Proceedings of IMECE'03
2003 ASME International Mechanical Engineering Congress
Washington, D.C., November 15–21, 2003

IMECE2003-55212

VEHICLE HEALTH MONITORING SYSTEM DEVELOPMENT AND DEPLOYMENT

Gerald B. Anderson
Transportation Technology Center, Inc.

Ryan S. McWilliams
Transportation Technology Center, Inc.

ABSTRACT

Over the last several years the North American railroad industry has seen a determined growth in the area of advanced vehicle health monitoring systems, such as wheel impact load detectors, truck performance detectors, hunting detectors; and more recently, in low hanging air hose detectors, acoustic bearing detectors, and wheel profile measurement systems.

The interest in performance-based monitoring is high and growing. Latest developments by Transportation Technology Center, Inc. (TTCI), a wholly owned subsidiary of the Association of American Railroads (AAR), are in the initial stages of deployment and include acoustic roller bearing detectors and truck performance detectors. Together, these detectors and others still in development look to provide railroads and car owners with information on car component performance that can lead to preventive or predictive maintenance. This paper will describe the development and deployment of the Trackside Acoustic Detection System (TADS) and Truck Performance Detector (TPD) by TTCI in North America and internationally.

INTRODUCTION

Advanced Bearing Detection

TTCI is involved in the growth of advanced vehicle health monitoring systems in North America and around the world. The development and implementation of an improved wayside roller bearing acoustic detection system is an ongoing railroad industry objective and TTCI has been deeply involved and committed to this work since 1994. Seven acoustic bearing detection systems are now operating in North America, South Africa, and Australia. The data these systems are generating is ultimately leading to a production detection system for tapered roller bearings, available for implementation on any heavy haul freight railway. The acoustic bearing detection system is intended to provide an early warning of internal bearing defects, which could allow for the removal of wheelsets before bearing overheating and without disruption of train service.

In the North American railroad system, there is an average of 40 to 60 reportable incidents per year related to bearing failure. These unacceptable bearing related derailment statistics continue to occur despite thousands of thermal scanners placed every 10 to 20 miles along the mainline. A detection system based on earlier warning of defects offers the advantage of eliminating train stoppages; thus avoiding delays and contributing to on-time performance and customer satisfaction. In the long term, a detector that provides an early warning will be beneficial by allowing more convenient and optimal removal of defective bearings from service, reducing hot bearing setouts, and providing data on the causes of defects.

Truck Performance Detection

North America has recently seen the volume of rail traffic increase to 300 million gross tons (MGT) per year in certain corridors. High adhesion locomotives are pulling 18,000-ton trains, and interchange wheel loads have increased from 33 to 36 tons. This combination of events may be pushing the infrastructure and rolling stock to its current limits. Indications of increased tie/fastener problems as well as increased wheel defects over the past decade allude to this possibility.

To evaluate the current railway load environment, North American railways have embraced the use of defect detection and condition monitoring technologies at an aggressive pace in the last decade. The primary motivation for the rapid implementation of these technologies is to lower the stress state of the industry, improve safety, and increase the efficiency of railway operations.

TTCI and the AAR have been developing wayside force measurement systems for more than two decades. There have been many advancements since the early days of single curve installations and far from robust data collection hardware. Advancements have not only occurred in the data collection system itself, but also in the analysis and general understanding of those forces being measured.

TRACKSIDE ACOUSTIC DETECTION SYSTEM

Objective

The initial objective of the Trackside Acoustic Detection System (TADS) development is to spearhead implementation of a detector that prevents in-service bearing failures (i.e., burn-offs) and reduces confirmed hot bearing setouts. This goal will be accomplished by providing an early indication of internal bearing defects and/or degradation. An additional goal is to provide information on the causes of bearing degradation and failure by means of earlier defect removals and subsequent visual inspections. It has been noted that earlier bearing removal and examination is extremely important to finding root causes and addressing them proactively. [1]

Approach

TTCI, under the guidance of the AAR Strategic Research Initiative (SRI) program, led an industry-wide effort to develop an improved wayside bearing detector. The Federal Railroad Administration (FRA) also supported efforts to develop public-domain data on acoustic emissions from defective bearings. These efforts, formally beginning in 1994, ultimately resulted in a single prototype detector built by TTCI. In 1999 at the conclusion of the AAR program, TTCI used internal development funds to develop and implement a detection system that would meet the original industry goals.

This development involved the construction and installation of several prototype systems that would be used to gather sufficient acoustic bearing service data to train algorithm(s) to recognize several types of bearing defects. In order to shorten the verification timeframe based on the need for hundreds of service bearing inspections, TTCI entered into cooperative agreements with several railways. These agreements involved the purchase and installation of TADS equipment, and the removal and inspection of bearings from service. TTCI sought to find railroads with captive fleets of cars that could be monitored over a significant period of time, which would allow for easier access to wheelsets for inspection.

Four such systems were in operation by mid-2001, producing data scanned by preliminary algorithms to select bearings for inspection. One site was in New Jersey, two in South Africa, and one in Australia. The bearing inspections, as confirmation of the acoustic data already obtained, were used as training for continuing algorithm development. Algorithm development, together with hardware improvements based on service experience, defined a production TADS for wider implementation. Four production systems were subsequently installed in North America between September 2002 and February 2003.

TADS Equipment Description

TADS is a fairly sophisticated device comprised of computer-based hardware controlled by custom software. The equipment runs continuously without intervention, taking data from passing trains, processing and sending data to a TTCI database (InteRRIS™), and then waiting for another train to arrive. InteRRIS™ stands for Integrated Railway Remote Monitoring Service. It is a database, developed by TTCI and accessible through the Internet, that is designed to integrate data from devices that monitor vehicle performance. Using this data, it returns action-based notifications to the railroad and/or car owner.

TADS hardware is comprised of three computers operating in a network. Two of the computers are dedicated to the acoustic data collection task, while the third handles oversight and communication functions. Alongside the track there are two microphone arrays, as seen in Figure 1. Thus, one computer collects data from the near side microphone array, while the other from the far side array. There are two passive magnetic wheel sensors mounted to the rail that are used to determine individual wheel position and axle speed.

Figure 1. Trackside Acoustic Arrays

In addition to the microphone array for capturing acoustic data, the equipment accomplishes numerous other tasks. The system must have an alert method for train approach to begin and end data collection. The system must account for each axle/bearing on the train, its position, and its speed relative to the microphone array. The trackside enclosures enable the microphone array to survive the service environment and operate in all kinds of weather with minimal maintenance. Automatic Equipment Identification (AEI) is integrated with TADS to provide correct car and axle identification. All the electrical and electronic components must be protected from lightning, a frequent occurrence alongside rail lines. Communication and power must be provided reliably to support the equipment, which can be difficult in remote areas.

TADS Operation Description

As stated, this system collects a continuous stream of data during train passing. Using the wheel sensor data to pinpoint bearing location, the microphone data is parsed to obtain a time history file of each car's roller bearings. Using AEI information, each bearing data file is matched to a car number and bearing position.

The data processing stream used on each bearing file includes a number of analytical techniques that attempt to identify the few defective bearings from among the good bearings and other spurious noises emanating from the train (wheel/rail contact or vehicle suspension) or the environment (wind). In addition to identifying defects, the processing also results in an estimate of the defective component within the bearing. The resultant outputs of the various algorithms are then transmitted to a database via an Internet connection. The bearing data file for a suspected defect is also sent to the database. These bearing files are then available for review. Current development is ongoing to quantify the approximate severity of the defect to aid the railroad in prioritizing bearing removals. TTCI staff reviews the data associated with suspected defective bearings before the railroad is notified. This review step is taken to minimize false indications resulting from spurious noise until such are quantified and algorithms built for exclusion. Most such problem areas have already been addressed.

Bearing Inspection Results

TTCI is currently involved with three North American railroads performing bearing inspections. The inspection process has been aided by cooperation from bearing re-conditioners, who have conducted many of the inspections at their facilities. There have been over 500 bearing inspections conducted in North America and over 100 internationally since 2001. These inspections have yielded condemnable bearing components (per AAR Standards) in 97 percent of the cases. In 38 percent of the cases, defects were found in the mate bearing as well. The hosting North American railroads are CSXT, Norfolk Southern (NS), and Burlington Northern Santa Fe (BNSF). The hosting international railroads are Spoornet (South Africa) and Queensland Rail (Australia).

The inspections have yielded a typical array of condemnable defects such as raceway spalls, water etching, roller defects, loose cones, and cracked components. Not all defects found were acoustically detected. Many bearings contain multiple defects, of which at least one triggered the detection and subsequent removal. The detectable defects include raceway spalls, raceway or roller brinells, water etching, other roller defects (spalled, seamed, missing), and cracked components. Examples of raceway spalling, water etch, and brinelling are shown in Figures 2, 3, and 4, respectively.

The defects found vary widely in size and severity, and in general defects in certain components are considered more serious than others (e.g. roller versus outer ring). The continuing development of TADS will be to accurately reflect those considerations in the assessment of a bearing. Smaller defects may be safely left in service and monitored, while others should be removed more expediently. Of those bearings to be removed, the list should be prioritized in order of severity.

Figure 2. Raceway Spalling Example

Figure 3. Water Etch Example

Figure 4. Raceway Brinell Example

The question typically raised in a discussion of bearing defects and severity is whether an impending failure can be predicted; and if so, how long should the defect be left in service before removal. There are various failure modes for a freight car roller bearing. Little data exists for tracking defect growth in service. Small defects can be detected, and may be tracked by the detector until it increases in size. Any larger defect or one involving multiple components is a risk to leave in service for any protracted period of time. The intent is to remove these before they cause overheating and any service disruption. A less severe defect that is removed may result in salvaged components for re-use as well as indications of defect cause(s). According to the design and results to date, TADS is best suited as a preventive maintenance tool.

TADS Conclusions

- The acoustic detection technology exhibited in TADS has matured considerably during the development cycle, and has shown the ability to detect various types of defects in tapered roller bearings.
- The TADS equipment can detect bearing defects on vehicles in different operating railroad environments (i.e., North America, Australia, South Africa).
- The success of the bearing inspections to date indicate that the system is able to recognize defects prior to overheating, and should prove useful in preventing many service failures.
- Further work is needed to determine more accurately the defect removal prioritization.

TRUCK PERFORMANCE DETECTOR

Background

June of 2000 saw the first official TTCI TPD (Truck Performance Detector) installed on the BNSF railway. This TPD was installed for use in the advancement of industry knowledge of the wheel/rail load environment, as a method of derailment prevention, and overall railway preservation. As of this publication, more than 14 additional TPD systems, along with various other performance measurement systems, have been installed to monitor North America's rail system. BNSF, CSXT, NS, and Union Pacific (UP) currently have one or more TPDs installed on their rail network to aid in running a safer and more efficient railroad.

TPD Equipment Description

TTCI's TPD is a strain gage-based tool that measures the vertical and lateral forces at the wheel rail interface. In addition, TTCI has a patented Angle-of-Attack (AoA) strain gage measurement technique incorporated into this system. The TPD is comprised of three separate acquisition computers. One located in a right-hand curve, one in tangent track, and one in a left-hand curve as illustrated in Figure 5. This allows the measurement of vehicles in all three modes of operation: turning left, turning right, and proceeding straight.

Figure 5. TPD Strain Gage Installation

TPD Operations

TPD data from around the network is being transferred to TTCI for storage, analysis, and industry access, allowing for continuous improvements in the way rail organizations run their business. This central data access brings remote monitoring full circle and allows the industry maximum benefit from all detector information. In addition, TPDs collect and transmit information immediately after train passage to notify the appropriate parties of safety-critical load levels. This tool has proven itself invaluable to those who have implemented the technology. Figure 6 is a map of North American TPD locations.

Figure 6. North American TPD Locations as of July 2003

TPD Objective

TPDs can evaluate truck performance, evaluate rail and vehicle lubrication conditions and products, prevent derailments, and increase the safety and efficiency of the railway as a whole.

These systems have been installed at many key locations throughout North America to monitor hazardous materials routes, evaluate strategic heavy traffic junctions, as well as monitor heavily traveled passenger corridors. Extensive care has been taken to properly place TPDs in the most beneficial and cost-effective manner throughout the North American rail network. It is estimated that approximately one-third of the necessary TPDs are in place at this time to monitor key traffic. Great progress is being made to install all priority TPDs as all major railroads are currently progressing their detector network.

TPD Benefits and Results

TPDs have been used to identify and correct the performance of more than 360 poorly performing vehicles on BNSF property in the past two years alone. Figure 7 shows some of the inspection findings. Most trucks that have been inspected exhibit multiple types of degradations. These tend to be grouped as hollow tread, side bearing, and center plate issues.

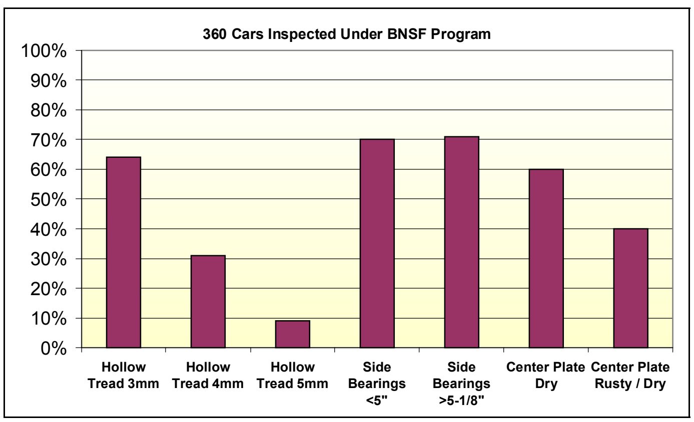

Figure 7. TPD Truck Teardown Results from BNSF Detectors

TPD data within the North American railway industry has been used to evaluate the current load environment. The knowledge gained from the measurement of wheel/rail forces is allowing the North American railway to take the appropriate actions for lowering contact stress as seen by the wheel/rail interface and reducing vehicle dynamics, which ultimately leads to a reduction in the stress state of the railway. The objective thus far has been to control and/or reduce the forces at the wheel/rail and to establish a cost-effective limit at which to strengthen the infrastructure and service vehicles.

To accomplish the task of reducing the stress state of the railroad, TTCI engineers have been and continue to evaluate the conditions that cause vehicles to perform poorly. Evaluation of truck warp, flange climb, gage spreading, track panel shift, and other undesirable conditions are evaluated on a daily basis for further advancement of the science behind the measured parameters. From this work, TTCI has developed performance indices for simplified ranking of vehicle performance. These performance indices are allowing the industry to make sense of the complex measurement system results for prioritization of vehicle performance. Figure 8 shows a severely worn wheel of a vehicle identified by TTCI's performance index. The areas of tread where the rust has been worn away indicate that two points of contact exist for this wheel. This wear results in an improperly steering truck.

Figure 8. Wear Pattern of Wheel in Warped Truck Identified by a TPD

The AAR's SRI program is also using TPD data for the advancement of predictive and preventative maintenance programs. The objective of one of the projects under the AAR SRI programs is to evaluate and promote new detector technologies, fill technological voids, and to enable preventive and predictive maintenance policies. The benefit of this complimentary work is a safer and more efficient North American railway system.

In addition to all of the railroad, TTCI, and AAR contribution, the FRA has advanced performance-monitoring technology by funding a 1 million-dollar program in 2001 that resulted in the installation of four TPDs and advancements in the national database.

Future Benefits

Solutions to achieving performance improvements are seen in a multitude of areas including center plate lubrication, improved truck maintenance, improved suspension trucks, improved track geometry, wheel/rail lubrication, rail profile maintenance, wheel profile maintenance, and further vehicle condition monitoring. The deployment of detectors is seen as a necessary part of identifying the defects and condition of rolling stock and for taking appropriate actions to remove poor performing equipment, as well as measuring the benefits from implementation of new and improved equipment. Systems that help in directly lowering the stress state or making the operations of railways more cost-effective and efficient are also being implemented to include top-of-rail lubrication, performance based track geometry, warm bearing trending, and an integrated database.

Infrastructure managers, product manufacturers, and vehicle owners have just begun to realize the benefits from these types of technologies. Eventually, rail customers and ultimately the consumer will be the major benefactors of advanced performance monitoring systems through a safer, more cost-efficient rail industry.

ACKNOWLEDGMENTS

The authors would like to thank BNSF for their cooperation in the use of TPD truck tear down statistics.

REFERENCES

1. Anderson, G., Marais, J., and Austen, A., "Initial Field Experiences with the Trackside Acoustic Detection System," International Heavy Haul Association, 2003 Specialist Technical Session, May 5-9, 2003, Dallas, Texas, Conference Proceedings, page 3.35.