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IDEA Innovations Deserving Exploratory Analysis Project

TRANSIT COOPERATIVE RESEARCH PROGRAM

Operational Evaluation of a Rail-Based Wheel Gauge Inspection System

Zack Mian
International Electronic Machines Corporation

Report of Investigation

TRANSIT IDEA

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INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS MANAGED BY THE TRANSPORTATION RESEARCH BOARD (TRB)

This investigation was completed as part of the TRANSIT-IDEA Project, which is one of four IDEA programs managed by the Transportation Research Board (TRB) to foster innovations in surface transportation. It focuses on products and results for transit practice in support of the Transit Cooperative Research Program (TCRP). The other three IDEA programs areas are: ITS-IDEA, which focuses on products and results for the development and deployment of intelligent transportation systems (ITS), in support of the U.S. Department of Transportation's national ITS program plan; NCHRP-IDEA, which focuses on products and results for highway construction, operation, and maintenance in support of the National Cooperative Highway Research Program (NCHRP); and HSR-IDEA, which focuses on products and results for high speed railroads in support of the Federal Railroad Administration. The four IDEA program areas are integrated to achieve the development and testing of nontraditional and innovative concepts, methods, and technologies, including conversion technologies from the defense, aerospace, computer, and communication sectors that are new to highway, transit, intelligent, and intermodal surface transportation systems.

The publication of this report does not necessarily indicate approval or endorsement of the findings, technical opinions, conclusions, or recommendations, either inferred or specifically expressed therein, by the National Academy of Sciences or the sponsors of the IDEA program from the United States Government or from the American Association of State Highway and Transportation Officials or its member states.

Operational Evaluation of a Rail Based Wheel Gauge Inspection System

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I. EXECUTIVE SUMMARY

On December 17, 1992, fourteen passengers of Bay Area Rapid Transit (BART) Train 278 were injured when a wheel climbed the switch point rail and caused the car to derail, hitting the wall of the tunnel. Initially, both the wheel and the rail were found to be within acceptable safety limits for wear. Subsequent analysis showed the wheel/rail wear patterns were such as to cause the train to leave the track. A study conducted by Zeta-Tech & Associates concluded that it was the pattern of wear, not the absolute level of wear, which caused the accident. ***Zeta-Tech recommended the routine measurement of wheel profile including flange angle measurements to avoid a recurrence of the accident.*** BART did not implement this recommendation since no cost-effective means of gathering this data was then available. Instead, they opted to reduce the allowable wear on the flanges using traditional measurement and inspection techniques. This solution has the potential problems of not directly addressing the flange angle question coupled with the potential for the premature condemnation of acceptable wheels. However, it was accepted as a reasonable alternative to the costs associated with commercially available wheel flange angle measurement techniques.

To provide safe, comfortable, rail passenger service, transit mechanical managers must take extraordinary measures to inspect and maintain railroad wheels. ***Unfortunately, existing wheel measurement technologies in the U.S. rail transit industry are inefficient, unreliable, inaccurate and inadequate. This leads to incurring many expensive, though largely hidden, costs.*** These costs include avoidable equipment downtime, high labor costs, excessive inventories of replacement wheelsets, and unacceptable safety risks. In the BART accident, the train remained in service with an unacceptably worn wheel due to inaccurate wheel measurements. This lead to a major personal injury accident.

Many inspections, recommended or even required by railroad authorities, are never even conducted simply because it is too difficult and/or expensive to do them. For example, the wheels that derailed in the BART accident would have been taken out of service had the railroad implemented a ***flange angle inspection***. However, since no efficient technique for conducting a flange angle inspection exists, the wheel remained in service.

Obviously, since railroad wheels are rigidly fixed on an axle and do not operate independently as do automobile tires, they need to be the same diameter to roll straight down the track. In fact, since there is no efficient means to accurately ***measure wheel diameter***, many wheels remain in service that do not meet federal wheel diameter matching requirements. These wheels will have a tendency to ride up over the rail, especially in curves, and represent a significant derailment threat.

In summary, railroad wheel inspection techniques have lagged far behind the demands of the industry. The existing steel finger gauge is inefficient, inaccurate and unreliable leading to expensive, and in some cases, unsafe operations. New techniques are required to ensure continued safe, efficient operations.

IEM has conducted a field demonstration of an automated, wayside wheel inspection station which meets the requirements of the system recommended by Zeta-Tech. We have also incorporate additional computations to check for such issues as flange angle, wheel diameter, hollow tread, etc. These conditions are not normally noted using existing practices. However, they can have a profound impact on vibration, ride quality, wheel rail adhesion, and safety (especially at higher speeds).

Benefits include:

- *More thorough and uniform wheel inspections leading to safer operations.*
- *Better profile maintenance contributing to superior ride quality and better overall performance at high speeds.*
- *Elimination of the time-consuming process of manually measuring the wheels; contributing to reduced labor costs.*
- *Improved scheduling of wheel maintenance activities; leading to reductions in equipment down time and improved ride quality.*
- *Better understanding of actual wheel wear patterns; leading to reduced inventories of replacement wheelsets.*
- *Better understanding of when to intervene with a wheel true, and the development of new, more cost-effective wheel profiles which in turn will result in longer wheel life.*
- *Improved high speed rail operation safety by catching cracked wheels.*
- *Extended track, tie, and rolling stock life due to elimination of flat wheels.*

CONTENTS

II. THE NEED FOR AUTOMATED WHEEL MEASUREMENTS

A. Importance of Wheel Inspections

Wheel inspection, maintenance and replacement are among the most important duties of a railroad mechanical department. Wheels themselves are costly. Since they are subject to high stresses and wear in service, there must be a substantial amount of routine inspection, repair, and replacement. A high standard of maintenance is essential to avoid damage to track, cars and passengers from rough, broken or deformed wheels. Most important, a service failure of any single wheel will, with a high degree of probability, result in a derailment with potentially catastrophic consequences.

B. Wheel Accidents are Expensive

FRA safety data points out the need to improve wheel inspection techniques. From 1985 through 1992, there was an average of 84 accidents a year attributable to wheel failures. These accidents were relatively expensive, costing the railroads an average of $109,000 each (57% more than the average accident caused by a mechanical or electrical failure). Of the total mechanical or electrical failures, wheel failures represented close to 30%.

C. Personnel Cutbacks

The railroad industry has seen some very substantial reductions in force over the past ten years. Many positions eliminated are lower middle management positions such as foremen. Consequently, there is much less direct supervision of field laborers, such as car inspectors, than has traditionally been the case. These cutbacks have the potential for creating opportunities for oversight in the performance of routine inspection operations.

III. PROBLEMS ASSOCIATED WITH CURRENT PRACTICES

A. Problems with Inspection Practices

Most inspectors are careful when they place the steel wheel gauge on the wheel to be measured. However, they tend to tilt the gauge to get a better look at it when they lean down to look at the rim thickness reading. This tilting usually results in the addition of at least 1/32nd of an inch to the rim thickness. The thicker the wheel, the greater the distortion and overstatement.

The second factor leading to an overstatement of wheel sizes is the practice that most inspectors have of removing the gauge from the wheel to read the flange thickness scale. Very often when they remove the gauge, the flange thickness finger will hit the flange and shift out, resulting in an overstatement of the flange thickness.

Presently there are no convenient methods to detect cracks in wheels. Portable ultrasonic gauges have been developed but have been found to be cumbersome and difficult to use.

Existing inspection techniques rely heavily on visual inspections which are difficult because:

- **Poor Line of Sight** - The wheel defect may not fall within the field of vision of the inspector. Changing freight car designs are limiting the direct line of sight to the wheels especially on axles two and three.
- **Poor Lighting** - Many inspections are performed at night when lighting conditions are poor.
- **Poor Weather** - Inclement weather may further obscure a wheel defect.
- **Limited Supervision** - Field inspectors have limited management supervision.

TRAIN ACCIDENTS RESULTING MECHANICAL FAILURES									
	1985	1986	1987	1988	1989	1990	1991	1992	Average
Wheel Accidents	92	74	73	95	106	82	75	74	84
% of Total	16.46%	17.09%	15.87%	18.55%	21.16%	19.29%	18.07%	20.96%	18.34%
Cost (Thousands)	$7,894	$10,548	$6,363	$13,544	$9,770	$6,751	$11,519	$6,545	$9,117
% of Total	16.59%	25.02%	16.69%	29.13%	22.53%	15.48%	23.93%	26.52%	21.83%
Total Accidents	559	433	460	512	501	425	415	353	457
Cost (Thousands)	$47,585	$42,1625	$38,1295	$46,4915	$43,356	$43,626	$48,1366	$24,6766	$41,7706
Cost Per Wheel Acc.	$85,802	$142,544	$87,171	$142,578	$92,171	$82,335	$153,583	$88,448	$109,329

Table 1

B. Safety Issues

Still another perspective emerges when you look at the AAR condemnations recorded from 1988 to 1992. If you break down the wheel accident data into the type of wheel defect that caused the accident you can see that worn flange, at 20%, is the single greatest cause of train derailments. Then, there is the group of broken rim, broken plate and other causes at 15%, 14%, and 13% respectively. Thermal cracks, an issue which causes a great deal of attention only registers 3% of the accidents, may be a contributor to the broken rim, plate and flange accidents. Based on this data, any system that effectively identified flange and rim wear has the potential to significantly reduce the overall number of derailments in the industry.

Another reason to begin focusing on the need to improve wheel inspection practices is ***wheel accidents will soon overtake bearing related failures as the number one cause of accidents***. For years bearing related failures were by far the leading component of mechanical related accidents and wheels were a distant second. However, with the advent of the roller bearing, the proliferation of hot box detectors and the development of the acoustic bearing detectors, the proportion of bearing related failures have been dropping while wheel related failures have been a constant.

IV. SOLUTION: WAYSIDE WHEEL INSPECTION STATION

A. IEM's Background in Wayside Wheel Measurement

IEM has worked on the problem of wayside wheel measurement for more than seven years. The progress of the work has been adversely affected by the lack of resources to conduct this work on our own. We have, however, had a number of small research projects from CSX Technology, the Federal Railroad Administration and the **Transportation Research Board - Transit Idea Program**. As a result of that work, we have done a comprehensive analysis of the market potential for this technology. We have also demonstrated the capabilities of the underlying approach that we intend to pursue. Specifically, we experimented with a variety of sensor technologies and concluded that an optical laser scanner technology could combine the elements of speed, resolution and durability required by the project. We then built a test track in our Albany, NY factory and acquired images of actual railroad wheels. We developed a technique for capturing these images and then, using software developed from our Wheel Profilometer, derived the key measurements from the captured image. This work is discussed more fully in the paper, "Automated Wheel Inspection Station" by Zack Mian. This paper includes detailed illustrations of the entire process of illuminating the wheel, capturing the image, importing the image into a digital environment, and deriving the actual wheel measurements.

B. IEM's Approach

IEM has shown the solution to these problems is the development of an automated wayside wheel inspection station. This station is placed on the rail and automatically and uniformly inspect every wheel that passed over it.

There are three primary benefits that the High Speed Transit market would derive from such a system.

- ***Every wheel would be uniformly measured leading to a higher quality inspection. This would eliminate those wheel failures which result from inadequate inspections.***
- ***The automated nature of the wayside wheel inspection station will lead to a significant labor savings.***
- ***A wayside wheel inspection station can perform much more quickly than the traditional walking of the train.***

IEM has developed a ***high speed laser scanning approach*** using: acousto-optics, line generating optics, image capturing, and graphic analysis software. This combination captures cross-sectional wheel profile images at high speeds and converts them to standard wheel measurements. We have added distance from the reference diameter groove and a calculation of flange angle to the traditional measurements of flange thickness, flange height and rim thickness. The flange angle measurement is vital to the determination of wheel/rail interaction and the maintenance of acceptable train dynamic conditions.

The laser beam illuminates the wheel. Then, the system captures and brings the image into the digital computer environment. Finally, the wheel profile analysis software converts the raw image into standard wheel measurements. In the production mode, this entire process is invisible to the operator and he would only see a report listing the worn wheels, their location and the type of wear.

V. BENEFITS OF A WAYSIDE WHEEL INSPECTION STATION

A. Need for Innovation - Safety

Despite the significant differences between transit operations and the freight rail industry, most transit operations utilize inspection and safety techniques developed for the maintenance and operation of freight cars. Some pertinent factors differentiating transits from freight railroads include lighter cars, more frequent stops and starts, tighter curves, higher speeds, and greater sensitivity to ride quality.

Several of these factors can result in a tendency for wheel lift-off that is greater in transit operations than in

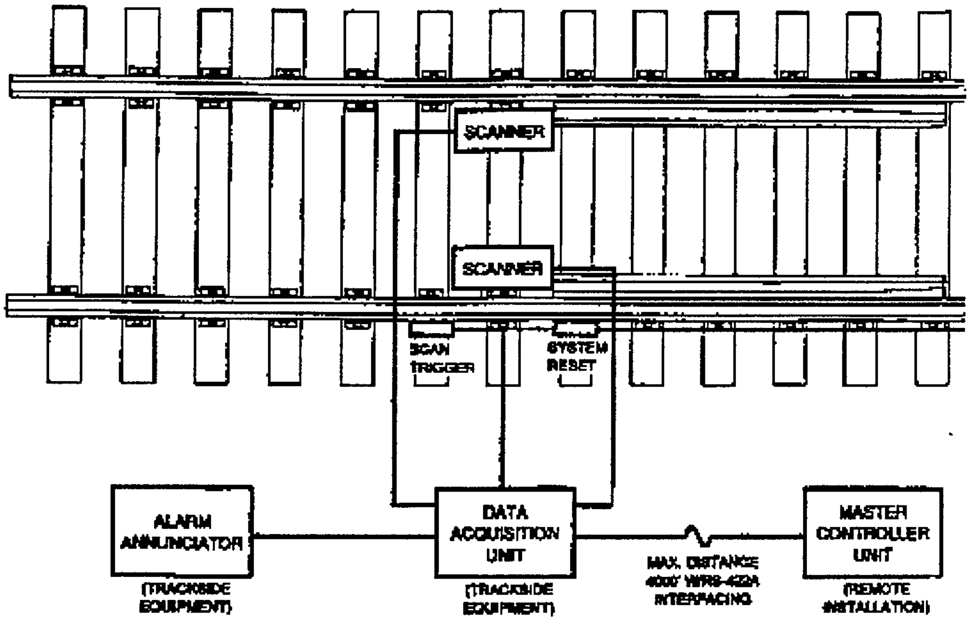


Figure 1: Wheel inspection station - schematic drawing.

freight operations. There are five factors which govern the build up of these lateral forces. They are: speed, weight, track geometry, the angle of the flange and the angle of the rail. Of these factors, only flange angle is still outside the realm of standard inspection procedures.

The safety benefits become obvious when we look back only one month ago to the train crash in Germany. German officials say **a total of 95 bodies have been found**. More than 40 others were seriously injured. A ***broken wheel*** has been found several kilometers away. Authorities temporarily withdrew most of the country's fleet of high-speed Intercity Express trains for urgent inspections.

B. Improved Management Control of Wheel Truing

An immediate application is in the area of wheel truing. Throughout the industry, there is a general pattern of removing more service metal than is absolutely necessary in the wheel truing process. The reason for this is a natural tendency for machine operators to want to get a "nice clean finish." By measuring all wheels before and after wheel truing and by establishing tighter management control of wheel truing, it will be possible to save at least 1/32nd of an inch and very often as much as 1/8th of an inch per wheel per true. Assuming an average of 1/16th per wheel and an average of three trues per wheel, results in a savings of 3/16ths of an inch of service metal over the life of the wheel which will be realized in: (1) the capital costs in the purchases of new wheels and (2) the operating costs in the reduction of the number of change outs.

C. Faster Identification of Abnormal Wheel Wear

Careful and regular tracking of wheel wear combined with routine analysis of the results can quickly detect abnormal wear patterns and trigger corrective action before reaching a condemnation limit. An example would be a slightly misaligned truck causing excessive flange wear.

D. Faster, More Accurate Wheel Inspections

Substituting the Wheel Inspection Station for the Finger Gauge at the periodic inspection will reduce the time needed to perform the required wheel measurements by approximately 70% or 20 minutes per car inspected.

E. Elimination of "No Defect Found"

The increased accuracy of the Wheel Inspection Station technology along with the built in condemning limits will eliminate the costs associated with bad data. The easiest to quantify are the costs of the "No defect found" wheels. In these cases, a car is assigned either to wheel truing or to change-out based on a faulty wheel inspection. Subsequently it is found to have either no defective wheels or wheels that should have been assigned to the alternate facility. In this case, the costs associated with this misassignment would include the loss of the use of the car for at least one day, the loss of the use of the wheel truing facility for one day, and the labor involved in moving the car.

F. Better Wheel Management Practices

The greatest impact produced by the Wheel Inspection System technology will be through the improved understanding of the process of wheel wear and the impact of different wheel specification and maintenance procedures on wheel life. While these areas will not have an immediate budget impact, they will produce the greatest long term savings. Using the IEM system, tracking wheel wear patterns will now be relatively easy and relate rates of wear to various controllable factors. Such wheel truing specifications including: scheduling and profile, wheel specifications, and, ultimately, track maintenance procedures. With this power identifying the cost impacts of changes in standard procedures or specifications in wide variety of areas will be possible.

G. Assessing changes in technology

Better wheel wear data will help the railroad industry evaluate the impact of a variety of technological changes on wheel wear. It will also help the railroad industry develop cost-effective responses to changes such as flange lubrication, harder wheels, harder rails, heavier loads, more powerful locomotives, and different braking technologies.

Quantifying the potential cost savings from a new technology is as difficult as assessing the broad variety of hidden costs associated with an existing technology. The existing finger gauge is clearly an imprecise tool which very often (up to 40% of the time in several studies) produces faulty readings in daily operation. It is also self evident that wheels are a tremendous cost center which has yet to benefit from an aggressive program of preventive maintenance. Finally there are many factors such as flange lubrication, rail hardness, wheel hardness, load and torque which are currently changing wheel wear patterns. To determine the most cost effective maintenance response to these changes using the data generated by the finger gauge would be next to impossible. To do the same using the measurement and data entry capabilities of the IEM Wheel Inspection Station is relatively straightforward. ***It is this power which will produce the greatest savings.***

VI. RESULTS OF WORK

IEM's basic system consists of two imaging subsystems: one for wheel profile and the second for wheel rim thickness measurement. As a result of field testing, IEM has added two additional sensor systems to the wheel profile measurement system. The first sensor system was added to collect the wheel rim thickness data and the second sensor was added to measure the distance of the wheel from the entire imaging system. The need for the second sensor arose from the fact that the lateral wheel placement can vary depending on the wheel gauge (distance between the two wheels on the same axle) as well as the wheel profile. The measurement extraction software algorithms depend on an exact placement of the wheel with respect to the rail to establish the measurement coordinate system. Using the additional distance sensor, any lateral placement related variation in other measurements can be corrected easily. The rim thickness is one of three necessary measurements.

In order to increase the operational speed of the unit, IEM has designed a high speed line scan camera. The high speed camera is capable of acquiring two image lines at line rates of up to 2000 lines/seconds. The camera will be used in finding the precise location of the wheel with respect to the the wheel inspection station also. The high speed line scan camera is also used in the Flat Spot Detection System along with other applications.

Figure 2 illustrates actual wheel measurements on the Profile System. The top half of the computer screen shows ten digital images of the same wheel with diagnostic information. The software then averages and compares the ten images to get a more accurate measurement. The bottom half of the screen shows a corresponding histogram of the information. This information is used to perform diagnostics on the system and to demonstrate the capabilities of the system. The customer does not see the detailed information. They will receive a printed report instead.

A custom rail segment was needed for the profile system. IEM designed and fabricated the segment. Stress analysis on the design was done by professional structural engineers. We installed the custom rail segment at Amtrak's Rensselaer site. Figures 3 and 4 show the profile installed at the Rensselaer site.

In order to guard against potential damage done by dragging equipment, we have designed a dragging equipment detector to notify the engineer when dragging

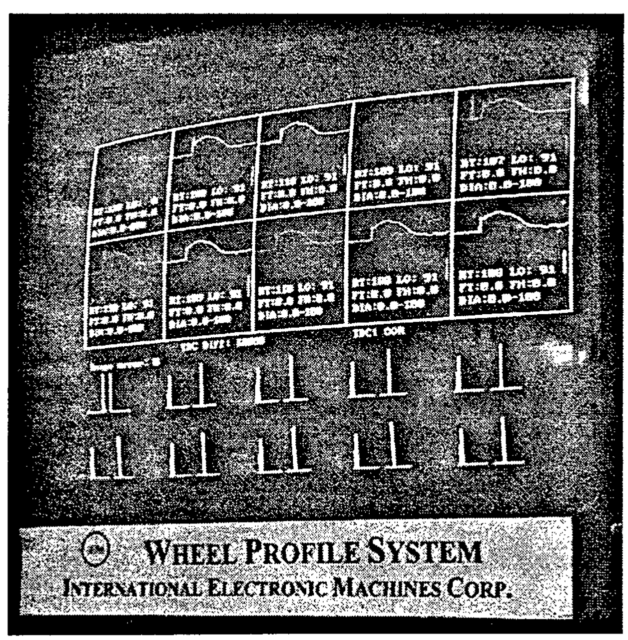


Figure 2: Actual profile and rim readings.

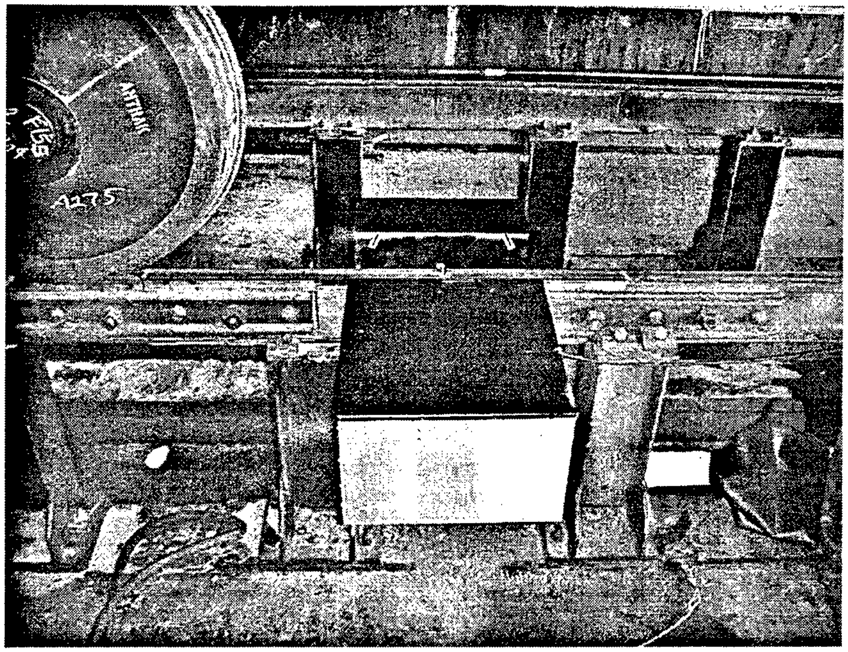


Figure 3: Profile system installed on custom rail.

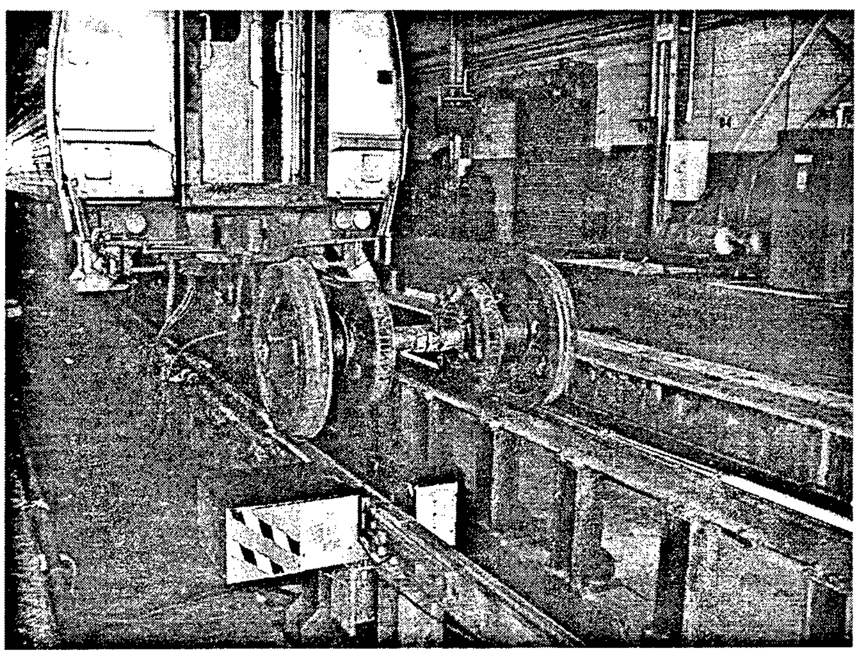


Figure 4: Profile system.

equipment from the train is in danger of striking the profile system. Our detector consists of a pair of rotating steel veins attached to an optical encoder (figure 5). The encoder triggers an electronic latching circuit which turns on a red quartz caution light and an 85-decibel horn (figure 6). We mound the detector approximately 40 yards down rail from the east entrance to the track. The light and horn are mounted at the east end of the track pit. They are within close proximity to the laborer who is responsible for guiding the train. It is the laborer's responsibility to notify the engineer by radio to stop the train should the detector be tripped.

It has come to our attention that the locomotive's third rail shoes are adjusted, repaired and replaced on the track where the profile system resides. It is possible for an improper third rail shoe to strike and damage the profile system. We have also designed the dragging equipment detector to test for and guard against this problem.

In order for the system to operate in real world railway environment, water and sand proofing the profile system is

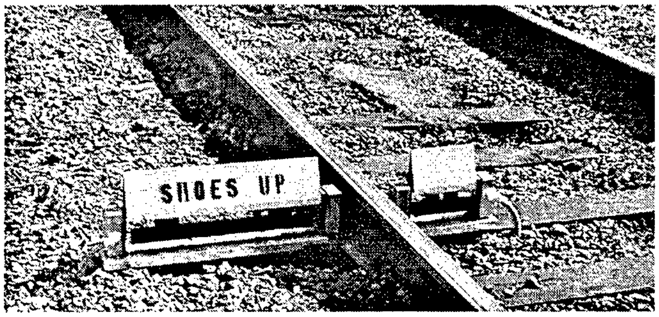


Figure 5: Rotating steel veins.

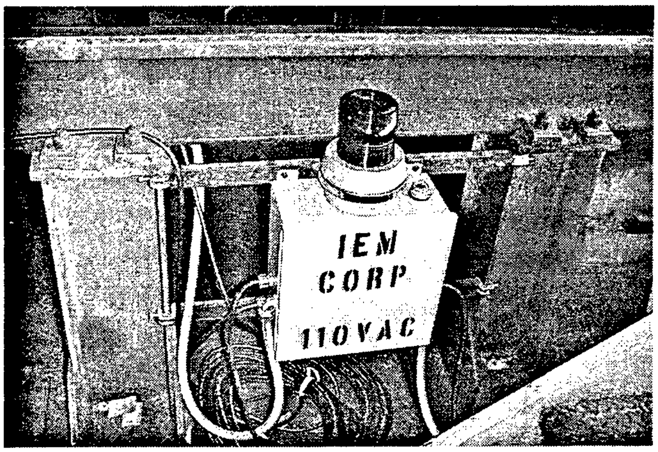


Figure 6: Caution light and 85-decibel horn.

also completed. We have designed and installed a positive air flow system to provide strong air curtains at every orifice of the profile system. Furthermore, optical shutters were installed on the system to guard against outside elements. An air flow system is the last component of our multilevel protection system to be installed.

We have installed a pair of heavy duty proximity detectors (figure 7), one on either side of the custom rail segment. The train triggers the proximity detectors as it approaches. The detectors then signal the profile system to turn on.

With all the various models of locomotives operating in the Northeast Corridor, a diverse range of electromagnetic interference is present within the range of the profile system. The high speed camera and its data cable are the most sensitive piece of the profile system. We have benchmarked the camera, cable and computer against the full range of locomotives to insure we have complete noise immunity. We conducted the following benchmark test:

- Step 1: A CCD camera was placed within close proximity to the rail. Many laser images were captured while no equipment was operating.
- Step 2: Subsequently, the same images were captured while each type of locomotive passed directly overhead. This was done several times.
- Step 3: Finally, we compared and found that data from step 1 and 2 were identical. We concluded from this test that our camera system was immune from electromagnetic interference.

The profile imaging system is installed about 50 feet away from the profile computer/controller at the Amtrak Rensselaer facility. We have designed, manufactured and installed a fully protective cable raceway to protect the cables connecting the camera system to the computer system. The raceway protects the cables from fork lifts driving over the cables. The computer/controller incorporates imaging system controls and data acquisition system. The system has been tested for repeatability using a single wheel segment and multiple roll by wheel sets to insure proper operation.

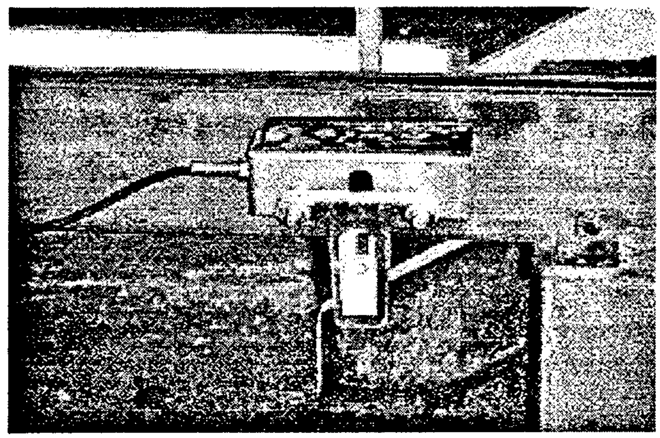
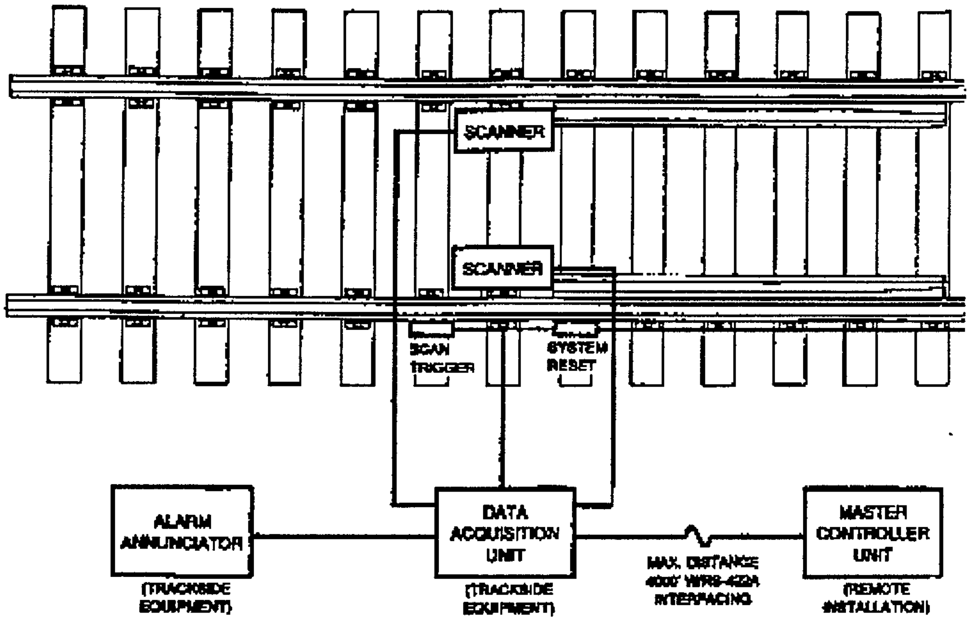


Figure 7: Proximity detector.

VII. CONCLUSION

IEM has successfully demonstrated innovative optical measurement techniques to measure railway wheels. These wheels are measured using laser based imaging techniques. The resulting design was a compact and easy to use wheel measurement system. Special mechanical design innovations were incorporated in the design to protect against the environmental elements such as dirt, water, and sand. The trial testing of the system resulted in a successful demonstration of the wheel measurement system. Please see the Wheel Inspection Station brochure in Appendix B for details on the design specifications.



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In order to guard against potential damage done by dragging equipment, we have designed a dragging equipment detector to notify the engineer when dragging

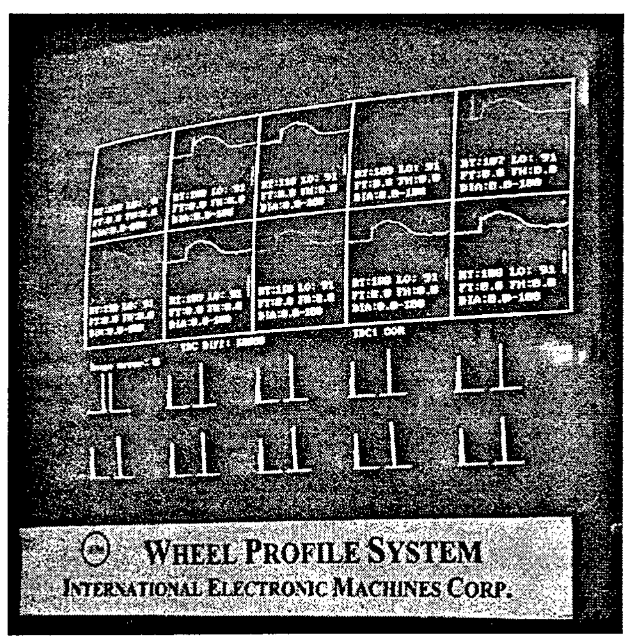

Figure 2: Actual profile and rim readings.

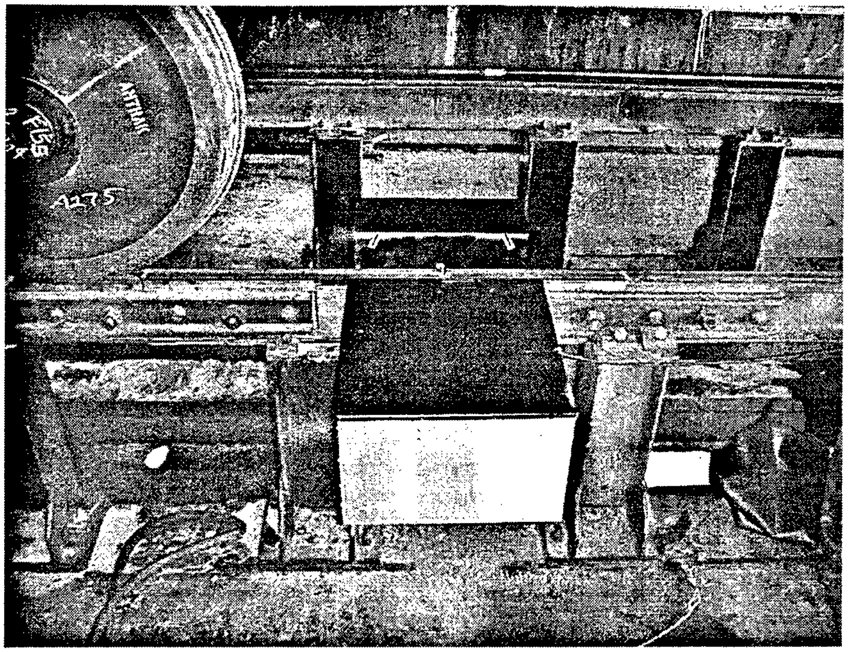

Figure 3: Profile system installed on custom rail.

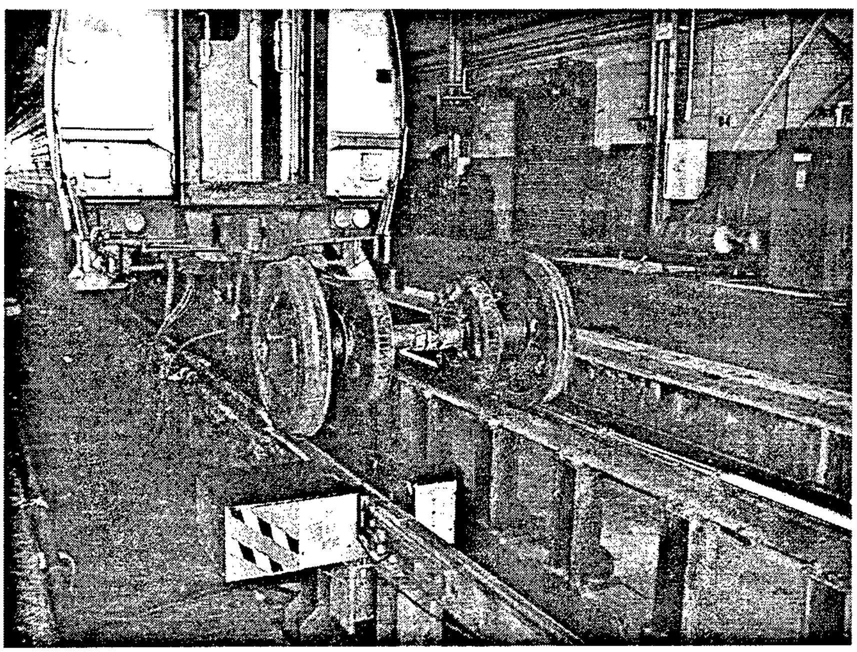

Figure 4: Profile system.

equipment from the train is in danger of striking the profile system. Our detector consists of a pair of rotating steel veins attached to an optical encoder (figure 5). The encoder triggers an electronic latching circuit which turns on a red quartz caution light and an 85-decibel horn (figure 6). We mound the detector approximately 40 yards down rail from the east entrance to the track. The light and horn are mounted at the east end of the track pit. They are within close proximity to the laborer who is responsible for guiding the train. It is the laborer's responsibility to notify the engineer by radio to stop the train should the detector be tripped.

It has come to our attention that the locomotive's third rail shoes are adjusted, repaired and replaced on the track where the profile system resides. It is possible for an improper third rail shoe to strike and damage the profile system. We have also designed the dragging equipment detector to test for and guard against this problem.

In order for the system to operate in real world railway environment, water and sand proofing the profile system is

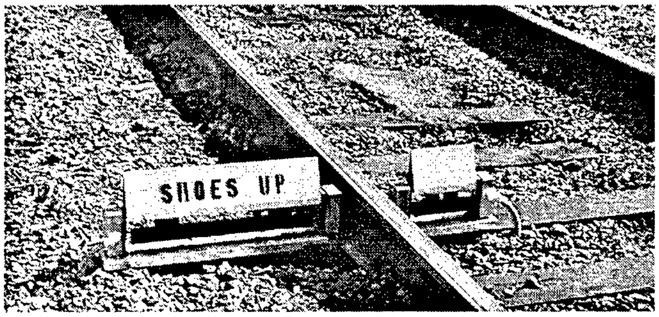

Figure 5: Rotating steel veins.

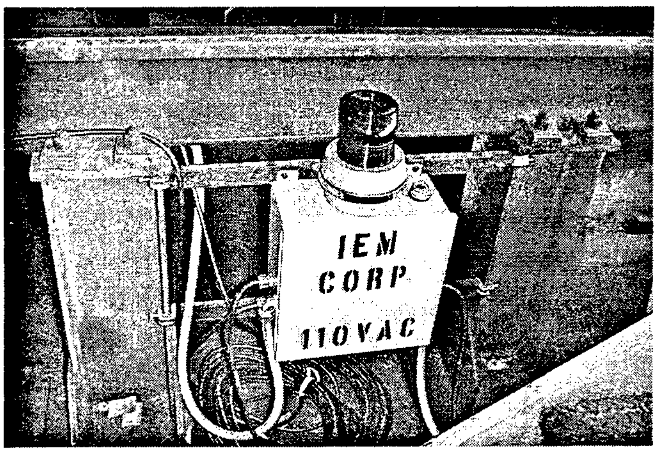

Figure 6: Caution light and 85-decibel horn.

also completed. We have designed and installed a positive air flow system to provide strong air curtains at every orifice of the profile system. Furthermore, optical shutters were installed on the system to guard against outside elements. An air flow system is the last component of our multilevel protection system to be installed.

We have installed a pair of heavy duty proximity detectors (figure 7), one on either side of the custom rail segment. The train triggers the proximity detectors as it approaches. The detectors then signal the profile system to turn on.

With all the various models of locomotives operating in the Northeast Corridor, a diverse range of electromagnetic interference is present within the range of the profile system. The high speed camera and its data cable are the most sensitive piece of the profile system. We have benchmarked the camera, cable and computer against the full range of locomotives to insure we have complete noise immunity. We conducted the following benchmark test:

- Step 1: A CCD camera was placed within close proximity to the rail. Many laser images were captured while no equipment was operating.
- Step 2: Subsequently, the same images were captured while each type of locomotive passed directly overhead. This was done several times.
- Step 3: Finally, we compared and found that data from step 1 and 2 were identical. We concluded from this test that our camera system was immune from electromagnetic interference.

The profile imaging system is installed about 50 feet away from the profile computer/controller at the Amtrak Rensselaer facility. We have designed, manufactured and installed a fully protective cable raceway to protect the cables connecting the camera system to the computer system. The raceway protects the cables from fork lifts driving over the cables. The computer/controller incorporates imaging system controls and data acquisition system. The system has been tested for repeatability using a single wheel segment and multiple roll by wheel sets to insure proper operation.

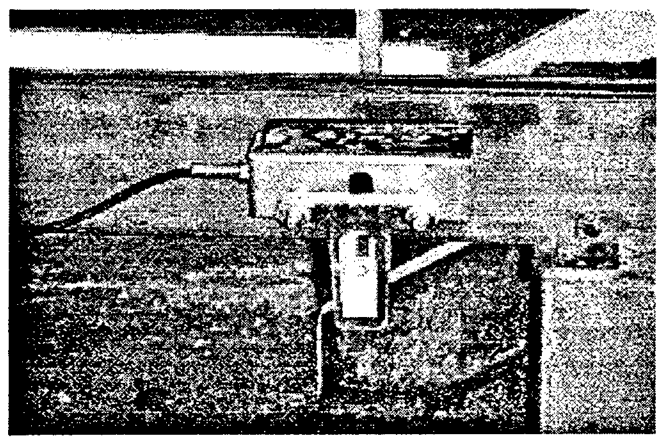

Figure 7: Proximity detector.

VII. CONCLUSION

IEM has successfully demonstrated innovative optical measurement techniques to measure railway wheels. These wheels are measured using laser based imaging techniques. The resulting design was a compact and easy to use wheel measurement system. Special mechanical design innovations were incorporated in the design to protect against the environmental elements such as dirt, water, and sand. The trial testing of the system resulted in a successful demonstration of the wheel measurement system. Please see the Wheel Inspection Station brochure in Appendix B for details on the design specifications.