Transit Cooperative Research Program

Sponsored by the Federal Transit Administration

RESEARCH RESULTS DIGEST

May 1997--Number 17

Subject Areas: VI Public Transit and VII Rail   Responsible Senior Program Officer: Christopher W. Jenks

Improved Methods for Increasing Wheel/Rail Adhesion in the Presence of Natural Contaminants

This TCRP digest summarizes the findings from TCRP Project C-6, "Improved Methods for Increasing Wheel/Rail Adhesion in the Presence of Natural Contaminants," conducted by Tranergy Corporation.

INTRODUCTION

This digest recommends methods for improving wheel/rail adhesion where railhead contamination by moisture, ice, grease, and leaves and other vegetation has adversely affected operation.

Light rail and commuter rail services may experience schedule delays during the year because of railhead contamination by moisture, ice, and leaves and other vegetation. These natural contaminants build up on the railhead, thereby causing slip and slide conditions, which affect the ability of light rail and commuter rail systems to safely maintain operating schedules. Frequent sanding, the means most often used to lessen the effect of slip and slide conditions, is costly. Other disadvantages of sanding include accelerated wheel wear; damage to the track structure because of fouling of ballast, drains, and switch points; disruption of train detection systems; and premature rotting of ties. As a result, there is a need to identify alternatives to sanding.

Research was conducted under TCRP Project C-6, "Improved Methods for Increasing Wheel/Rail Adhesion in the Presence of Natural Contaminants" by Tranergy Corporation. This research, completed in 1996, evaluated current practices for the control of railhead contamination by moisture, ice, and leaves and other vegetation and identified new or modified alternatives to sanding that show promise for improving wheel/rail adhesion under these conditions. The research focused on light rail and commuter rail operations. This digest summarizes the work performed in the research.

BACKGROUND

The need for increased wheel/rail adhesion for transit rail services has been recognized for a long time. Improved wheel/rail adhesion results in better operating performance and system cost savings. Locomotive manufacturers have made great strides in improving the adhesion levels of their locomotives. New technologies developed by these manufacturers have considerable relevance for improving adhesion in rail passenger services. In metropolitan rail passenger services, loss of adhesion can cause problems in schedule reliability and can contribute to development of wheel flats. Wheel flats can be an expensive maintenance item and can make the system noisy. The initial loss of adhesion in such services results in excessive wheel slip, the proof of which can be seen as "rail burns" in stations at the point where train movement begins. Although schedules are significantly affected by the initial acceleration of the train, on the basis of its maximum adhesion capability, adhesion also affects braking. Insufficient adhesion can result in wheel slips and slides that can lead to wheel flats on wheel treads. Development of wheel flats leads to increased loss of adhesion, damage to the rail surface, increased damage to bearings and axles, and increased wheel noise. Extreme loss of adhesion may lead to collisions or derailments. Although passenger rail service schedule performance is generally of primary concern, economical operation is also a consideration in these systems. One important economic aspect of commuter rail is the possible need for two power units or two locomotives instead of one in areas where loss of adhesion is significant.

Tractive effort of a locomotive or self-propelled car can be increased by increasing vehicle weight. This approach, taken by most designers, has limitations the axle loads can be increased only up to a value that is permissible for the available rail and track. Therefore, it is essential to improve adhesion in order to develop and maintain needed tractive effort.

The conventional approach for improving wheel/rail adhesion has been the application of sand. Sand is inexpensive and simple to apply; however, it produces 10 to 100 times more wheel and rail wear. It damages all bearing surfaces of the vehicle and damages the track by contaminating the ballast. Sand should be used only for cases of extreme rail contamination.

The research approach for this project was to first develop a theoretical analysis of adhesion, including the factors affecting adhesion and the mechanisms by which adhesion is reduced. A survey was then taken of two dozen commuter and light rail systems regarding their experiences and observations. A laboratory investigation of adhesion, an intensive search and review of literature, and a study of the properties of rail contaminants were then completed. A field investigation of rail contaminants was then done in two parts. The first part was a study of rail contaminants conducted by the Association of American Railroads (AAR). The second part was the analysis and experimentation with rail contaminants collected with the help of three commuter and light rail systems. The results of the above work were then used to develop methods for improving adhesion. Finally, a cost-benefit analysis was conducted using the numbers of one transit system as an example. Conclusions and ideas for suggested research are given at the end of the report.

FINDINGS

Rail surface contamination is the primary reason for loss of adhesion. Fallen leaves (especially leaves with oil [e.g., pine and cedar leaves]); a little water, frost, or light drizzle; and morning hours produce the worst conditions for maintenance of adhesion. Rust, dry dirt, and other dry contaminants on top of the rail, by themselves, do not affect adhesion much; however, the presence of small amounts of water and oil results in the formation of a thin slurry or paste that reduces adhesion. Heavy rains do not reduce adhesion as much because they tend to wash the rail and remove the slurry.

High-speed passenger trains (i.e., those traveling at 100 mph or above) or those transit trains needing high accelerations or decelerations near stations require high adhesion coefficients. Most passenger trains traveling at speeds below 100 mph do not seem to suffer insufficient adhesion in traction modes, except under the environmental conditions discussed above or when braking, where wheel slip and slide conditions develop more readily. (This is especially true for train decelerations greater than 0.83 m/s2 [1.8567 mi/hr/sec] on contaminated rail.) Large creep (i.e., longitudinal slip at the wheel/rail interface) levels, followed by wheel skidding and eventual locking, result in wheel flats even with the most advanced slip and slide control systems used in the high-speed trains of Japan. Japanese railway companies have developed a classification system of wheel tread damage to compare the degree of wheel flat occurrence. This classification system can be adapted for North American light and commuter rail systems.

Removal of leaves and other organic material from the rails during the Fall is a very direct way to reduce Fall problems of adhesion. Such removal can be done by vehicles designed for this purpose. The presence of water, along with other contaminants, is a major contributor to loss of adhesion, but can be handled in many ways. Overseas, a special composite cleaning block, mounted on tractive wheels, is used to enhance traction, especially in the presence of water and high speeds. This cleaning block has also helped in achieving higher train speeds, reducing wheel flats, and reducing train noise (5-7 db). Advantage should be taken of the dry hot-air jets and creep-based cleaning and drying systems for developing a drier, cleaner rail surface.

Sand application is a standard method of adhesion improvement. Sand equivalent products, such as sandite, and other particulate material, such as alumina, can be used to enhance adhesion. Sand continues to be the preferred material--even for modern, high-speed trains, such as TGV. The sand must be extremely clean (99% quartz) and must not contain clay. Large quantities of sand, applied manually by the train operator, are not desirable because the sand damages the track and ballast and leads to reduced adhesion levels. Certain commercial adhesion enhancers being promoted involve rubbing a solid stick on the wheel. The stick leaves a layer of the material on the wheel that comes between the wheel and rail contact as a "third layer," and it "modifies friction" between the two surfaces. Although this approach achieves improvements in friction under certain conditions--high creep, for example--it is not possible for a film (which is weaker than steel) to develop shear strength comparable to a good steel-on-steel contact. There is also a question of what this layer, once transferred to the rail by tractive wheels, will do to the nontractive wheels with respect to their friction, ride quality, and lateral forces produced on the rail.

Loss of adhesion develops on road crossings because of the mud contaminants deposited on the rail surface by automobile wheels. In short tunnels, loss of adhesion, resulting from an oil spray spill over on the rail and moisture seepage usually present in tunnels, has been observed. Use of oil sprays on wheel flanges should be avoided in tunnels.

Cleaning the rail mechanically (e.g., by brushing or scrubbing has not enhanced adhesion. Most chemical methods of cleaning the rail have also not enhanced adhesion.

Wheel creep and its control constitute the second largest influence on adhesion, after the influence of contaminants. Light and commuter rail systems can make significant gains by using the latest advances in this area. By using proper power and creep control methods, locomotive manufacturers are achieving adhesion levels up to 40%, twice the value achieved in the light and commuter rail systems. Real-time control by modern microprocessors, together with an understanding of wheel/rail adhesion creep characteristics, can greatly enhance adhesion during acceleration and braking. Three-phase AC traction has proven superior to DC traction in controlling creep and enhancing adhesion. Adhesion levels above 40% have been claimed by several companies. For new systems, or for existing systems where a change to 3-phase AC traction is possible, serious thought should be given to use of AC traction along with a modern, microprocessor-based, frequency creep control system. Use of radial trucks in self-powered vehicles, where economics permits the small increase of capital investment, will also improve the adhesion performance of light and commuter rail systems.

A survey of the experiences of 24 North American light and commuter rail transit agencies was conducted. The survey included questions about adhesion on their system, *conditions* under which insufficient adhesion developed, slide wheel flats, rail lubrication, methods used for improving adhesion, type of rail used, traffic information, type of wheels, and any additional comments. The results showed that most systems were concerned about adhesion; however, low adhesion did not affect their schedules except in the Fall when leaves covered the rails. Insufficient adhesion also occurred in the early mornings and on icy, frosty rails. Light drizzle also reduces adhesion. The major problem for the systems, however, is the development of wheel flats because of slip and slide during braking. More than 30% of wheels were replaced in some systems because of wheel slide flats. Wheel flats increase noise, damage the rail, and increase the cost of maintaining the system. Dry stick lubricants, rail weight/metallurgy, and wheel profile do not noticeably improve adhesion. This survey also pointed out a need for inclusion of a leaf-removing system, a rail cleaning and drying system with hot-air jets, and a wheel-cleaning system with special cleaning blocks. The costs of such new systems are estimated to be much lower than the present costs of the development of wheel flats.

A study of physical and chemical properties of rail contaminants was done by British Rail, and a similar study is being done by AAR. These studies have revealed that the rail surface is coated with a thin film of surface active oils, grease, and solid debris. The oils contain large organic molecules, acid ester, ketone, amines, and sulphur-containing compounds, which form a strongly absorbed surface film that reduces adhesion. The solid debris was mostly oxides of iron in the United Kingdom and a mixture of brake dust, oxides of iron, and mud and dirt in the United States. These films cannot be removed chemically or by scrubbing.

Five series of adhesion creep experiments were conducted on a quarter-scale laboratory facility using simulated organic and inorganic contaminants. The data show that creep has a dominating influence on the adhesion levels reached. Higher creep levels tend to improve adhesion by consuming the contaminant between the wheel and the rail. The contact adhesion performance seems to jump from a lower level curve to a higher adhesion level curve with the control of creep. Contact noise develops significantly under very high creep. A micro stick and slip phenomenon and a macro stick and slip phenomenon are believed to be developing in the contact.

A commuter and light rail surface contaminant investigation was conducted on three rail systems as follows:

- Santa Clara County Transportation Agency, San Jose, CA;
- Niagara Frontier Transportation Authority, Buffalo, NY; and
- Southeastern Pennsylvania Transit Authority, Philadelphia, PA.

The investigation of these systems yielded worthwhile results. These three systems are from distinct environments in the country, so the conclusions drawn can be considered reasonably representative of the North American systems. In all, seven samples were tested in two different ways. The first test was a chemical analysis of elemental composition and organic fraction composition, using scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR) techniques. The SEM results for essentially all the insoluble fractions of the contaminants-were characteristic of rust (iron oxide) and dirt (silica and aluminum). Iron was the most abundant element found by weight (5195%) and silica was next (2-39%). On freight train tracks, the AAR study showed as much silica (9-74%) as iron (18-62%) on the tracks. Elements found on light and commuter rails but not found on freight tracks included potassium, sodium, chlorine, and sulphur. These reflect the presence of salt and dirt resulting from winter road conditions and automobile traffic.

It was found from the rail contaminants (90% iron) that tunnels develop the most rust in a temperate climate. Silica (dust) is higher on rails exposed to city traffic. The calcium chloride, sulphides, and mineral and synthetic oil present with water produce a surface active environment that reduces adhesion.

The laboratory adhesion investigation, which used rail contaminant samples, showed the following:

- The presence of moisture, even a small amount, produces a significant initial slip of the wheels.
- With increased creep levels (creep control), higher adhesion levels can frequently be produced. This is attributed to the presence of a large percentage of iron oxide in the contaminants.
- Adhesion levels remain low for rails where surface active compounds are present along with moisture.
- The most important finding of this research was that, even in the presence of surface active compounds, when a hot-air jet was applied to the rail and/or wheel, good adhesion levels could be attained. This is based on quarter-scale laboratory adhesion creep tests of contaminants gathered from field rails.
- A cost-benefit analysis was completed using data from one sample transit system. Improvement of adhesion proved very cost-effective. The largest benefit was found to be in reduction of capital costs. Improvement of revenues and reduction of maintenance costs were also significant. The total payoff ratio per year was 30:1, and the payoff ratio per year, without including capital costs, was 16:1.

CONCLUSIONS

The following conclusions can be drawn:

- Most North American light and commuter rail systems are concerned about loss of wheel/rail adhesion. However, loss of adhesion does not affect schedule reliability, except in the Fall when leaves cover the rails. Occasionally, during early morning, with dew or light drizzle on the rails, loss of adhesion has been a concern. Most systems use sand to increase adhesion.
- The major loss of adhesion occurs during braking, which results in development of wheel flats. More than 30% of the wheels were replaced in some systems because of wheel slide flats. Wheel flats increase noise, damage the rail, and seriously increase maintenance costs. Many systems do not have modern slip and slide controls. Even with such controls, as they are used overseas, wheel flats develop unless other steps are simultaneously undertaken.
- Loss of adhesion was experienced on road crossings because of the mud contaminants deposited on the rail surface by automobile wheels. Loss of adhesion and high levels of rail rust are common in tunnels, largely because of the presence of moisture along with other surface active contaminants.
- Moisture, even in small amounts, on the rail surface is the single most important contaminant responsible for loss of adhesion.
- Creep control systems can significantly improve adhesion by consuming surface contaminants by local heat produced in the shearing process in the wheel/rail contact. Adhesion levels start low in such conditions, but, as creep increases, adhesion levels jump to higher levels that provide satisfactory performance. Large gains can be made by many systems by using modern creep control.
- Removal of leaves and other organic debris on the rails before the start of the day, each day during the Fall, can help in maintaining adhesion. In the peak season, another removal of leaves midday might be necessary. This can be accomplished by use of special dedicated "Hi-Rail" or other vehicles. Specially designed and built attachments mounted on the front of these vehicles will remove the leaves and dry the rail. Care should be taken in design of rail-drying and leaf-removing attachments so that runaway or skidding of the rubber tires of the Hi-Rail vehicle on rail does not develop.
- Special wheel-cleaning blocks, mounted on the powered-car wheels, can help improve adhesion and drastically reduce the development of wheel flats.
- Hot-air jets applied to the rail and/or wheel surfaces can restore adhesion dramatically, even in the presence of other dry contaminants.
- A combination of 3-phase AC traction, appropriate creep control, and radial trucks can help in maintenance of high adhesion levels.
- Use of hot-air jets also reduces wheel/rail contact noise.
- Maintenance of adhesion is very cost-effective with a total payoff ratio of 30:1. On a short-term basis, not including capital costs, the pay off ratio is 16:1.

SUGGESTED RESEARCH

Current analytical and experimental research indicates that the following areas in field prototyping and testing need to be investigated urgently:

- Special vehicle equipment for removing leaves and other organic debris from the rails and drying the rails in the Fall should be designed, developed, and tested. This equipment can be installed either on a dedicated cleaning vehicle, such as a "Hi-Rail" vehicle, or on the revenue vehicles themselves, depending on the cleaning needed on the rails of the system. The first vehicle on the rails in the morning will provide most of the cleaning and drying needed.
- Composition of wheel-cleaning blocks appropriate for wheel cleaning to enhance adhesion should be investigated. Making and getting of special blocks for this purpose and limited laboratory tests and field tests will be necessary.
- Cleaning blocks on wheels should be designed, installed, and tested for effectiveness.
- Hot-air jet systems for removing moisture from the rail and wheel should be investigated. Designs of these systems should be developed; and prototypes should be produced and tested in the laboratory and in the field.
- Available wheel slip and slide control systems for wheel brakes should be analyzed and investigated for loss of adhesion in braking. The most suitable brake control system or systems should be used in field tests.
- Hot-air jets used for drying the rail can probably blow leaves and other debris off the railhead. For heavy fall

of leaves and/or heavy leaves (e.g., pine needles), air jets may not be adequate and a rail leaf deflector may have to be installed ahead of the air jets; therefore, such a deflector should be designed and tested in the field during the Fall.

- A rail-sanding system that starts when adhesion deteriorates should be developed. This could be incorporated in the slip and slide control electronics and software and activated during braking.

FINAL REPORT

The final report (prepared by Tranergy Corporation), "Improved Methods for Increasing Wheel/Rail Adhesion in the Presence of Natural Contaminants," gives a detailed account of the project and its findings and conclusions. The report is available on request to the Transit Cooperative Research Program, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, DC 20418.

ACKNOWLEDGMENTS

The research described herein was performed under TCRP Project C-6 by Tranergy Corporation. Dr. Sudhir Kumar served as principal investigator. The Association of American Railroads and Texaco Port Arthur Research Lab also participated in the project.