IDEA

Innovations Deserving Exploratory Analysis Programs

HIGH-SPEED RAIL

New IDEAS for High-Speed Rail

Annual Progress Report

January 2009

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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NEW IDEAS FOR HIGH-SPEED RAIL SYSTEMS

Annual Progress Report of the High-Speed Rail IDEA Program

JANUARY 2009

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

HIGH-SPEED RAIL IDEA PROGRAM COMMITTEE

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INTRODUCTION

IDEA (Innovations Deserving Exploratory Analysis) programs explore promising but unproven concepts with potential to advance surface transportation systems. The High-Speed Rail (HSR) IDEA program is funded by the Federal Railroad Administration (FRA). HSR IDEA projects are selected for their potential role in upgrading the existing U.S. rail system to accommodate operations up to 100 mph and beyond. The HSR IDEA program is one of the four integrated IDEA programs managed by the Transportation Research Board. The other three IDEA programs are:

- NCHRP Highway IDEA, which focuses on concepts for advancing the design, construction, safety, and maintenance of highways;
- Safety IDEA, which promotes innovative approaches to improving ground transportation safety; and
- Transit IDEA, which supports innovative approaches for improving transit operations and safety.

Since its creation in 1997, HSR IDEA has received commitments for more than $5.5 million in support from FRA. Since 1996, FRA also committed $1.5 million to intelligent transportation system projects that support high-speed rail implementation through general improvements in surface transportation infrastructure and operations in the other modes.

Approximately 30 percent of HSR IDEA awards have been to small companies (fewer than 10 employees); 40 percent to larger research, manufacturing, and consulting companies; and 30 percent to universities. HSR IDEA has made awards to about 25 percent of the proposals it has received. The investigations that resulted from these awards are reported in this document, which is organized by these four categories: operations, communications, and train control; highway-railroad crossing safety; track and structures; and rolling stock.

For additional information on these IDEA projects and how to prepare and submit research proposals, visit our website at www.trb.org/idea.

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ROLLING STOCK

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EXECUTIVE SUMMARY

2008 was the last year for which the High-Speed Rail IDEA Program funded new research projects. The program is no longer inviting new proposals. Accordingly, this will be the final High-Speed Rail IDEA Annual Progress Report. Discussions with the Federal Railroad Administration were held regarding the establishment of a new Rail IDEA program designed to foster innovations in railroad technology, both passenger and freight. In September 2008, however, FRA informed us that it would not fund the Rail IDEA Program.

During 2008, four High-Speed Rail IDEA projects were completed, and progress on two ongoing projects was significant enough to deserve special mention. One of the projects completed this year was the development of a cost-competitive alternative to conventional steel or reinforced concrete bridge beams that is lighter in weight and more resistant to corrosion (HSR-43). The concept is a hybrid-composite beam system (HCB) using plastic, steel, and concrete components. Test results indicate that HCB bridges have the same strength and stiffness characteristics as bridges constructed using steel or pre-stressed concrete girders but would offer greater corrosion resistance and increased load-carrying capacity at a competitive cost. A prototype full-scale 30-foot HCB beam was tested in the lab using hydraulic actuators, where it was subjected to a two-million cycle fatigue test and an ultimate load test. The beam met all relevant objectives as specified in AREMA recommended practices for railroad bridges. Eight additional 30-foot HCB beams were fabricated and installed in a bridge span at the Transportation Technology Center (TTCI) in Pueblo, Colorado, for preliminary load tests. These tests were successful and the span was then installed in the high-tonnage loop at TTCI in October 2008 for prolonged service testing. The test objective is for the span to accumulate 100 MGT (million gross tons) by 2009. To date, the bridge has accumulated over 15 MGT without any problems. In addition, an HCB highway bridge with 55-foot beams was installed in Lockport, Illinois. This bridge was completed and opened to traffic in September 2008. Installation of another HCB highway bridge in New Jersey is now underway. This IDEA project was jointly funded by the HSR-IDEA and NCHRP Highway IDEA programs.

Another completed project was the development of a smart sensor system to continuously monitor the health and safety of railcar braking systems (HSR-51). These smart sensor systems are small (15 mm × 60 mm × 2 mm thick) and contain sensors, their own power supply, a data processor, a data transmitter and antenna, and a self-configuring RF network capability. In the brake system application, strain gage smart sensors are installed on the brake beams of each car in a train. The output of these sensors is used to determine whether the brakes are applied or released. This will enable detection of stuck or nonfunctioning brakes, facilitate initial terminal brake inspections, and provide continuous monitoring of train braking forces to enhance the real-time calculation of braking distances. Commercially available networking software is used. This software is designed to provide security and avoid interference, such as RF signals from other trains. Prototypes were installed on railcars in revenue service to assess performance, including how well the system operates in the presence of other networks and the typical RF and EMI environments found in railroad operations. A prototype power harvester to power the system was developed and integrated into the system. The prototype system performed successfully in the initial field tests, and additional revenue-service testing for long-term durability is underway on both Norfolk Southern and CSX.

A project to develop a low-cost remote wireless system for fatigue crack detection and growth monitoring in steel bridge beams (HSR-54) was also completed in 2008. The goal was to transition the contractor's (WavesInSolids) existing wired acoustic emission system to a lower-cost wireless system. The wireless device consists of a 4-sensor array and is installed on the fracture-critical bridge member of interest. As trains travel over the bridge the fracture-critical member is stressed. If a fatigue crack is active, it will emit acoustic signals when the structure is subjected to a maximum or near-maximum stress. The sensors detect the acoustic emission and the wireless instrument digitizes the information, analyzes, compresses, and then transmits the filtered information back, through a network of wireless sensors, to a central processing station for review by bridge engineers. Railroad engineers may use the information to load-rate bridges and prioritize maintenance action. The wireless system was sought to accommodate the emerging requirement for long-term monitoring and to significantly reduce the overall cost for system implementation. The wireless system derived from this project is estimated to be one-tenth the cost of the hardwired system.

Also completed in 2008 was a project to measure the transmissibility of vibration signals from defective wheel bearings through the rolling wheel/rail contact patch to fixed accelerometers mounted on the rail (HSR-56). If adequate signal strengths and signal-to-noise ratios from defective bearing vibrations can be transmitted through this rolling contact patch, it would indicate the feasibility of a track-side system that uses arrays of accelerometers attached to the rail to detect bearing defects. A wheel bearing with known defects was installed in a test railcar. The bearing housing for the defective bearing and the housing for a bearing in good condition were equipped with accelerometers. Accelerometers were installed on the rail of a test track. Although the field tests were limited to low speeds (10 mph), which greatly reduced the bearing defect noise and the signal-to-noise ratio, the bearing signatures were still evident. Since distressed bearing noise increases with the square of speed, a doubling of the speed would be expected to yield up to a four-fold increase in the bearing noise signature. Also, the tests had to be conducted on bolted, rather than on continuously-welded rail. Each factor significantly raised the noise floor during the tests. Further testing at higher speeds with better track conditions will be required for a more thorough assessment of this concept.

Significant progress was achieved on the investigation of the use of long-range ultrasound technology for the inspection of steel bridge pile (HSR-57). Electromagnetic acoustic transducers (EMATs) are mounted on a bridge pile. One EMAT injects ultrasonic energy into the pile and another receives signals reflected back from any wall loss due to corrosion. Analysis of the reflected signals is then performed to determine the extent to which this approach can characterize wall loss, including the area and depth of material loss due to corrosion. The concept is expected to work on pile submerged in water, soil, and mud. This technology is currently used to inspect underground pipelines. Project tasks included lab tests of prototype EMATs mounted on H-pile specimens with simulated defects machined into the specimens, and field testing of the prototype on a Norfolk Southern bridge with pile submerged in water. Test results to date show good correspondence between EMAT data and actual measurements of simulated corrosion. This project is scheduled for completion by January 2009.

Significant progress was also achieved on the feasibility assessment of a permanent magnet DC locomotive traction motor that would be significantly smaller and lighter in weight than today's motors, while delivering enhanced control of both traction and dynamic braking. A major challenge was the survivability of the solid-state switch units when subjected to the high voltage spikes associated with switching the large electrical coils in the motor. This problem has been resolved, and improved control modules are being developed. These will be installed in a full-scale permanent magnet DC test motor that will be bench tested to evaluate its performance. This project is scheduled for completion by October 2009.

The completed projects and projects for which there was significant progress in 2008 are identified with asterisks in the Table of Contents.

Operations, Communications, and Train Control

HSR-3/ITS-31: Laser Optics Communications System

State University of New York at Stony Brook

IDEA Concept and Product

There is an increasing need for the rapid exchange of large data files between high-speed trains and wayside facilities. One example is the data exchange requirements of communications-based train control systems. These systems, which rely on on-board and central computers, navigation systems, and communications links between trains and central control facilities, require downloading and uploading of large data files such as track and route characteristics, and train-consist data. There are situations when conventional radio communications links may not be the most effective means for such data exchanges because of factors such as data volume, interference, and communications coverage problems.

Another example is the need to exchange health monitoring and diagnostic data for various train components. Increasingly, such data are collected and stored in computers on board locomotives. High-volume train-to-wayside communications links are required to download such data for analysis to provide real-time diagnosis and support the scheduling and management of maintenance and repair activities.

The objective of this IDEA project was to develop a communications system using infrared laser beams and servo-controlled antenna systems to provide high-speed, high-volume data exchange between moving trains and wayside terminals.

The concept uses servo-directed laser beams to provide a communications link between a moving train and a railroad wayside terminal. This technology has the potential to transmit 10^6 bytes of information in 0.2 seconds. The servo system would enable the train-mounted and wayside antennas to track each other in the brief period during which the high-volume data exchange occurs. Data communications begin when the train is approximately 30 meters from the wayside terminal, and end at a distance of approximately 10 meters. Tracking of the train and wayside terminals is controlled by servo motors that align photo-optic reflectors based on the strength of the laser signals received.

The contractor, State University of New York, worked with Telephonic Corporation, a commercial communications equipment manufacturer, to determine the most effective strategy for the development and marketing of a production version of this system.

Project Progress

HSR-3 was completed in December 1998. The definition of the requirements and specifications for a laser open-air communications system for high-speed rail application were completed. Prototypes of the train and wayside terminals, including photo-optic assemblies and servomotors, were fabricated and successfully demonstrated in a laboratory environment.

Principal Investigator: Sheldon Chang

Technical Advisor:
Howard Moody
Association of American Railroads

IDEA Contract: $91,024

Cost Sharing $100,000

Project Total: $191,024

Start: December 1995

Complete: December 1998

HSR-4/ITS-37: Using Rail Vibration Analysis to Detect Approaching Trains

Raven Inc.
Alexandria, Virginia

IDEA Concept and Product

The concept was to sense induced rail-vibration signals to detect the approach of trains to warn maintenance crews. IDEA project results indicated that vibration signatures could potentially be used to determine train position, speed, and direction.

CSX Transportation, Inc., and the Washington Metropolitan Area Transit Authority participated in the data collection and field experimentation. A vibration sensor/analyzer showed the potential to detect a train at a distance or to determine that the train is right at the sensor. This attribute led to the design of two different devices with the potential to alert a flagman that a train is approaching. These same devices might also be adapted as an inexpensive means of operating a warning system at a grade crossing.

Project Progress

This project was completed February 1997. A follow-on project (HSR-17) was funded to fabricate and test an automatic warning system for track maintenance workers.

Principal Investigator: James Genova

Technical Advisor:
Charles Taylor
Association of American Railroads

IDEA Contract: $73,750

Cost Sharing: $16,800

Project Total: $90,550

Start: January 1996

Complete: February 1997

HSR-5/ITS-39: Proximity Warning System for Locomotives

Pulse Electronics Inc.
Rockville, Maryland

IDEA Concept and Product

There is growing interest and activity among railroads, suppliers, and government agencies in communications-based train control systems. These systems rely on sophisticated computers on-board locomotives and at train control centers, combined with train location and navigation systems, and digital data communications links for the control of train operations. They have the potential to maximize the use of railroad track and equipment and to improve safety and service reliability. These systems would replace the conventional track-circuit-based signal systems and allow safe operations with much shorter headways between trains to improve system throughput and increase track capacity. They would also enable the monitoring of train crews for compliance with computer-generated train movement authorities using the on-board computers and enforce compliance with automatic brake applications.

Most of the systems developed and tested to date have required a significant infrastructure investment, with both trackside and dispatch office hardware and systems. Their highly centralized approach requires implementation on a wide scale and requires a substantial data radio communications system and trackside equipment infrastructure investment.

The objective of this IDEA project was to develop and test a low-cost train navigation and communication system to enable location information to be exchanged between trains on a local area basis. Each locomotive could then compute the distance and relative direction of other trains in its proximity to warn the engineer of potential conflicts.

The proximity warning system is based on the integration of rail navigation and communications subsystems. A rail navigation system on locomotives uses on-board computers, GPS receivers, a gyro, and axle generator interface to determine train location and track ID using an on-board track database. Shared use of the locomotive to end-of-train data communications system provides local area data exchange with other locomotives. Trains periodically broadcast their current track ID, location, direction, speed, and routing plans, which are received by other trains in the area. A color graphics display provides an illustration of the engineer's own train, as well as other trains in the area, against the track profile. The system is able to advise of potential movement conflicts based on comparison of data among trains in the area.

Project Progress

This project was completed in October 1997. Three Burlington Northern Santa Fe (BNSF) locomotives were equipped with prototype systems and tests were conducted in August and September 1997. Radio frequency communications coverage was shown to be sufficient, without need for repeater units. Initial data communications was typically achieved within a distance of about five to six miles, with consistent coverage within three miles. Subsequent to the completion of this project, eight BNSF locomotives were equipped with the system for an expanded pilot project in southern California. These tests were successful. Many of the concepts explored in this project are being incorporated in the design of new communications-based train control products.

Principal Investigator: Robert Kull

Technical Advisor:
Mr. Lynn Garrison, BNSF

IDEA Contract: $99,000

Cost Sharing: $120,000

Project Total: $219,000

Start: March 1996

HSR-14/27: Multiple Sensor Inertial Measurement System for Locomotive Navigation

ENSCO Inc.
Cocoa Beach, Florida

IDEA Concept and Product

There is growing interest and activity among railroads, suppliers, and government agencies in the development of communications-based train control systems. These systems rely on sophisticated computers on-board locomotives and at train control centers, combined with train location and navigation systems, and digital data communications links for the control of train operations (see Figure 1). They have the potential to maximize the use of railroad track and equipment and improve safety and service reliability. These systems would replace the conventional track-circuit-based signal systems and thereby allow safe operations with much shorter headways between trains to improve system throughput and increase track capacity. They would also enable the monitoring of train crews for compliance with computer-generated train movement authorities using the on-board computers and enforce compliance with automatic brake applications if these authorities are violated.

A key component of such systems is the locomotive navigation system. For the computer system to determine whether the train is in compliance with movement authorities, precise, real-time train location data are required, including identification of which track the train is on. GPS or DGPS alone does not provide the accuracy required, as trains often operate in multiple-track territory with track centers as close as 13 feet. Accordingly, there is a need for a low-cost alternative to conventional rate gyros or laser fiber-optic gyros for precise navigation.

The objective of this project was to investigate the use of micro-electromechanical systems (MEMS) accelerometer arrays, combined with GPS, to provide the accurate location of locomotives.

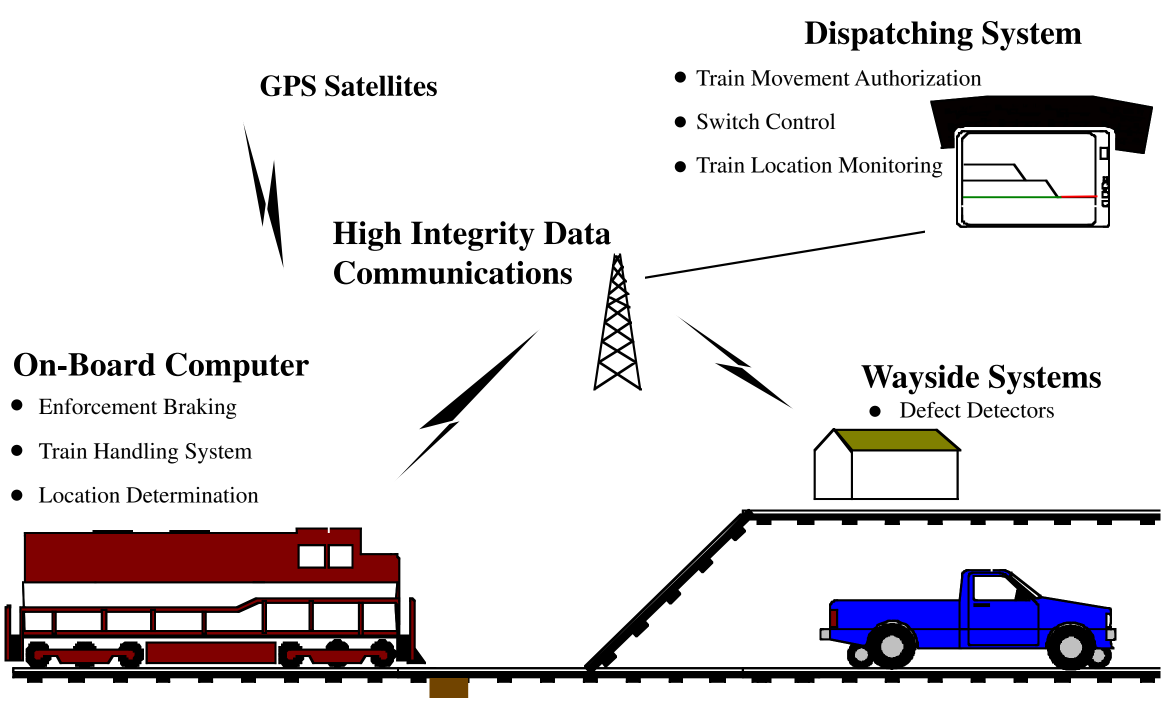

Figure 1

Positive Train Separation (PTS) architecture.

This project examines the possibility of using an array of inexpensive MEMS accelerometers and integrating the accelerometer data with GPS or DGPS data using Kalman filtering techniques instead of the more expensive conventional accelerometers and gyros for locomotive navigation.

Project Progress

This project was completed June 2004. In the first stage of this project the system requirements, initial system architecture, and navigation and Kalman filtering algorithms were developed. Alternative sensor technology was evaluated, and sensors were selected. The sensor system was designed, and the system configuration was optimized. A laboratory inertial system using MEMS accelerometers and micromachined gyros was then developed and evaluated. Software was developed for navigation and filtering. An inertial navigation system consisting of four 3-axis MEMS accelerometer modules was installed on the Amtrak 10002 Track Geometry Car and field-tested on the high-speed Washington-to-New-York Metroliner run. The test recorded data from the field navigation system, the laboratory inertial system, and independent higher-resolution sensors. The test data indicate that this system has the potential to provide a low-cost alternative to conventional accelerometers and gyros for locomotive navigation. A final report documenting the system design and test results was completed in March 2000.

Figure 2

Locomotive navigation systems must not only determine train location along a track, but must also detect movement into a parallel track.

A follow-on product application project to develop improvements to the system software and hardware, and install and test a production prototype of the system in a locomotive was recently completed. Project tasks included development of improved navigation and Kalman-filtering algorithms, definition of the hardware requirements for the inertial measurement system, and assembly and lab testing of the revised prototype system. These lab tests revealed that the sensor system did not have the required accuracy. ENSCO concluded that it is impractical to base an inertial navigation system for locomotives on existing low-cost MEMS sensors. As a result, no field-testing on a locomotive was conducted. A final report was prepared documenting the work accomplished, problems encountered, and recommendations regarding any further research and development of this technology.

Principal Investigator: Fred Riewe

Technical Advisor:
Denny Lengyel, ARINC

Project Panel:
Lt. Laura Kelly, USAF
Ron Lindsey, CSX
Bill Matheson, GE-Harris
Bill Petit, Safetran

IDEA Contract: $84,961 Initial/$84,000 Follow-on

Cost Sharing: $19,865/$150,270

Project Total: $104,826/$234,270

Start: June 1998/June 2001

Complete: March 2000/June 2004

HSR-17: Automatic Warning System for Track Maintenance Workers

Raven Inc.
Alexandria, Virginia

IDEA Concept and Product

The safety of track maintenance workers is a vital concern, especially where high-speed trains are operating. These maintenance workers must often rely on a so-called flagman or watchman who is assigned the responsibility of watching for approaching trains and alerting workers in time to clear all personnel and equipment from the right-of-way before the arrival of trains. This technique is labor intensive and not always effective. Occasionally, those assigned the job of spotting trains do not see them in time to provide adequate warnings. This can, and does, result in fatal accidents and untold near collisions.

As a result of this concern, there is a need to develop a low-cost, reliable, automatic system to provide effective warnings to track workers of approaching trains.

The concept on which this project was based was the detection of train-induced rail vibrations to activate a warning system for track maintenance workers. The application of this technology for train detection was examined in a previous IDEA project (HSR-4). This follow-on project was to develop a warning system that combines the moving train sensor with a robotic signaling and train stop device. Initial application was to be designed for rail transit applications, such as on the Chicago Transit Authority (CTA). Currently, a "slow zone" is established at a track maintenance work site, and a "trip staff" that will automatically stop the train is installed on the tracks. When a train approaches the "slow zone" the flagman sounds a horn to alert the track workers that a train has entered the zone and signals the train operator to halt with a flag or light. After receiving a track-clear signal from the foreman, the flagman removes the trip staff and signals the train to proceed.

This project was to investigate the feasibility of a robotic signaling device to replace the flagman (Figure 1). The robot would be designed to place and remove the trip staff, and would be under the control of the track maintenance foreman by means of a hand-held device with

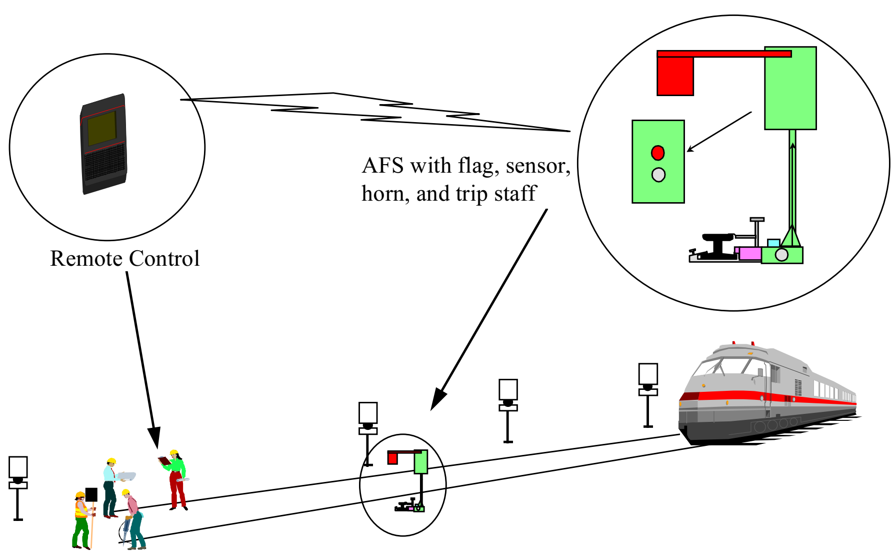

Figure 1

Transit slow zone with automatic flagging system.

a radio frequency link to the robot. The primary objective was to determine whether rail vibration technology could be used to detect the presence and speed of trains approaching track maintenance work zones.

Project Progress

This project was completed in March 2000. Prototype design drawings for all of the mechanical assemblies were completed. Initial measurements of the acoustic signatures in the rails of approaching trains were analyzed to determine whether approaching trains could be distinguished from background noise from other sources. The next steps were to be the fabrication and preliminary testing of a design prototype. The final stage was to consist of operational testing and evaluation of the prototype on the CTA and an evaluation of the potential of the concept for high-speed rail applications.

Analysis of the acoustic signature data generated by approaching trains revealed that it was difficult to distinguish between trains and background noise. Moreover, the signatures could likely not be detected far enough down the track to provide adequate warning to track maintenance crews, particularly in territory with high-speed train operations. Consequently, fabrication and testing of a prototype was not undertaken. A report documenting the prototype design and preliminary analysis of the acoustic data was prepared in February 1999.

Principal Investigator: James Genova

Technical Advisor:
Howard Moody, AAR

Project Panel:
Christopher Schulte, FRA
Bea Hicks, WMATA
Alan Lindsey, BNSF

IDEA Contract: $20,000

Cost Sharing: $202,000

Project Total: $222,000

Start: October 1998

Complete: March 2000

HSR-18: An Investigation into the Use of Buried Fiber-Optic Filament to Detect Trains and Broken Rail

Texas Transportation Institute
College Station, Texas

IDEA Concept and Product

For decades, railroads have relied on track circuits to detect train presence and broken rails. However, track circuitry is expensive to maintain and does not always reliably detect trains due to such factors as contamination at the wheel-rail interface. Moreover, a substantial percentage of rail breaks occur in which electrical continuity is maintained and are therefore not detected by the track circuits. This research investigated the feasibility of using fiber-optic filaments buried along the right-of-way to detect trains and to detect the energy released when rail breaks occur. The approach was to use coherent optical time-domain reflectometry (C-OTDR) in concert with advanced signal-processing techniques and neural networks in buried fiber-optic filaments to detect and locate trains and the ballistic event characteristic of rails breaking under stress.

An optical transmission through a continuous length of low-loss, telecommunications-grade fiber buried along the right-of-way, yet away from track maintenance operations, was investigated to determine whether it held any promise for providing an inexpensive, reliable alternative to conventional track circuitry for train presence and broken rail detection. Another potential advantage is that buried fiber-optic filament is free of the problems associated with the electromagnetic interference encountered with track circuits. The objective was a low-cost, reliable alternative to conventional track circuits for near real-time detection and location of rail break events, as well as for detection and location of moving trains, that can be commercially developed for application to the railroad. If successful, this technology could also facilitate the railroad industry movement toward communications-based train control systems and away from track-circuit dependent train control.

A state-of-the-art coherent laser is used to pulse a buried communications-grade optical fiber. Information is extracted from polarization shift in the laser pulse backscatter light to establish train presence and rail break events as well as the location and time of events. The laser employs coherent continuous waves with a line width of approximately 10 kilohertz. The laser beam is pulsed at 30 nanoseconds over a 0.1 millisecond period to provide a 2-meter resolution in a 20-kilometer fiber length. The concept was that the system would recognize that a train has stopped by registering the cessation of activity at the last known location.

The system has the potential to continuously monitor train movement, direction, and location while monitoring the track structure for rail breaks. Additionally, the system has the potential to detect and discriminate among various in-train defects, e.g., flat wheels, dragging equipment, and stuck brakes.

Project Progress

This project was completed in December 2001. The project team developed a coherent laser system and demonstrated its capability to detect very low-energy perturbations on single-mode fiber. Laboratory tests revealed that backscatter is not localized for the event of interest alone, but by all environmental noise along the fiber. The large amount of noise accumulated along the fiber makes the signal of interest, e.g., from a rail break or train, undetectable in fiber lengths in excess of 50 meters. As a result the contractor, Texas Transportation Institute, recommended that the contract be terminated. TTI prepared a final report that documents the work accomplished and the findings.

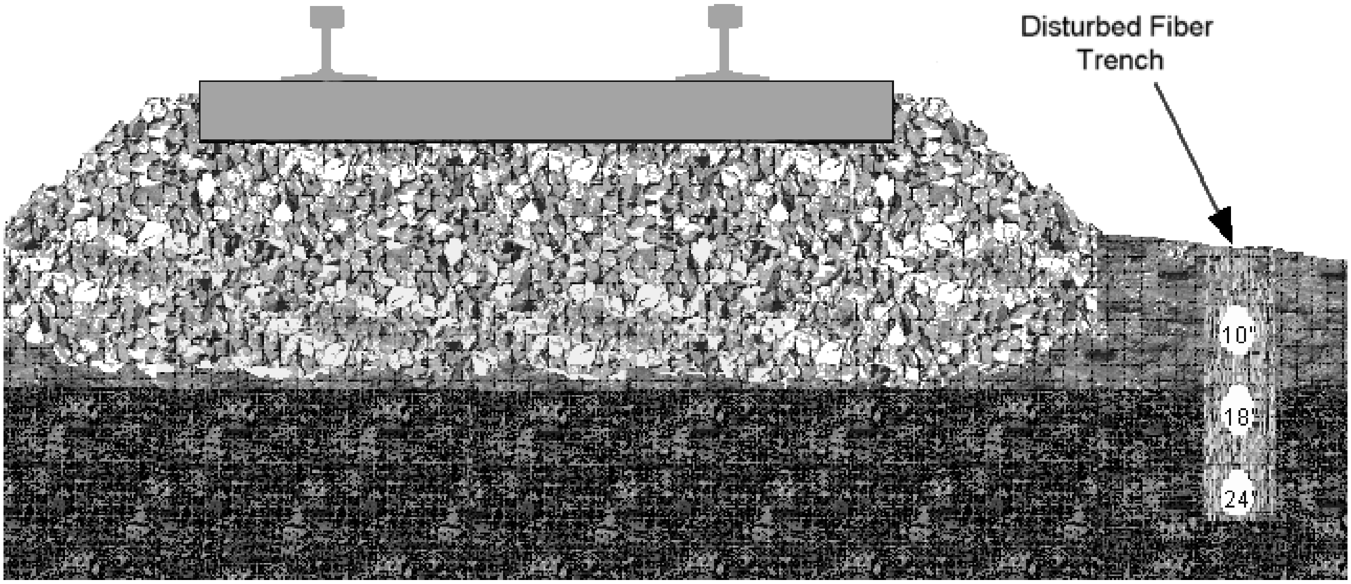

Figure 1

Cross-section of track, ballast, and subgrade with buried optical fiber.

Principal Investigator: Steve Roop

Project Panel:

Henry Lees, Burlington Northern Santa Fe Railway
James Lundgren, Transportation Technology Center, Inc.
William Petit, Safetran Systems, Inc.

IDEA Contract: $60,000

Cost Sharing: $47,000

Project Total: $107,000

Start: February 1999

Complete: December 2001

HSR-19: Fiber-Optic Sensors for High-Speed Rail Applications

University of Illinois
Champaign, Illinois

IDEA Concept and Product

This research investigated the feasibility of an alternative to HSR-18 for using fiber-optic filaments to detect trains and broken rail. Rather than using fiber-optic filaments buried along the track structure, this project investigated the application of the filaments directly to the rail. Specifically, the project developed, tested, and evaluated a system employing fiber-optic sensors attached to rail to detect rail breaks, track buckling, and the location and speed of trains. Any break or displacement of the rail, such as would result from a train or rail buckling, would affect the light-transmitting characteristics of the attached fiber. This change in the light signal would be detected and analyzed to provide information on the exact location of the train or track defect. The objective is a low-cost, reliable alternative to conventional track circuits for near real-time detection and location of rail break events, as well as detection of rail buckling and location of moving trains, that can be commercially developed for application to the railroad. If successful, this technology could facilitate the railroad industry movement toward communications-based train control systems and away from track-circuit dependent train control.

The project investigated alternative types of optical fibers for these applications, optimum location of fibers on the rail, and fiber attachment and removal methods. Other tasks included development of a fiber installation device, development of a computerized optical time-domain reflectometry measurement system, and fabrication and testing of a prototype system.

Project Progress

This project was completed August 2001. The investigation of alternative optical fibers to determine which are best suited for detection of rail breaks, track buckling, and train location and speed revealed that conventional glass fiber has the best combination of low attenuation and low cost. Other optical fibers investigated were polarization-maintaining glass fiber and plastic fiber. The optimum location of fibers on the rail was determined to be on the vertical surface of the web directly under the rail head. The most promising methods for attachment and removal of fibers was determined and a rail-mounted cart was developed for installation. The cart automatically applies fiber, epoxy, and a protective tape to the web as it rolls down the rail. A computerized optical time-domain reflectometry measurement system to determine the precise location of rail breaks and track buckling was also developed. A prototype system was installed on test track at the Transportation Technology Center. Tests were conducted and data analyzed to determine the performance of the fibers, attachment methods, algorithms, OTDR system, and the accuracy and reliability of the detection of rail breaks, track buckling, and train location and speed.

Test results indicated that this technology has significant potential, particularly for rail break and track buckling detection. Initial applications of such systems could be on relatively short segments of track at critical locations, such as on railroad bridges with the potential for damage from maritime traffic and in locations with a high potential for track buckling.Widespread application of the technology will require additional development to increase the application speed, lower the application costs, increase the temperature range within which application can occur, and protect the fiber from various track maintenance operations. Also, techniques would have to be developed for cost-effective inspection and diagnosis of fibers installed on rail.

Principal Investigator: S. L. Chuang

IDEA Contract: $95,000

Cost Sharing: $137,000

Project Total: $232,000

Start: November 1999

Complete: August 2001

Figure 1

Cart for application of optical fiber to rail.

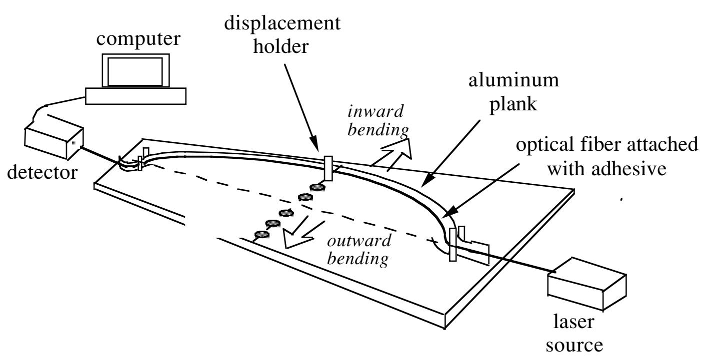

Figure 2

Rail buckling experimental setup.

HSR-22/35: Low-Cost, Drift-Free DGPS Locomotive Navigation System

Seagull Technology Inc.
Campbell, California

IDEA Concept and Product

There is growing interest and activity among railroads, suppliers, and government agencies in the development of communications-based train control systems. These systems rely on sophisticated computers on-board locomotives and at train control centers, as well as train location and navigation systems and digital data communications links for the control of train operations. They have the potential to dramatically increase the utilization of railroad track and equipment and improve safety and service reliability. These systems would replace the conventional track-circuit-based signal systems and thereby allow safe operations with much shorter headways between trains to improve system throughput and increase track capacity. In addition, they would also enable the monitoring of train crews for compliance with computer-generated train movement authorities using the on-board computers and enforce compliance with automatic brake applications if these authorities are violated.

A key component of such systems is the locomotive navigation system. In order for the computer system to determine whether the train is in compliance with movement authorities, precise, real-time train location data are required, including identification of which track the train is on. GPS or DGPS alone does not provide the accuracy required, as trains often operate in multiple-track territory with track centers as close as 11.5 feet. Accordingly, there is a need for a low-cost alternative to conventional rate gyros or laser fiber-optic gyros for precise navigation.

The objective of this project was to investigate the use of a three-receiver, three-antenna GPS heading reference system, as illustrated in Figure 1. The system includes a low-cost, drift-free highly accurate navigation system hardware design and parallel-track resolution software. A prototype GPS attitude system, which was used to gather field-test data, is shown in Figure 2. For robustness, the system is augmented with a low-cost heading gyro and the odometer output from the locomotive. Both the gyro and the odometer are dynamically calibrated by the GPS receiver system when GPS satellite coverage is available. When GPS satellite coverage is temporarily interrupted, the calibrated gyro and odometer are used to augment the GPS-derived position, velocity, and heading. The parallel-track resolution software takes the train heading and path distance traveled and compares this to a rail database that identifies where turnouts are located. When the train passes through one of these turnouts, the algorithm determines the probability that the train has continued on the original track or has switched onto another track.

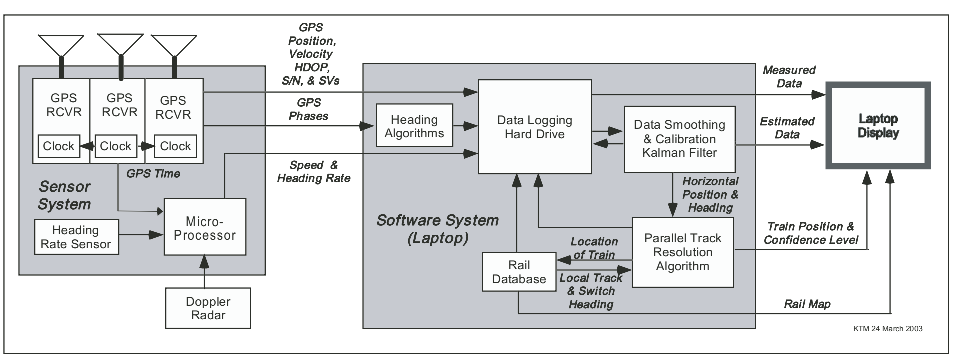

Figure 1

Prototype GLLS hardware architecture.

Project Progress

This project was completed September 2003. A prototype system was mounted on a locomotive and a series of tests conducted on the Burlington Northern Santa Fe railroad. Testing was conducted on a mainline and in a large yard. The mainline testing was conducted in territory with turnouts and switchovers as well as overhead bridges, tunnels, and other obstructions. Analysis of the test results compared the GPS/DGPS position, velocity, and heading data as well as the odometer and heading gyro data with reference location data from a rail database.

The performance objective for the system required that the passage of a train through a high-speed turnout (number 20 with a 1.75 degree frog angle) onto a siding (with 11.5 foot distance between track centers) can be determined with a confidence level of 0.99999. This translates into a locomotive heading accuracy requirement of 0.20 degrees (1 sigma) or a lateral position accuracy of 1.3 feet (0.4m, 1 sigma). The measured (unfiltered) GPS heading accuracy was 0.18 degrees (1 sigma). Using either a 6-state or a simple heading 2-state Kalman filter increased the heading accuracy to 0.16 degrees (1 sigma). Since the heading accuracy requirements for the parallel track resolution software is 0.20 degrees, the hardware and software design met the requirements. In addition, using the data collected on a mainline while passing over two number 11 switches (with a 6 degree frog angle), together with the rail database, a confidence level of 0.99999 was demonstrated. Moreover, since Selective Availability (SA) was removed from the GPS signal in 2000, raw GPS position accuracy appears to be sufficient for this application.

Figure 2

Seagull GPS prototype.

Based on the success of this initial project, the HSR-IDEA Program Committee approved a follow-on project to develop a production prototype of the system. Tasks included development of prototype hardware and software specifications and design to interface the GPS system, a radar speed sensor, and a track data base. The software for sensor calibration and parallel track resolution was refined and a prototype GPS Locomotive Location System (GLLS) fabricated and lab tested. The system was installed on a UP GE C44 AC locomotive and tests were run to determine if RF interference from AC traction would affect the performance of the GPS receiver. Tests included accelerations up to 70 mph, dynamic braking, and under full load conditions. No interference was observed.

A three-day field test on Union Pacific in and near Portland, Oregon, was then performed. The system hardware performed well. The accuracy requirements were not met, however, due to such factors as a coordinate system conversion error, inaccuracies in the track data base, and GPS position inaccuracies caused by ionospheric delay errors. Post-test adjustments for the conversion and track database errors substantially improved the accuracy. Seagull Technology has identified software and hardware improvements that should enable the GLLS system to meet all performance requirements. Subsequent to the completion of this project, the FRA contracted with Seagull for further development and applications of GLLS.

Principal Investigator: Tysen Mueller

Project Panel:
Tom Atkins, BNSF Railroad
Jeff Young, Union Pacific Railroad

IDEA Contract: $94,706 Initial/$195,089 Follow-on

Cost Sharing: $50,000/$105,000

Project Total: $144,706/$300,089

Start: November 1999/December 2001

Completed: May 2001/September 2003

HSR-52: Low-Cost, Precise Railroad GPS Location System

Sensis Corporation
Campbell, California

IDEA Concept and Product

This project examined the feasibility of a GPS system for the precise location of railroad maintenance-of-way vehicles and equipment, both on and adjacent to the tracks. Such a system would have the potential to accurately identify and communicate the precise location of on-track maintenance equipment, off-track equipment such as construction equipment, and the location of small track maintenance gangs. Such accurate and timely data would enable dispatchers to more efficiently and safely manage train traffic through locations where track maintenance is underway. The proposed system uses dual-frequency GPS receivers, broadcast measurements from a GPS reference station network, and dead-reckoning sensors when GPS coverage is interrupted. The design objective was a system with horizontal position accuracy of 0.4 meters with a confidence level of 0.9999999 (seven-nines), after averaging position measurements for one minute, as required for operation in Positive Train Control (PTC) territory. The project focused primarily on the development of a key system algorithm, the Carrier Differential GPS (CDGPS) Position Algorithm, and testing of this algorithm using archived Continuously Operating Reference Station (CORS) GPS data.

Figure 1

Maintenance vehicles on mainline track.

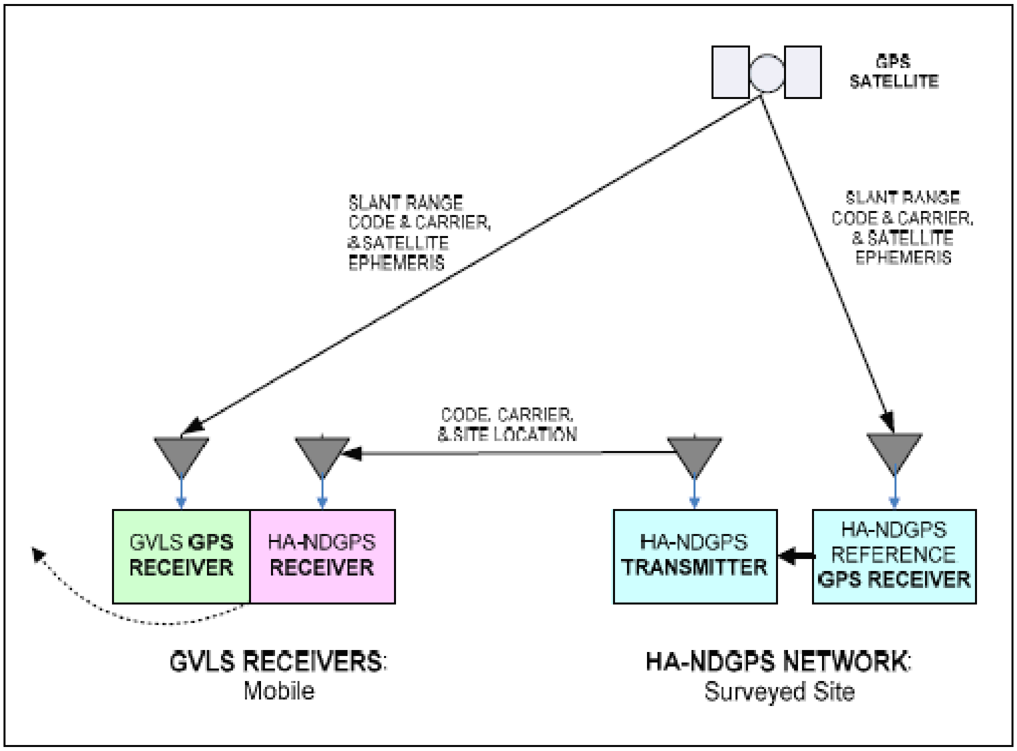

Figure 2

Railroad GPS vehicle location system architecture.

Project Progress

This project was completed in July 2006. When the CDGPS Algorithm developed in this study was tested with the archived CORS data, it was not able to achieve the required position accuracy of 0.4 meters for reference station distances greater than approximately 70 km from the user receiver. The goal was distances greater than 150 km. The primary limitations are the ionospheric delay (due to measurement errors) and multipath errors in the GPS measurement data. The results were sufficiently promising to encourage future development of this concept based on a linear error analysis of the CDGPS algorithm for the longer distances.

Principal Investigator: Tysen Mueller

Project Panel:

- Leonard Allen, FRA
- Michael Coltman, Volpe Center
- Rick Lederer, BNSF
- Fred Meeks, Union Pacific Railroad
- Howard Moody, AAR
- Alan Polivka, TTCI

IDEA Contract: $95,411

Cost Sharing: $13,583

Project Total: $108,994

Start: August 2005

Highway-Railroad Crossing Safety

HSR-1/ITS-29: Scanning Radar Antenna for Collision Avoidance

WaveBand Corporation
Torrance, California

IDEA Concept and Product

This IDEA product was a compact, low-cost, scanning millimeter wave (MMW) antenna used to detect obstacles and warn of collision risk for both railroads and automobiles. The Spinning Grating antenna system is unique in that it uses the phenomenon of diffraction to define and steer a beam of MMW energy. This technology was first devised for imaging radar systems for aircraft landing guidance.

This IDEA project investigated the potential of using MMW radar with the Spinning Grating antenna to provide surveillance of highway-railroad grade crossings. Scanned microwave radar has the potential to reliably detect the presence of obstacles in the path of a train under a wide range of weather conditions to initiate preventive action.

Millimeter wave sensors are also candidates for providing the raw data needed by intelligent cruise control and collision warning systems for ITS automotive applications. A scanning sensor is needed to provide more complete spatial information about the roadway ahead. Unlike electronically steered antennas and more traditional gimbal-mounted antennas, the IDEA antenna would likely be inexpensive enough to install in passenger vehicles. The IDEA antenna was chosen by the National Highway Traffic Safety Administration as a candidate for comparative testing to define requirements for collision warning and intelligent cruise control.

Project Progress

This project was completed in February 1997. The California Manufacturing Technology Center, commissioned to develop a low-cost manufacturing approach, found that the antenna can be manufactured primarily of molded plastic with a few metal parts. The antenna has few pieces and can be easily assembled by a multi-axis industrial robot with minimal hand labor. It has just a single moving part.

The findings of this project indicated that the scanning antenna technology had potential for grade crossing surveillance. Accordingly, the investigator received follow-on IDEA project support to test the application of this technology to railroad crossing safety (see HSR-13).

Principal Investigator: Lev Sadovnik

IDEA Contract: $93,974

Cost Sharing: $12,020

Project Total: $105,994

Start: October 1995

Complete: February 1997

HSR-2/6: Wide-Angle Video System for Grade Crossings

Intelligent Highway Systems Inc.
White Plains, New York

IDEA Concept and Product

This IDEA project explored the potential of a wide-angle, single-camera machine video system for surveillance of highway-rail grade crossings. Potential uses of such a system would include detecting vehicles on crossings for sequencing four-quadrant gates, detecting stalled or disabled vehicles, and monitoring the performance and condition of grade crossing warning system components. Other uses could be preemption of highway traffic signals to prevent backups onto railway tracks, and detecting and identifying vehicles that trespass railroad tracks after warning systems have been activated.

A single 160° field-of-view, optical surveillance system was developed that could replace multiple sensors that are presently required to monitor, evaluate, or control the traffic flow within an entire crossing area. Such an area may include each inbound and outbound or exiting lane on both sides of the grade crossing.

The system was also designed to provide real-time detection and tracking of the position of crossing gate arms on each side of the railway tracks, even when a train is present in the intersection. Supplemented with machine vision logic, the system provides potential for the detection of

- objects that are stopped or stuck on the tracks,
- vehicles that are waiting in a queue that extends to within a critical distance of the tracks,
- malfunctioning crossing signals or gates, and
- objects that cross the tracks in violation of crossing signals.

Project Progress

This project was completed in December 1997. The exploration of this concept for surveillance of an entire, non-orthogonal, omni-directional traffic intersection, rotary, or freeway using a single camera system was the objective of an IDEA project completed in July 1996 (HSR-2). Application for highway-rail grade crossing surveillance was the objective of this follow-on IDEA project (HSR-6). Project tasks included refinement of the system software for application to grade crossings, and field-testing on active crossings. The system was designed to monitor the crossing and adjacent roadways and issue predefined alert signals, e.g., when vehicles were detected in the crossing after gate activation, when any crossing warning system malfunction was detected, or if vehicles entered the crossing after the gates were activated.

HSR-6 was completed in December 1997. A prototype system was successfully tested at an active grade crossing on the Long Island Railroad. The contractor, Intelligent Highway Systems, subsequently established a teaming arrangement with Nestor, Inc., another IDEA project contractor (see HSR-19), to examine the use of Nestor's neural network technology for interpretation of the video images.

Principal Investigator: Eugene Waldenmaier

Technical Advisor:
Panos G. Michalopoulos
University of Minnesota

IDEA Contract: $44,250

Cost Sharing: $36,075

Project Total: $80,325

Start: April 1997

Complete: December 1997

HSR-8: Microwave Train Detection System for Grade Crossings

O'Conner Engineering Inc.
Benicia, California

IDEA Concept and Product

Despite substantial reductions in accidents at highway-railroad intersections over the past decade, such accidents remain a major cause of fatalities and injuries related to railroad operations. Accordingly, both high-speed and freight railroads, as well as local, state, and federal highway agencies and the Federal Railroad Administration are interested in innovative, low-cost alternatives to conventional grade crossing warning systems. A key component for such systems is the technique for detecting the presence of approaching trains to activate warnings such as flashing lights and gates. Conventional systems rely on the shunting of track circuits by approaching trains for such activation. However, track circuits are expensive to install and maintain and are not 100 percent reliable under conditions of rail contamination or lightweight rolling stock. Moreover, as conventional train control systems are replaced by communications-based train control systems, track circuits will no longer be required for activation of train control signals. This has resulted in a search for alternatives to conventional track circuits to detect train presence. The objective of this project was a low-cost, reliable alternative to conventional track circuits for activating grade crossing warning systems.

A state-of-the-art microwave system was used to determine the presence, position, velocity, and direction of movement of trains for activation of highway grade crossing warning systems. The ranging sensor used frequency modulated continuous wave (FMCW) processing to determine the distance of trains from the crossing (within a frequency range of 24.35 to 24.7 GHz), and Doppler processing to measure train velocity. The ranging sensor had a power output of .005 watts, a range of about one mile, and a range resolution of two feet. The velocity sensor was a Doppler module radar operating at 24.125 GHz with a power output of .005 watts and a range of one mile. It was capable of detecting closing or receding velocities from 0.5 mph up to 150 mph.

The system had the potential to monitor train progress continuously to update the train's estimated time of arrival at the crossing. Variations in train speed were therefore compensated for and a constant advanced warning time could be maintained. The system could also sense when a train has stopped and the warning system should be deactivated.

Project Progress

This project was completed in May 2000. O'Conner Engineering developed prototype systems to be evaluated in a series of field-tests. A project evaluation panel was convened to review the system design and field-test and evaluation plans.

Initial testing of the system was conducted at a single-track crossing on the Kansas City Southern Railroad with a high percentage of stop-and-reverse train movements. A second test series was conducted at a double-track crossing on BNSF that has a mixture of freight and passenger train traffic. Data were collected to evaluate such performance measures as range and train-speed sensor accuracy, trains not detected, false alarm rate, and the accuracy and consistency of advanced warning time provided. Event recorders accessed via telephone

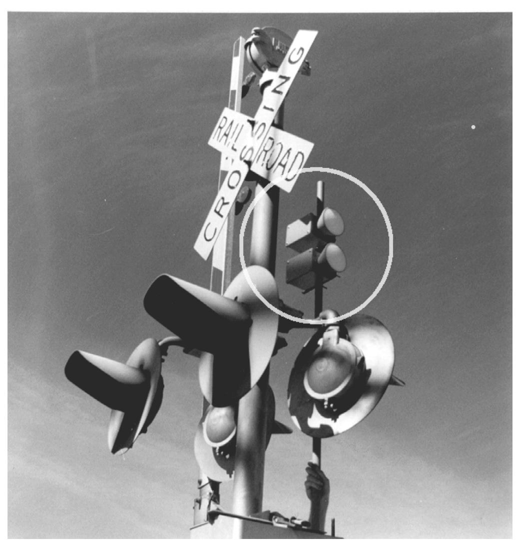

Figure 1

Microwave range sensor.

were installed at the test sites. These event recorders were dialed up and their data downloaded on a daily basis. The data enabled comparisons between the performance of the prototype system and the conventional track circuit system.

Results of these tests identified the need for additional improvements to the system if it is to be used in a full range of crossing configurations and railroad operations. These include earlier detection of high-speed passenger trains due to their lower, more aerodynamic profile. Test results also revealed that applications where extended detection distances are required, e.g., for high-speed trains, and where the tracks approaching the crossing contains curves or other obstructions, require remote radar sensors with radio links to the crossing system. The capability of the system to distinguish among two or more trains in the field of view of the radar sensors was not tested, and may require further development. Subsequent to the completion of this contract, the contractor continued development of an improved product to overcome these limitations. To date, more than ten of these improved systems have been sold.

Principal Investigator: Joe O'Conner

Technical Advisor:
Janie Page Blanchard

Project Panel:
Ernest Franke, Southwest Research Institute
Fred Perry, MPH Industries
Buck Jones, Kansas City Southern Railroad

IDEA Contract: $78,500

Cost Sharing: $23,000

Project Total: $101,500

Start: April 1997

Complete: May 2000

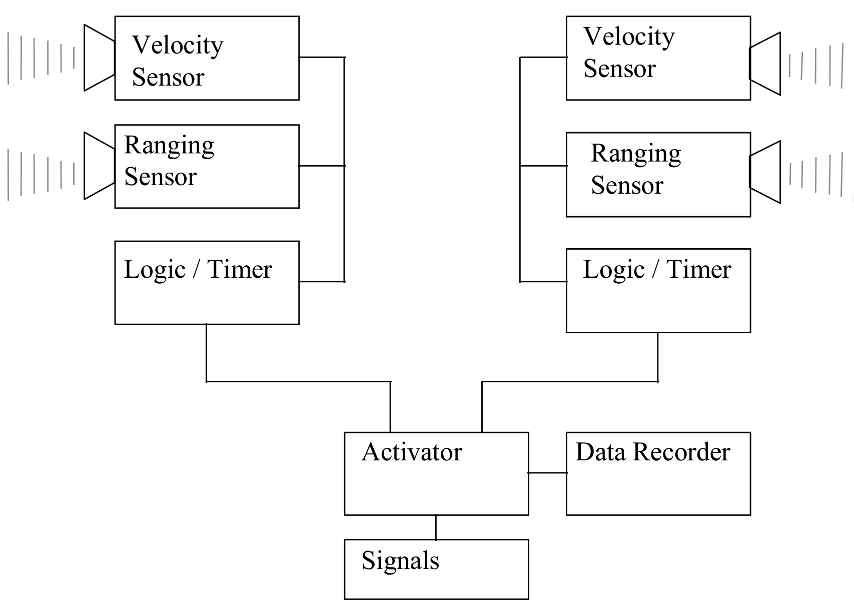

Figure 2

Typical track installation block diagram.

HSR-10: A Neural Network Video Sensor Application for Railroad Crossing Safety

Nestor Inc.
Providence, Rhode Island

IDEA Concept and Product

The introduction of four-quadrant gate systems that block both the entrance and exit of traffic lanes to railroad grade crossings has resulted in the need for information regarding highway vehicles within the crossing area when these systems are activated by approaching trains. There is also a widespread and growing need for a low-cost crossing surveillance system that could observe motorist behavior at crossings and detect the presence of pedestrians and bicyclists in the crossing area; the raised, lowered, or altered condition of crossing arms; and the functional status of signal crossing lights.

The objectives of this project were to determine the feasibility of using video for real-time detection of the presence of vehicles and trains at railway grade crossings and to monitor crossings equipped with gates and signal lights to determine whether these devices are functioning properly.

This IDEA project developed and tested software necessary to implement a video-based grade crossing surveillance system using a neural network-based video detection technology. The neural network must be able to accurately interpret the objects that move across a grade crossing as well as the condition and functioning of the crossing warning system components. The system could be used for such functions as providing alarm signals to motorists in extreme danger, messages to maintenance personnel regarding damaged or malfunctioning crossing system components, data for assessing grade crossing risk, and enforcement of grade crossing violations.

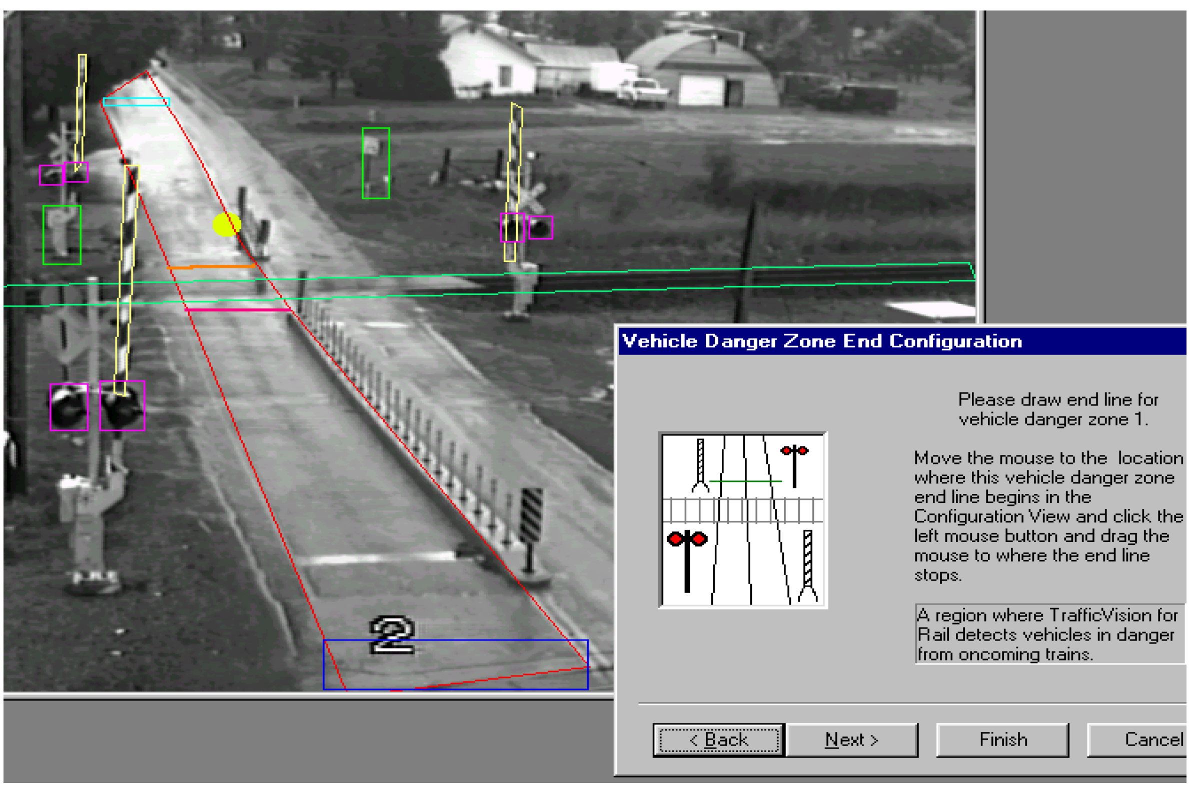

Figure 1

Example of the graphical user interface for initializing the system at each crossing.

Project Progress

This project was completed January 2000. The first stage of this IDEA project involved the definition of specific functional requirements for an automated video surveillance system for grade crossings. The second stage of the project, which concluded at the end of August 1999, consisted of collecting video of grade crossing activity for the purpose of follow-on software development and demo construction. A library of videotapes of grade crossing activity was collected from nine different crossings in California, Connecticut, Florida, and Washington. Data were collected from single- and multiple-track crossings, crossings equipped with standard gate arms and flashing lights as well as quad-gate arms. Train traffic at the crossings consisted of freight, passenger, and commuter rail service. Video data were collected at different times of day and under different weather conditions (including snow) in order to represent a variety of visibility conditions under which the video sensor capability could be tested.

The final stage of the project included software development to apply the neural network and other image processing technologies to the interpretation of the grade crossing video data as set forth in the project objectives. User interface functionality has been developed to support the system configuration necessary to interpret a grade crossing scene. Software for vehicle, train, and crossing warning system status detection was developed. Specific technical issues addressed included detection accuracy (e.g., incidence of false negatives and false positives), number and configuration of video cameras required, speed of operation and effects of visibility conditions. A desktop demonstration that can showcase the system was developed as part of the final project deliverable.

This system was installed and successfully tested at five crossings in the Ft. Lauderdale area under contracts with the Florida DOT and the Federal Railroad Administration. This project demonstrated the system's capability for video-based vehicle and train detection, as well as monitoring the health of the grade crossing warning system (gates and lights). In addition, an enforcement version was installed at a grade crossing in DuPage County, Illinois. This installation was to evaluate the use of the technology for the detection and identification of vehicles that continue through crossings after the warning system has been activated.

In a subsequent contract with FRA, Nestor developed a mobile surveillance system. The mobile system can be quickly set up at a crossing to monitor such things as highway and train traffic volumes and driver behavior.

Principal Investigator: Doug Reilly

Technical Advisor:
Ron Ries, FRA

Project Panel:

Bill Browder, Association of American Railroads
Anya Carroll, Principal Investigator, Volpe Transportation Systems Center
Dennis Hamblett, Washington DOT
Anne Brewer, Florida DOT, Administrator of Rail Operations
Haji Jameel, California Public Utilities Commission

IDEA Contract: $100,000

Cost Sharing: $117,307

Project Total: $217,307

Start: June 1998

Complete: January 2000

HSR-11: Quad Gate Crossing Control System

Rail Safety Engineering Inc.
Rochester, New York

IDEA Concept and Product

A major cause of highway-railroad grade crossing accidents is attributed to vehicles driving around the traditional entrance-only crossing gates. As a result, there is great interest in so-called four-quadrant gate systems typically consisting of two pairs of entrance/exit gates providing a complete crossing barrier to prevent drive-around. Existing gate control systems are expensive to modify for four-quadrant gate operation, especially when required to incorporate methods of detecting vehicles stopped on the tracks.

The objective of this IDEA project was a fail-safe, microprocessor-based, application-specific controller that can directly interface to various vehicle detection schemes and will operate exit gate mechanisms and the currently installed entrance gates.

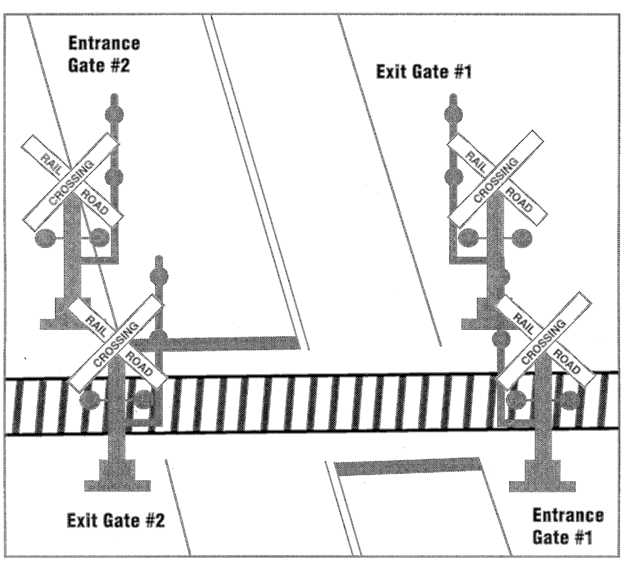

Figure 1

Typical four-quadrant gate system.

This project developed and tested a four-quadrant gate control system based on a novel programmable controller. The product was to be an integrated control system consisting of a simulation-design/verification tool, application-specific vital software generator, and solid state vital quad-gate crossing controller hardware. Existing techniques for on-crossing vehicle detection and approaching train detection were to be supported to assure that vehicles would be given sufficient train warning and could not be trapped within the crossing. A software-based application tool set to assist and streamline the design of individual applications of the controller was also developed.

Project Progress

This project was completed May 2000. The project began with the specification of functional and system requirements based on input from potential users of quad-gate crossings. The results were used to develop a high-level system design. Project objectives, approach, and the functional requirements were reviewed by a panel of experts. An external interface specification was completed to describe the interface with crossing surveillance systems. The quad-gate controller was based on a GE-Fanuc Series 90-30 programmable controller. Software requirement specifications and detailed designs were completed. A prototype system was fabricated and laboratory tested. The test data were analyzed to assess performance and reliability. Test results indicated that the prototype system met all performance and reliability objectives. A final report documenting the system design and the results of the testing was completed in May 2000.

Subsequent to the completion of this contract, the contractor was bought by GE, which subsequently bought Harmon, a major railroad signal supplier. The Principal Investigator for this project reported that many of the ideas developed during this project have been incorporated into Harmon's product line.

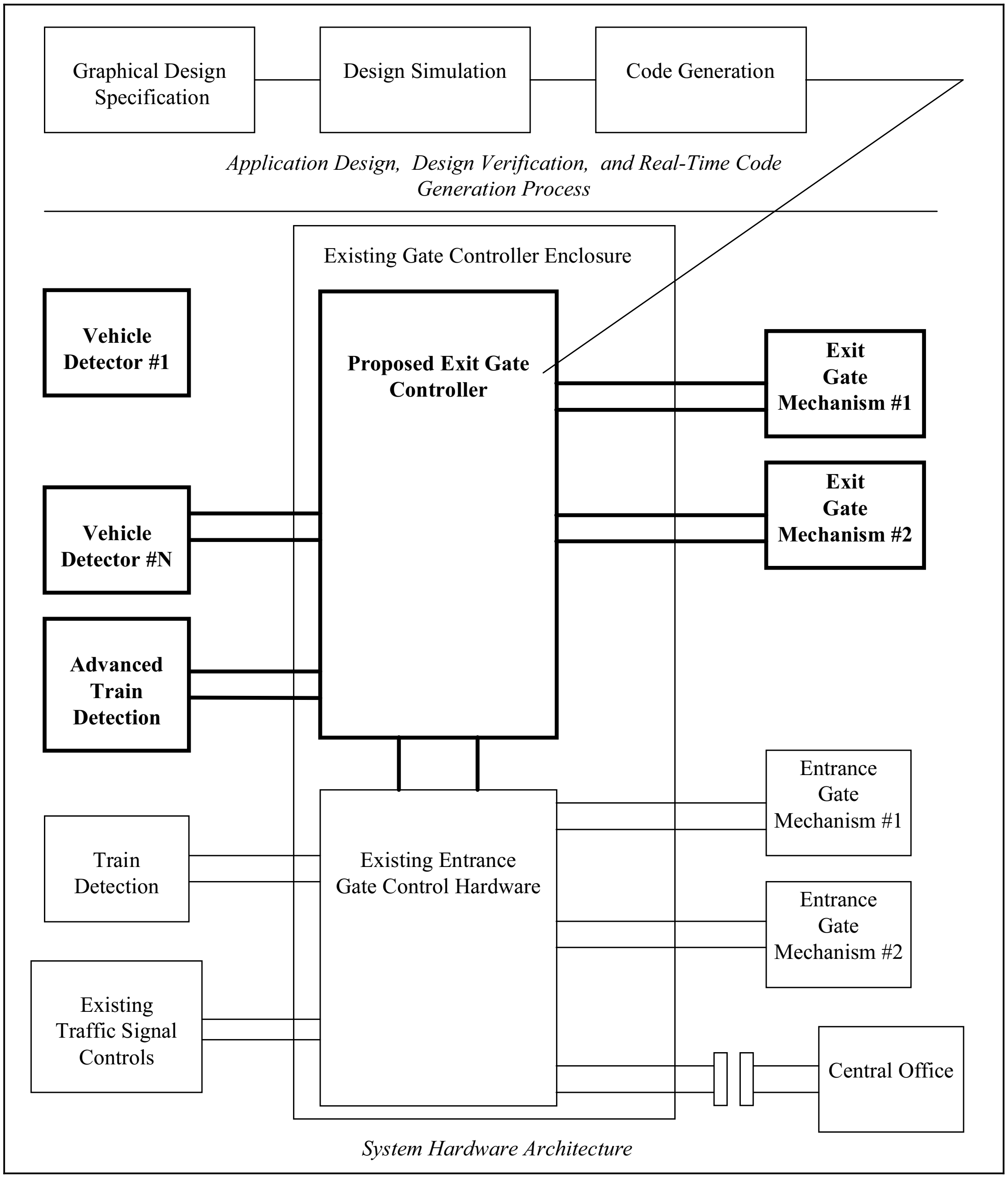

Figure 2

Proposed quad-gate crossing system.

Principal Investigator: Jeff Twombly

Technical Advisor:
Fred Coleman, University of Illinois

Project Panel:
Fred Coleman (Chair)
Richard McDonough, NYDOT

IDEA Contract: $80,000

Cost-Sharing: $139,000

Project Total: $219,000

Start: September 1998

Complete: May 2000

HSR-13: Grade Crossing Obstacle Detection Radar

WaveBand Corporation
Torrance, California

IDEA Concept and Product

There is growing interest in the use of four-quadrant gate systems at railroad grade crossings to prevent motorists from driving around gate arms that block only the entrance lanes to crossings. The introduction of four-quadrant gate systems that block both the entrance and exit of traffic lanes across railroad tracks (see Figure 1) has resulted in the investigation of technologies to provide information regarding highway vehicles within the crossing area when these systems become activated by approaching trains. Such systems could detect vehicles on the tracks in order to time activation of the exit gate to avoid trapping vehicles between the gates.

The objective of this project was to determine the feasibility of using a millimeter-wave (MMW) radar system to detect highway vehicles within grade crossings. The sensor system would be designed to provide a standard interface with four-quadrant control systems for intrusion detection and sequencing the activation of the exit gates.

WaveBand Corporation has developed a novel scanning MMW radar antenna system (See HSR-1). This system has the potential for use in detecting intrusions in grade crossing areas for automated sequencing of multiple gate arms such as four-quadrant gate systems. The system uses a spinning grating antenna. The narrow-beam scanning antenna provides the spatial resolution required for obstacle detection at railroad crossings. Since the system operates in the MMW frequency band, it should be able to detect objects in adverse weather conditions. The objective was a product that could interface with four-quadrant gate controllers to provide data on vehicle presence in the crossing necessary to sequence gate operation.

Project Progress

This project was completed April 2000. The project (HSR-13) was a follow-on to a previous IDEA project (HSR-1) to investigate the concept of a spinning grating MMW scanning antenna for application to railroad and automotive obstacle detection and collision avoidance (see Figure 2). The follow-on project began with the collection and analysis of information from current and potential users of crossing gates, including four-quadrant gate systems, to develop functional and design specifications for intrusion detection. Design and fabrication of the system hardware and software was then completed. The next steps included laboratory shakedown tests

Figure 1

Typical 4-quadrant gate.

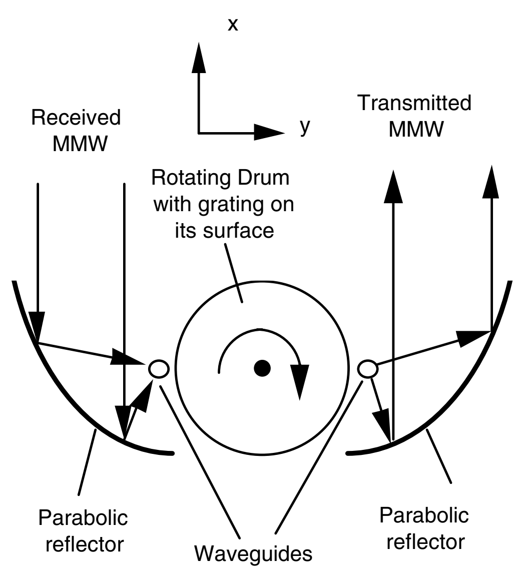

Figure 2

Spinning grating antenna.

followed by preliminary field-testing at an active grade crossing. Analysis of the radar signals collected during field tests indicates that this concept has promise. Further development of the system will require software to interpret the radar signals and testing under a full range of operating and weather conditions. A final report documenting the system design and the results of the preliminary field-testing was prepared in April 2000.

Principal Investigator: Lev Sadovnik

Technical Advisor:
Fred Coleman, University of Illinois

Project Panel:
Fred Coleman (chair)
Richard McDonough, NY DOT

IDEA Contract: $92,123

Project Total: $92,123

Start: March 1998

Complete: April 2000

HSR-16: Advanced Intersection Controller Response to Railroad Preemption

Texas Transportation Institute
College Station, Texas

IDEA Concept and Product

Traffic signals that are located near railroad-highway grade crossings are designed to permit vehicles that may be stopped on the tracks to move to safety when a train approaches the crossing. In some cases, the warning time provided to the traffic signal system is as little as 20 seconds before the train arrives at the crossing. Often, the short duration of this warning time can cause crossings to operate in a potentially unsafe and inefficient manner. Further, existing standards, primarily the Manual on Uniform Traffic Control Devices (MUTCD), allow traffic signal controllers to cut short the pedestrian phases and vehicle phases that conflict with the track clearance phase. Such heavy-handed preemption treatment, while effective at arriving at the track clearance phase, may leave pedestrians with curtailed WALK flashing DON'T WALK indications, or both, while they are crossing the street, and it may lead to short and confusing signal indications for motorists. This project developed a new method for controller treatment of railroad preemption calls that is based on advanced train detection and controller notification. Detection and preemption systems that are in use today would remain as a fail-safe default preemption where the new strategy, known as the transitional preemption strategy (TPS), is implemented.

The objective of the TPS logic developed and refined during this research was a reliable method for providing improved intersection controller response to the preemption of adjacent highway-rail grade crossings. TPS would ensure that phases that conflict with the track-clearance phase receive the minimum time required for vehicles and pedestrians to clear the intersection; if such time is not available, the phases would never be initiated. The smooth transition into intersection phases that clear vehicles from the highway-rail grade crossing was made possible by advanced detection and warning of the arrival of approaching trains. Placement of advanced train detection devices (Doppler radar) was intended to provide the necessary minimum times for both pedestrians and vehicles on phases that conflict

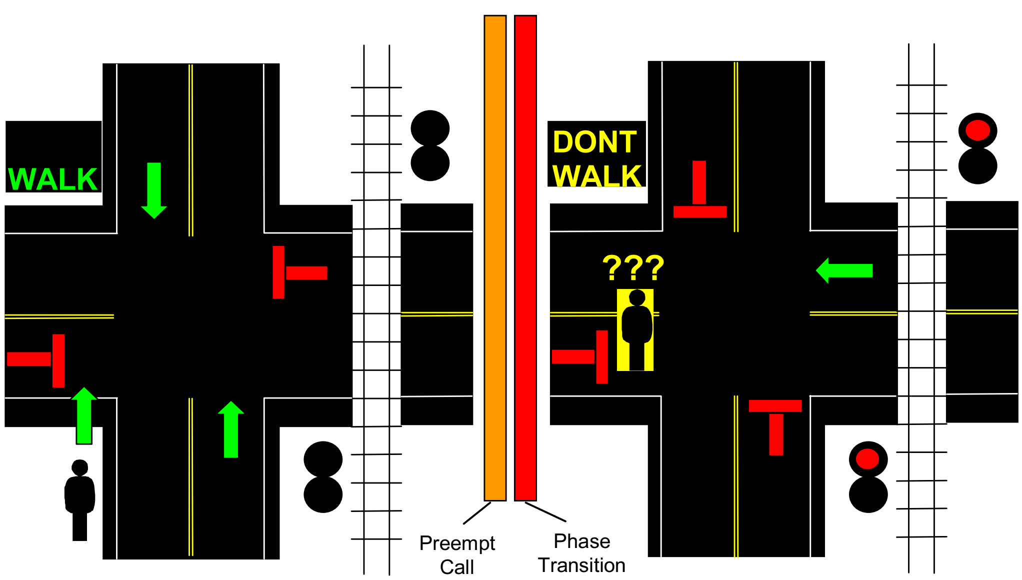

Figure 1

Standard preemption scenario illustrating MUTCD pedestrian "relative hazard" position.

with the track-clearance phase before it was initiated. The fact that TPS avoided the display of short green indications for motorists at the intersection could also lead to operational improvements in terms of the intersection's ability to smoothly and safely process vehicles.

Project Progress

This project was completed in February 2000. Development of the TPS logic was organized into three stages. During Stage I, researchers at the Texas Transportation Institute (TTI) synthesized background research and current practice pertaining to railroad preemption of traffic signals near highway-rail grade crossings. Once this was completed, the TPS logic algorithm was developed.

Stage II of the research had as its primary objective the simulation testing of the TPS logic. The TPS algorithm was software encoded and integrated into a unique simulation and testing environment with the staff support and hardware of TTI's TransLink® research laboratory. The testing environment, known as hardware-in-the-loop simulation, allows a traffic or traffic and highway-rail grade crossing simulator to be connected to an actual traffic signal controller device. A piece of electronic hardware known as a controller interface device connects to the controller's standard input/output connectors and to a PC's USB port, allowing the use of the traffic signal controller's functionality for traffic control and preemption for vehicles, pedestrians, and trains simulated on the PC. During the testing and simulation stage, the logic was refined and improved. The results of the simulation effort included a side-by-side comparison of results from cases that did and did not include the TPS logic.

Stage III of the project, which included field-testing the algorithm at a signalized intersection adjacent to a grade crossing, was completed. Advanced train detection information at the field site was obtained using TTI TransLink's Doppler train-detection equipment and train arrival-time estimation software.

Results of the field-testing revealed substantial variability between predicted and actual arrival of trains at crossings. This problem was because the Doppler radar system made only a single-point estimate of train speed for predicting crossing arrival times. This estimate did not account for any subsequent acceleration or deceleration of trains. Further development of this concept would require the capability for frequent updates of train speed and arrival predictions. A final report documenting the algorithm, system design, and test results was completed in February 2000.

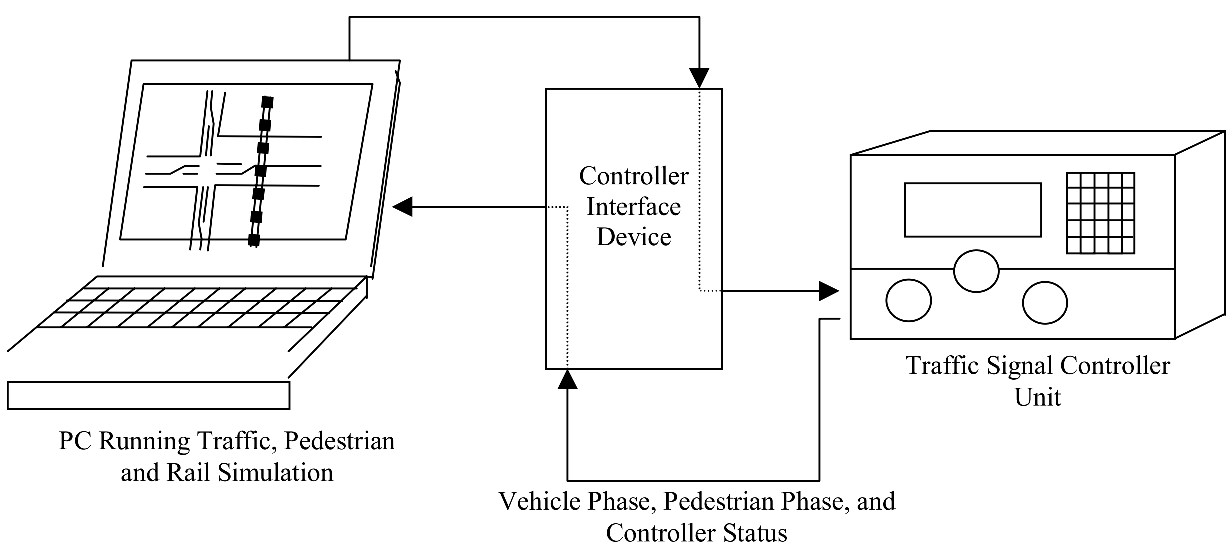

Figure 2

Simulation environment for transitional preemption strategy development and testing.

This project led to the development of a training course on railroad preemption techniques. The contractor, Texas Transportation Institute, is now giving this course to state and local transportation engineers.

Principal Investigator: Steve Venglar

Technical Advisor:
Hoy Richards, Richards and Associates

Project Panel:
Cliff Shoemaker, Union Pacific Railroad
Arnold McLaughlin, Eagle Traffic Control Systems
Mark Smith, City of College Station, Texas

IDEA Contract: $65,000

Cost-Sharing: $15,310

Project Total: $80,310

Start: February 1999

Complete: February 2000

HSR-50: A Track Sensor System for Predicting Train Arrival Time

Analogic Engineering Inc.
Guernsey, Wyoming

IDEA Concept and Product

This project will examine the concept of introducing coded, differential RF pulses into the rail at grade crossings and, using Time Domain Reflectometry (TDR) techniques, determine the distance to reflections of these pulses caused by approaching trains. Measurements of this train distance information and how it changes over time will be used to predict train arrival time for the activation of grade crossing warning systems. The investigative approach includes the development and bench and field-testing of a prototype system. These bench and field-tests will be designed to address a number of issues identified in a previous HSR-IDEA project that explored this technology (HSR-38). These included performance of the system near turnouts, bolted and insulated joints, rail welds, the effects of various ballast conditions and concrete ties, and possible interference or damage to or from lightening protection circuits, coded track circuits, EMI, and so forth. The work plan calls for bench testing at the laboratories of two manufacturers of conventional grade crossing warning systems to confirm compatibility with existing track circuit controllers, and field testing at the Transportation Technology Center at Pueblo, Colorado.

Project Progress

The system performance requirements have been developed and the system design has been completed. A bench prototype system also has been completed and tested. Arrangements are being made for an initial field test at the Transportation Technology Center in Pueblo, Colorado. Remaining tasks include measurements at TTCI to determine track electrical properties at the proposed pulse frequencies, completion of the prototype, bench testing to determine whether it meets the performance requirements and is compatible with existing track circuit controllers, and final field-testing at TTCI. The project is scheduled to be completed in January 2009.

Principal Investigator: Steven Turner

Project Panel:
- Jeff Gordon, Volpe
- Robert Kubichek, University of Wyoming
- Don Plotkin, FRA
- Rich Reiff, TTCI

IDEA Contract: $99,934

Cost Sharing: $24,444

Project Total: $124,378

Start: November 2004

Complete: January 2009

HSR-53: Magnetometer Sensors for Railroad and Highway Equipment Detection

Sensis Corporation
Campbell, California

IDEA Concept and Product

This contract is to study the feasibility of a train and vehicle detection system based on magnetometer sensor technology. The proposed applications to be investigated include train location and speed detection for the activation of grade crossing warning systems; detection of highway vehicles and other obstructions at grade crossings; detection of Hi-Rail and other track maintenance equipment on or adjacent to the track; and detection of right-of-way incursions by non-railroad vehicles and equipment. The proposed sensor technology is Anisotropic Magnetoresistive (AMR) magnetometers. These sensors consist of a nickel-iron (Permalloy) thin film deposited on a silicon wafer. When exposed to the earth's magnetic field, the electrical resistance of the Permalloy film changes with changes in the field, such as would be caused by the nearby movement of a large ferrous metal mass such as a locomotive or an automobile. The output of these sensors is a unique signature that can be analyzed to determine not only the presence of an object, but the characteristics of the object, e.g., locomotive or Hi-Rail vehicle, its location and direction of movement (see Figure 1), and its speed. Contract tasks included selection of candidate sensors, and laboratory and field tests of those sensors. Field-testing included tests using automobiles, locomotives, rail cars, and Hi-Rail vehicles.

Project Progress

This project was completed in June 2006. Field-testing determined that the sensors can accurately and reliably detect trains approaching and occupying crossings and highway vehicles in or adjacent to crossings. Locomotive electromagnetic interference (EMI) effects were found to be minimal. Train speeds measured using two sensors along the tracks were found to be accurate within 5 percent based on comparisons with a radar speed gun.

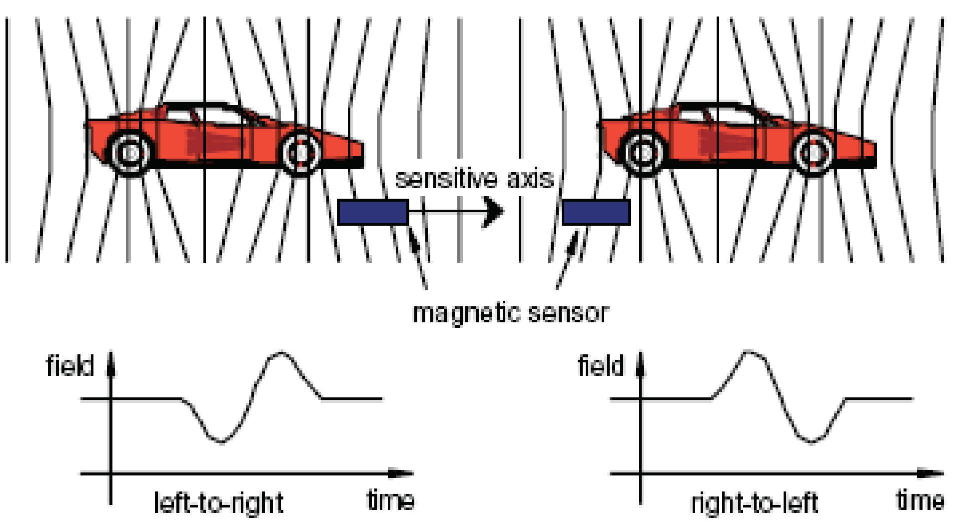

Figure 1

Vehicle direction sensing with AMR magnetometer
(Car in left panel moves forward and reverses direction in right panel).

Principal Investigator: Tysen Mueller

Project Panel:

Pete Mills, FHWA
Rich Reiff, TTCI
Jim Smailes, FRA
Corey Wills, BNSF

IDEA Contract: $79,987

Cost Sharing: $10,000

Project Total: $89,987

Start: August 2005

Completed: June 2006

Track and Structures

HSR-15/28: Hybrid Uni-Axial Strain Transducer

University of Utah
Salt Lake City

IDEA Concept and Product

The collection and analysis of data on the fatigue history of high-speed railroad components such as rail, bridge members, and wheels is extremely difficult using traditional sensors and data acquisition systems. Strain-gauge systems typically require cumbersome data collection, preprocessing and storage devices, signal processing devices, substantial power sources, and complex wiring. And these systems do not provide high resolution and are not drift free. Uni-axial and bi-axial strain transducers are micro-electromechanical systems (MEMS) with such characteristics as high resolution and high sampling rate, absolute encoding, no calibration requirements, no drift over time, and less measurement noise than analog-based strain sensors. They measure strain by measuring the displacement between two overlapping pads attached to a structure such as a beam or rail. One pad contains an array of electrostatic field emitters, and the other pad contains an array of field effect transistor gates on an IC chip. Displacement of one pad relative to the other pad causes the emitters to move over the surface of the IC chip. Digital processing of the resulting signal is used to calculate strain. The system can measure displacements as small as 50 Angstroms (5×10^{-7} cm). The sensor sampling rate is dynamically configurable and up to 128 sensors can be linked on a common 5-wire digital bus, eliminating the need for shielding and considerably reducing the number of wires which have to be routed through the structure to be measured. Because they have low DC power requirements, they can be used in remote locations. The small size and on-chip signal processing features provide the potential for a truly portable testing device.

The objective of this research was to determine the potential of these transponders as a new tool to continuously monitor, analyze, and store the strain history of components such as rail. This data could be periodically downloaded and used for such purposes as measuring rail stress induced by axle loadings or thermal loadings. The research was to develop a prototype transponder system, which includes nonvolatile RAM to store strain cycling history, e.g., tracking how many times the transponder crosses each of specified strain thresholds across its dynamic range, and temporarily storing the preprocessed data. The prototype system consists of three parts, a sensor, a networking controller box, and a communication cable. Figure 1 shows a schematic design of a hybrid uniaxial strain transducer (HUAST)

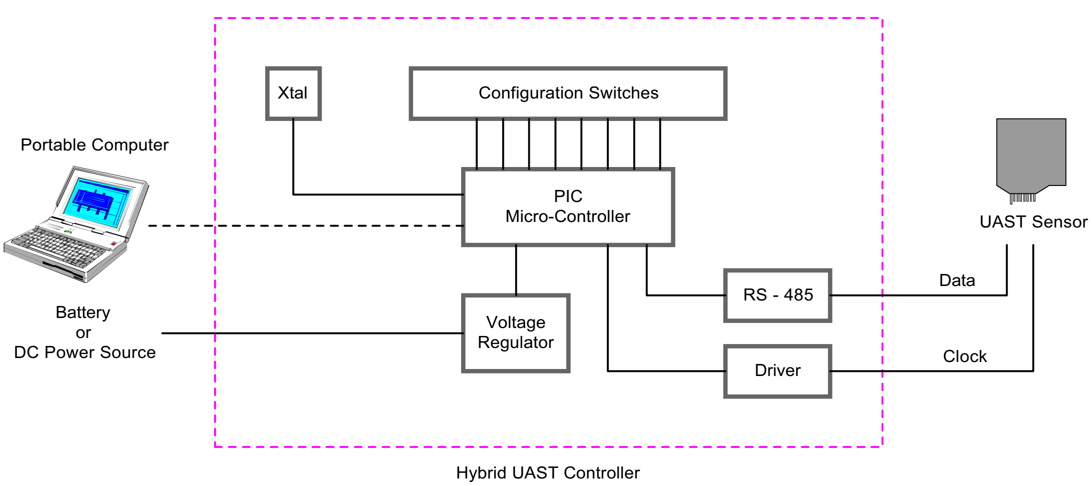

Figure 1

Schematic diagram of a prototype Hybrid UAST.

Figure 2

Strain data collection from a rail using UAST™ and a microcontroller.

controller to be operated by a battery. A load cycle counting algorithm is integrated into a microcontroller, which is programmable using configuration switches. Using this HUAST controller, eight different strain levels can be collected at four different sampling rates.

Project Progress

This project was completed September 2004. Laboratory tests using an aluminum beam equipped with UASTs and conventional foil strain gauges demonstrated the accuracy and repeatability of the UASTs. A series of cyclic loading tests was performed to simulate a moving trainload applied on a rail using an MTS loading machine in the laboratory. The main purpose was to determine an optimum sampling rate for rail. A technique for mounting the HUAST to rail was developed. A prototype HUAST design and load cycle counting algorithm were developed and tested using actual HUAST strain data taken from a rail section at a field test site on a railroad in Salt Lake City. A prototype HUAST package was fabricated and laboratory tested. Field testing of the HUAST prototype package in a rail operating environment was conducted, and analysis of the test data completed. A final report documenting the system design and test results was completed in March 2000.

This concept exploration project was sufficiently successful that a follow-on contract was awarded to develop and build a production prototype system based on this concept and test it at the Transportation Technology Center, Inc. (TTCI). The prototype system used bi-axial strain transducers, which can simultaneously measure strains in two directions, rather than the previous uni-axial transducers. Tasks included development of a model to predict rail fatigue life, and a network of five bi-axial strain transducers was constructed for use in field-tests at TTCI. Initial field tests indicated the need for further improvements to the prototype. Problems were encountered with attaching the bi-axial sensors to the rail, only two of the five sensors functioned, and none of the sensors proved to be accurate and reliable. The manufacturer of the bi-axial strain transducers was unable to finish the development of a final prototype system. Accordingly, the University of Iowa project team attempted to finish the prototype system and to analyze and correct the problems encountered in the initial field-tests. They were unable to successfully resolve the problems with mounting the sensors on the rail and in determining the causes of the unreliable sensor performance. For that reason, a planned second series of tests at TTCI had to be cancelled. The University of Iowa team prepared a final report that documented the work accomplished and the problems identified.

Principal Investigator: Hosin Lee

Technical Advisor:
James Lundgren,
Transportation Technology Center, Inc.

Project Panel:
David Warnock, Utah Transit Authority
Crosby Mecham, Utah Transit Authority
Rick Campagna,
Utah Department of Transportation

IDEA Contract: $45,000 Initial/$145,000 Follow-on

Cost Sharing: $20,000/$60,000

Project Total: $65,000/$205,000

Start: November 1998/January 2001

Complete: April 2000/September 2004

HSR-23/43: Investigation of a Hybrid-Composite Beam System

Teng & Associates Inc.
Chicago, Illinois

IDEA Concept and Product

Many of the railroad bridges in the United States were built in the early 1900s or before. Time and tonnage have taken their toll on these structures, and railroads today are confronted with the necessity to replace them or upgrade them with selective replacement of critical components. The objective of this project was to develop a cost-competitive alternative to conventional steel or reinforced concrete beams that would be lighter in weight and resistant to corrosion. The concept explored was a composite structural beam system using both plastic and concrete components.

The beam system consists of three main components. The first of these is the plastic beam shell that encapsulates the other two components. The second component is the compression reinforcement that consists of a concrete arch that is pumped or pressure injected into a continuous conduit fabricated into the

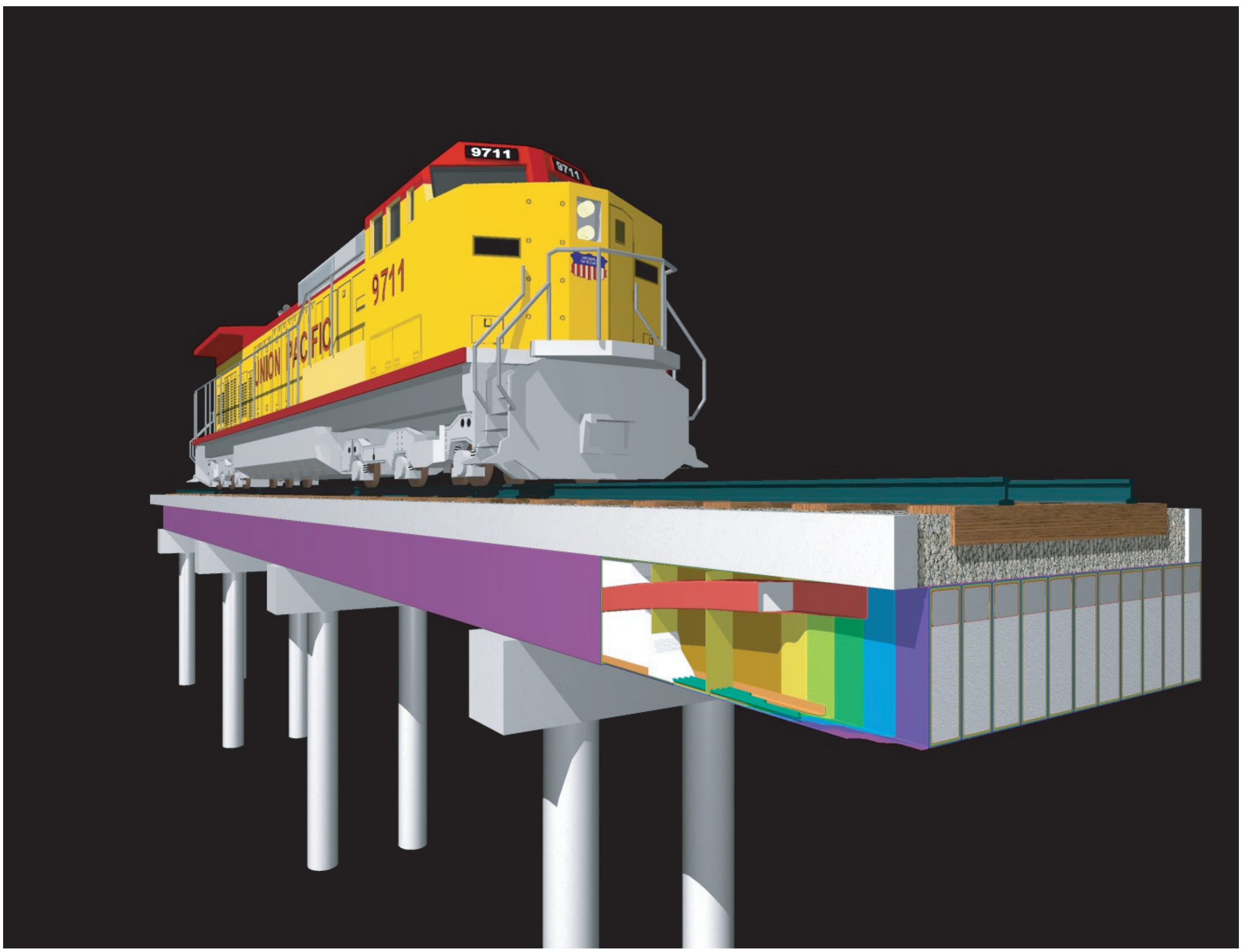

Figure 1

Cut-away view of hybrid composite beam system.

beam shell. The third component is the tension reinforcement that is used to equilibrate the internal forces in the compression reinforcing. This tension reinforcing could consist of unidirectional carbon or glass fibers or steel fibers anchored to the ends of the concrete arch.

Project Progress

This project was completed in July 2008. Project tasks included a life-cycle cost comparison of a generic hybrid-composite beam system with conventional steel and reinforced concrete beam systems. Costs related to manufacturing, installation, and maintenance and inspection were compared. Research to identify the materials most suitable for hybrid-composite beam fabrication, including best fiber and matrix composition, concrete mix designs and tension reinforcement materials was performed. A hybrid-composite beam system was designed based on such criteria as bending shear, live-load deflections, and fatigue. An analysis of the proposed design using mathematical models was performed and design modifications made based on results of these analyses. A 19-foot scale model prototype of the beam system was designed and fabricated. Tests of the prototype beam system were conducted and test data compared with mathematical model predictions. Findings indicated that bridges constructed with the hybrid-composite girders would have the same strength and stiffness characteristics as bridges constructed using steel or pre-stressed girders, but would offer greater corrosion resistance and increased load-carrying capacity at a competitive cost. A follow-on

Figure 2

Three-point load testing of a prototype beam at University of Delaware's Center for Composite Materials.

product application contract (HSR-43) was then awarded to construct 30-foot full-scale prototype beams and subject them to additional laboratory tests and also test them in a railroad operating environment. The contract included field-testing of an eight-beam bridge where it was subjected to repeated loads by test trains with heavy-axle cars.

A 30-foot prototype full-scale beam was tested in the lab using hydraulic actuators, where it was subjected to a two-million cycle load test and an ultimate load test. The prototype met all specifications as defined in the AREMA recommended practices for railroad bridge beams. Eight additional 30-foot HCB beams were fabricated for field testing. A consortium of five Class I railroads funded the installation of the eight-beam bridge span at TTCI for preliminary load tests. Eight additional 30-foot HCB beams were fabricated and installed in a bridge span at the Transportation Technology Center (TTCI) in Pueblo, Colorado, for preliminary load tests. These tests were successful and the span was installed in the high-tonnage loop at TTCI in October 2008 for prolonged service testing. The test objective is for the span to accumulate 100 MGT (million gross tons) by

Figure 3

Composite Bridge Beam performed within limits of the AREMA design codes during load tests at TTCI.

2009. To date, the bridge has accumulated over 15 MGT without any problems. An HCB highway bridge with 55-foot beams was installed in Lockport, Illinois. This bridge was completed and opened to traffic in September 2008. Installation of another HCB highway bridge in New Jersey is now underway. This IDEA project was jointly funded by the HSR-IDEA and NCHRP Highway IDEA programs.

Principal Investigator: John Hillman

Project Panel:
- Mike Franke, Amtrak
- Duane Otter, AAR/TTCI
- Ian Friedland, FHWA
- Brian Hornbeck, Tardek

IDEA Contract: HSR 23: $99,931/HSR 43: $240,557

Cost Sharing: $14,267/$214,834

Project Total: $114,198/$455,391

Start: August 2000/September 2003

Complete: August 2002/July 2008

HSR-24/41: Improved Reliability of Thermite Field Welds

University of Illinois
Champaign, Illinois

IDEA Concept and Product

Failures of field-welded rail joints are a significant cause of derailments in the North American railroad industry. As such, they contribute significantly to train delay and have a major impact on rail service reliability. The increasingly heavy axle loads characteristic of current and future railroad freight operations will only make this problem worse. Moreover, since most high-speed passenger operations are on track shared with heavy-haul freight operations, the search for improvements in field weld technology is important to both freight and passenger operators.

This project investigated techniques for improving the fatigue performance of thermite welds by diminishing the likelihood of initiating fatigue cracks in two critical locations: the rail web and the rail base. Cracks develop at the weld toes in these locations (Figure 1) because of local geometric discontinuities (notches). The project investigated new designs to improve the local notch-root geometry of welds and new types of sealant between the rail and the mold used in thermite welding that will produce smoother surfaces in these fatigue-critical notch-roots. Alternatives to the currently used fluxes and techniques to coat the interior weld molds to produce a smoother cast surface were also investigated.

At the conclusion of the project recommendations were developed to alter the equipment, materials, and techniques used by track maintenance personnel when they perform thermite welding in the field.

Project Progress

This project was completed in September 2004. Methods of modifying thermite weld molds to reduce the severity of the weld profile of the base and web regions were developed. Mold washes and fluxes to coat the interior of weld molds to produce a smooth cast surface were studied. Techniques and materials to seal the mold against the rail were investigated. Full-size thermite welds were fabricated using modified molds with improved weld geometries and internal coatings and using mold-to-rail sealants (Figure 2). A test fixture for 4-point bend tests of thermite welds was constructed and fatigue tests were performed on the fabricated weldments. Modifications of weld molds produced welds that extend the fatigue life of thermite welds two to five times beyond that of normal thermite welds. Specific improvements were reducing the flank angles and increasing the weld toe radii.

Based on these findings, the HSR-IDEA Committee recommended a follow-on contract with the University of Illinois (UI) to investigate additional methods to improve thermite welds and conduct more extensive testing. These include methods to reduce the surface roughness of weld metal and tighter control over the thermal conditions during welding. A major supplier of thermite welding equipment provided samples of its current welds and welds based on the UI-developed new designs.

Extensive laboratory testing indicated that the improved welds had an average fatigue life approximately 2.5 times longer than that of standard welds. A major supplier of thermite welding equipment has incorporated the improved mold designs and tighter control of the thermal conditions during welding in an improved thermite welding technique. Welds using this improved technique were installed in test track at the Transportation Technology Center in Pueblo, Colorado. Data on the performance of the new welds are being compared with performance data on conventional thermite welds.

Principal Investigator: Fred Lawrence

IDEA Contract: HSR-24: $89,929/HSR-41: $155,894

Cost Sharing: $69,699/$38,832

Project Total: $159,628/$194,725

Start: July 2000/January 2003

Complete: April 2002/September 2004

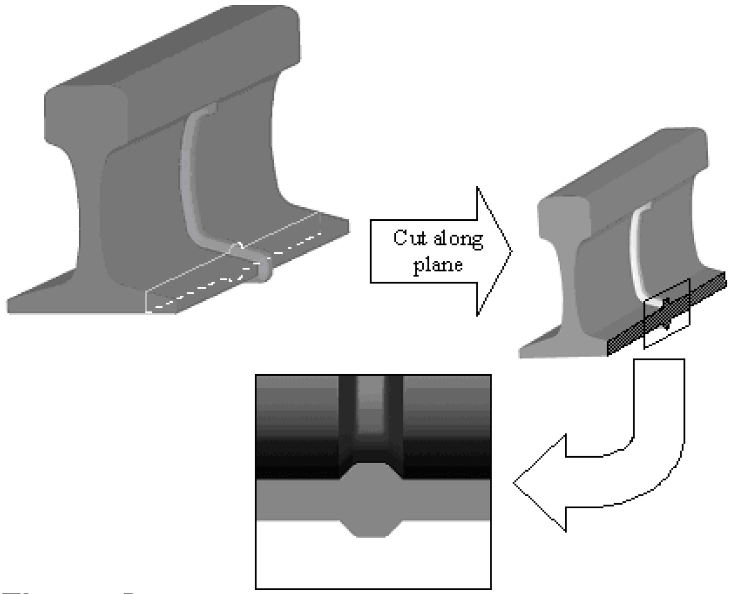

Figure 1

The thermite rail-weld weld-toe. Section of a thermite weld in the rail base. The circled regions are at weld-toes.

Figure 2

Thermite welding in the Newmark Structural Engineering Laboratory at the University of Illinois at Urbana. Personnel from the CN/IC railroad are present to ensure industrial practice.

HSR-25: Neural-Network Based Rail Flaw Detection Using Unprocessed Ultrasonic Data

University of Illinois
Champaign, Illinois

IDEA Concept and Product

Field inspection to detect rail flaws is performed primarily using ultrasonic transducers mounted on track-mounted vehicles (see Figure 1). Failure to promptly detect and repair these flaws imposes service reliability problems for both freight and passenger operations and can pose safety concerns. Current ultrasonic rail flaw detection technology limits inspection vehicle operating speeds to about 15 mph and detects only about 70 percent of the flaws. Both of these restrictions result from the limitations of the human operator's ability to interpret the signal from the detection equipment. When flaws are indicated with the current system, it is often necessary to stop the inspection vehicle and perform a hand test. This limits efficient management of rail repair and delays traffic.

Neural networks have the potential to substantially enrich the capability to efficiently and reliably extract comprehensive information from the ultrasonic signal used to inspect rail, and to do so in a more automated manner. Neural networks can improve the capability to recognize flaws using the ultrasonic signal after it has been filtered by the signal processor. However, the information in the processed signal is substantially abridged because of limitations in the human operator's ability to interpret it and much useful information about flaws is discarded.

Figure 1

Rail flaw inspection vehicle.

In this project, laboratory and field techniques were to be used to develop neural networks that use all of the information, not just the processed signal. The end product envisioned was a rail inspection car that can operate at significantly higher speeds, detect flaws earlier and more reliably, and detect flaws that currently cannot be detected.

Project Progress

This project was terminated in July 2003. A rail flaw detection laboratory was planned to generate and record data under controlled laboratory conditions, and to perform verification tests during the development of the neural network systems. Ultrasonic inspection data were then to be generated and recorded under controlled conditions in the laboratory. These data were to be used in the development and verification of the neural network system.

Sperry Rail in Danbury, Connecticut, had initially agreed to generate and record inspection data under controlled conditions in the laboratory to be used in the development and verification of the neural network system. The system was then to be subjected to a series of tests at Sperry's facilities, and revised as necessary. After the project began, Sperry reported that it could no longer support the project. Because Sperry's support was essential, the contract was terminated. The project team prepared a final report that included the concept and application, the intended investigative approach, work performed, and recommendations for any future investigation of this idea.

Principal Investigator: Jamshid Ghaboussi

Technical Advisor:
Tom Wright, BNSF RR

IDEA Contract: $90,000. Revised to $40,000

Cost Sharing: $85,000

Project Total: $175,000

Start: September 2000

Terminated: July 2003

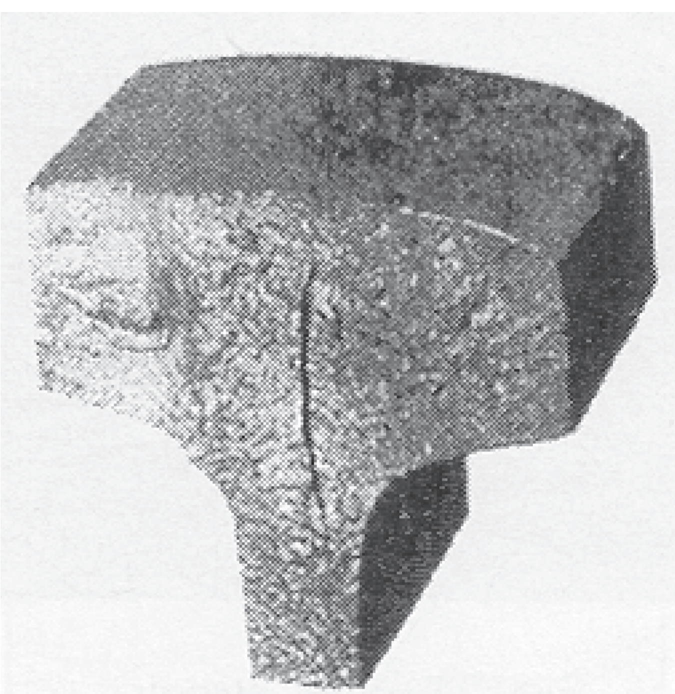

Figure 2

Rail cross section showing vertical split. The objective of this project is more reliable and efficient detection of such flaws.

HSR-26: High-Precision GPS for Continuous Monitoring of Rail

University of Illinois
Champaign, Illinois

IDEA Concept and Product

A fast, precise, low-cost method for predicting conditions that can lead to track buckling or rail breaks is a high-priority research need in both the freight and high-speed passenger railroad industries. One precursor of such events is minute changes in track geometry. These can result from temperature-induced longitudinal stress that begins to exceed the capacity of the lateral restraint system (e.g., spikes, ties, ballast). This project was to develop, test, and evaluate a high-precision GPS (HPGPS) system for monitoring minute changes in rail geometry, and assess the likelihood that these changes can be used to reliably estimate rail stress and predict incipient rail buckling and rail breaks. Precise measurements of small changes in rail geometry (2-3 cm) using HPGPS, combined with data on current and laying temperature for the rail, would be used to calculate rail stress and predict the likelihood of buckling or breaks. In addition to predicting such potentially catastrophic events, such a system could be used to pinpoint track locations where maintenance is required, as determined by geometry changes due to such causes as changes in track bed conditions and rail anchoring. If this concept was found to be viable, such a system could be used on locomotives and/or track inspection vehicles.

Project Progress

This project was completed September 2003. Kinematic differential GPS data were collected on a railroad in both warm and cold weather conditions. The data were collected by mounting a DGPS system on a highway-rail inspection vehicle and were then analyzed using previously surveyed benchmark points along the test section of track. Software was developed for a track monitoring system based on the HPGPS data.

The findings of the investigation were that (a) rail movement prior to a buckle or break is probably too small to detect, and (b) the requirements for repeatable, high-accuracy measurements (2-3 cm) of rail movement could not be achieved. This was due to inaccuracies in the HPGPS system attributable to such factors as inadequate integer cycle ambiguity resolution and to the loose coupling between the HPGS system and the rail. Literature reviews and interviews revealed that buckles and breaks often occur under trains and are not usually preceded by measurable lateral movement. Accordingly, it is unlikely that an HPGPS system mounted on a rail inspection vehicle could reliably detect an incipient buckle or break. Other potential applications, such as detection of small lateral movement of rail caused by subgrade movement, would require improvements in the accuracy of HPGPS systems.

Principal Investigator: David Munson

Project Panel:
- Jeff Baker, GE Transportation Systems
- Evan Jacobson, Rockwell Collins
- Mike Roney, Canadian Pacific Railway
- Randall Walker, Cedar Rapids and Iowa City RR

IDEA Contract: $100,000

Cost Sharing: $18,360

Project Total: $118,360

Start: July 2001

Complete: September 2003

HSR-30/48: Vibration Measurements of Rail Stress

University of Illinois
Champaign, Illinois

IDEA Concept and Product

A reliable, low-cost, easy-to-use technology for measuring longitudinal stress in rail continues to be a high-priority objective for both freight and passenger rail operators. The fact that three other HSR-IDEA projects are addressing this need (HSR-15/28, HSR-19, and HSR-26) is evidence of its importance. The effects of thermal expansion and contraction and train forces can produce tremendous stress in rail, especially long strings of welded rail. Various rail-anchoring systems are used to prevent these stresses from pulling or pushing the rail out of alignment, or breaking it. These stresses can occasionally exceed the capacities of the anchoring system, or the strength of the rail, or both, resulting in rail breaks or buckling, which continue to be significant causes of derailments and train delays (Figure 1).

These two projects are to evaluate "vibro-elastic" methods for measuring longitudinal stress in rails. This concept is based on the known sensitivity of bending vibrations to contained longitudinal stress. The rail is excited at a specified frequency using an electromagnetic shaker. A laser vibrometer that is scanned along the rail is used for dynamic displacement measurements to determine the frequency and wavelength of the resulting rail vibrations (Figure 2). The resulting wavelength, along with the rail rigidity (which can be determined by the rail dimensions and modulus) can be used to determine contained longitudinal load.

Project Progress

Project HSR-48 was terminated in October 2006. Tasks completed include development of a wave number categorized by rail shape and frequency and development of a numerical simulation of the effect of longitudinal

Figure 1

Rail buckling caused by thermal expansion.

load on guided waves, including a study of the propagation of errors. Laboratory tests with the rail under no load and under longitudinal loads up to 100 kips using a hydraulic actuator were conducted. Field-tests were then conducted and the results compared with data from strain gages attached to the rail. The results were encouraging but identified instability in the system and the need for further improvements if the system is to become commercially viable. A follow-on contract for additional development of the concept was awarded. The contract called for development of a more robust laser spot positioning system, an improved scan platform that will allow faster scans, more convenient calibration procedures, and a method to accommodate variations in rail profiles. Techniques to mitigate the effects of intermittent structural changes in the track system that occur while measurements are being taken were also to be developed. Such structural changes can be caused by rail and highway traffic in the vicinity of the measurement site. Tasks included the design and fabrication of a new, more robust portable scanning platform and development of techniques capable of adjusting for a changing track structure. Laboratory tests of the improved system on rails of arbitrary cross section and wear were conducted. The system was then installed for field-testing at TTCI. Rail forces measured by the system were compared with strain gage data. Based on these comparisons, the system did not perform satisfactorily, as very large differences between the two data sets were observed. During the period of this contract, another system for measuring rail stress using the same basic concept was developed in New Zealand. This system was also tested at TTCI and the results compared very favorably with strain gage data. As a result, further development of this system was terminated. A final report was prepared documenting work accomplished, results, possible explanations for the problems encountered, and recommendations for any future research on this concept.

Principal Investigator: Richard Weaver

Project Panel:

Keith Hjemsted, University of Illinois
Hayden Newell, Norfolk Southern RR
Martin Schroeder, TTCI

IDEA Contract: $99,960/$130,000

Cost Sharing: $48,000/$60,000

Project Total: $147,960/$190,000

Start: April 2001/August 2004

Complete: April 2004/October 2006

Figure 2

Prototype System Installed in Track.

HSR-37: Electroslag Field Welding of Rail

Electroslag Systems
Portland, Oregon

IDEA Concept and Product

This project investigated the use of electroslag welding (ESW) techniques as an alternative to thermite or flash-butt welding for field welding of rails. Heat is generated by resistance as the welding current passes through a molten flux pool that floats on top of the liquid metal. Containment components, e.g., cooling shoes on the sides of the rails, are used to contain the welds, and a consumable electrode directs weld wire to the weld.

Electroslag welding has the potential to produce a stronger, better quality field weld than the current thermite field welding process.

The investigative approach included developing an efficient electroslag welding process. Elements of that process included consumable electrode configuration, starting sump design, weld chemistry, welding parameters (volts, amps, travel speed, wire feed, etc.), flux, and cooling requirements. Alternative weld wires, fluxes, and cooling shoe materials were selected, as well as various configurations of consumable guide tubes, cooling shoes, and fixturing. The most promising was then used to weld test rail segments, and these welds evaluated using ultrasonic inspection and destructive testing based on American Railway Engineering and Maintenance of Way Association (AREMA) recommended practices. Metallographic specimens of the weld were prepared to examine weld and heat-affected zone dimensions and microstructures, and weld specimens were tested for hardness.

Project Progress

This project was completed October 2003. Tasks completed include the selection and evaluation of alternative weld wires, fluxes, and cooling shoe materials, and various configurations of consumable guide tubes, cooling shoes, and fixtures. The most promising were then used to weld test rail segments and

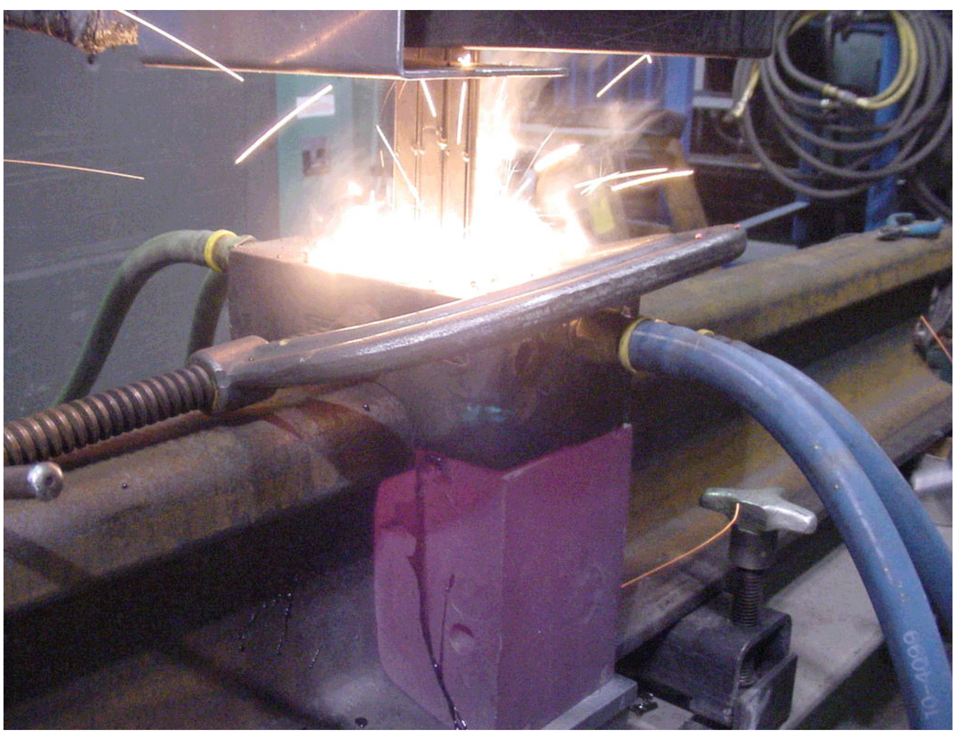

Figure 1

Electroslag weld in progress during lab test.

evaluated using ultrasonic inspection and destructive testing that is based on AREMA specifications. This led to the design and casting of a new version of weld cooling shoes. Tests were also conducted to determine the effects of different weld currents on the heat-affected zone of the welds. Subsequent tasks included development of further improvements to the technique, including the development of optimum values for weld duration, voltage, amperage, chemical composition, wire speed, weld geometry, and preheating. A comparative analysis with thermite welding was conducted, including track time requirements, weld quality, training requirements, and costs.

When the work was completed in October 2003, some, but not all, of the objectives were achieved. The hardness and microstructure objectives were met. The rupture modulus objective was 125,000 psi, but the test specimens achieved only 119,300 psi. The maximum deflection objective was at least 0.75 inch, but deflections of only 0.35 inch were achieved. The contractor, Electroslag Systems, Technology and Development, is confident these two objectives can also be met or exceeded, and is pursuing these improvements to develop a commercially viable product. The Association of American Railroads' Transportation Technology Center is providing support for the development of such a product.

Principal Investigator: Dan Danks

Technical Advisor:
Bob Galloway, BNSF RR

IDEA Contract: $94,160

Cost Sharing: $10,000

Project Total: $104,160

Start: September 2002

Complete: October 2003

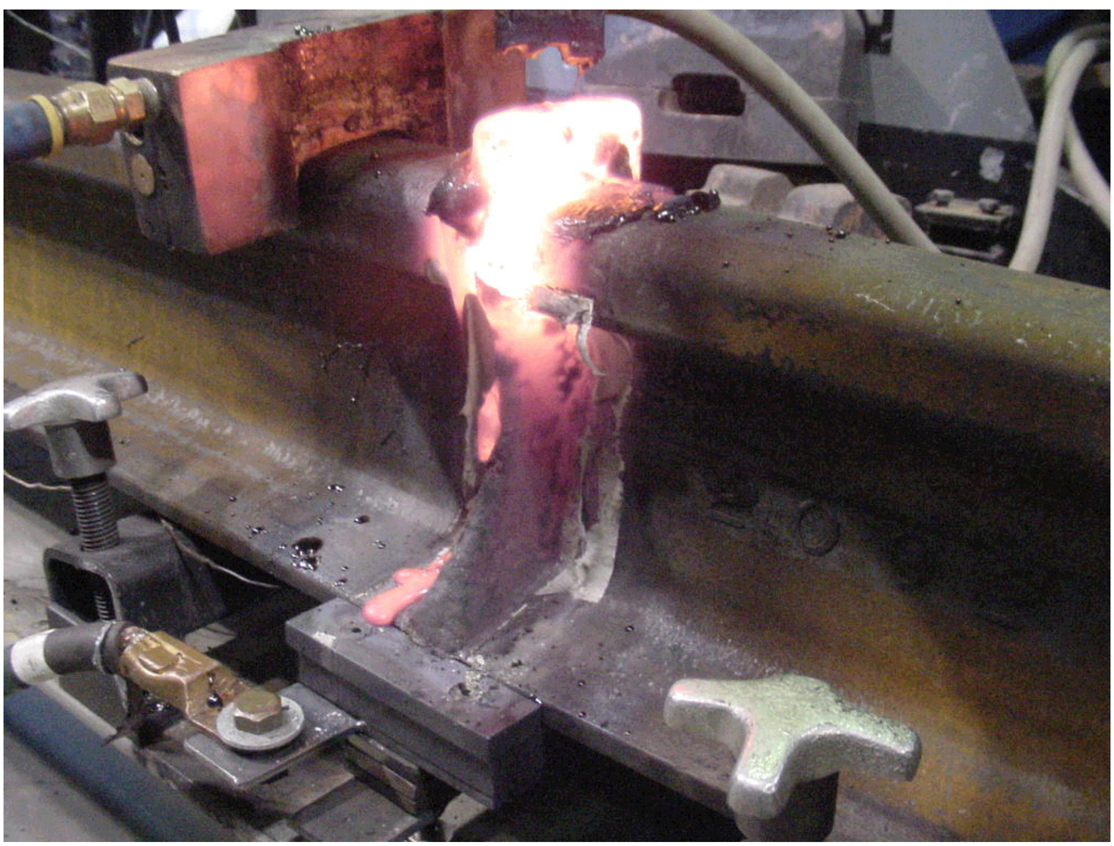

Figure 2

Electroslag weld after cooling shoes have been removed and before removal of excess weld metal.

HSR-38: Feasibility of Locomotive-Mounted Broken Rail Detection

Analogic Engineering Inc.
Guernsey, Wyoming

IDEA Concept and Product

This is a project to extend the capability of existing Multiconductor Transmission Line (MTL) models of railroad track to simulate and explore the effects of broken rails and track occupation. The objective is a preliminary assessment of the feasibility of transmitting coded bursts of radio frequency (RF) energy into the rails ahead of locomotives and analyzing the reflected pulses to detect rail breaks. The models will be used to determine how RF pulses will propagate through the rails and how they will interact with rail breaks as well as with normal discontinuities such as turnouts. Specifically, they will be used to test the feasibility of coupling coded, differential RF pulses into the rails (ahead of the locomotive's lead axle) and analyzing reflected pulses to detect and calculate the distance to the rail break or track occupancy. The existing models would be extended to simulate combinations of track conditions, rail break types, train location, and movement patterns. The investigative approach is basically to extend the capabilities of an existing model and use it to perform a series of simulations. These would be designed to assess how well the proposed technology would work for accurately detecting broken rail and the location of other trains ahead of the locomotive on the rail on which the system would be installed. The findings of this project would be used to determine whether further development of this concept, including prototype development and testing, would be warranted.

Project Progress

This project was completed April 2003. A literature review and analysis, initial model development, and preliminary feasibility testing were performed. Subsequent tasks included investigation of alternative techniques for coupling the RF pulses into the rail, the effects of insulated joints, turnouts, the effect of the local train axle shunts immediately behind the measurement point, and possible radiation hazards to personnel in the locomotive and on the ground. The investigation revealed that three or more combinations of pulse frequency and duration would be required to cover the range from just ahead of the locomotive out to a maximum distance of one to two miles. Detection as far as one to two miles would require RF pulses between 60 kHz and 120 kHz with peak power in the order of 10 kW. Detection beyond turnouts would require electrical circuit switching operating in parallel with mechanical track switching. Investigation of the potential for radiation hazards using a model and current radiation exposure limits revealed that even at these power levels, frequencies in the 60 kHz to 120 kHz range pose no risk to humans. Further development of this concept will require the design and development of a prototype system. The prototype system would then be subjected to laboratory and field trials to determine how performance would be affected by such factors as insulated and bolted rail joints, rail welds, various kinds of ballast contamination, and turnouts.

Principal Investigator: Steven Turner

Project Panel:
- Jeff Gordon, DOT Volpe Center
- Robert Kubichek, University of Wyoming
- Bob McCown, FRA
- Don Plotkin, FRA
- Rich Reiff, TTCI

IDEA Contract: $41,264

Cost Sharing: $11,094

Project Total: $52,538

Start: October 2002

Complete: April 2003

HSR-40: Rubber-Modified Asphalt Concrete for High-Speed Railway Roadbeds

Case Western Reserve University
Cleveland, Ohio

IDEA Concept and Product

This project is investigating the potential of a layer of rubber-modified asphalt concrete (RMAC) under track ballast to improve the durability and reduce the deformation, vibration, and noise of track structures for high-speed rail (see Figure 1). Preliminary studies indicate that the damping ratio of rubber-modified asphalt concrete is 6–11 percent compared with 2–3 percent for compacted soil and 3–4 percent for conventional asphalt concrete. In addition, it has stiffness two to three orders of magnitude higher than typical compacted soil. Based on these findings, RMAC has the potential to significantly reduce the pressure on soil subgrade and reduce the vibration from passing trains to the surrounding environment. The IDEA product will include specifications, performance assessments, and cost estimates for use by the high-speed railroad industry to determine whether and how such installations should be made in the track structure.

Project Progress

This project was completed April 2005. A series of two-dimensional and three-dimensional numerical simulations and laboratory tests were performed to compare the performance of ballast, concrete, asphalt concrete, and rubber-modified asphalt concrete underlayments. These simulations evaluated performance with respect to such variables as axle loads, thickness of the underlayment, train speed, and temperature. Results indicated that RMAC is superior to the other underlayments in reducing vibration directly under the rail, but at 20 and 40 meters away the differences were negligible. At lower temperatures, e.g., 0° and –10° C, the damping ratio of both AC and RMAC drops significantly. This may be offset, however, by corresponding increases in stiffness at lower temperatures. The effect of train speeds on vibration amplitudes was nonlinear, possibly due to the resonance frequencies of vibration of the underlayment. The IDEA product includes preliminary specifications, performance assessments, and cost estimates to help determine whether and how such installations should be made in the track structure. Further development of this concept would require additional simulations, lab tests, and field testing to more accurately determine the effects of the variables investigated, develop precise specifications for a prototype RMAC material, and compare ground vibrations and train noise associated with various underlayments during field tests.

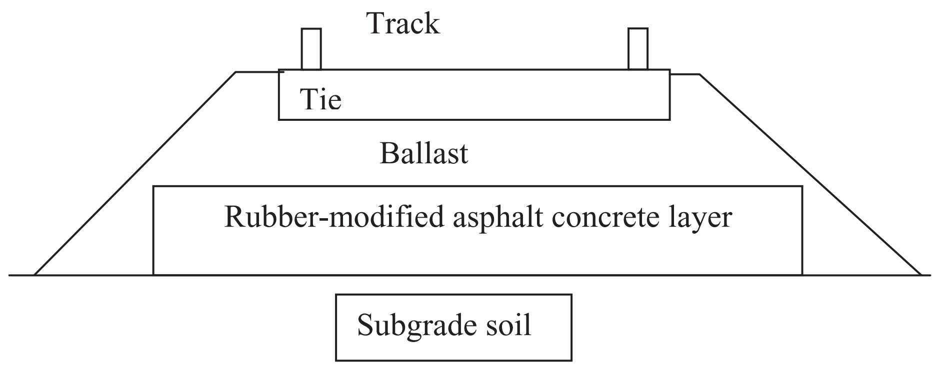

Figure 1

Schematic for location of RMAC layer.

Principal Investigator: David Zeng

Project Panel:

Bob Grace, GDE, Inc.
Dingqing Li, AAR/TTCI
Jerry Rose, University of Kentucky
Tom Schmidt, CSX Transportation

IDEA Contract: $100,000

Cost Sharing: $72,039

Project Total: $172,039

Start: January 2003

Complete: April 2005

HSR-42: Acoustic Broken Rail Detection System

San Francisco Bay Area Rapid Transit District
Oakland, California

IDEA Concept and Product

This is a project to develop a system of acoustic transducers to detect broken rail. Nodes of these acoustic transducers would be installed on the rail at spacings approaching one mile. Each transducer would excite the rail at specific frequencies as well as sense the presence of acoustic energy in the rail. These acoustic nodes would be networked such that each node would relay the data it receives to the next node up the rail to deliver the information to a central control location. Each node could detect reflections from rail discontinuities (breaks) and time the reflections to determine the distance from the node. This information would be transmitted through the rail via the network of acoustic transducer nodes to a control location such as a dispatch center (Figure 1).

The San Francisco Bay Area Rapid Transit District (BART) has already spent $600,000 on a proof-of-concept study of this approach under a Cooperative Research and Development Agreement (CRADA) between BART and Sandia National Laboratories. The study is part of the development of an Advanced Automatic Train Control (AATC) system at BART under a $20 million DARPA grant administered by the Federal Transit Agency. Research under the CRADA has discovered a mode of vibration and specific frequencies of excitation that enable acoustic energy to travel distances of more than two miles in (continuous welded) rail. The scope of the project included recording acoustic signal profiles from various rail discontinuities, including complete and partial breaks, and cracks and flaws, and the development and testing of an algorithm for detecting time of arrival of reflected signals. A prototype system would then be developed and field-tested on BART's 2.5-mile test track in Hayward, California.

Project Progress

This project was completed August 2004. Initial tasks included incrementally cutting rail test sections vertically and at angles to simulate partial rail breaks. The acoustic signal profiles of reflections from these cut rail sections, and from complete rail breaks, were recorded. A time-of-arrival algorithm was developed and verified using the recorded test data. On BART'S mainline, signals were recorded for different frequencies and different trains using a broadband transponder. Analysis of this data was used to determine optimum

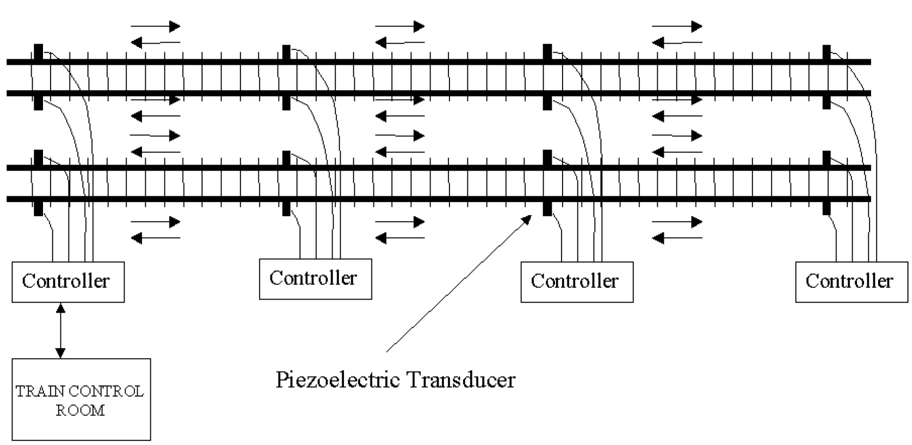

Figure 1

Diagram of the proposed acoustic broken rail detection system.

transponder frequency and bandwidth. Other tasks included development of time-of-arrival software, fabrication of a prototype system, and field testing and evaluation. The BART project team encountered problems in the development of the prototype. These included significant changes in the optimal transmission frequency with changes in rail temperature; side-mounting transducers on the rail web did not produce significant longitudinal waves, severely limiting the range; inability of the prototype to detect various types of rail defects and breaks; inability to develop robust transmission algorithms; and significant reductions in range during rain. As a result, further development and testing were discontinued. A final report was prepared that documents the tasks performed, problems encountered, and recommendations for future research should this concept be further pursued.

Principal Investigator: John Evans

IDEA Contract: $100,000

Cost Sharing: $400,000

Project Total: $500,000

Start: July 2003

Complete: August 2004

HSR-46: Magnetorheological Damping for Spring Rail Frog Switches

Texas A&M Research Foundation
College Station, Texas

IDEA Concept and Product

This contract is to investigate the application of a magnetorheological (MR) damper in place of a conventional hydraulic shock retarder in spring rail frog switches. The spring rail frog switch is used in mainline track where the preponderance of traffic is through trains with only occasional diverging route usage for passing sidings or infrequently used industry tracks (see Figure 1). The spring rail frog switch is useful for this service because no power machinery is required and manual throwing of the switch machine is required only for train entry. The spring rail frog switch closes against the frog after the trailing axle of each car truck using the force of the springs in the system (see Figure 1). However, the cycling action of the spring rail frog switch contributes to rapid wear and loosening of the entire system. Currently, hydraulic retarders are used to minimize cycling of the spring rail frog switch against the point-of-frog as trains exit spring switches. These hydraulic retarders (shock absorbers) are used to keep the spring rail away from the frog for extended periods to allow multiple car trucks to pass. Railroads report that the current retarder system does not have a reliable or long life due primarily to high internal forces in the retarder during train passage.

An MR damper resembles an ordinary dashpot or linear viscous damper. It uses a special MR fluid and has one or more electromagnetic coils wrapped around the piston head. The MR fluid contains small particles that can be magnetically polarized. As a result, when current is supplied to the coils, the MR fluid becomes semi-solid (see Figure 2). Damping is proportional to the amount of current applied. The proposed system would include a control algorithm designed to prevent or minimize cycling of the spring rail frog switch until all cars in the

Figure 1

Typical spring-rail frog switch. Main track rail is on the right. Wheel flanges on diverging trains (entering main from upper left) force open the spring rail.

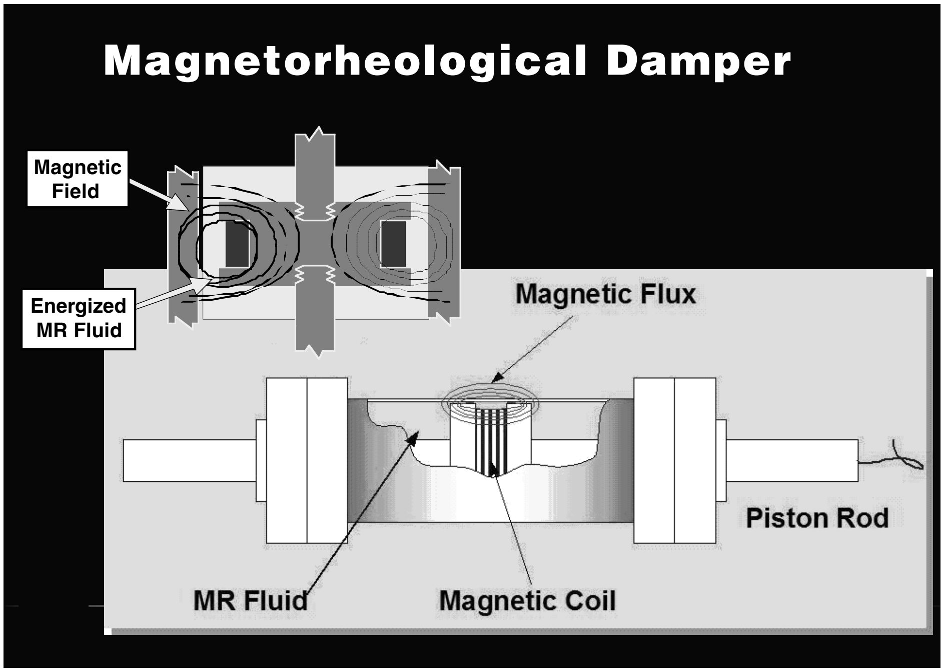

Figure 2

Schematic of magnetorheological damper.

train have passed through. An accelerometer or other sensor attached to the piston rod would detect acceleration and velocity of the rod when activated by a passing train. The sensor signal would be used by the algorithm to activate the MR damper and determine the amount of damping required. A 12-volt battery kept charged by solar cells would provide power to the system.

Project Progress

This project ended in July 2007. Tasks included the design and fabrication of a two-stage MR damper, development of a control algorithm, and preliminary lab testing of the system. The prototype system was installed in place of a hydraulic retarder in a spring rail frog switch on the Union Pacific for test and evaluation. When the MR damper was activated by a passing train, the cylinder shaft failed due to a fatigue fracture. Analysis of the failure determined that the cause was due to the method used to adapt the MR cylinder to the existing retarder mounting brackets, resulting in off-axial loading on the shaft. The cost to repeat the field testing, including a new retarder cylinder, and the redesign and fabrication of a modified bracket, would have exceeded the remaining budget. Accordingly, a final report was prepared that documented all work completed and attempted, findings, conclusions, and recommendations for any future R&D on this concept. The conclusions of this research were that magnetorheological damping holds promise as an improvement over hydraulic damping for this application but that future applications should include an integrated damper mounting design that avoids off-center loading.

Principal Investigator: Les Olson

Project Panel:
Dave Davis, TTCI
Hank Lees, BNSF
Bob McCown, Consultant

IDEA Contract: $100,000

Cost Sharing: $57,000

Project Total: $157,000

Start: February 2004

Complete: July 2007

HSR-54: Wireless Remote Structural Integrity Monitoring System for Railroad Bridges

WavesInSolids
State College, Pennsylvania

IDEA Concept and Product

This was a project to develop a low-cost remote wireless system for fatigue crack detection and growth monitoring in steel bridge beams. The goal was to develop the technology required to transition the contractor's (WavesInSolids) existing wired acoustic emission system to a lower-cost wireless system. Acoustic Emission testing is a mature nondestructive testing technology commonly used to detect fatigue cracks in pressure vessels, storage tanks, and steel bridges. During an acoustic emission test, the tested structure must be stressed (e.g., by passing trains) to stimulate fatigue crack growth. If a fatigue crack grows under stress, it will emit a sound wave, (an acoustic emission), that travels through the structure. Acoustic emission sensors and instrumentation are designed to detect sound waves emitted from active fatigue cracks while filtering out environmental noise. The rate and intensity of acoustic emission from fatigue cracks is used to characterize crack growth rate. The information may then be used by bridge engineers to assess the requirement for maintenance action.

The wireless device consists of a 4-sensor array and is installed on the fracture-critical bridge member of interest. As trains travel over the bridge the fracture-critical member is stressed. If a fatigue crack is active, it will emit acoustic emissions when the structure is subjected to a maximum or near-maximum stress. The sensors detect the acoustic emission and the wireless instrument digitizes the information, analyzes, compresses, and then transmits the filtered information back, through a network of wireless sensors, to a central processing station for review by bridge engineers. Railroad engineers may use the information to load rate bridges and prioritize maintenance action. The wireless system was sought to accommodate the emerging requirement for long-term monitoring and to significantly reduce the overall cost for system implementation. The wireless system derived from this project is estimated to be one-tenth the cost of the hardwired system.

Project Progress

This project was completed in February 2008. Baseline data was acquired on a steel railway bridge using the hardwired technology. The prototype wireless hardware and proposed sensors were designed and assembled. The performance of the wireless technology was compared with the wired technology in the laboratory. The results showed that the wireless instrumentation could perform the required signal processing at the sensor level and transmit the compressed data back to a remote laptop. Acoustic emission features extracted by the wireless system compared well with those extracted using the hardwired system during the same tests. The wireless system was installed on the same bridge location for evaluation. From a detection, acoustic emission measurement, and source location perspective, the wireless system performance compared favorably with the hardwired system. WavesInSolids is now moving ahead to use the wireless system for commercial inspection services.

Principal Investigator: Thomas Hay

Project Panel:

Jose Covaco, Canadian National Railways
Kenneth Jennison, BNSF Railway Company
Jacob Patnaik, United States Coast Guard

IDEA Contract: $99,000

Cost Sharing: $16,000

Project Total: $157,000

Start: May 2006

Complete: December 2007

HSR-55: Characterization of Rail Surface Condition

WavesInSolids
State College, Pennsylvania

IDEA Concept and Product

This was a project to investigate the use of guided ultrasonic waves to detect and characterize surface and subsurface defects in rail. An ultrasonic pulse is introduced into the rail using a noncontact electromagnetic acoustic transducer (EMAT). This pulse travels down the rail and interacts with rail defects, ends, cold-worked layers, and various surface conditions. Upon encountering one of these discontinuities, a portion of the wave will be reflected back to the transducer. The amount of energy reflected will depend upon the size and shape of the defect. An analysis of the returned signal is then performed to identify and characterize the defect. The system would be mounted on a track inspection vehicle such as a hi-rail truck and would theoretically be able to operate at speeds up to 25 mph. This could not be accomplished due mainly to insufficient coupling of the ultrasonic energy generated from the noncontact EMATs. However, an interim objective was achieved that led to the development of a commercial prototype that utilizes handheld contact piezoelectric transducers capable of detecting and measuring the depths of traffic-hardened layers in rails.

Rolling contact fatigue (RCF) cracks in traffic-hardened (work-hardened) rails initiate and propagate to a critical size if left unmitigated by either frequent MGT (million gross tons) driven preventive grinding or, less frequently, on a time-based schedule, by corrective grinding practices. However, MGT- or time-based maintenance procedures sometimes cause unnecessary downtime and lead to loss in productivity, increased labor and train delay costs and other associated costs. Therefore, there has always been a need for a nondestructive inspection methodology that could provide a condition-based maintenance solution. Rolling contact cracks grow to increasing lengths—and hence result in increased safety hazard potential—in increasing thicknesses of the traffic-hardened layers. Thus, one way to provide condition-based maintenance is to monitor the deterioration of the rail's surface condition

Project Progress

This project was completed in August 2008. Project tasks included the development of system performance requirements, laboratory tests to determine the measurement capabilities and limitations of the sensor system, the design and fabrication of a prototype system, and field tests of the prototype on a railroad. Tests were undertaken on rail samples supplied by Class I railroads with known, quantified work hardening and microcracking conditions. The performance requirements included the inspection requirements for detection of microcrack-like defects and work-hardened layers. Laboratory tests were conducted to determine the measurement capabilities and limitations of the sensor system using rail samples with known surface and subsurface conditions and defects and with rail contaminants to determine whether the system could meet performance requirements. Tests using piezoelectric transducers confirmed that it is possible to resolve traffic-hardened layers of thickness < 1 mm, 1–3 mm, and 4–7 mm. The technology was evaluated on lubricated rail as well. Data were acquired on dry and lubricated rail. The results show that a small 2-5 dB drop in signal-to-noise ratio on lubricated rail can be expected over the desired test ranges. This small drop should not pose a problem. Experiments were also carried out to generate ultrasonic waves in the traffic-hardened layers of the rail using non-contact EMATs to study the feasibility of integrating this measurement technology with WavesInSolids' Hy-Rail vehicle rail flaw detection technology. This effort was unsuccessful due mainly to insufficient coupling of ultrasonic energy generated from the noncontact EMATs into the rail.

A commercial product based on the outcome of this project has been developed. It is a handheld device using contact piezoelectric transducers capable of detecting and resolving traffic-hardened depths in the millimeter range of interest. It may be used to assist track management by prioritizing sections of track for internal rail flaw inspection and/or grinding. This is based on the logic that deeper traffic-hardened layers pose more risk to track safety and operation due to the probability that serious flaws may initiate and propagate faster in thicker layers. The technology, however, does not provide a point-by-point traffic-hardened depth profile across the head laterally. It was determined that the noncontact EMAT technology could not be integrated practically into a rail inspection vehicle due to its inefficiency in generating ultrasonic waves with significant signal strength. An alternative laser ultrasonic generation and air coupled ultrasound receiver sensor is recommended for future research.

Principal Investigator: Thomas Hay

Project Panel:

Jeff Gordon, Volpe National Transportation Systems Center
Bob McCown, Independent Consultant
Nick Nielsen, Canadian National Railways
Don Plotkin, Federal Railroad Administration

IDEA Contract: $91,000

Cost Sharing: $26,000

Project Total: $117,000

Start: June 2006

Complete: August 2008

HSR-57: Steel Bridge Pile Inspection Using EMAT Technology

Waves in Solids
State College, Pennsylvania

IDEA Concept and Product

This is a project to evaluate the use of long-range ultrasound technology for the inspection of steel bridge pile. Electromagnetic acoustic transducers (EMATs) are mounted on a bridge pile. One EMAT injects ultrasonic energy into the pile and another receives signals reflected back from wall loss due to corrosion. Analysis of the reflected signals is performed to determine the extent to which this approach can characterize wall loss, including the area and depth of material loss due to corrosion. The concept is expected to work on pile submerged in water, soil, and mud. This technology is currently used to inspect underground pipelines.

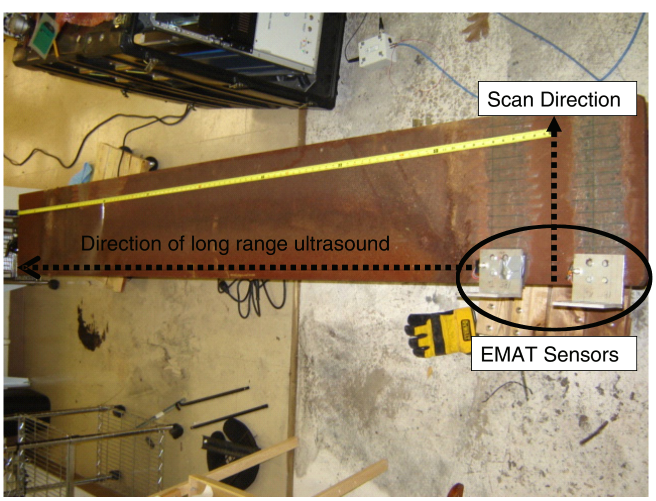

Figure 1

Long-range ultrasound test setup on H-pile showing wave propogation and scanning direction.

Project Progress

Project tasks include the development of the performance requirements in terms of the minimum area and thickness of corrosion losses that the system would need to detect (in consultation with Norfolk Southern bridge personnel), design and fabrication of prototype EMATs for this application, lab tests of prototype EMATs mounted on H-pile specimens with simulated defects machined into the specimens, and field testing of the prototypes, including pile submerged in up to 10 feet of water. Lab testing included testing of H-pile submerged in 9 feet of water. Lab test results confirmed that the prototype system could meet the performance requirements (e.g., detect 50 percent wall loss in submerged pile). Preliminary field testing with the prototype revealed that the system is performing within specs at submerged pile depths of 36 inches. Further field testing is planned provided sufficient rainfall in the southeast results in submerged pile depths greater than 36 inches, ideally up to 10 feet. This project is scheduled for completion by January 2009.

Principal Investigator: Thomas Hay

Project Panel:
Willie Benton, NS Corporation

IDEA Contract: $50,000

Cost Sharing: $20,000

Project Total: $70,000

Start: July 2007

Complete: January 2009

Rolling Stock

HSR-20/34: Metal Foams for Improved Crash Energy Absorption in Passenger Equipment

Fraunhofer Center
Newark, Delaware

IDEA Concept and Product

Lightweight cellular materials known as metal foams are a newly emerging class of engineering materials that are currently being evaluated for a broad range of transportation applications. Fraunhofer has developed a powder metallurgy process for producing ultra-lightweight metal foams from aluminum, steel, and other metals and alloys. Because of their very low mass density, controlled porosity, and closed-cell structure, aluminum foams, especially, are finding engineering uses as lightweight stiffeners in automobiles; as energy absorption in crash management, ballistic protection and mine blast mitigation; vibration damping; and as sound/thermal insulation. Aluminum foam structures can be designed to provide multifunctional properties, thus providing a high value/cost ratio.

The objective of these two projects was to identify and evaluate the potential benefit of aluminum metal foams in structural members of locomotives and passenger cars for improvement of crush energy absorption. An additional goal was to identify other potential advantages of using aluminum foams in locomotive and passenger car structures. Potential applications of aluminum foam were identified and assessed, such as reducing equipment weight, strengthening collision posts, enhancing fire resistance, and increasing overall passenger safety and comfort.

Project Progress

This project was completed March 2004. The axial crushing tests on both hollow aluminum tubes and tubes filled with low-density aluminum foam revealed that the foam filling increases the stability of the profile and prevents instantaneous buckling. The aluminum foam inserts increased the energy absorption of both aluminum and 304 stainless steel tubes by 30-40 percent (Figure 1). Three-point bending specimens of empty and aluminum foam-filled tubes of aluminum and 304 stainless steel were also fabricated and tested to evaluate the effectiveness of aluminum foams in increasing the bending strength and side-impact, load-bearing capability. The measured peak bending loads of foam-filled tubes were up to 50 percent higher than the summation of the aluminum foam and empty tube specimens tested individually. Results from these tests indicated that aluminum foam-filled tubes not only increased the overall peak load-bearing capability of

Figure 1

Deformed aluminum foam-filled stainless steel tube after axial compression.

tubular structures, but also prevented the structure from experiencing rapid deformation under load. This combination of features makes foam-filled profiles good candidates for both light-weight stiffening and energy-absorbing elements.

Joining methods for attaching aluminum foams to other construction materials were also investigated. Experimental results demonstrated successful joining of aluminum foams using conventional tungsten inert gas (TIG) welding, laser welding, soldering, low-temperature, active brazing, and adhesive bonding.

Project results identified several potential applications of aluminum foams in high-speed rail equipment. These include improving crash energy absorption, strengthening collision posts and side impact beams, and reducing equipment weight through use of aluminum foam sandwich panels. These foam sandwich panels have very high stiffness-to-weight ratio and superior fire resistance, vibration damping, and sound insulation compared with conventional aluminum plates for floor panels, walls, and bulkheads.

Based on the findings of this concept exploration project, a follow-on product application contract was awarded to continue this work. Tasks included the redesign, fabrication, and testing of conventional passenger car components using aluminum foam-filled structural elements. Finite element model calculations were performed to determine the stiffness of various aluminum foam panel designs. These values have been compared with those for steel panels, and the estimated weight savings by substituting aluminum foam panels for steel panels are substantial. These foam panels provide the additional benefits of vibration and sound dampening, and increased thermal insulation. Candidate tubular components for aluminum foam inserts were also designed. These were fabricated and subjected to test and evaluation. An energy-absorbing sliding rail for installation on passenger car seats was subjected to full-scale testing. This application uses an aluminum foam-filled piston/cylinder design that can be placed at the seat mounting points. Instrumented test dummies mounted on a test sled were used to simulate train collisions (Figure 2). The crushing of the foam in the cylinders absorbed sufficient crash energy to significantly reduce the potential for passenger injury.

Principal Investigator: Ken Kremer

Project Panel:
George Binns, Amtrak
Steve Sill, FRA
Dave Tyrell, DOT Volpe Center

IDEA Contract: $100,000 Initial/$200,000 Follow-on

Cost Sharing: $80,000/$150,000

Project Total: $180,000/$350,000

Start: October 1999/March 2002

Complete: May 2001/March 2004

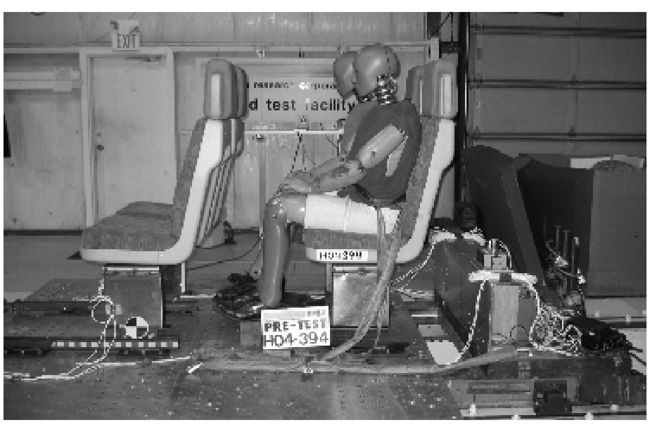

Figure 2

Test sled with instrumented test dummies.

HSR-29: Continuous Locomotive Emissions Analyzer

Scentczar Corporation
Fredericksburg, Virginia

IDEA Concept and Product

In 1998 EPA promulgated new emissions regulations that phase-in more restrictive NO_x standards for locomotives. This, combined with rising diesel fuel costs, confronts railroads with challenging tradeoffs between fuel economy and compliance with emission standards. Greater locomotive fuel economy can be achieved with leaner fuel mixtures, but leaner mixtures increase NO_x emissions. Currently, railroads do not have a convenient instrument for measuring NO_x emissions, so optimizing fuel use while meeting EPA standards has to be based on guess work and indirect measurements such as cylinder temperature.

This project investigated a locomotive emissions analyzer that could be mounted on locomotives and continuously monitor their exhaust emissions. Ion Mobility Spectrometry (IMS) was selected for the sensor technology because of its rapid response time, low cost, and small size. IMS sensors consist of a reaction tube and a drift tube, separated by a shutter grid (Figure 1). Exhaust gas entering the reaction tube is ionized, and the ions are gated into the drift tube through the shutter grid. The ions are drawn down the drift tube toward a Faraday cup where they impact a metal plate and transfer their charge, creating an electric current. This current is amplified and digitized, and the analysis of this signal can be translated into concentrations of NO_x. The analyzer output would be used to continuously control engine settings such as injector timing to achieve the optimum balance between engine efficiency and exhaust emissions.

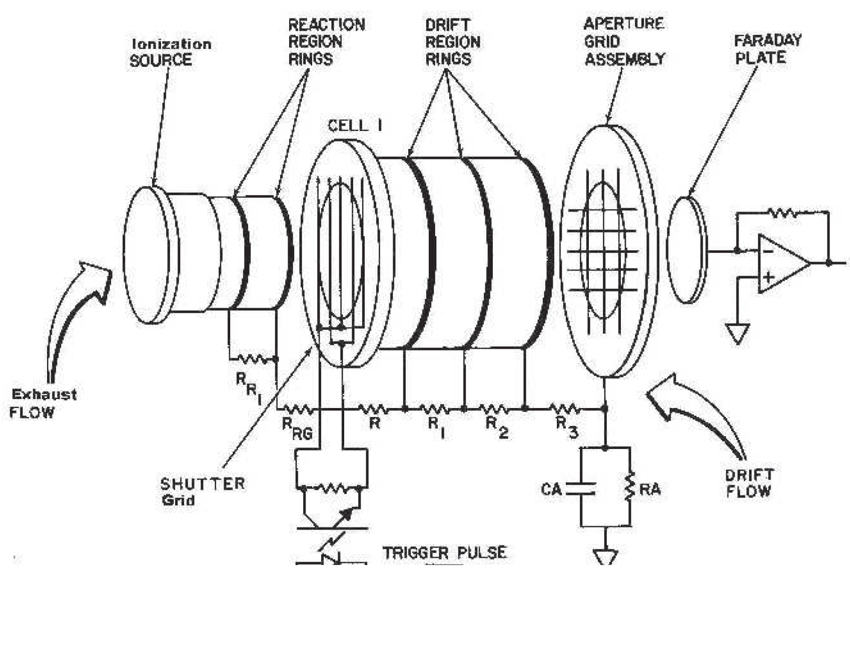

Figure 1

Schematic of ion mobility spectrometry sensor.

Project Progress

This project was completed January 2002. A prototype analyzer was developed and laboratory tested using known concentrations of NO and NO_2. The analyzer was then tested on an 8-cylinder diesel engine (Figure 2). The stationary engine was equipped with a chemiluminesence analyzer to enable comparisons of the prototype sensor data with the standard EPA method. Preliminary analysis of the test data revealed calibration and data recording problems. Efforts to determine whether more sophisticated statistical analysis techiques can be used to provide a more definitive assessment of the prototype system proved unsuccessful. A final report was prepared that documents the work performed, findings, an explanation of the problems with the diesel engine testing of the analyzer, and recommendations for any future investigation of the technology.

Principal Investigator: Joe Roehl

Project Panel:
- Dick Cataldi, Virginia Railway Express
- Chuck Horton, EMD
- Kevin Kirby, HRL
- Mark Stehly, BNSF RR

IDEA Contract: $99,917

Cost Sharing: $20,151

Project Total: $120,068

Start: December 2000

Complete: January 2002

Figure 2

Diesel engine test stand.

HSR-32: High-Strength, Lightweight Car Bodies for High-Speed Rail Vehicles

Surface Treatment Technologies Inc.
Baltimore, Maryland

IDEA Concept and Product

This project examined a novel approach for building safer high-performance, high-speed passenger car shells. The objective was to evaluate the potential of using scandium-containing aluminum alloys in combination with advanced joining and fabrication approaches to increase performance, reduce operating costs, and improve the safety of high-speed passenger rail vehicles. The approach combined three key elements: 1) lightweight, high-strength, weldable aluminum scandium alloys; 2) advanced joining techniques (friction stir welding); and 3) advanced processing to fabricate net-shaped panels. A major task was to select the optimal scandium-containing aluminum alloy composition for high-speed passenger rail applications. At present, aluminum scandium alloys are seeing widespread use in "high-tech" sporting good products such as ball bats, bicycles, golf clubs, and lacrosse poles. Although this family of alloys is now available commercially, it has not been optimized or qualified for use in rail passenger vehicles.

Scandium provides the highest increment of strengthening per atomic percent of any alloying element when added to aluminum. Small amounts of scandium are very effective at improving mechanical properties and refining the microstructure of wrought aluminum alloys. In addition, scandium additions have been shown to improve weldability of aluminum alloys by reducing

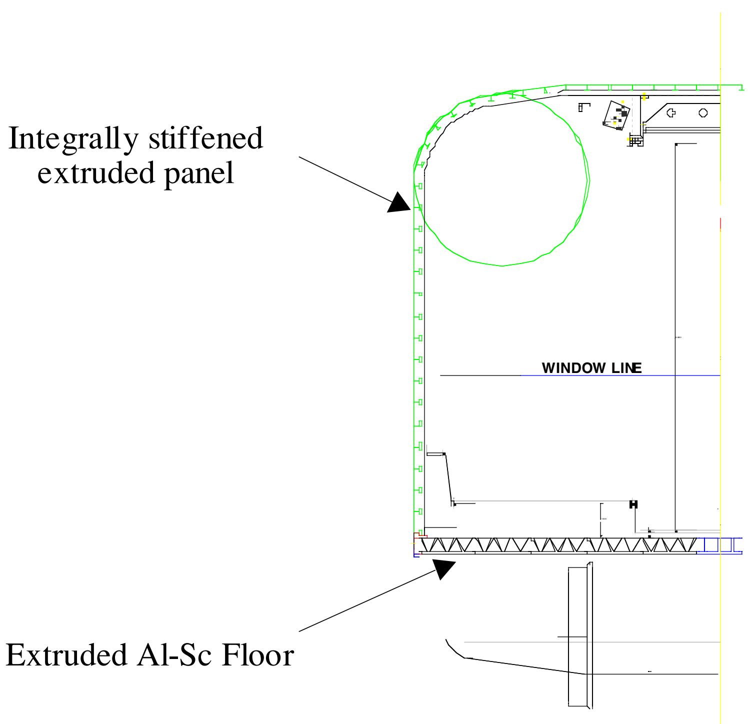

Figure 1

Preliminary design for car body shell using Surface Treatment Technology's net shaped extrusion concept.

hot cracking in the weld region. In the current study, researchers performed a trade-off study to determine if scandium additions would improve the performance of conventional Al-Mg 5XXX and Al-Mg-Si 6XXX alloys and if a scandium containing Al-Zn-Mg-Cu 7XXX series alloy could be used to fabricate car body shells.

Project Progress

This project was completed January 2004. Ease of fabrication, mechanical properties, weldability, and corrosion resistance were evaluated for candidate and conventional alloys. The ability to fabricate complex extrusions was evaluated for the candidate and conventional alloys using a porthole die. All alloys were successfully extruded using common commercial practices. Metallographic evaluation of the extrusions showed that, as expected, the Sc addition refined the grain size in an Al-Mg 5xSc alloy and an Al-Zn-Mg-Cu 7xSc. The key result was the good corrosion resistance and high base metal and weldment strengths observed for the selected aluminum-scandium alloy (Al-Zn-Mg-Cu 7xSc). These properties, in combination with the ease of fabrication, led to its selection as the optimal composition for high-speed rail applications.

Advanced design and fabrication techniques were also evaluated. Car body shells for passenger cars are fabricated using various approaches, including mechanically fastened sheet and stringers. Recent efforts in Japan and Europe have focused on building shells from welded aluminum extrusions. The use of large, integrally stiffened extruded panels was evaluated. In this approach

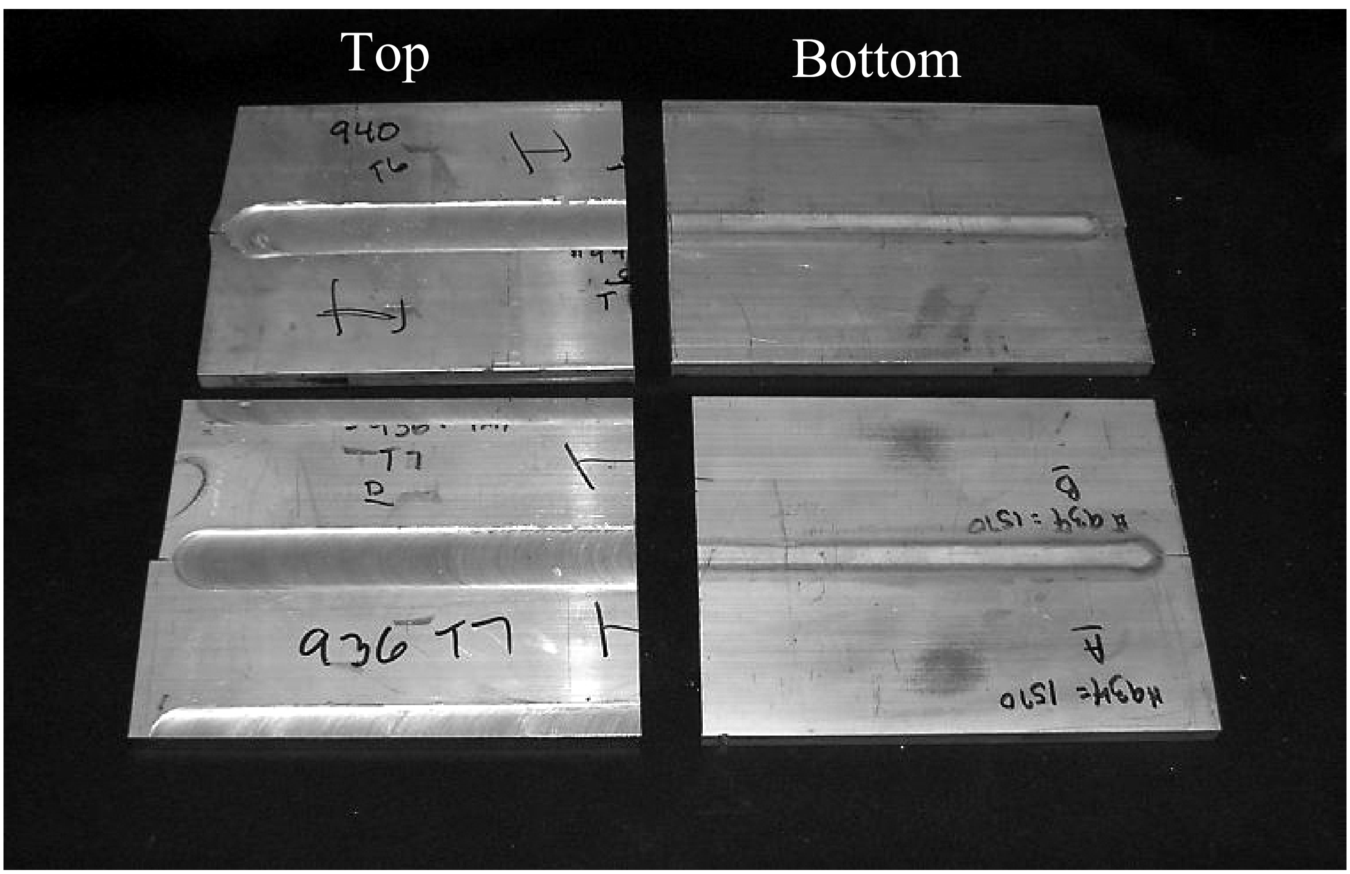

Figure 2

Friction stir-welded, high-strength advanced aluminum scandium alloys. This welding technique appears to be well-suited for these new, lightweight alloys.

the side walls and top of the car body are fabricated from large, net-shaped scandium-containing aluminum alloy extruded panels. Integrally stiffened extruded panels as large as 8 ft wide × 35 ft long have been fabricated for aerospace applications. The safety of the passenger car shell is greatly improved by removing longitudinal welds currently used to join aluminum extrusions, thereby increasing resistance to side impact. A finite element analysis showed that car bodies fabricated using integrally stiffened extruded panels are more resistant to side impact. The project team for this project collaborated with the Fraunhofer project team investigating metal foam technology (HSR-20/34). Both teams developed ways to incorporate their respective technologies and techniques into new train set designs.

Principal Investigator: Tim Langan

Project Panel:
George Binns, Amtrak
Steve Sill, FRA
Dave Tyrell, DOT Volpe Center

IDEA Contract: $96,703

Cost Sharing: $0

Project Total: $96,703

Start: June 2001

Complete: January 2004

HSR-39: Handheld Wheel Crack Detection Device

International Electronic Machines
Albany, New York

IDEA Concept and Product

This project developed and demonstrated a portable, hand-held device to probe railway wheels for cracks. The concept used electromagnetic acoustic transducer (EMAT) technology and digital signal processing techniques. The EMAT sensor consisted of two non-contacting electromagnetic coils: a transmitting coil to propogate an ultrasonic wave into the wheel and a receiving coil to receive an ultrasonic echo signal from the wheel. These echo signals were processed and interpreted to detect defects such as cracks, voids, and splits in the flange, plate, or tread of the wheel.

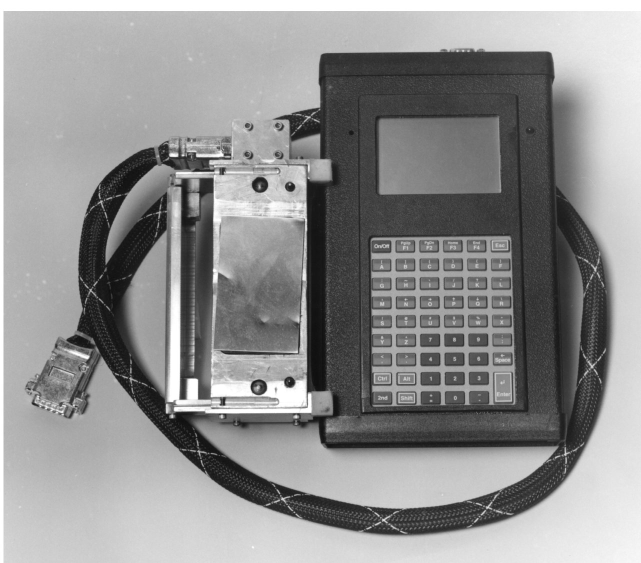

Figure 1

A prototype wheel crack detector that can inspect the wheel tread surface. Further enhancements will include the capability to detect rim defects, cracks, voids, or splits in the wheel flange and plate.

Potential advantages of this technology were that it could see beneath surface defects, rust, grease, and surface flaws. It was to be designed to inspect both mounted and removed wheels. Current wheel crack detectors are too large for use in the field. The portability of this device would enable field use, e.g., for yard inspections. The software and display would be designed to characterize defects for easy decision making rather than just displaying a waveform, which is often difficult to interpret. The approach included the design and development of hardware and software, and the prototype was tested using wheels with known defects.

Project Progress

This project was completed July 2004. Tasks included: development of functional and performance requirements based on frequency of types and locations of defects, portable pulser and power supply designs, defect sensor design, and prototype system design and fabrication. Laboratory and field-testing of the prototype were conducted. These tests assessed the system's ability to positively identify defects of different types, sizes, orientations, and depth beneath the surface. The tests were conducted using wheels with known defects. Based on the preliminary test results, improvements were made to the prototype. The initial version is designed to detect tread and flange defects. Future versions will be improved to include the capability to detect rim defects.

Principal Investigator: Zack Mian

Technical Advisor: Greg Garcia, AAR/TTCI

IDEA Contract: $99,596

Cost Sharing: $200,000

Project Total: $299,596

Start: August 2002

Complete: July 2004

HSR-44/58: Permanent Magnet DC Traction Motor

SPAD Engineering Company
Vienna, Virginia

IDEA Concept and Product

This is a project to design, fabricate, and test a brushless permanent magnet direct current (PMDC) motor that could be adapted to a locomotive traction motor. This motor has the potential for higher torque and power capacity than either conventional DC or AC traction motors, and at less than one-fourth the size and weight. The PMDC traction motor will have an electronic commutator arrangement that reconfigures the stator windings from series to parallel combinations to reduce the rate at which back-electromotive force (back-EMF) increases with speed. This reduces the voltage increase normally required to overcome the increased back-EMF that is associated with increasing speed, and thus improves the torque-speed performance. The initial design, analysis, and testing of this motor was performed under contract HSR-44. The findings of this previous work demonstrated that the concept has potential but problems with the control circuit design were identified. Tasks for this follow-on contract will include the redesign of the control circuits, and the fabrication and bench testing of a prototype motor.

Project Progress

Initial tasks included analyses to assess the feasibility of the concept. A small proof motor was developed and tested and the proof motor test data analyzed. A preliminary design of the prototype motor was developed. The design was analyzed, including finite element analysis verification and thermal and electromagnetic modeling. To date, the PI has achieved sustained motor operation in smaller 'proof' motors using the PMDC concept, but

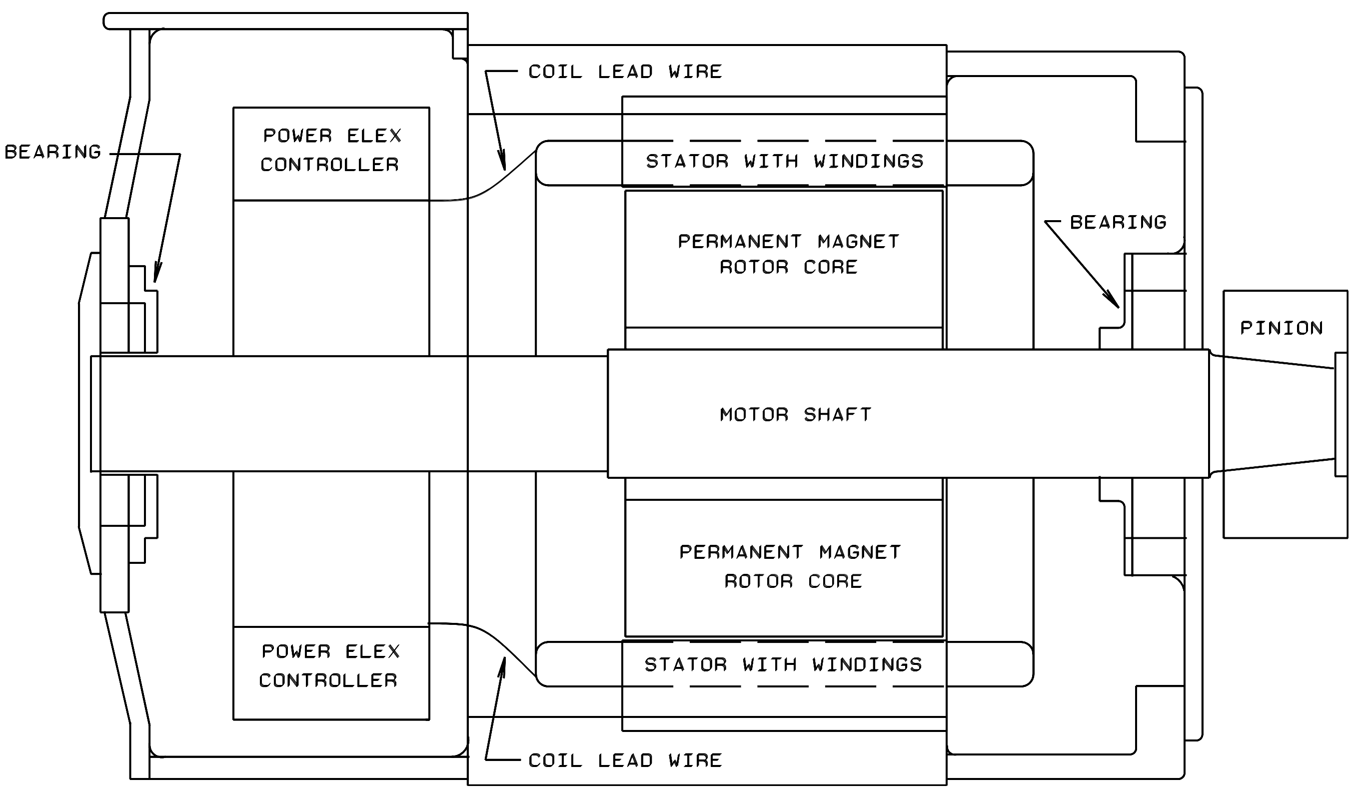

Figure 1

Schematic of a permanent magnet DC traction motor.

sustained operation of a full-scale prototype motor has not been attained. A major challenge to the success of the motor concept is survivability of the solid-state switch units when subjected to the intense voltage spikes associated with switching the large electrical coils in the motor. Results to date demonstrated that these inductive energy switching problems appear to be resolved by redesigning the control modules. Remaining tasks include the fabrication of new motor control modules, installation of these modules in the full-scale prototype motor, and performance testing of the prototype to determine its torque/speed characteristics. Test data will be analyzed to determine whether the prototype concept would be a suitable replacement for current locomotive traction motor technology. This project is scheduled for completion in October 2009.

Principal Investigator: Nick Rivera

Project Panel:
Bob McCown, FRA

IDEA Contract: $150,000

Cost Sharing: $89,366

Project Total: $239,366

Start: June 2003

Complete: October 2009

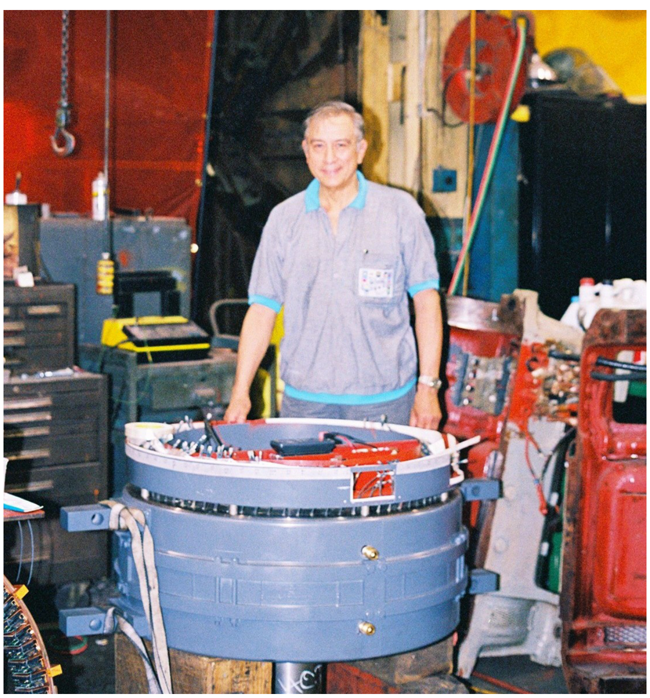

Figure 2

Full-scale 1,000 horsepower permanent magnet DC motor with integrated controller, designed for propulsion of Navy ships.

HSR-45: Crash Energy Absorption System for Rail Passenger Seats

Paragrate
Bellevue, Washington

IDEA Concept and Product

This was a concept exploration project to assess the potential of Solid Ejection Material (SEM) crash energy absorption technology for high-speed rail applications. A basic SEM model consisted of an impact piston inside a shock housing, and the end of the piston inside the housing was in contact with a ductile or yieldable solid (polymer). The housing contained an ejection groove or ejection ports. If the piston was impacted, such as in a collision, the other end of the piston forced the ductile or yieldable solid through the ejection groove or ports, thereby absorbing much of the crash energy. The specific application of this proposed technology was the development and testing of an SEM shock track for mounting seats in rail passenger cars (Figure 1). For example, in the event of a head-end or rear-end collision, the SEM shock-track mounting would provide controlled acceleration and deceleration of the seat assembly. Although rail passengers do not wear seat restraints, the controlled acceleration-deceleration would provide some protection to passengers thrown into the back of the seat ahead in the event of a head-end collision. In the event of a rear-end collision, the shock track would absorb much of the energy forcing the seats to the rear. The shock track would also reduce the likelihood of the breakaway of seat assemblies.

Project Progress

This project was completed in October 2007. Project tasks included the identification of relevant railcar seat crashworthiness specifications (FRA, APTA, overseas), the design of the SEM crash energy absorption system for the seats and impact barrier, fabrication of an impact test Bogie vehicle equipped with railcar passenger seats and an instrumented test dummy, and a series of crash tests using the previously mentioned hardware and test dummies. These SEM energy absorbers were incorporated into the floor and wall attachments of passenger seats mounted on a Bogie crash test vehicle. The rear seat of the two-seat test vehicle contained three test

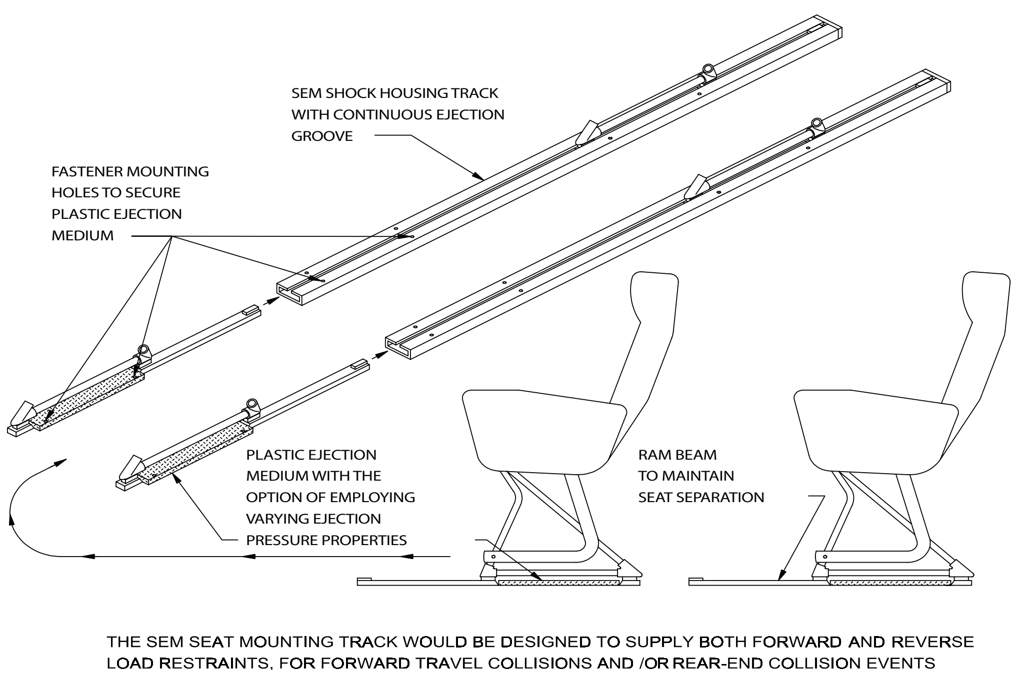

Figure 1

dummies, one of which was instrumented to record the dummy's secondary impact loads with the forward seat when the test vehicle impacted a barrier. Comparison of impact data (e.g., head impact and femur load values), with and without the SEM shocks revealed no significant differences in injury levels. This was due to several factors, including the relatively high velocity differential between the seat and test dummies at impact, and the relatively high seat mass that needed to be accelerated by the colliding test dummies (both of these factors contributed to the high initial spike loads). But the primary reason there was little variance in the load performance between the SEM modified and stock seats was primarily due to the seat structures, which were designed to yield under impact loadings specified in the relevant APTA seat specification. So the seats underwent some level of yielding even with SEM shocks. If a stiffer test seat model had been employed in this study, there likely would have been more discernable injury load improvements with SEM shocks. These project results emphasized the need for some sort of "soft catch" type surface in seat backs to reduce initial impact loads to unbelted railcar passengers.

The SEM shocks used in both the seat attachments and the impact barrier performed in accordance with desired specifications. Accordingly, other applications of this concept are now being considered.

Principal Investigator: Stephen Knotts

Project Panel:

Kent Barnes, Raytheon
Kris Severson, DOT Volpe Center
Dean Alberson, Texas Transportation Institute

IDEA Contract: $104,129

Cost Sharing: $0

Project Total: $104,129

Start: August 2003

Complete: December 2005

Figure 2

Bogie vehicle for impact tests. Instrumented test dummies were mounted in seats.

HSR-47: Application of LAHUT Technology for Wayside Detection of Cracked Wheels

Transportation Technology Center Inc.
Pueblo, Colorado

IDEA Concept and Product

This was a contract to design, develop, and test a prototype system to detect cracks in rail wheels from the wayside using a laser/air hybrid ultrasonic technique (LAHUT). The LAHUT used laser pulses to excite ultrasonic waves in the object to be tested, e.g., a wheel. Air-coupled capacitive transducers received the ultrasonic signals subsequently emitted by the test object after the waves had traveled through the area of inspection. The innovative feature of this technique was that no direct contact with the test object (wheel) was required. This enabled automated inspection of wheels as trains rolled by a wayside inspection station. A dynamic detection station (DDS) track was used to carry the DDS inspection carriage alongside the wheel during inspection. The DDS carriage included a mirror/lens assembly, used to steer the laser beam to the wheel. A control system aligned the DDS carriage to the wheel for inspection (see Figure 1). The system developed in this contract was designed to detect shattered rim cracks. Future developments could include detection of flange stress cracks and tread stress cracks.

The major portion of the funding for this project, $300,000, was provided by the Association of American Railroads.

Project Progress

This project was completed April 2005. The investigative approach included the development of system requirements, the design and fabrication of the prototype system, and the test and evaluation of the prototype in the laboratory and in the field. Laboratory tests on wheels with known shattered rim cracks indicated that the system was capable of distinguishing between the non-defective and defective wheels. Field-testing was conducted in TTCI's Precision Test Track using a dedicated test train with wheels containing selected wheel flaws previously characterized using conventional non-destructive testing techniques. Data from the consist testing in the field were not sufficiently

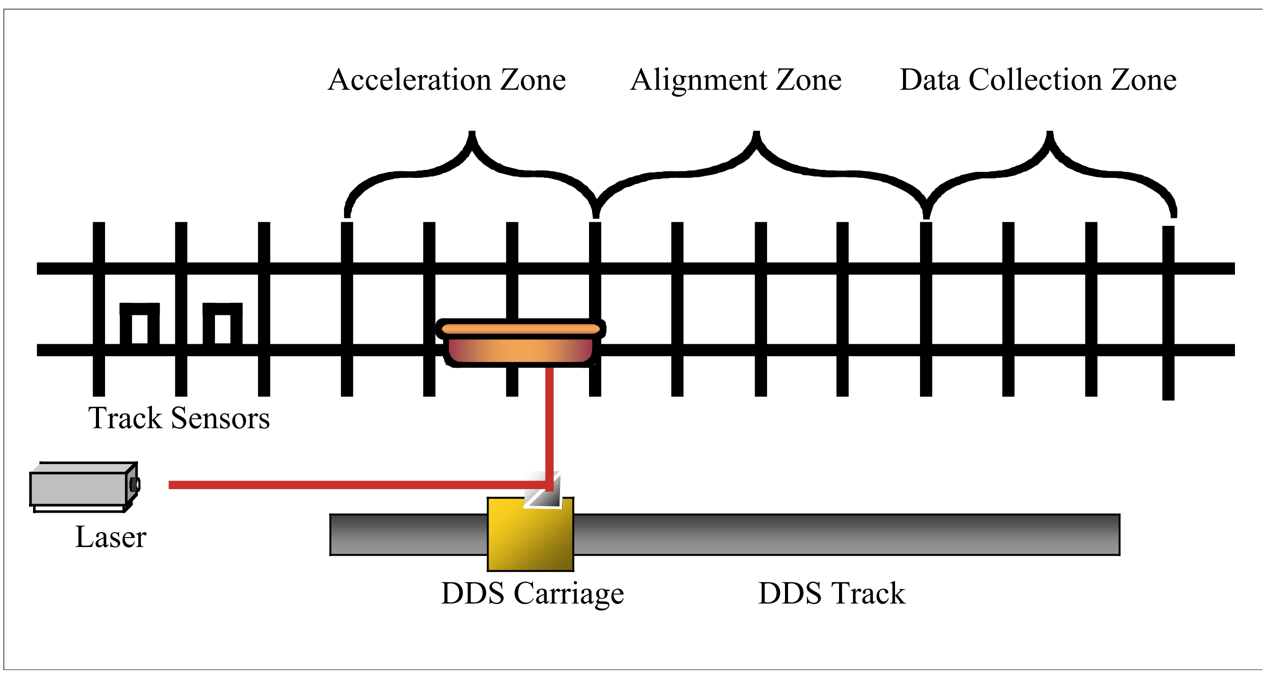

Figure 1

Prototype Concept Overview.

accurate to reliably identify wheel cracks. This was due to such factors as instability of the system for wheel tracking and laser beam placement. Development of a viable product will require modifications to better stabilize the system to improve wheel tracking and laser beam delivery. Other modifications required include the capability to detect actual flaw size rather than just whether a flaw exceeds a threshold limit, increasing the maximum inspection speed above the current 5 mph, and detection of flaws other than shattered rim cracks, e.g., split rim defects and surface cracks on the tread and flange.

Principal Investigator: Greg Garcia

Project Panel:

Shant Kenderian, NASA Jet Propulsion Laboratory
Dan Stone, Hunter Holiday Consulting
Clay Norman, Burlington Northern Santa Fe

IDEA Contract: $100,000

Cost Sharing: $300,000

Project Total: $400,000

Start: March 2004

Complete: April 2005

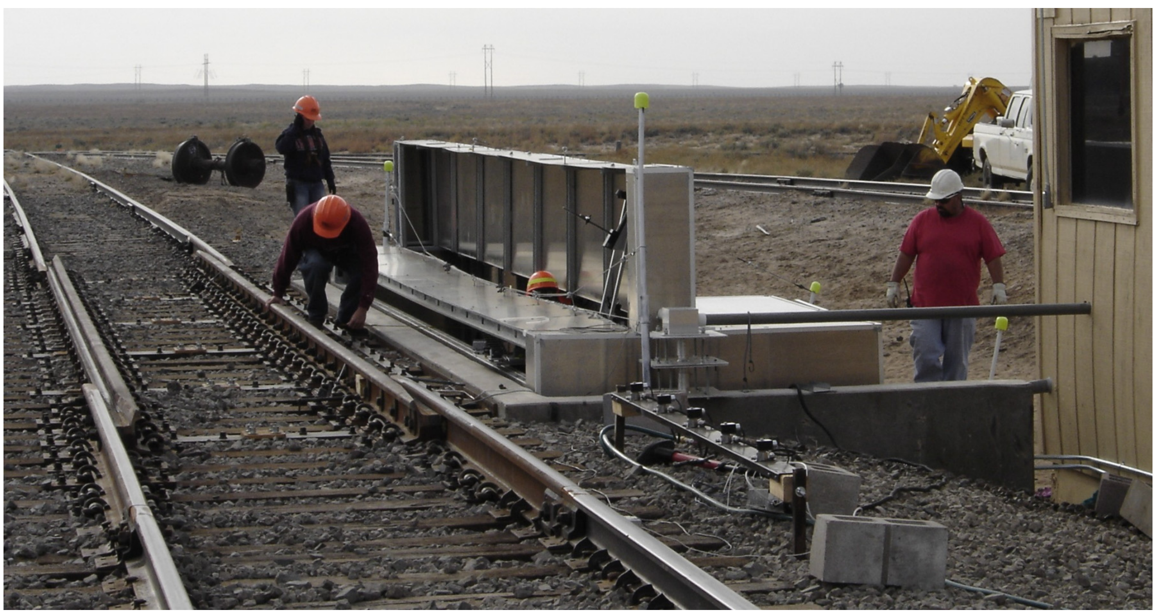

Figure 2

Installation of wayside LAHUT system at TTCI.

HSR-49: Machine Vision for Improved Safety Inspection of Railcars

University of Illinois
Champaign, Illinois

IDEA Concept and Product

This was a project to build on previous work by the University of Illinois in the development of a machine vision system for wayside inspection of rail vehicles. Work accomplished prior to this project included the development of component identification algorithms that use image data from a conventional digital camera to identify wheels, bolts, and brake shoe location. This work was funded by the Association of American Railroads. This contract developed additional capabilities for such systems for the inspection of the underside of railroad passenger equipment. Critical passenger car inspection tasks investigated include disk brake malfunctioning and condition, incipient failure of under-car electrical circuitry, missing equipment, and the presence of foreign objects under the car. The inspection system uses both visual and infrared images.

Project Progress

This project was completed in August 2007. Algorithms were designed and tested that integrate a priori knowledge about the structure and appearance of various passenger car types. A prototype trackside unit was designed and tested using actual images of the underside of rail vehicles currently in service at Amtrak's Chicago facility. These and images obtained from other sites were used for the design of machine vision algorithms to identify wheels, brakes, axles, and traction motors. Preliminary tests of the algorithms were conducted using the acquired images, which helped refine the inspection algorithms and preliminary performance requirements. Templates and template-matching algorithms to identify missing or foreign objects and incipient failures were developed. These use images of both normal and damaged or missing components. Analysis was also conducted to estimate the effects of image degradation caused by adverse weather conditions. This project confirmed the potential of such machine vision systems to automate the car inspection process.

Principal Investigator: Narendra Ahuja

Project Panel:
Jim Lundgren, TTCI
Paul Streets, Amtrak

IDEA Contract: $99,849

Cost Sharing: $39,619

Project Total: $140,000

Start: September 2005

Complete: August 2007

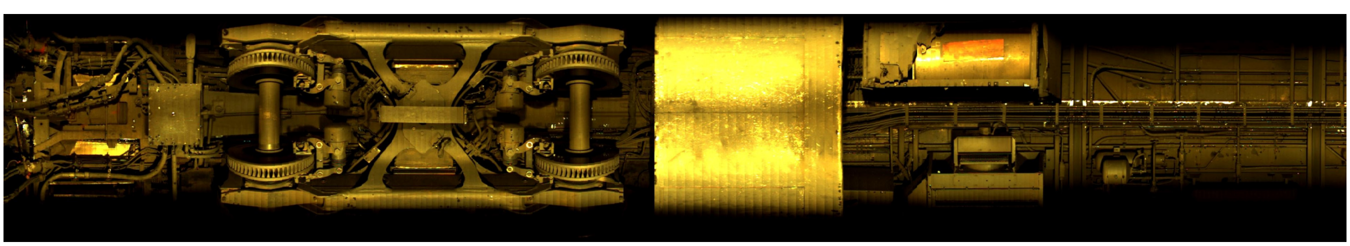

Figure 1

Panoramic image of the undercarriage of an Amfleet-II coach.

HSR-51: Smart Sensor System for Monitoring Railcar Braking Systems

University of Illinois
Champaign, Illinois

IDEA Concept and Product

This project developed the application of a smart sensor system to continuously monitor the health and safety of railcar braking systems. These smart sensor systems are small (e.g., 15 mm × 60 mm × 2 mm thick), and contain sensors and their own power supply, processor, data transmitter and antenna, and a self-configuring RF network capability. In the brake system application, strain gage smart sensors were installed on the brake beams of each car in a train (Figure 1). The output of these sensors was used to determine whether the brakes are applied or released. This would enable detection of stuck or nonfunctioning brakes, facilitate initial terminal brake inspection, and provide continuous monitoring of train braking forces to facilitate the real-time calculation of braking distances. Commercially available networking software was used. This software is designed to provide security and avoid interference, such as RF signals from other trains.

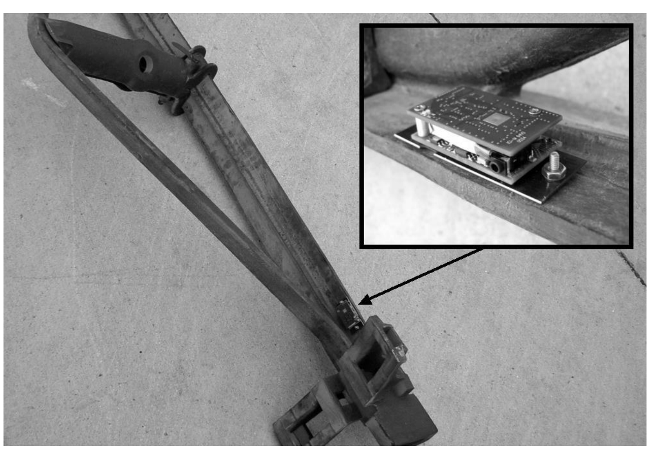

Figure 1

Sensor (see insert) installed on a brake beam.

Project Progress

This project was completed in June 2008. The investigative approach included development of a prototype system, laboratory tests, and field testing. The laboratory tests confirmed that the prototype performed satisfactorily. For the field testing, battery-powered prototypes were installed on railcars on Norfolk Southern, and tests conducted to assess performance, including how well the system operates in the presence of other networks and the typical RF and EMI environments found in railroad operations. A coupled electrical, magnetic and mechanical model of a power harvester was constructed and employed to design a power harvester for this application. Tests were conducted on a prototype harvester. Field tests to measure the vibration of a brake beam were conducted to determine whether ambient vibrations on a moving car could reliably drive a power harvester. These tests showed considerable variability in the vibration environment that will have to be considered in the final design. Application of this power harvester technology is dependent on knowing the vibration environment for each application. The radios were able to transmit data to adjacent cars. Some unanticipated problems with the radios used in the sensors required a new circuit board layout, which was developed. For the initial over-the-road tests on NS, the sensors were attached to the brake beams using a simple clamp. These clamps proved to be inadequate for this environment, and all of the sensors were lost. These over-the-road tests have been successfully repeated on both NS and CSX with a redesigned mounting system. Additional revenue service testing for long-term durability is currently underway on NS and CSX.

Principal Investigator: Darrell Socie

Project Panel:
Keith Hawthorne, AAR/TTCI
Henry Lees, BNSF
Gary Nelson, NS

IDEA Contract: $99,387

Cost Sharing: $26,726

Project Total: $126,113

Start: August 2005

Complete: June 2008

HSR-56: Signal Transmissibility of Railcar Bearing Vibrations

ENSCO Inc.
Springfield, Virginia

IDEA Concept and Product

This is a project to measure the transmissibility of vibration signals from defective wheel bearings through the rolling wheel/rail contact patch to fixed accelerometers mounted on the rail. If adequate signal strengths and signal-to-noise ratios from defective bearing vibrations can be transmitted through this rolling contact patch, this would indicate the feasibility of a track-side system using arrays of accelerometers attached to the rail to detect bearing defects. Such a system would conceivably be able to capture and analyze the distinguishable vibration signatures produced by various kinds of bearing defects.

Project Progress

This project was completed in February 2008. A wheel bearing with known defects was installed on a test railcar. The housing for the defective bearing and the housing for a bearing in good condition were equipped with accelerometers. The defective bearing and its associated acoustic-bearing signature data collected from a wayside acoustic detection system (TADS) were provided by Norfolk Southern. Three accelerometers were installed on the rail of a test track (see Figure 1). The test railcar was moved along the test track at various speeds. Data from the rail-mounted accelerometers were compared with that from the accelerometers on the bearing housings. The accelerometer data, together with the acoustic signatures previously obtained for the bearings were analyzed to assess whether signal strength and signal-to-noise ratios were adequate for the development of a track-side acoustic-bearing diagnostic system based on this concept. Results of this analysis indicated that the defective bearing signals were detected by the rail-mounted accelerometers. These tests were performed on Class 1 track at low speeds (10 mph) with jointed rail—a worst-case scenario. The original plan was to conduct the tests at speeds up to 35 mph on welded rail, but the desired test site became unavailable. The 10 mph restriction reduced the bearing defect noise and therefore significantly reduced the signal-to-noise ratio. The rail joints introduced significant noise spikes that further compromised the bearing signals. Despite these test conditions, the defective bearing signals were detectable at the rail. Further development of this concept will require testing at higher speeds and on welded rail.

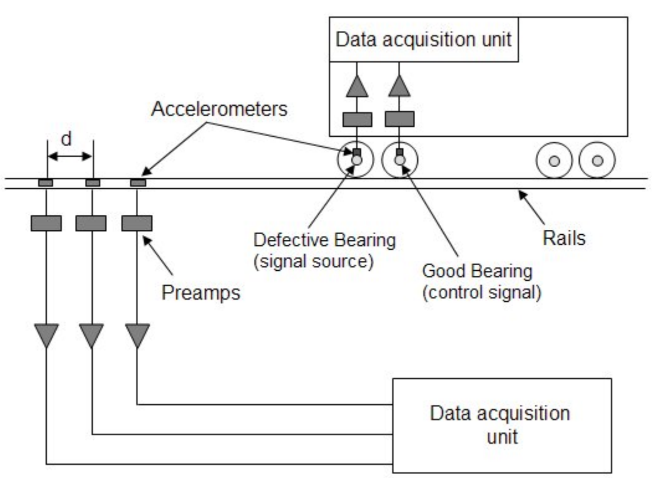

Figure 1

Test system for bearing signal transmissibility.

Principal Investigator: Yu-Jiang Zhang

Project Panel:
- Robert Blank, Norfolk Southern
- Paul Steets, Amtrak
- Gary Carr, FRA

IDEA Contract: $58,329

Cost Sharing: $11,200

Project Total: $69,529

Start: April 2007

Complete: February 2008