose communication microphones. They are used in base and mobile installations by police, fire and other public service agencies, including railroads, in broadcast and radio amateur communications, and in any application where rough handling and resistance to the elements and environment are required. Some dynamic microphones are built so ruggedly, in fact, that one manufacturer routinely used to demonstrate that they could bang nails into a length of board with their microphone (nicknamed “the hammer”) and it would still work perfectly! Some microphones, still operating satisfactorily in major concert P.A. Systems, were manufactured in the 1950's, testifying to their longevity on the job. A simplified illustration of the operation of a dynamic microphone can be found in figure 6.

The basic principal of dynamic microphones is similar to ribbon microphones except in this case a coil of very fine wire is attached to a metallic or mylar diaphragm and the coil is suspended in the gap of a magnetic field. As external sound waves impinge on the diaphragm they cause the coil to move back and forth within the field cutting lines of magnetic force thereby generating a small voltage. This output is sent on to active “pre-amplifying” circuitry and then to the audio amplifier and speaker system. Dynamic microphones come in varying sizes and shapes and can be made directional (cardioid) or highly directional (super cardioid or “shotgun” pattern), focusing on sound coming from directly in front and eliminating unwanted noise from the sides and rear of the microphone. This feature has made shotgun microphones popular in film and TV production.

Many rail and bus vehicles come equipped from the factory with dynamic microphones. Their *advantages* are: relatively wide “price point” costs (a karaoke microphone for example can retail for about $10.00 while professional studio dynamics can cost hundreds of dollars). Other advantages include: high fidelity (50-15,000 Hz nominal), low impedance (50-250 ohms), which allow for long wiring runs to the amplifier; electrically balanced transformer operation is possible (to reject unwanted RF signals); and immunity to environmental and shock hazards. External power is not needed to operate dynamic microphones. One other advantage of note is that dynamic microphones are essentially loudspeakers in reverse; that is, in some circuits a small loudspeaker may act as a microphone albeit with altered impedance and frequency response. The speaker's wired voice coil may be connected to the input of the transmitter when speaking, and connected to the receiver when listening – thus the intercom or transceiver or walkie talkie, allowing one device to do double duty!

Figure 6. Dynamic Microphone Operation



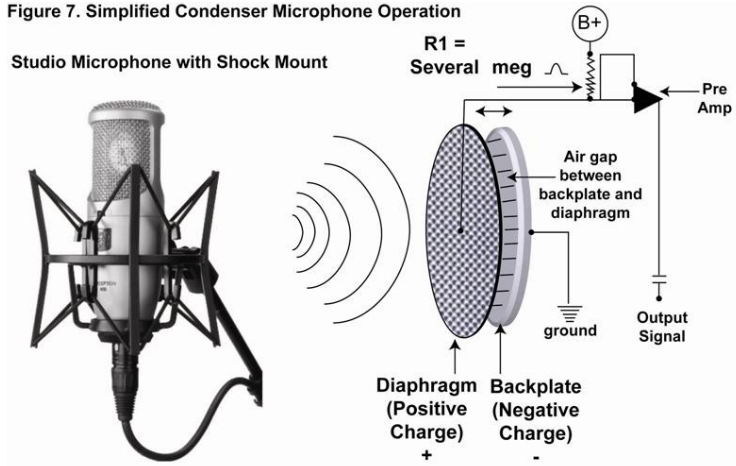
Capacitive Microphones
Often referred to also as *condenser* or *capacitor* microphones, this type of microphone is beginning to show up in many train communications systems because of new and more cost effective manufacturing techniques developed primarily from offshore manufacturers. Originally designed at state-of-the-art high-end microphones priced in the range of $500-$5,000 each, including an external power supply, the latest miniaturized versions compete effectively with dynamic microphones costing under $100, and the power supply can be internally battery powered or “phantom powered” from a device such as an audio mixing console or a modern

video camcorder. A simplified illustration of the operation of a condenser microphone can be seen in figure 7.

The operation is much more complex in this type microphone due to its construction. A very thin circular diaphragm of metal, or alternatively, a thin membrane of plastic or mylar (think plastic wrap stretched tightly across a small circular hoop) is sputtered with pure gold while in a vacuum. A wire signal lead is attached. Next the diaphragm is placed near - but not touching - a metal backplate to which another wire lead has been placed. The separation distance between the two can be micro meters. We have, in effect, created a capacitor, or condenser as it was once called in electronics.

When voltage is applied to the diaphragm through a large resistor, polarity on the diaphragm will be opposite that of the backplate. As sound waves impinge on the diaphragm it moves closer and further away from the back plate, *varying the capacitance between the two and generating a corresponding voltage across the large resistor.* This high impedance voltage is sent to a powerful pre-amplifying stage (usually a vacuum tube or Field Effect Transistor- F.E.T.) which lowers the impedance and preserves the frequency response of the diaphragm. The signal is drawn off to the amplifier as a low impedance input allowing for long wiring runs with minimal RF interference.

Figure 7. Simplified Condenser Microphone Operation



In high end recording studio microphones of the 1960's through the1980's, the polarizing voltage was often in the hundreds of volts as generated by a separate vacuum tube power supply which sat on the studio floor. In the 1970's a new type of condenser mike, the *electret condenser,* allowed for battery operated polarization of the diaphragm using a Field Effect Transistors (FET). The polarizing voltage has now dropped from hundreds of volts to only 9 - 48 volts D.C.! Amazingly, in the mid 1970's or thereabouts, some microphone manufacturers further reduced this to voltages to as low as 1.5 volts allowing for standard AA batteries or "watch" batteries to become the power source. Today, many recording consoles, input pre-amplifiers and other audio/video devices generate 48 vdc "phantom power". The polarizing voltage is generated at the mixing console or pre-amplifier and sent *over the audio signal wires* to the microphone using a resistor network to isolate it from the sound signal. The ability to physically remove the polarizing power supply from the microphone housing itself, allows for smaller, more compact microphone installations on railcar comm. systems today.

The *advantages* of capacitive microphones are: very smooth, wide frequency response (18 – 20,000 Hz is common), low distortion, difficult to overload the microphone, and relative immunity to temperature variations. *Disadvantages* include a tendency towards "breath deterioration." This is a condition where the gold sputtered diaphragm could gradually flake off, deteriorate and then suddenly fail due to continued humidity and chemical reactions from saliva and blowing into the microphone. Unlike other microphones, a power supply is needed to activate it, adding additional circuitry to an already crowded PC board.

Capacitive or condenser microphones are also sensitive to rough handling, especially when mounted on a “gooseneck” (flexible) accessory arm.

Microphone Precautions

All types of microphones tend to fail if shouted into on a regular basis while trying to communicate in noisy environments such as those found on a moving train. Another consideration for users is that most radio microphones use Automatic Gain Control (A.G.C.). Because of this feature, shouting messages into microphones will automatically be reduced in volume and may even add distortion when heard over the air. A.G.C. circuits also self adjust to noisy environments such as when the air conditioning is operating, or transmissions are made with cab windows open.

“Testing” by car inspectors and railcar technicians by blowing into the microphone is a prime cause of P.A. and Radio System “failures” on many trains. Another *maintenance technique to be avoided* is sticking sharp objects such as toothpicks, paper clips and pencil points into the grill of any microphone to clean out the mouthpiece. There are techniques, approved by most manufacturers, for removing the grillwork from the microphone’s diaphragm and cleaning it with a cotton swab and an approved solvent such as alcohol, or simply replacing the entire assembly.

By personal observation, it has been this author's experience that nearly half the microphones inspected on my job as a subway car inspector were out of service on one line, within 5 years of installation, due to improper use. For this reason, it is my recommendation that the dynamic microphone should be the “weapon of choice” when specifying trainline communication transducers.

4.0 Signs

Introduction to Sign Displays

Trains have used signage of some sort since the earliest days of railroading. Whether a hand-painted destination sign, or a printed scroll listing various destinations that could be set to correspond with the train's route, the net purpose was to inform passengers of the train line and route they were riding and where the train was going – its final destination.

Today's newest trains meet all the requirements stated above, but with electronic technology come an added advantage – flexibility! Utilizing electroluminescent displays (liquid crystals – LCDs), Light Emitting Diodes (LEDs), and video displays consisting of LCD's or plasma (gas charged), the train operator and/or the conductor may easily and efficiently create signage and change it nearly instantly.

LCD Displays

There are typically two types of electronic display signs currently in common use. The **LCD** sign utilizes a pre-set "backlight" or background (usually grey or green). Dark alphanumeric characters are created by sending signals to a matrix of wires causing them to either block the backlight or allow it to pass through. The lettering is often "blocky" or "stairstepped"; that is the edges, especially around curved letters and numbers, are not smooth. Battery operated digital wristwatches, and portable calculators use LCD technology almost universally.

LED Displays

Tiny "light bulbs", which are not light bulbs at all, but semi-conductor diodes which glow when a voltage is passed through them are contrasted against a black or dark surround. This is the principle behind LED technology. Often used inside railcars, most LED signage is red, green, blue or yellow. LED lettering is often characterized by close up inspection which will reveal characters to be composed of individual glowing diode "bulbs". The more bulbs, the greater the resolution of the characters. But in most railcars "just enough to read the sign", because of LED costs, is often the main consideration.

Plasma Displays

A third type of signage used in many railcars is the "plasma display". While not as commonly found in train signage as yet, it will be only a matter of time before you encounter it, if you have not already. Therefore, a short description of plasma is in order.

Plasma displays are capable of the highest resolution in current use in stations and on trains. They are for all intents and purposes "TV screens" and have routinely been a standard in TV studios around the world for quality monitoring, although LED & LCD displays are rapidly catching up. Plasma display contrast ratio, (the ability to resolve the deepest blacks and whitest whites on the same screen) , and accuracy of color, (the most like the cathode ray TV screens we've grown accustomed to since the 1950's), make them ideal for displaying informational or promotional videos while riding in a train or standing on a platform while waiting for one. Their image tends to be viewable across a wide axis from the screen's centerline. Unlike Liquid Crystal Displays, plasma's bright image doesn't fade as you walk to the left or right of the screen. Plasma displays also do not require backlighting as do LCD displays.

Plasma displays make use of advanced physics which involve sending small currents of electricity into a gas charged envelope (screen). The plasma gas glows in the presence of the electrical charge and using a electronically variable control grid, a video picture is formed. The technology is relatively expensive, but economies of production hope to counter the earlier availability of LCD displays in the marketplace. Thus, plasma display prices are beginning to drop rapidly. Plasma screens do have limitations, such as ambient lighting washing out the picture, and the screen may be easily damaged by scratches and careless handling. Advertising revenue will most probably be the main spur in plasma's acceptance in city transit systems. “If it looks like television”, people will tend watch the screen...and get the message.

Testing

Like the audio system, which uses test tones to verify the operation of microphones and speakers in each car, including the operating cabs (e.g., audio loop-back test), the sign network can, in most systems, broadcast a pre-recorded test announcement message while simultaneously lighting all the LEDs on every sign in a predetermined test pattern. The selection of audio and sign tests are generally accessed by a button on the Maintenance Screen or from a laptop computer attached to the CMC.

Flexible Information Network Display (F.I.N.D. Signs)

Although most signs are addressable as a group from the CMC, such as destination signs and interior message displays, there are *independently addressable* signs which also operate on the sign network. These signs *allow pre-run setting up of detailed items* such as route information showing the *actual progression of stations and operating transfer points along the route as the train is running (events).* By using previously set flexible signs it is not necessary to transmit large files of data to them when events change rapidly. These signs are generally triggered by events received by the CCU from various speed and/or distance sensors, or radar detectors, monitoring the rotation of the train's wheels.

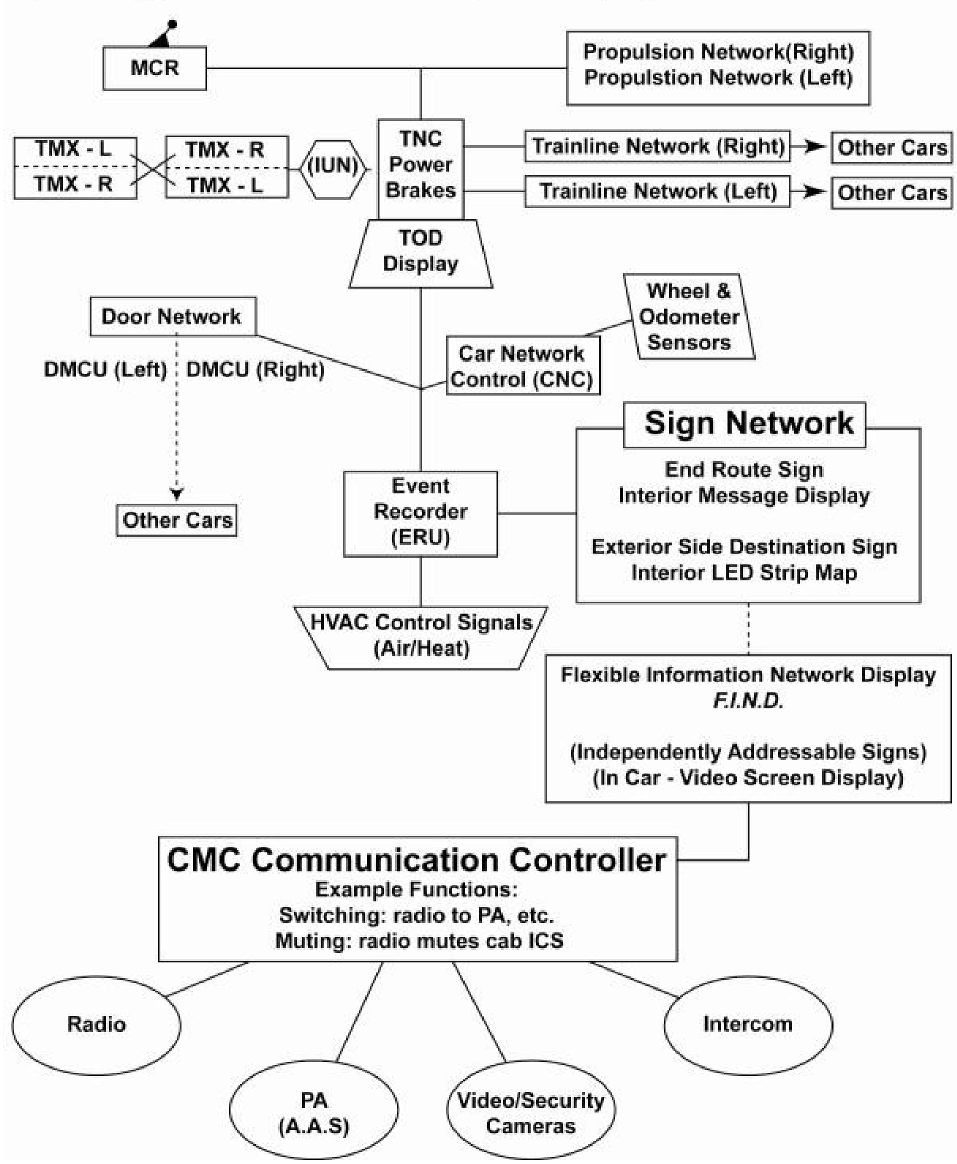
5.0 “Background” Communications

Although not in plain sight as are other communications systems, the “background” or “housekeeping” signals are operating all around train crews, maintainers and passengers whenever they board a New Technology rail vehicle. One has only to try receiving a broadcast A.M. Radio signal onboard a railcar with a pocket radio, even when a new tech train is layed up in a yard to hear a cacophony of synchronizing pulses, high pitched whines, and other such communications that represent the heartbeats of today's modern train. They are in fact the sound of various units “talking amongst themselves” as they log information and report status and faults through a network of wires concealed in walls and channels throughout the train.

6.0 LONWORKS

Many intercity rail lines make use of computer components from a company known as **LONWORKS** which manufactures Large Scale Integrated Circuits (LSI's) which can be programmed and wired in many circuit variations, to perform a large assortment of tasks needed on today's trains. Train networks are often broken up into “nodes” or units which speak to one another over a digital transmission protocol known as “E1”. For example, the train network on an operating (“A”) car may link 2 TNC's and 5 CNC's for a total of 7 nodes. Over this network, information on the many systems in each car may be gathered and recorded in the Monitoring and Diagnostic System's Log.

Figure 8. Typical Network Connections (Housekeeping)



As noted earlier, it is not within the scope of this lesson to detail the inner workings of each and every system or "box" on your train. But a brief description of the system, coupled with specific glossary descriptions given earlier, should give the student a basic familiarity of the purpose and workings of the "background communications" system. So here, presented in no specific order, are the "silent systems" of modern train technology:

Train Network Controller

The Train Network Controller (TNC) is the major network which carries status information and commands such as a Train Operator's Master Controller (MCR) for powering and "brakes released", "door closed and locked" status and signage commands. The TNC provides *synchronization and timing information with other cars in the consist.* This information also feeds the IUN (Inter Unit Network) through the TNC (Train Network Controller) which is connected to a Multiplexer**.** The two devices (TNC & MPX) coordinate and synchronize data with duplicate equipment in an adjoining section, so that both halves of a consist or section (i.e. 4-5 cars) might operate as a single train (i.e. 8-10 cars).

Car Network Controller
As its name implies, the Car Network Controller (CNC) monitors systems and networks inside a car such as, door, sign, lights, HVAC, propulsion and brake networks. It records and reports status information such as faults, tripped circuit breakers and other anomalies, and relays this information in a predetermined sequence, usually via hardwired harnesses to the Train Network and also, to a Railcar Technician's or Car Inspector's *Maintenance Screen* (a sub-screen page on the Train Operator's Display (TOD) which gives mainly operational data to the train crew.

Train Line Controller
This unit interfaces the “A” Car's Master Controller (MCR) with the Train Command Networks (Right and Left Side) to allow CBTC (Communication Based Train Control). It's logic circuits facilitate and monitor Automatic Train Operation so that the train may operate under control of computers, starting, stopping, making station announcements through the CMC, and operating doors at stations, with little or no human intervention. It has an additional interface with the Event Recorder to document operations on the train.

Event Recorder Unit
While technically not a “network” per se, the ERU may be thought of as the “black box” as found on an airplane. It sits on information from nearly every network on the train and is capable of recording the most minute of data on a second-by-second basis. The system originally recorded about 48 of data on hard drives, but gradually has expanded to capture over of 8 days of information on a multitude of train systems including propulsion, braking, doors, MCR encoder values and operating handle positions, among about 20 others. A valuable asset in the event of train accidents or system failures, the ERU is designed to withstand crash impact forces. Information from this recorder can be downloaded using a laptop computer and its information presented in graph form which can be magnified, to analyze functions of all major equipment pieces in minute detail. When the recorder reaches capacity, it starts to erase and record over older data.

TMX, TMS
The Multiplexer, located in “A” Car on most systems, encodes, sends and receives data from various networks, such as the TNC and Inter Unit Network, and transmits it, often through the electric portion of the coupler head, to another Multiplexer, located in an adjoining “A” Car, which simultaneously decodes, sends and receives its own data, in the second section or half of a consist. The units “talk” to one another using an E1 or T1 data communication protocol with the “Left” side of the sending TMX communicating with the corresponding side of the receiving unit and vice versa, often diagrammed as “crisscrossed”. The Multiplexers constantly “scan” information from each network in succession and serially pass this data on, so that both sections of a train effectively work as one.

Trainline Clock Master
Communications trainline use an internally generated clock, or often multiple clocks, to which equipment may be synchronized and allowed to communicate along a common network or bus. The CMC-A generates an Audio Trainline Clock Master which synchronizes among other items, other CMC's (slaves) in other “non-operating” (no crew) cars, the Automatic Announcement System, which includes pre-recorded safety announcements (on a Compact Flash Card) route information, train location, station stops and transfer points, door closing announcements, the blinking of various lights and timing and switching of function on the Communications Control

Panel. The clock generates a time base for logging of maintenance information such as faults, failures, speed and distances traveled. Clock circuits are generally designed to have Large Scale Integrated Circuits (LSI's) to insure the accuracy of data transmission and to reduce “jitter” or fluctuations of time bases as digital “words” are transmitted and received by various piece of equipment in the network. However, because equipment can generate faults or breakdown in service, there are in-built auxiliary buses, alternate modes of transmission and redundancies in circuitry to reduce failures. These depend on the design of individual systems and go into detail beyond the scope of this lesson.

Sign Network

The Sign Network interfaces route signs, end route signs (A Cars), interior information displays, flexible information signs, outside destination signs with the CMC.

NOTE: There are several other Networks, not covered here, such as the IUN or Inter Unit Network which links the TNC's of multiple cars together when coupled. These units and pieces of hardware are essentially redundant and are similar in nature to those discussed above.

7.0 Closed Circuit TV

(Material to be added)

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Motorola	http://www.motorola.com	http://www.motorola.com/Business/US-EN/Pages/Contact_Us
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Supplemental Courseware Materials

None for this Module

Attachment: Industry Training Standard
Communication Systems: Introduction and Preventive Maintenance

210.1 Communication Control Unit

Inspecting and maintaining radio (two-way)
- Test radio (two-way)
- Replace radio (two-way)
- Repair radio (two-way)

Maintaining dedicated power supply (radio)
- Replace dedicated power supply (radio)

Inspecting and maintaining handset/mic
- Test handset/mic
- Replace handset/mic
- Repair handset/mic

Inspecting and maintaining public address system
- Test control unit public address system
- Repair public address system

Inspecting and maintaining amplifier(s)
- Test amplifier(s)
- Adjust amplifier(s)
- Replace amplifier(s)
- Rebuild amplifier(s)

Inspecting and maintaining automatic announcement circuit
- Test automatic announcement circuit
- Replace automatic announcement circuit
- Rebuild automatic announcement circuit

Inspecting and maintaining interior communications
- Test interior communications
- Replace interior communications

Inspecting and maintaining passenger emergency intercom
- Test passenger emergency intercom
- Repair passenger emergency intercom
- Replace passenger emergency intercom

Inspecting and maintaining passenger emergency switch
- Test passenger emergency switch
- Repair passenger emergency switch
- Replace passenger emergency switch

Inspecting and maintaining switch
- Test speakers
- Measure speakers
- Repair speakers
- Replace speakers

Inspecting and maintaining antenna
- Test antenna
- Measure antenna
- Replace antenna

210.2 Signs

Inspecting and maintaining destination signs
- Inspect destination signs

- Test destination signs
- Repair destination signs
- Replace destination signs

Inspecting and maintaining next stop signs

- Inspect next stop signs
- Test next stop signs
- Repair next stop signs
- Replace next stop signs

Inspecting and maintaining route sign

- Inspect route sign
- Test route sign
- Repair route sign
- Replace route sign

210.3 Closed-Circuit TV

Inspecting and maintaining digital video recorder

- Inspect digital video recorder
- Replace digital video recorder
- Reformat digital video recorder
- Download digital video
- Test digital video recorder
- Program digital video recorder
- Repair digital video recorder

Inspecting and maintaining removable hard drives

- Inspect removable hard drives
- Replace removable hard drives
- Reformat removable hard drives

Inspecting and maintaining cameras

- Inspect cameras
- Replace cameras

Inspecting and maintaining amplifier(s)

- Test amplifier(s)
- Replace amplifier(s)
- Program amplifier(s)

Inspecting and maintaining monitors

- Test monitors
- Replace monitors

Inspecting and maintaining wiring

- Inspect wiring
- Replace wiring
- Repair wiring

Inspecting and maintaining mounts/hardware

- Inspect mounts/hardware
- Replace mounts/hardware
- Repair mounts/hardware

RAIL VEHICLE LEVEL 200
SUBJECT OVERVIEW

Module 211: Automatic Train Control

Note: All 200 level courses should be delivered only after completion of 100 level training

About the Author

James Loos has worked as a rail car maintainer and a technical trainer at the Washington Metropolitan Area Transit Authority (WMATA) since 1977. WMATA is a tri-jurisdictional government agency that operates transit service in the Washington, D.C. metropolitan area.

Overview/Purpose

This material provides a general overview of automatic train control to give technicians a basic introduction to the subject and prepare them for national qualification testing.

Material presented here is intended only as a primer to the subject, keeping in mind that rail systems have different characteristics. It follows the National Training Standards established jointly by representatives from both labor and management. As a primer additional knowledge will be needed to become fully qualified on this subject. Material presented here does not address every possible aspect because current collection and distribution vary at each transit agency. Supplemental courseware and other resources to help technicians become qualified on this subject are listed below.

Table of Contents

Table of Contents

Suggested Tools/Training Aids:

- power point presentations
- transparencies
- manuals
- schematics
- mock-up
- on board self-test feature
- PTU
- lap top
- EEPROM burner

Topics Covered:

Topics listed below are covered in this introduction of Couplers. A full copy of the National Training Standards from which these topics were taken is attached.

- Automatic Train Control (ATC)
- Automatic Train Protection (ATP)
- Automatic Train Operation (ATO)
- Automatic Train Supervision (ATS)
- ATP Functions
- ATO Functions
- ATS Functions

Definitions, Abbreviations and Acronyms

For the purposes of this lesson, the following glossary of terms, definitions, acronyms, and abbreviations shall apply. They are not all inclusive, and the reader is encouraged to explore the text, footnotes and bibliography sources for further information.

- **Aspect:** the visual indication presented to an approaching train by a wayside signal; also, the display presented by a cab signal to an operator in the cab.
- **Audio Frequency Track Circuit:** a track circuit energized by an electrical current alternating in the audio frequency range (15,000 - 20,000 Hz); also called "high frequency" or "overlay" track circuit.
- **Automatic Block Signal System:** a series of consecutive blocks governed by block signals, cab signals, or both, actuated by occupancy of the track or by certain conditions affecting the use of a block; such as an open switch or a car standing on a turnout and blocking the main track
- **Automatic Train Control (ATC):** the method for automatically controlling train movement, enforcing train safety, and directing train operations.
- **Automatic Train Protection (ATP):** assuring safe train movement by a combination of train detection, separation of trains running on the same track or over interlocked routes, overspeed prevention, and route interlocking.
- **Automatic Train Operation (ATO):** controlling speed, programmed station stopping, door operation, performance level modification, and other functions traditionally assigned to the train operator and conductor.

AUTOMATIC TRAIN CONTROL FOR RAPID TRANSIT

Introduction

The principles of modern rail rapid transit automatic train control (ATC) are based on the older and usually simpler system of railroad signaling. Railroad signaling is one of the oldest practical applications of electronics outside of communications. Both automatic train control and railroad signaling share the following safety features:

- Track circuits are used for train detection
- Block systems are used for train separation with adequate stopping distance
- Interlockings are used for protection against conflicting routes and improper switch operation

Some of the equipment in a modern transit ATC system, such as relays and switch machines, are identical to those used with railroad signaling. Other devices, such as wayside signals, differ in detail but provide the same function. Rapid transit service also has unique considerations not met with in railroad signaling. Safe control of car doors is one example.

Older transit systems often operate under manual control in conformance with wayside signal indications and operating rules, backed up by mechanical trip stops. Power frequency AC track circuits with insulated joints are used for train detection. Station stopping, platform positioning, and door opening is controlled by the motorman or operator. Although manual systems have been in use for decades with satisfactory results, safety and smooth performance depend greatly on the skill of the operator.

When applied to rapid transit, the designation ATC has been broadened to include functions not normally found in railroad signaling. Thus, a rapid transit ATC System provides not only assurance that trains operate in conformance with signal indications, but also provides fully automatic train operation as well as some additional functions.

Automatic Train Control (ATC)

ATC is the process by which the movement of rail rapid transit vehicles is regulated for the purposes of safety and efficiency. This process is accomplished by a combination of elements (some human, some machines) located on the train (referred to as carborne equipment), along the track and in stations (referred to as wayside equipment), and at remote central facilities (referred to as central control). The carborne, wayside and central control elements interact to form a command and control system with three major subsystems:

- Automatic Train Protection (ATP) which prevents collisions and derailments.
- Automatic Train Operation (ATO) which controls train movement and stopping at stations.
- Automatic Train Supervision (ATS) which directs train movement in relation to the schedule.

A variety of safety features have been designed into the ATC system to assure that any component failure does not result in a dangerous situation. In case of a failure or malfunction the systems are designed to slow and stop the train, rather than accelerate. Figure 1 shows an ATC block diagram of how the various systems interact with one another.

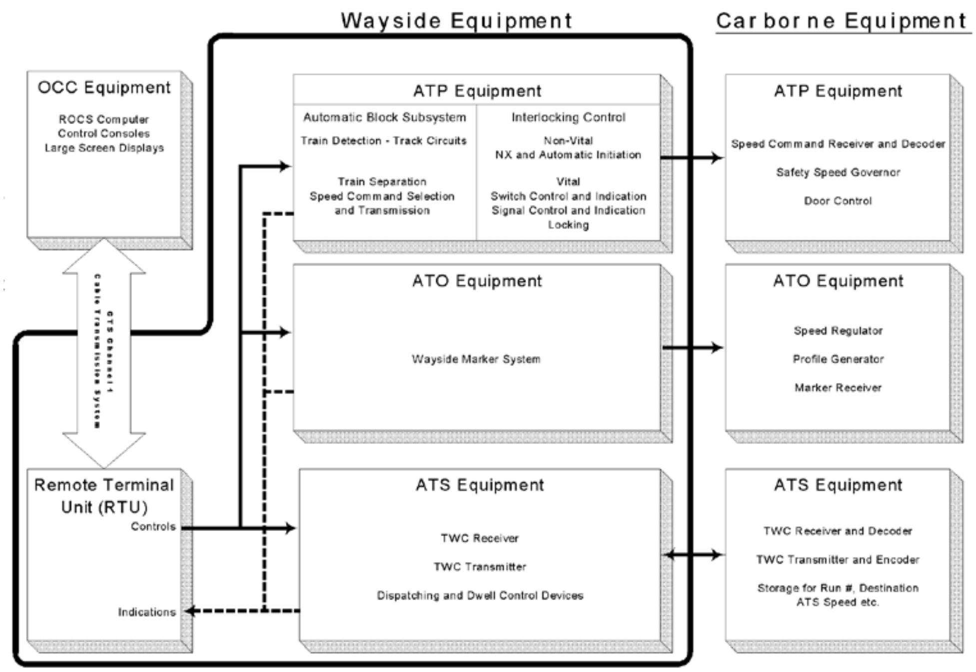

Figure 1. ATC System Block Diagram

Automatic Train Protection (ATP)

The ATP assists in enforcement of safe operation of the system. It imposes speed limits both to maintain safe train separation and to operate trains in accordance with civil speed restrictions. At interlockings, (locations containing track crossings), ATP ensures that train movement is permitted only when a clear, uncontested route is available through the interlocking, and the track switches are locked in position. In all cases where two or more trains are competing for the use of a common segment of track, the system allocates the track to one train at a time in an orderly fashion and locks out all others.

Automatic Train Operation (ATO)

The ATO subsystem performs the functions normally performed by the motorman or operator. Those functions include the smooth acceleration of the train to running speed, regulation of the train's speed to the command speed, and stopping the train smoothly at the proper position in the station. The command speed (reference speed) for the ATO's speed regulation function may be the ATP speed limit, the ATS speed limit, or the ATO station stopping profile speed command. The ATO subsystem selects the lowest of the three as the command or reference speed. The ATP speed limit and the ATS speed limit are explained in later paragraphs.

Automatic Train Supervision (ATS)

The ATS system controls the arrival and departure of trains from all stations, first by automatic equipment at the wayside and secondly by central control computer programs automatically called into operation to accomplish minor schedule adjustments. The central control operator's console displays are updated from data supplied by the ATS subsystem; data are also provided to other central control computer programs that compile operating statistics on each transit car. An important element in the Automatic Train Control installation is the TWC (Train/Wayside Communication) system which provides for two-way train/wayside communication. Although nominally a part of the ATS subsystem, the TWC system has important functions in Automatic Train Protection and Automatic Train Operation. (See Module 210, Communication Systems, by Frank Grassi)

ATP Functions

Train Detection: The key to automatic train protection is the use of multiple track blocks. Track segments are divided into sections that are continuously monitored for train occupancy by track circuits. There are two types of track circuits typically used in rapid transit; high frequency track circuits and AC track circuits.

In high frequency track circuits, trains are detected by coupling a coded signal to the rails through an impedance bond. That signal is then decoupled by another impedance bond at a distance from the transmit bond. As long as the signal reaches the receiving equipment, that track area is considered unoccupied. If the signal fails to reach the receiving equipment for any reason, the track area is considered occupied. As a train travels down the track, the axles short out (shunt) the signal, preventing it from reaching the receiver thus indicating that the track circuit is occupied.

AC track circuits operate on similar principles using an un-coded 60Hz signal directly connected to the rails. Insulated rail joints separate one AC circuit from another. The circuits are designed and adjusted to drop when the train's axles and wheels shunt the rails again indicating that the track circuit is occupied.

Both types of track circuits are designed according to fail-safe principles. In order to indicate that a section of track is unoccupied, the track circuit must be in proper working order. If a rail or wire should break, if an insulated joint breaks down, or excessive noise is present the track circuit gives an occupied indication.

Track occupancy indications are supplied both to the local control panel and/or track and alarm panel, and to the central control facility. This information is also supplied to the interlocking subsystem, where it is used to establish a locked route and switch locking within the selected route. It is also used to develop speed command signals. Figure 2 shows track circuit applications for train detection.

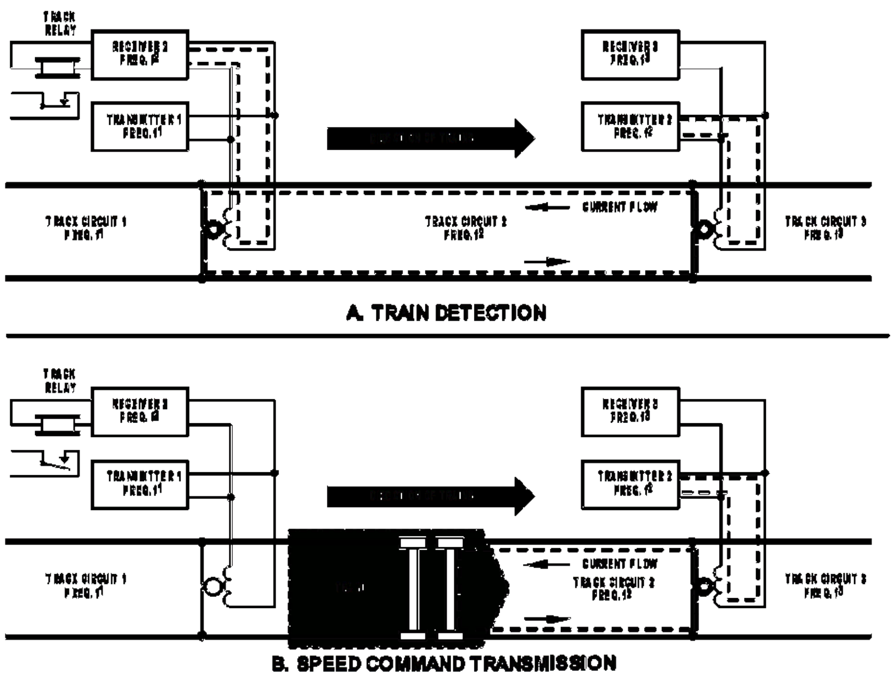

Figure 2. Train Detection

Speed Commands: The speed command or speed limit provided by the wayside ATP to a train following another train on the same track is based on the number of unoccupied blocks separating the two trains. The speed limit is reduced as the distance between the following train and the train ahead decreases to prevent collisions resulting from the following train going too fast to stop within the available distance. Minimum separation is usually one unoccupied block between two trains. Under normal conditions, two trains are never allowed to occupy the same block. Speed command signals are transmitted to the train using the same impedance bonds as the detection signals. The train in turn receives these signals using a set of coils mounted in front of the axle.

Interlockings: Interlockings are placed at several locations along the system. An interlocking is an area of track where equipment is installed to permit the movement of trains between tracks. Interlockings can be manually controlled either at the local control panel or remotely at the central control facility. Some interlockings also can operate automatically for several different purposes.

The track switches in the mainline interlockings are all electrically operated, mechanically locked switches. Fixed wayside color light signals are installed at the limits of all interlockings. The switches and light signals are controlled by vital interlocking subsystem logic circuits, assuring the train's safe passage through these areas.

The carborne ATP equipment receives coded speed command signals from wayside ATP equipment. These signals are transmitted through the impedance bonds and rails and picked up by coils in front of the train wheels. The carborne ATP equipment receives and decodes the signals. The resulting speed command is displayed as a speed limit, also known as a cab signal, in the operator's cab. The speed limit is also used by the carborne ATP's over-speed protection function. The ATP subsystem senses the train's actual speed by use of a tachometer on the train's drive system. The actual speed is also displayed in the operator's cab. The ATP subsystem applies penalty brake whenever the actual train speed exceeds the speed limit. The penalty brake application is maintained until the train's actual speed is below the speed limit. Figure 3 shows how ATP speed commands are communicated between the car and wayside equipment.

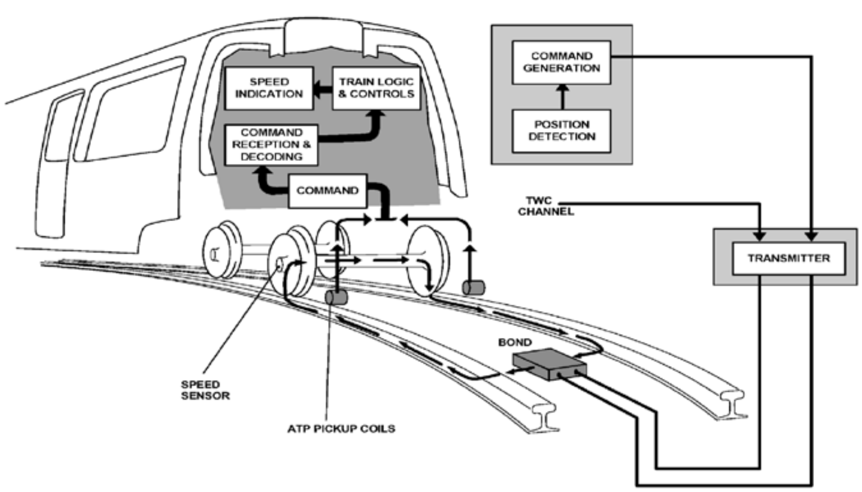

Figure 3. ATP Speed Commands

The over-speed protection function assures that trains on the same track maintain a safe following distance. By requiring that the train's speed remains at or below the wayside ATP speed limit the carborne ATP prevents collisions resulting from the following train going too fast to stop within the available distance.

ATO Functions

The ATO is the subsystem that moves the train and stops it at station locations to board and discharge passengers. Train movement, as controlled by the automatic train operation subsystem, always operates within the constraints of automatic train protection subsystem. The functions performed by the automatic train operation subsystem are:

- Speed regulation - controlling the train speed, within the constraints of the ATP subsystem's over-speed protection function, to make the train run according to schedule.
- Station stopping - bringing the train to a stop within a specified area in a station.
- Door control - opening the train doors in stations to permit passengers to board or exit the train and closing the train doors when the train is ready to leave the station.
- Train starting - initiating train departures from a station after the doors are closed.

Speed Regulation: Speed regulation, as the name implies, is basically a comparator function for matching the actual train speed to the command speed. Speed commands received from coded track circuits are picked up by a carborne receiver, decoded, and compared to actual train speed. Up to this point, the speed regulation function works like the ATP over-speed function. The difference is in how this comparison is used. With the ATP over-speed function, the comparison between the speed command and the actual speed is used to apply a penalty brake to slow or stop the train when the actual speed exceeds the command speed. With the ATO speed regulation function, the comparison is used to control the propulsion and braking to maintain the actual speed close to the commanded speed. In effect, speed regulation removes the human operator from the control loop for running the train and provides for a constant response by propulsion and braking, without the delay of human reaction time and without the variability inherent in manual train operation.

Station Stopping: The other basic function of the ATO subsystem is station stopping, which involves bringing the train to a stop automatically at a predetermined location in each station. This is accomplished by special wayside units working together with receivers, logic circuits, and speed regulation equipment on the train. The wayside units consist of triggers or "markers" spaced some distance from the station as reference points for programmed stopping. The first trigger, farthest from the station initiates on board the train the generation of a velocity vs. distance profile which the train is to follow to a stop. Additional triggers, nearer the station platform, correct the station stopping velocity vs. distance profile for the effects of wheel slip and slide. The ATO speed regulation function monitors the velocity vs. distance profile and controls the braking effort to bring the train to a stop at a predetermined point at the station. Figure 4 shows the proximity of carborne markers and wayside marker coils.

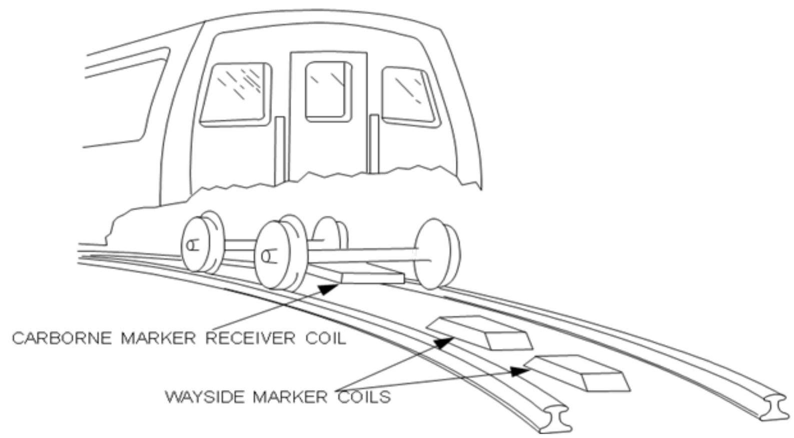

Figure 4. Wayside Markers

Door Control: Other automated functions may be added to the basic ATO subsystem. Doors can be opened automatically after the train is brought to a stop in a station. This requires an interface to allow the ATO subsystem to operate door opening mechanisms and appropriate safety interlocks to assure that the train is in fact stopped and at a station platform before the doors may be opened. Doors can also be closed automatically by adding a timing circuit to sense how long the doors have been open and to provide a door closing signal automatically after the predetermined time at the station (dwell time) has elapsed. The ATO subsystem then initiates the train's departure from the station by applying propulsion power after confirming that doors on the train are closed and locked.

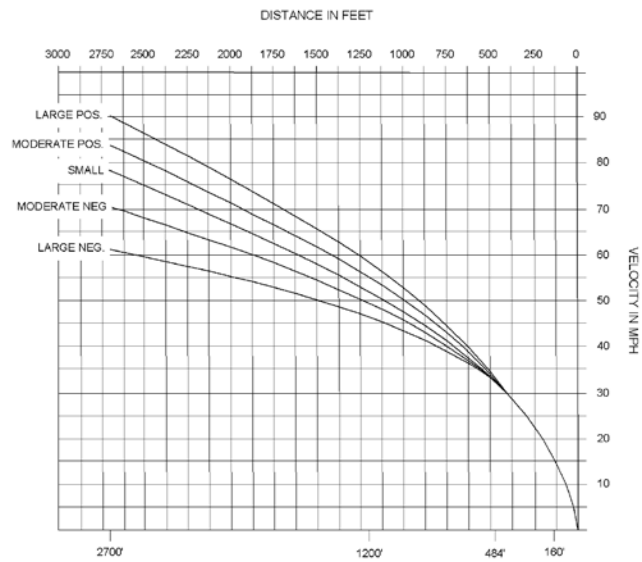

Figure 5. Velocity vs. Distance Profile

Provisions are made to allow the operator to override the automatic system to prevent the doors from opening or closing. The operator may vary the station dwell times, or initiate or prevent the train's automatic departure from the station.

ATS Functions

The ATS subsystem performs routing control and schedule maintenance functions. It also provides a means of communications between the central control facility and wayside locations.

Train-to-Wayside Communications (TWC): Route information, train number, train length, train ready, train berthed, train motion, and doors status information stored onboard the train is transmitted to the wayside via a Train-to-Wayside Communications (TWC) link. The wayside logic responds to the TWC transmissions to perform various supervisory functions such as setting routes, making performance level modification, etc. Route changes and station dwell times may be altered by the central control operator through the ATS subsystem.

Wayside-to-Train Communications (WTC): The Wayside-to-Train Communications (WTC) provide a supervisory speed limit, which is more restrictive than the wayside-supplied ATP speed limit, and is used by central control for maintaining track headway.

Glossary of Train Control Terms

ASPECT - the visual indication presented to an approaching train by a wayside signal; also, the display presented by a cab signal to an operator in the cab.

AUDIO FREQUENCY TRACK CIRCUIT - a track circuit energized by an electrical current alternating in the audio frequency range (15,000 - 20,000 Hz); also called “high frequency” or “overlay” track circuit.

AUTOMATIC BLOCK SIGNAL SYSTEM - a series of consecutive blocks governed by block signals, cab signals, or both, actuated by occupancy of the track or by certain conditions affecting the use of a block; such as an open switch or a car standing on a turnout and blocking the main track

AUTOMATIC TRAIN CONTROL (ATC) - the method for automatically controlling train movement, enforcing train safety, and directing train operations.

AUTOMATIC TRAIN PROTECTION (ATP) - assuring safe train movement by a combination of train detection, separation of trains running on the same track or over interlocked routes, overspeed prevention, and route interlocking.

AUTOMATIC TRAIN OPERATION (ATO) - controlling speed, programmed station stopping, door operation, performance level modification, and other functions traditionally assigned to the train operator and conductor.

AUTOMATIC TRAIN SUPERVISION (ATS) - monitoring of system status and directing traffic movement to maintain the schedule or minimize the effect of delays.

BERTHING - the positioning of a train in its assigned berth.

BLOCK - a length of track of defined limits, the use of which is governed by block signals, cab signals, or both.

ABSOLUTE BLOCK - a block into which no train is allowed to enter while it is occupied by another train.

PERMISSIVE BLOCK - a block into which a train is allowed to enter even though occupied by another train.

BRAKING - the process of retarding or stopping train movement by any of various devices:

DYNAMIC BRAKING - a system of electrical braking in which the traction motors are used as generators and convert the kinetic energy of the vehicle into electrical energy.

FRICTION BRAKING - braking supplied by a mechanical shoe or pad pressing against the wheels or other rotating surface; also called “mechanical braking”.

FULL SERVICE BRAKING - a nonemergency brake application that obtains the maximum brake rate consistent with the design of the primary brake system.

SERVICE BRAKING - braking produced by the primary train braking system,

CAB SIGNALS - a signal system whereby block condition and the prevailing civil speed commands are transmitted and displayed directly within the train cab.

CENTRAL CONTROL - the place from which train supervision and direction is accomplished for the entire transit system; the train command center.

VITAL CIRCUIT - an electrical circuit that affects the safety of train operation.

CONSIST (noun) - the number, type, and specific identity of cars that compose a train.

DISPATCH - to start a train into revenue service from a terminal zone, transfer track, or designated intermediate point.

DWELL (or DWELL TIME) - the elapsed time from the instant a train stops moving in a station until the instant it resumes moving,

FAIL SAFE - a characteristic of a system which ensures that a fault or malfunction of any element affecting safety will cause the system to revert to a state that is known to be safe; alternatively, a system characteristic which ensures that any fault or malfunction will not result in an unsafe condition.

FREQUENCY SHIFT KEYED (FSK) - a technique used with high-frequency AC track circuits, in which the frequency of the track signal is varied between two or more discrete states to convey information (used as an alternative to rate modulation where the track circuit is turned on and off as an information code).

Hz (HERTZ) - the unit of frequency equal to 1 cycle per second.

IMPEDANCE BOND - a device of low resistance and relatively high reactance, used to provide a continuous path for the return of propulsion current around insulated joints and to confine alternating current signaling energy within a track circuit.

INDUCTIVELY COUPLED IMPEDANCE BOND - an impedance bond in which transmitter energy and receivers are inductively coupled into a track circuit, INSULATED JOINT - a joint placed between abutting rail ends to insulate them from each other electrically.

INTERLOCKING - an arrangement of signals and control apparatus so interconnected that functions must succeed each other in a predetermined sequence, thus permitting train movements along routes only if safe conditions exist.

MANUAL BLOCK SIGNAL SYSTEM - a block signal system operated manually, usually based on information transmitted by telephone or telegraph.

MARRIED PAIR - two semi-permanently coupled cars that share certain essential components and are usually operated as a unit.

MASTER CONTROLLER - a carborne device that generates control signals to the propulsion and braking systems.

OPERATOR - the transit employee on board the train having direct and immediate control over the movement of the train.

OVER-SPEED CONTROL - that onboard portion of the carborne ATC system that enforces speed limits in a fail-safe manner.

RAIL RAPID TRANSIT - a mode of transportation operating in a city or metropolitan area and high-speed passenger cars run singly or in trains on fixed guide ways in separate rights-of-way from which all other vehicular and foot traffic is excluded.

RELAY - a device operated by variation in the condition of one electric circuit and used to effect the operation of other devices in the same or another circuit; commonly, an electromagnetic device to achieve this function.

TRACK RELAY - a relay receiving all or part of its operating energy through conductors having the track.

SHUNT - a conductor joining two points in an electrical circuit so as to form a parallel or alternate path through which a portion of the current may pass.

SIGNAL - a means of communicating direction or warning.

CIVIL SPEED LIMIT - the maximum speed allowed in a specified section of track as determined by physical limitations of the track structure, train design, and passenger comfort.

SAFETY SPEED LIMIT - the maximum speed at which a train can safely negotiate a given section of track under the conditions prevailing at the time of passage. (Safety speed may be less than or equal to civil speed,)

SPEED PROFILE - a plot of speed against distance traveled.

SPEED REGULATOR - an onboard subsystem, usually part of the automatic train operation (ATO) system, that controls acceleration and braking to cause the train to reach and maintain a desired speed.

FULL SERVICE STOP - a train stop achieved by a brake application, other than emergency, that develops the maximum brake rate.

PENALTY BRAKE - irrevocable open-loop braking initiated by an onboard automatic system or by a wayside trip stop as a result of a block violation or uncorrected over-speed.

PROGRAMMED STOP - a train stop produced by closed-loop braking such that the train is stopped at a designated point according to a predetermined speed-distance profile.

STOP SIGNAL - a signal indication requiring a train to stop and stay stopped and permitting no exceptions such as running at reduced speed, movement within restricting limits, or similar alternatives.

TRAIN PROTECTION STOP - a train stop initiated by the automatic train protection (ATP) system.

SWITCH - a device that moves rails (switch points) laterally to permit a train to transfer from one track to another

TRACK CIRCUIT - an arrangement of electrical equipment, including the rails of the track, that forms a continuous electrical path used for the purpose of detecting the presence of trains on the rails.

TRAIN - a consist of one or more cars combined into an operating unit.

TRAIN DETECTION EQUIPMENT - the track circuits and associated apparatus used to detect the presence of trains in blocks,

TRAIN IDENTIFICATION - a method of designating trains by means of such information as train number, destination, or length; may be accomplished automatically for functions such as routing or dispatching.

TRIP STOP - a mechanical arm, located on the wayside, that can initiate a penalty brake application on a train that passes it by engaging a brake-triggering device (trip cock) on the train.

YARD - a network of tracks for making up trains and storing cars.

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Example: Smith, John, “Rail Vehicle Maintenance”, 1965, Popular Library Edition, North American Philips Co. Inc.

Relevant OEM Contact Information

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US&S		
GE		
Siemens		
Bombardier		
PHW		
Thales		

CBTC (ATP-ATO): Introduction and Preventive Maintenance

- **211.1 Automatic Train Protection**

  Inspecting and maintaining coils
  - Test coils
  - Inspect coils

  Inspecting and maintaining modules/CPU
  - Test modules/CPU
  - Replace modules/CPU

  Inspecting and maintaining circuit boards
  - Test circuit boards
  - Replace circuit boards

  Inspecting and maintaining vital relay
  - Test vital relay
  - Replace vital relay

  Inspecting and maintaining power supply
  - Test power supply
  - Replace power supply

  Inspecting and maintaining radio/antenna
  - Test radio/antenna
  - Replace radio/antenna

  Inspecting and maintaining operator acknowledgement button
  - Test operator acknowledgement button
  - Replace operator acknowledgement button

  Inspecting and maintaining operator bypass switch
  - Test operator bypass switch
  - Replace operator bypass switch

  Inspecting and maintaining visual and audible alarms
  - Test visual and audible alarms
  - Replace visual and audible alarms

  Inspecting and maintaining train operator display
  - Test train operator display
  - Replace train operator display

  Inspecting and maintaining operator interface panel
  - Test operator interface panel
  - Replace operator interface panel

  Inspecting and maintaining speed measuring device
  - Test speed measuring device
  - Replace speed measuring device

- **211.2 Automatic Train Operation**

  Inspecting and maintaining train operator display
  - Test train operator display
  - Replace train operator display

  Inspecting and maintaining train operator panel
  - Test train operator panel
  - Replace train operator panel

  Inspecting and maintaining ATO modules/CPU
  - Test ATO modules/CPU
  - Replace ATO modules/CPU

  Inspecting and maintaining power supply
  - Test power supply

- Replace power supply

Inspecting and maintaining radio antenna
- Test radio/antenna
- Replace radio/antenna

Inspecting and maintaining train-to-wayside communication
- Test train-to-wayside communication
- Replace train-to-wayside communication

Inspecting and maintaining operator acknowledgement button
- Test operator acknowledgement button
- Repair operator acknowledgement button
- Replace operator acknowledgement button

Inspecting and maintaining operator bypass switch
- Test operator bypass switch
- Replace operator bypass switch

Inspecting and maintaining visual and audible alarms
- Test visual and audible alarms
- Replace visual and audible alarms

Inspecting and maintaining operator interface panel
- Test operator interface panel
- Replace operator interface panel

- **211.3 Automatic Train Supervision**

Inspecting and maintaining monitor
- Test monitor
- Replace monitor

Inspecting and maintaining module/CPU
- Test module/CPU
- Replace module/CPU

- **211.4 Speed Regulator**

Inspecting and maintaining power supply
- Test power supply
- Replace power supply

Inspecting and maintaining module/CPU
- Test module/CPU
- Replace module/CPU

RAIL VEHICLE LEVEL 207
SUBJECT OVERVIEW

Module 212: Troubleshooting

About the Author

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Overview / Purpose

This material provides a general overview of the troubleshooting process along with related general strategies, tips and pitfalls.

Table of Contents

Suggested Tools/Training Aids:

- power point presentations
- transparencies
- manuals
- schematics
- railcar
- laptop

Topics Covered:

Topics listed below are covered in this introduction of Troubleshooting.

1. Troubleshooting Safety
2. The Troubleshooting Process
3. Troubleshooting Tips and Pitfalls
4. General Troubleshooting Application
5. Electrical Testing and Troubleshooting for Rail Vehicles

Definitions, Abbreviations and Acronyms

For the purposes of this lesson, the following glossary of terms, definitions, acronyms, and abbreviations shall apply. They are not all inclusive, and the reader is encouraged to explore the text, footnotes and bibliography sources for further information.

Acronyms

- Vdc: DC Voltage
- Vac: AC Voltage
- mA: milli Amps
- A: Amps
- Hz: Hertz
- mVdc: mili Volts

Introductory Text by Topic Area

- **1. Troubleshooting Safety**

Follow all local safety procedure at all times. Safety procedures are for your protection and other around you. Always become familiar with all local safety procedures before troubleshooting. When working on equipment you should always wear PPE (safety glasses, safety boots, elect…). Before working on new or unfamiliar equipment it is in your best interest to review any Running Maintenance Manuals (RMM) or other relevant document to familiarize yourself with the equipment.

- Hazards are especially prevalent when working with:
- Power supplies, both high voltage and low voltage - Arc/Flash, Explosion, Toxic gasses, and Death.
- Hydraulic systems there are many hazards - Pin hole injuries Add
- Pneumatics

- **2. The Troubleshooting Process**

Troubleshooting is an integral part of the maintenance of rail vehicles. Whether a "symptom" is noticed or a report is made that equipment is simply not working, troubleshooting to get to the heart of the problem so that corrective solutions are found and implemented are key to quickest solution and excellent service.

This module will explore general troubleshooting in terms of a basic troubleshooting process, general strategies, tips, pitfalls, and application procedures. Later, we will explore this process in the specific context of rail vehicle systems by looking at common failures and some discussion examples.

Troubleshooting is defined as a systematic approach to find the source of a problem in an effort to restore an operation or process. In other words, troubleshooting is complex problem solving in a methodical and organized manner. In situations where multifaceted systems need to be maintained, symptoms and problems may have causes difficult to diagnose or even have multiple causes. In any case, an orderly and logical troubleshooting approach is required. Some may compare troubleshooting to that of a doctor who observes and lists symptoms, theorizes possible problems, performs tests, finds a prescription or solution, and then re-evaluates in order to restore optimum health to their patient. Sometimes troubleshooting requires a simple solution, and other times "symptoms" may be a sign of a larger problem that is more hidden from "surface" view. Either way, troubleshooters are like a doctor for their assigned system. In this case of rail vehicles, a troubleshooter is a doctor for the rail vehicle.

With troubleshooting, once the source or **root cause** of a problem is found, the problem can then be solved and appropriate repairs or adjustments made. Follow-up analysis is also critical to test and ensure the accurate solution was found. If the operation or process is not normal after initial repairs or adjustments are made, then the source of the problem was not found and the troubleshooting process must be repeated. Thus, finding the source of a problem early on is better than later in order to avoid frustration and lost service.

There are many benefits of effective troubleshooting. Some of these include long-term time and cost savings, fewer failures, equipment life extension, technician job satisfaction and enhanced capabilities, better supervisor flexibility and efficiency, improved service, and increased safety.

A general systematic approach to troubleshooting involves a series of steps. The steps needed for each particular problem will most likely vary, and subsequent steps will also vary depending on results obtained during the troubleshooting process itself. Setting a goal and planning probable steps for troubleshooting a particular problem will be beneficial in remaining focused. Without a goal, improper tests may be performed, problems not readily solved, money and time wasted, and the situation can become rather frustrating. While "setting up" to troubleshoot may take a little time at first, the time and energy it will save later can make all the difference.

The following is a list of steps one can follow for troubleshooting. Again, this is only a sample list and each problem will most likely vary and consequently steps taken in conjunction with possible strategies may vary. However, this is a basic approach and model one can follow to begin the troubleshooting process.

Troubleshooting Steps

1. **<u>Getting Started</u>: Know the system, state the problem, and adopt a troubleshooting attitude.**

   Know the system. Hopefully by the time troubleshooting begins, this step of the process will be complete. If not, then some research may need to be done in order to learn more about the system or part of the system. But, knowing the system and its parts regarding normal and expected operation is crucial before beginning to troubleshoot a problem.

   If we compare troubleshooting to the job of a doctor, we know a doctor would have a difficult time identifying the problem and solution for a patient if they did not have knowledge of anatomy and how the body works. The same is true for anything that needs troubleshooting: one must know and understand the parts and how they work together in the larger system in order to identify, analyze, and find an effective solution to any problem that should arise.

   Document the problem. While this may seem tedious, documenting the problem will help to bring clarity and possibly additional thoughts initially to the situation. Once again, if we compare this process to one a doctor would employ, they will almost always begin with a patient’s chart and by documenting their process stating the initial complaint and symptoms their patient is experiencing.

As you move through the process of troubleshooting, documentation should continue in the form of note taking. These notes will also help establish a goal to meet as well as steps you are taking or have taken. Complex problems will especially benefit from the process of documentation as one can get lost in the process of troubleshooting and easily forget a step taken or symptom observed. If needed later, documenting and notes will provide an immediate resource for the problem at hand and for any later occurrences of problems either directly or indirectly related to the current problem at hand.

Adopt a Troubleshooting Attitude. Troubleshooting can sometimes be an easy process with a simple and obvious solution right away. Other times, troubleshooting can be complicated and more intense. Either way, keeping a “cool head” and adopting a “**troubleshooting attitude**” can be key in solving a problem, especially when the problem is complex or difficult. Some important factors to keep in mind in an effort to adopt a troubleshooting attitude include:

- Stay focused.
- Block out “noise” as best as possible. Sometimes you may be required to address a problem in a heavy pedestrian traffic area with many distractions.
- Stay positive
- Deal with patrons in the area in a helpful, cheerful way.
- Keep a “cool head”
- Perseverance and patience
- Step back and take a break when needed and when possible. Sometimes those answers will come to you when you remove yourself from the situation and take a little time to reflect.
- Converse with someone about the problem. Sometimes talking it out may help bring clarity, or talking with another may bring a new perspective or ideas not yet considered derived from different experiences.
- Remember: you know the system. Confidence is important.

2. <u>Expand Your Knowledge of Problem</u>: Collect information, establish involved systems, and define problem.

Collect information, identify symptoms, and ask key questions. Now is the time to begin expanding the documentation process by identifying symptoms, asking key questions, and collecting information. Again and just like a doctor, by taking a few notes and writing down this information, you will be able to “see” your path through the troubleshooting process and the particular case you are working on. Again, this could also help later if the derived solution does not completely fix the problem or if the case is especially complex.

Collecting information is a two-step process that is actually done at the same time and continues throughout the duration of the problem. The first step is to collect information, and the second involves deciding what is relevant to the problem and what is not. If one came out to find their car unable to start, they would immediately begin this process by determining what may be the source of the problem and what is unrelated. Obviously, the driver of the car would not check the tires deciding almost immediately that they are not relevant to the situation. However, the driver may consider and begin to think about the parts of the car which are relevant to the problem such as testing the battery, checking the starter, etc.

At this step, it is important to again recognize what is normal operation. Understanding how something acts or exists under normal conditions is critical in knowing identifying what is not normal. Re-creating the problem will also be helpful, especially if the problem is intermittent. Likewise, if the problem is intermittent, it may be difficult to re-produce. All the same, knowing the system and knowing what is normal is critical at this step.

As you proceed, further clarifying the problem and enlarging the realm of possible avenues to follow in the troubleshooting process is important. Considering the example of a car not starting, perhaps one may also look at the level of gas or oil as they begin a closer examination and perhaps broader look at the situation. These two areas are not directly related and come to mind immediately when a car will not start, but could certainly prevent a car from starting if levels are not as they should be or empty altogether.

As you begin to collect information, some key considerations or questions to ask may include:

- Gather immediate information about the situation – Ask about the situation or anyone who may have relevant knowledge about the problem or condition.
- Investigate initial complaints or situation, employ sensory inspection – check the problem out for yourself. Use your eyes, ears, nose, touch when possible to get a feel for the problem.
- What kinds of historical problems have there been with the generic equipment (routine breaks) – check for general problems with this generic type of equipment or manufacturer, if possible ask around to others who may have previously worked on this type of equipment.
- Check log book for problems with the specific equipment – has the equipment displayed the same symptoms previously? Perhaps the symptoms have been treated but the problem not solved.
- Complete a **sensory inspection**. What environmentally is going on (hot, cold, rain, wind, ice, snow..) – Is there an environmental condition that is impacting the equipment performance? Have temperatures dropped too low? Is

something overheated? Do you notice any unusual smells or sounds? Do any parts of the system seem unusual to the touch?

- Check equipment manufacturer manual for manufacturer troubleshooting suggestions and recommendations.
- What is going on and what is not going on, characteristics of the problem – Look at all facets and angles of the problem and filter out what may be symptoms and problem related and what is not.
- What is the electrical data output is from PLC and controller? – Check electrical readings. What are the basic power or voltage readings, measurements?
- What other local equipment is having trouble? Look at broader, larger picture?
- Determine root cause, who owns problem? Sometimes, a problem may lie outside of the immediate situation and beyond the specific equipment.

Establish systems and subsystems involved. This is the point where scope of the problem should be considered. You now have the symptoms and have defined the problem, what areas or parts of the equipment may be contributing or related to the problem at hand? Again, this all part of the process of divide and conquer – what is related and what is not related. This step is of looking at the smaller picture: the actual problem, and also the bigger picture: what else may be contributing to the problem. What additional parts of the larger system may and which may not be part of the problem?

3. <u>Theory & Test</u>: Select best probably cause(s), test, and evaluate.

List possible causes & develop your theory. Remember the scientific method in school? This is the step to state what you think may be going on, or make a hypothesis. A **hypothesis** is an educated guess. You have educated yourself as to the nature of the problem, and now is the time to use your background knowledge of the equipment along with the new information you have gathered to make an educated guess about what is happing and the cause of the problem.

One way to go about developing your theory, or guess, is to list all possible causes for the problem. From there, begin a process of elimination by checking off what you think is most likely not the cause thus eventually leaving one or two probable causes. During this step, keep in mind the systems and subsystems in mind being careful not to confuse symptoms with point sources for problems. In following this process for developing your theory, you will most likely come up with a cause for your problem. Additionally, if after testing the problem is still occurring, then you will have a list already developed of other possible causes to investigate.

Test. Some may want to jump to this step right away and skip other steps. However, a good troubleshooter will go through the previous steps of documentation & taking notes, establishing the problem, collecting information sorting what is related and what is not, looking at the whole picture, and developing a theory prior to any testing. These previous steps will help determine what tests are appropriate for the situation and therefore save time, resources, and frustration in the long run. Also, be sure to consider all the symptoms and information you collected and test accordingly. Do not ignore a symptom and be sure to keep the documentation & note taking process going since recording those test results will help in the deciding if you've found the solution. If a solution is not found, recorded test results will be beneficial for further consideration of the problem.

4. **<u>Evaluate and Decide.</u>**

Evaluate test results. What happened in the tests? What were the results? Now is the time to look at data collected and determine if the hypothesis was correct or not? Are more tests needed? Should you "back up" and collect more information? What have you learned from the tests? Can a solution be determined? Again, be sure to document your results for future reference should the problem or something similar occurs again or a solution was not found and test results may be needed for additional data in problem analysis.

Decide. Once you have evaluated your test results, determine if a solution was found.

5. **<u>Go Back OR Fix, Test, & Record.</u>**

If test results indicated your theory was wrong, it will be time to go back to the troubleshooting process. If this is the case, review information you had initially collected and take another look at the system along with the problem. Was there anything missed the first time through?   Was the problem identified correctly? Look at your possible causes? Are there some you did not consider and/or should take a closer look at now? Are other systems not considered previously possibly part of the problem?

Or

Tests were completed and a solution found. Now it is time to apply the solution and make the necessary repairs. Once the repairs have been made, it is important to re-evaluate and decide if the equipment has been adequately repaired and restored to proper working condition by testing once more.

The last step in the troubleshooting process is to record and document your conclusions. This recording and documentation should occur in two places. The first place is to conclude your final results in your own troubleshooting notes. The second place is to document in your transit authority's equipment maintenance log book. This is an important step and will be covered more later in the module.

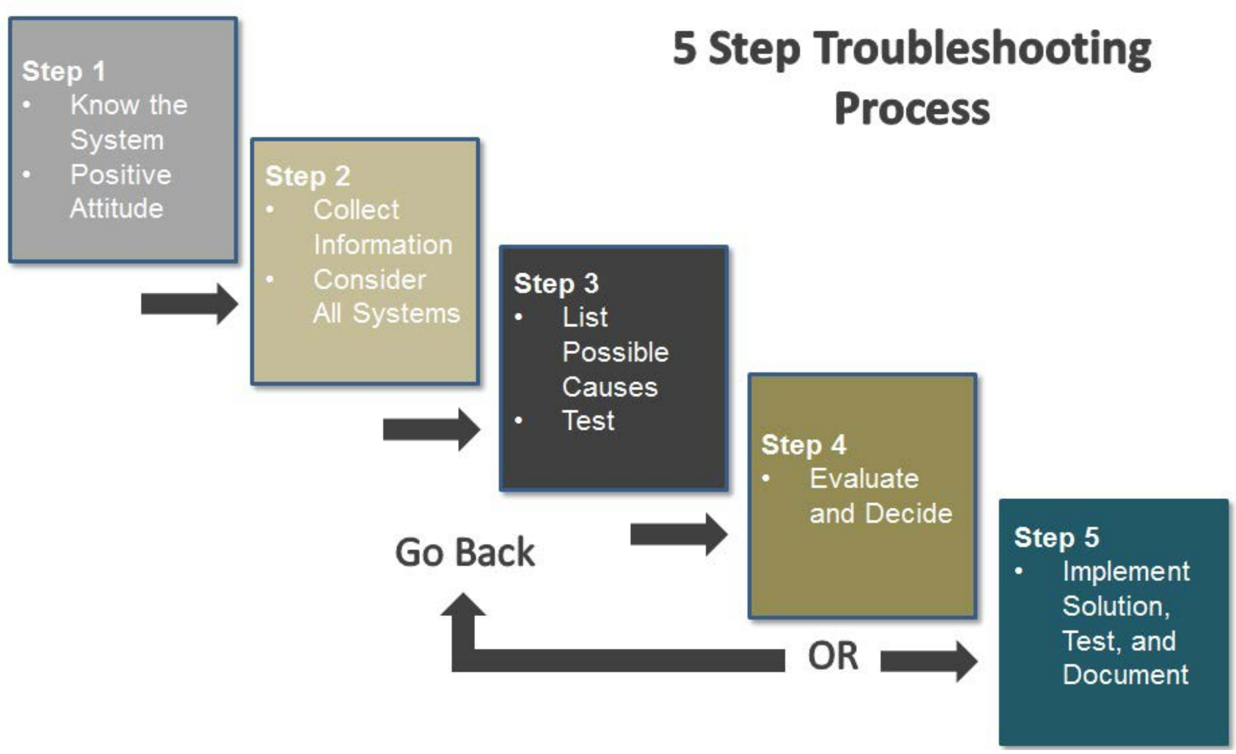


Figure 1 Five Step Troubleshooting Process

Troubleshooting Strategies

The steps above are a general series of steps to utilize and follow in the trouble shooting process. Other approaches for troubleshooting are also possible. These approaches, or strategies, can be used as part of these steps or can stand on their own in the appropriate situation. Some of the various strategies to also use may include:

- **The "Half-Split" or "Half Half" Method**. Essentially what the method does is allows one to determine where a problem exists within the equipment. This strategy is characterized by a binary search across a range of dependencies. In other words, the idea behind this strategy is that with each step in troubleshooting, half of the system or part of the system is eliminated as a possible cause of the problem.
- **Process of elimination or Function vs. non-function.** This is a simple method and typically what inexperienced/novice technicians go to first in troubleshooting and involves eliminating areas or possibilities that are not part of the problem. In other words, identify where the problem *is not*, and focus your efforts elsewhere. Whatever components or subsystems necessary for the properly working parts to function are probably okay. The degree of fault can often tell you what part of it is to blame. In a complex problem, or in various stages of the troubleshooting process, process of elimination can be used as part of the process itself. If the drive system is not producing the desired end result, look for what it is doing correctly.
- **Recent Alterations**. Check to see if the problem occurred immediately after some kind of maintenance or other change to the drive. Chances are the new problem could be a result of that change or adjustment.
- **KISS principle**. "Keep it Simple, Stupid" or "Keep It Short and Simple" or "Occam's Razor". Look for the easy solutions first. An example may be if something does not turn on, check to see if it is plugged in before checking the wires. Or, if you see hoof prints, look for a horse instead of a cat.
- **Inducing or Deducing.** This strategy is a top-down, deductive method which employs a logic diagram displaying the system and what parts connect directly and indirectly to others. One can use this to work backwards from the symptom source or use to look at the systems and subsystems.

- **3. Troubleshooting Tips and Pitfalls**

Troubleshooting Tips
A good troubleshooter will know and utilize specific strategies within the troubleshooting process. They have learned these strategies from their own experience or the experience of others. Some of these strategies and tips are listed below

- **Persistence and open-minds.** The "real world" does not always provide helpful resources. Be persistent and open minded in the troubleshooting process.
- **Re-examine previous questions**. Maybe information collected was disregarded too quickly. Go back and re-examine previous questions that may need to be re-asked.
- **Examine prior occurrence:** Look at the maintenance log and other records to see how this problem was resolved before. If the log shows a common solution to the problem, then the technician should check that solution first. If the previous solution did not adequately and effectively solve the problem, then one can avoid repeating what hasn't already worked and use this information to start in a new direction.
- **Look for easy solutions first.** Is it plugged in?

Troubleshooting Pitfalls
On the contrary, a good troubleshooter knows what pitfalls to avoid which result in saved time and frustration. A few of these include:

- **Don't jump to conclusions.** Do not "fix it before you get there", and do not determine the solution before fully investigating and asking initial questions.
- **Limited investigation.** Do not rely just on past problem information. This problem could be different, or perhaps the problem was not solved correctly before.
- **Treating only symptoms.** Look for an underlying root cause to the problem, and do not just "treat" symptoms. This will result in only "putting a band-aid over a gaping wound" and will not only miss on solving the problem, but may also lead to additional problems, further equipment breakdown, and potentially compromise the safety of yourself others.
- **Poor information.** Unfortunately, this can be a problem that adds to the problem. Inadequate documentation, prints, schematics, and OEM books are sometimes not complete or even have wrong information. Be sure to use your senses, further investigate, and trace the system. Don't settle when something is incomplete.

- **Repeating.** Do not always rely on same technique over and over again. For example, do not immediately check the voltage meter when “symptoms” do not indicate a need. Give careful thought to the situation and specific symptoms before you.
- **“Not thinking”**. Not giving something enough of your attention and expecting the answer to be obvious can result in missing important information, steps, and consequently the right solution.
- **Do not “over think”**. Overthinking a situation can lead to possibly ignoring simple solutions.
- **Narrow view**. Remember to consider the bigger picture or whole system, especially important in step 4, systems and subsystems. This is the time to consider what is connected to what, and what beyond the initial scope could be contributing to the problem.

Recommendations for Troubleshooting in a Group

Troubleshooting in a group setting can offer benefits and challenges. When more than one person is involved in the troubleshooting process, the opportunity to benefit from multiple experiences and ideas can be very useful. Each person that is present brings to the group various backgrounds and experiences offering a wider range of perspectives which can be especially helpful when a problem is particularly difficult. When more than one person is involved, the immediate chance to discuss and talk the problem out is also readily available and clarity of the problem may develop more quickly.

While troubleshooting in a group can be beneficial, some challenges from working in a group setting could develop. With more than one person, and especially in a larger group, a leader for the group is important. Likewise, if other roles or duties need to be filled such as a note-taker, safety leader, tester, etc, then it is important for the group to decide and more-or-less assign those roles. With various individuals responsible for different parts of the problem, communication and progress should be more efficient. In addition, when more than one person is involved, safety awareness becomes more critical especially with regard to communication. Transit authority safety regulations and procedures should be reviewed along with communication and any other task procedures or troubleshooting plans should be discusses up front before the troubleshooting process begins.

Ground Rules

- Select a leader and possibly a recorder, everyone else is doing/testing/observing/etc
- Review safety procedures, checklists, communication procedures, and troubleshooting plan with the entire group before starting. If a new person joins the troubleshooting group later on, update that individual with this information and the status of the problem immediately.

Troubleshooting Documentation

Troubleshooting documentation occurs in two phases: throughout the troubleshooting process and as part of the record keeping process. The first phase of note taking occurs during the troubleshooting process itself. This is an important step especially when a problem is complex and various systems are involved and has been covered to some extent already in this module As mentioned before, writing down notes about the problem and can help bring clarity to the problem itself along with a record of the process to consult with if needed later. If tests are run and the solution is not found, these notes then become a record to go back to and consult with so that one knows what has been tried and what has not been tried or considered in solving the problem. Writing down details regarding the problem thus becomes critical in the troubleshooting process. If one must stop for some reason before a solution is found, then there is also a record to review before beginning again therefore preventing the possibility of repeating steps. Additionally, if more than one person is involved in the process, notes can be helpful in the communication process.

The second part of the documentation process is the last step in troubleshooting: record keeping. Record keeping is your transit authority's official process of officially documenting the problem and how it was solved. Each transit authority usually keeps a log or record book with each system, and some may maintain records in a computer data base using specific software. For long term maintenance and evaluation of a system and its parts, this document is important part of the overall system. Follow your specific transit authority procedures regarding their specific policies regarding documentation.

4. General Troubleshooting Application

As stated before, note-taking during the troubleshooting process can be very helpful, especially for those new to troubleshooting in a given field or for a complex problem. Sometimes having a note-sheet for this process can assist in providing structure for the troubleshooting process when needed. The following document can be used for the purpose of practice exercise in your course as well as later when you are in the field and on a particular job.

Troubleshooting Note Record
<u>Initial Problem or Complaint</u>:

<u>Information Collected</u>:

Problem Reported By -

Sensory Inspection -

Environment -

Log Book Information -

Any Other Relevant Information -

<u>Systems or Subsystems Involved:</u>

<u>All Possible Causes:</u>

<u>Tests to Perform:</u>

<u>Findings:</u>

<u>Solution:</u>

5. Electrical Testing and Troubleshooting for Rail Vehicles

In order to perform electrical tests on and troubleshoot rail vehicle systems, it is important to have an understanding of certain key terms, how to make calculations related to electrical power and how to use the appropriate meter to take electrical measurements

Electrical Terms

Series circuits are circuits that only have one path of current.

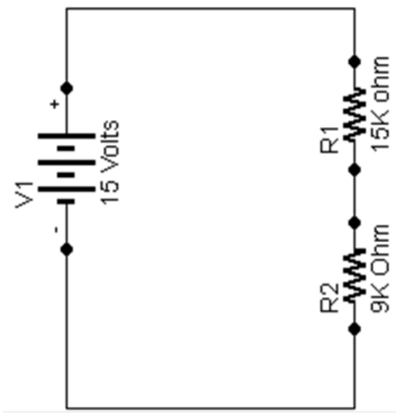


Figure 2 Example of Series Circuit

Parallel circuits have multiple paths of current.

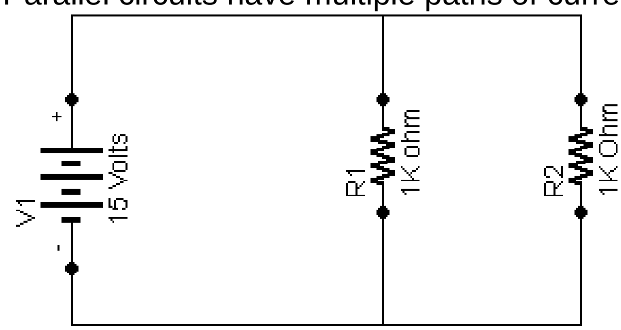


Figure 3 Example of a Parallel Circuit

Series/Parallel circuits are a combination of parallel and series circuits.

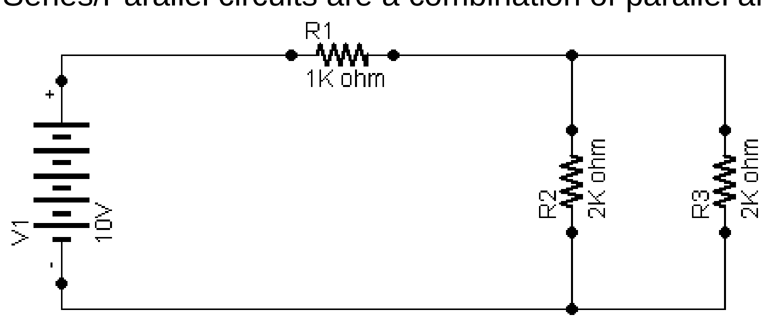


Figure 4 Example of a Series/Parallel Circuit

An open is where there is no path of current.

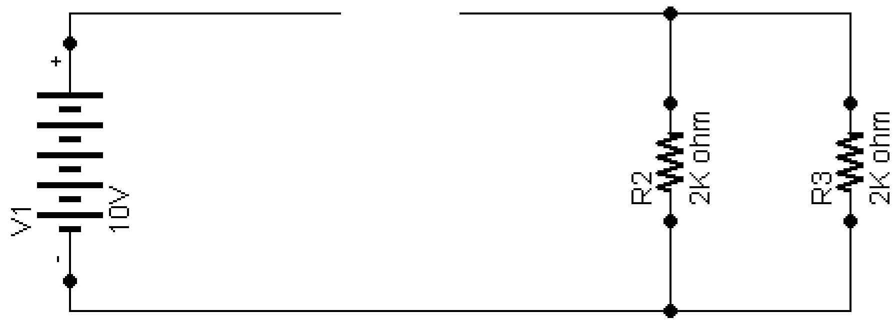


Figure 5 Example of An Open

In this example R2 is shorted out. In a short circuit condition there will be a higher than normal current draw which will produce more heat. In some cases you can detect a hot component by its color or even a temperature meter.

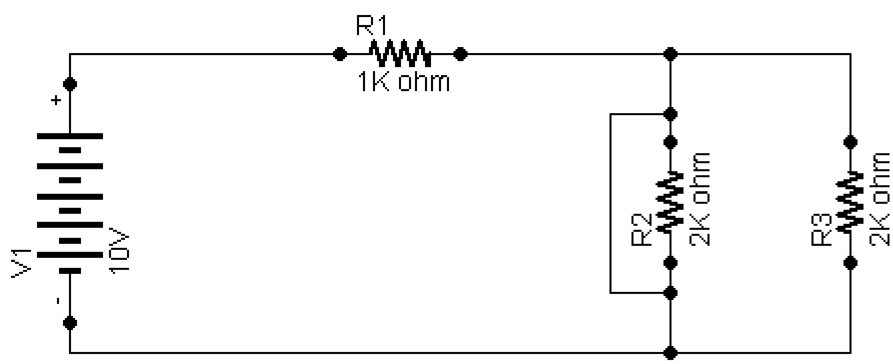


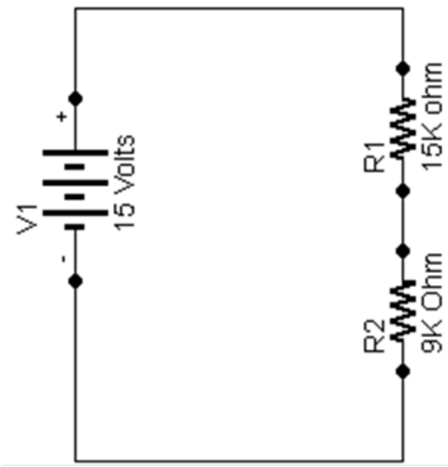
Figure 6 Example of a Short

Partial shorts are similar to a direct short. It just has more resistance than direct short. This type of defect can be difficult to isolate.

Partial opens are similar to opens but there will be a path of current. Partial open are very hard to troubleshoot.

Electrical Calculations

Series

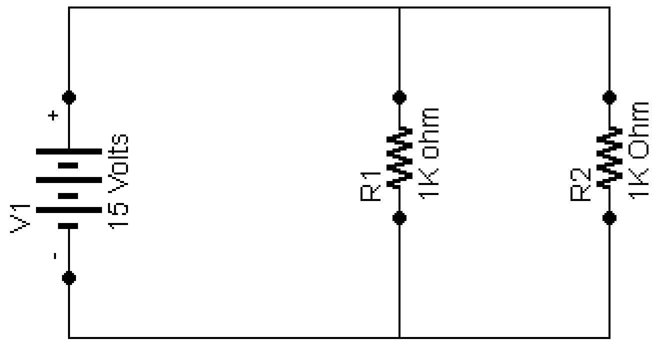


Rtotal = R1 + R2	24Kohms = 15Kohm + 9Kohm
Itotal = V1 / Rtotal	625uA = 15 / 24Kohm
IR1 = I total	625uA = 625uA
IR2 = I total	625uA = 625uA
VR1 = R1 * IR1	9.375V = 15Kohm * 625uA
VR2 = R2 * IR2	5.625V = 9Kohm * 625uA

Check your answers: If V1 does not equal VR1 + VR2 you have done something wrong.

V1 = VR1 + VR2	15V = 9.375V + 5.625V

Parallel



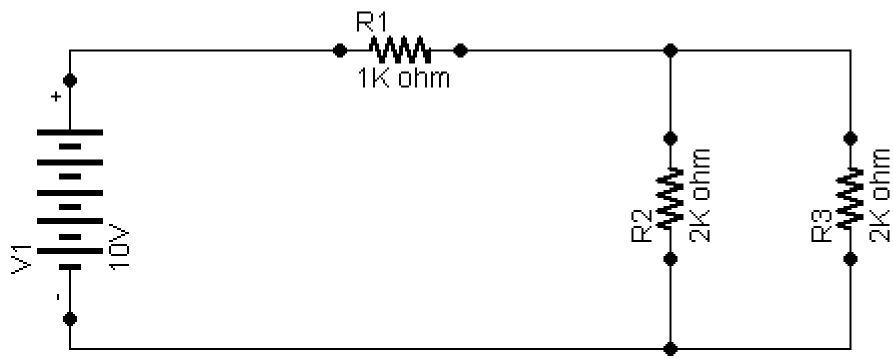
Rtotal = 1 / (1/R1 + 1/R2)	500ohms = 1 / (1 / 1Kohm + 1 / 1Kohm)
Itotal = V1 / Rtotal	30mA = 15V / 500ohms
VR1 = V1	15V = 15V
VR2 = V1	15V = 15V
IR1 = VR1 / R1	15mA = 15V / 1Kohm
IR2 = VR2 / R2	15mA = 15V / 1Kohm

Check your answer

Itotal = IR1 + IR2	30mA = 15mA + 15mA

Series/Parallel

As you analyze the circuit you can draw out the current paths this may help you keep things straight.



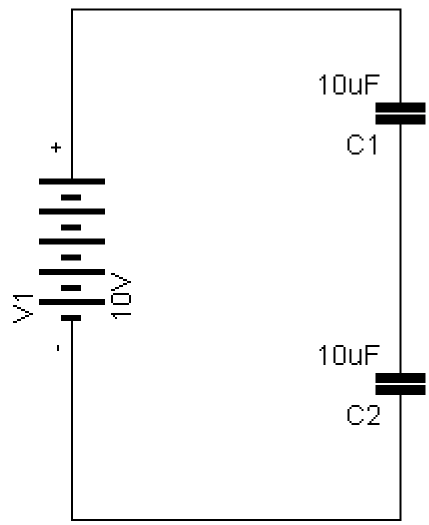
R2,3 = 1 / (1 / R2 + 1 / R3)	1Kohm = 1 / (1 / 2Kohm + 1 / 2Kohm)
Rtotal = R1 + R2,3	2Kohm = 1Kohm + 1Kohm
Itotal = V1 / Rtotal	5mA = 15V / 2Kohm
IR1 = Itotal	5mA = 5mA
VR1 = IR1 * R1	5V = 5mA * 1Kohm
VR2 = V1 - VR1	5V = 10V - 5V
VR3 = V1 - VR1	5V = 10V - 5V
IR2 = VR2 / R2	2.5mA = 5V / 2Kohm
IR3 = VR3 / R3	2.5mA = 5V / 2Kohm

Check your Answers

Itotal = IR2 + IR3	5mA = 2.5mA + 2.5mA

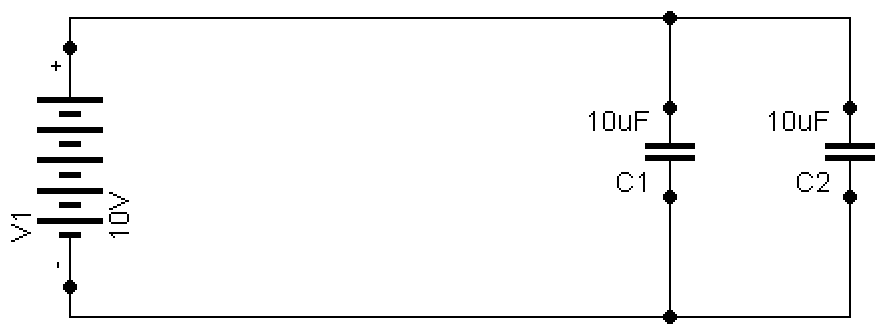
Calculate total capacitance.

Series



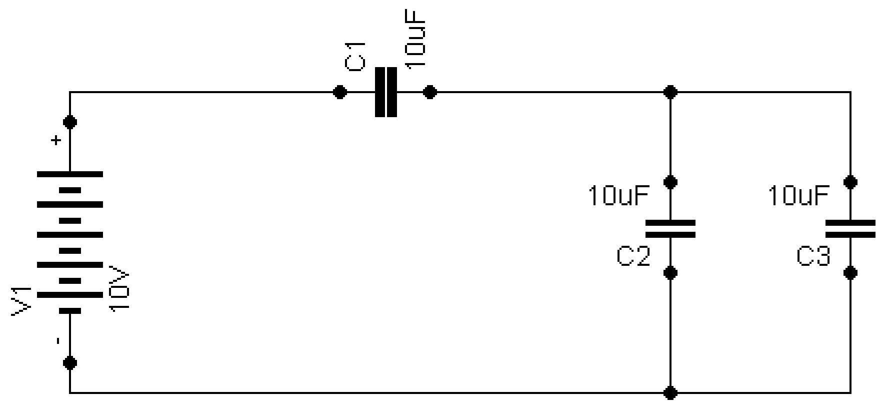
Ctotal = 1 / (1 / C1 + 1 / C2)   5uF = 1 / (1 / 10uF + 1 / 10uF)

Parallel



Ctotal = C1 + C2   20uF = 10uF +10uF

Series\Parallel



C1,2 = 1 / (1/C2 + 1/C3) 5uF = 1 / (1 / 10uF + 1 / 10uF)

Ctotal = C1 + C1,2 15uF = 10uF + 5uF

Using Meters for Testing and Troubleshooting

Understanding your meter and what it is capable of doing is pivotal to good troubleshooting of rail vehicles. Most meters are capable of measuring many types of measurements, such as voltage, current, temperature, capacitance and resistance.

Voltage measurement: A Voltage measurement is a measurement of potential deference between two points. This means all measurements are done between two points. The majority of measurements are done from ground to a test point. Measuring from ground to a test point is usually the safest route, because you can easily attach one side of your meter to ground. When you attaching one side of your meter to ground, the measurement will only require one hand to take, which will reduce the chances of electrical shock. There are times where measuring voltage with ground being your reference is not beneficial, for instance if you suspect a bad relay contact it may be more effective to measure the voltage drop across the contact.

Current measurement: Current is a measurement of the number of electrons passing a point. Measuring current requires you to put your meter in series with the circuit you are trying to measure.

Temperature measurements: The temperature function of your meter can be used to measure temperatures of components which may help in determining a component failure. Usually hot is bad!

Capacitance measurements: The capacitance function is typically not used on a DMM for troubleshooting because they do not really help you determine if a capacitor is bad or not. To check a capacitor properly it requires a special meter called capacitor checker. The capacitor will allow you to check the dielectric leakage.

Resistance measurements: The resistance function is very straight forward, it is for measuring resistance. One thing you need to keep in mind is if you are using the resistance function be aware that your meter can actually charge a capacitor on this setting, this can create electrical shock hazard.

Identify Abbreviations on Your Meter

Vdc	DC Voltage
Vac	AC Voltage
mA	milli Amps
A	Amps
Hz	Hertz
Temp.	Temperature
mVdc	mili Volts
ohm	Resistance

Identify Other Terminology on Your Meter
Range - Allows you to manual select you range. Use if the measurement fluctuates a lot
MinMax - measures and display the min, max and average value during a sample time.
Hold - This will hold the current value when pressed

State of Measured Values Using Both Digital and Analog Meters

Measurement	Appropriate Meter to Use
Root Mean Square (RMS) value	Digital Multi Meters (DMMs)
Average Value	Analog meters
Peak Value	Oscilloscope and some higher end DMMs
Peak to Peak Value	Oscilloscope and some higher end DMMs

Determine the Proper Setting of Your Meter
Range When you are using a meter the requires you to manually enter your range setting. It is best to set your meter to a higher range setting and work your way down, until you reach a setting that give you the maximum resolution.

Most current DMM have Auto Range settings, which will automatically set the range setting to the most accurate range setting.

Resolution - The higher the resolution the better the accuracy of the measurement. With DMM this usually this means the meter will display more digits after the decimal point.

Frequency - The Frequency function is used to measure frequency. Typically DMM will have multiple frequency functions HzAC, HzDC.

Duty Cycle - the Duty Cycle function will measure the duty cycle of a square wave.

Volt - The voltage function is for measuring voltage. On this setting your meter will have a very high impedance, which will minimize your effect on the circuit being measured.

Amp - The Amp function is for measuring amperage. You do not want to try to measure voltage with this function or you can damage your meter. On this setting the impedance of the meter is very low, which if connected across a battery it will draw a lot of current and will damage your meter.

Resistance - This function is used to check continuity and resistance of a circuit. While in this function you may not want to test the circuit while power is applied or you may damage your meter. If you see a negative number it usually means there is an external voltage affecting the meter. Typically the external voltage will be from a capacitor in the circuit. Also be aware that you can slowly charge a capacitor with meter. So be careful especially if you are dealing with very large capacitors.

Hz - Use this function to measure frequency.

Using Your Meter for Troubleshooting

Relays.
To test relays you must first off need to know what each contact state should be. You can find this in the schematics or on the relay itself. Once you know the normal state of the relay you can test each contact with meter, remember NC means normally closed, NO means normally open. Use the continuity function of your meter or the resistance function to test the relay in its normal state, which means it is off or not energized. Check all contacts. Next step is to test all contact in its energized state.

The next step is to check the coil this can be done with resistance function and compare it with a known good relay. Make Sure that you disconnect the relay from the driving circuit or you may not get the correct measurement. Also don't forget about any diode or varresistor that may be connected to the coil, they may have the same effect as the driving circuit.

Another way to test for a bad contact is to set your meter the voltage setting and measure across the closed contacts, if there is voltage across the contact then the contact is bad. This is a good way if you relay is still in a live circuit.

Useful Tips:

- When energizing the relay, check for mechanical movement.
- Also check the length of time it takes to change state and compare it with a known good relay.

Wires.

Wires can be tested with the resistance function. Connect each side of wire to the meter and you should read a very low resistance.

PWM.

Test PWM signals with the duty cycle setting on your meter.

Diodes.

Diodes can be checked with the diode function or with the resistance function.

To test diodes with the diode function. The red lead will be connected to the Anode and the black lead to the Cathode, the meter will beep and/or display a voltage. This voltage is the diode forward voltage drop; this value will vary with the type of diode being tested. If you do not measure a value your diode junction is most likely damaged.

The next part will test the blocking capability of the diode. You will reverse the leads to were the red lead is connected to cathode and black lead to the anode. The meter will not beep or display a voltage and will display OL which means over load. This means the diode passed.

To test diodes with the resistance function. Connect the red lead to the cathode and the black lead to the anode. The meter will read a low resistance. This means it passed

Next, connect the black lead to the cathode and the red lead to the anode. The meter will read a high resistance. This means it passed.

Line Chokes.

Line chokes are tested with a meter called a megger. The megger test the insulation on the line choke. This type of meter uses very high voltages to test the insulation. You will want to disconnect the line choke from the car before the test or it may result in damaging the car.

Motors.

Motors are tested with a meter called a megger which tests the insulation between windings.

Grounds.

Bad grounds are usually the last thing a tech checks but are the most common problems. You can test for a good ground using the resistance function of you meter. Put one test lead on a known good ground and the other test lead on the suspected bad ground if there is a high resistance you have a bad ground/wire.

Additional Resources

General Troubleshooting Practice Exercises

http://www.ibiblio.org/kuphaldt/socratic/output/trouble2.pdf

http://www.allaboutcircuits.com/worksheets/trouble2.html

Scientific Method

http://www.sciencebuddies.org/science-fair-projects/project_scientific_method.shtml

Cognitive Components of Troubleshooting Strategies

http://act-r.psy.cmu.edu/papers/714/gugerty_2006_TAR_troubleshooting_preview.pdf