INTERNATIONAL ELECTRONIC MACHINES CORPORATION
71 Fourth Street, Troy, New York 12180 (518) 273 2445 FAX (518) 273 2446

IEM

The Development

of an

Automated Rail Based Wheel Gauge

Phase I Report

Final Project Summary Report

Contract DTRS-57-94-00001

Automated Rail Based Wheel Gauge

The purpose of this contract was to assess the feasibility and need for an automated rail based approach to inspecting and measuring wear on rail road wheels.

In the course of producing this document, IEM personnel conducted face to face interviews with senior officials with three major transits and four Class I railroads. We also conducted extensive phone and mail surveys soliciting the opinion of representatives of all the Class I railroads, all major private car owners and all the leading rail transit operators. We also visited technical installations in North Platte, NB as well as NIST headquarters in Boulder, CO.

We developed a comprehensive set of product performance specifications for the proposed gauge.

In our evaluations of the various available technologies, we created working prototypes of actual wheel measurement systems utilizing ultrasonic and laser sensors. We wrote "C" language source code to convert the raw data into meaningful RR wheel measurements. We tested the various technologies for resolution, repeatability, and durability.

We conclude that changes in the rail industry are creating an increasing need to automate the wheel inspection process. We find that a laser based wheel inspection station is capable of meeting the target performance requirements. While it is not presently feasible to create a comprehensive wheel inspection station idnetifying all wheel defects, a wheel inspection station that measures flange and rim wear would provide a significant contribution to the industry. We propose the creation of such a station and propose as well that it incorporate a capacity to be upgraded to include crack detection and the identification of tread defects in the future.

APPENDIX

ATTACHMENT J-1

FINAL PROJECT SUMMARY REPORT

PROJECT IDENTIFICATION INFORMATION

1. BUSINESS FIRM AND ADDRESS	2. DOT PROGRAM	3. DOT CONTRACT NUMBER
INTERNATIONAL ELECTRONIC MACHINES Corp 71 Fourth Street Troy, NY 12180	SBIR - 1993 Phase I	DTRS-57-94-00001
	4. PERIOD OF PERFORMANCE From 11/93	To 6/94

5. PROJECT TITLE

Automated Rail Based Wheel Gauge

SUMMARY OF COMPLETED PROJECT

The data in this final report shall not be released outside the government without permission of the contractor for a period of two years from the completion date (6/94) of this project from which the data were generated.

APPROVAL SIGNATURES

1. PRINCIPAL INVESTIGATOR/ PROJECT DIRECTOR *(Typed)*	2. PRINCIPAL INVESTIGATOR/ PROJECT DIRECTOR *(Signature)*	3. DATE
Zahid F. Mian	[signature]	6/16/94

IEM

Table of Contents

INTRODUCTION

This report is the fulfillment of Contract # DTRS-57-94-C-00001. It analyzes the feasibility and necessity of developing a rail based wheel inspection station.

The report is divided into four main sections. Section I develops a system specification by first presenting background data regarding the need for such a gauge, second reviewing industry standards, statistical accident/defect data, and feedback from our market research. It concludes with a proposed set of specifications regarding the type of measurements that will be required.

Section II summarizes the effectiveness of the products that currently exist in meeting the performance requirements spelled out in Section I. It represents the conclusion of our various site visits, interviews with industry and technology leaders and reviews of available technical documentation.

Section III analyzes the capabilities of existing technologies in meeting the requirements listed in Section I. Its conclusions are largely based on in-house bench-top and test track testing of various products and sensor technologies.

Section IV presents a feasible system design based on the above discussions.

In the course of producing this document, IEM personnel conducted face to face interviews with senior officials with three major transits and four Class I railroads. We also conducted extensive phone and mail surveys soliciting the opinion of representatives of all the Class I railroads, all major private car owners and all the leading rail transit operators. We also visited technical installations in North Platte, NB as well as NIST headquarters in Boulder, CO.

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SECTION I

THE NEED FOR AUTOMATED WHEEL MEASUREMENTS

1. SUMMARY

1.1. 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 of the approximately 12 million wheels in service under the nation's car fleet. A high standard of maintenance is essential to avoid damage to track, cars and contents from rough, broken or deformed wheels. Most importantly, a service failure of any single wheel of the millions in use will, with a high degree of probability, result in a derailment with potentially catastrophic consequences.

1.2. Wheel Accidents are Expensive

Recent FRA Safety data point out the need to improve wheel inspection techniques. Over the last nine years, there have been an average of 90 accidents a year attributable to wheel failures. These accidents were relatively expensive, costing the railroads an average of $142,000 each (57% more than the average accident caused by a Mechanical or Electrical failure). In addition, of the total Mechanical or Electrical Failures, wheel failures represented close to 30%.

1.3. Changing Nature of the Fleet

Current operating practices have produced a fleet of freight cars that is getting smaller, growing older, carrying heavier loads, travelling further and spending less time in classification yards where most wheel inspection activities take place.

1.4. Changing Freight Car Design

The same trends that are increasing the need for more reliable wheel inspections are in fact making wheel inspecting more and more difficult. As freight car designs have changed to carry increasing loads, the bodies of the cars are hanging down further over the wheels blocking the direct line of sight from the inspector. Thus wheel defects that might have been obvious in a smaller, lighter freight car are much more difficult to detect as the cars become larger and heavier. And, as will be discussed in greater detail below, the growing emphasis on express freight and unit train operations is reducing both the opportunities and time available to conduct thorough inspections.

1.5. Growth in Unit Train Operations

Increasingly, the railroad industry is moving away from traditional hub and spoke hump yard operations to more efficient and profitable point to point unit train operations. In unit train operations, covering such bulk commodities as coal and grain as well as such high speed cargo such as intercontinental containers and automobiles, cars are not available for the level of scrutiny currently applied in yard inspections. In the growing intermodal market, the heavy emphasis is on moving the freight as fast as possible from point to point. Taking time out to have inspectors walk the train every several hundred miles is simply a bygone practice. Consequently there has been a shift to roadside visual inspections in much of this service. In IEM's interviews with industry leaders, several RR professionals voiced the concern that the intensity of the inspection process to which these cars were subjected was degrading and could become a cause of concern. The concern was that either the need for inspections would become a hindrance to the growing profitability of this kind of service and/or alternatively, safety issues may emerge as a result of the change in the way these cars are inspected.

1.6. Personnel Cutbacks

The railroad industry has seen some very substantial personnel reductions over the past ten years with the number of employee hours has been reduced by over one third from 801,000,000 to 530,661,000. Many of the positions that have been eliminated are lower middle management positions such as foremen. Consequently there is significantly less direct supervision of field laborers such as car inspectors than has traditionally been the case. These cutbacks have had the potential for creating opportunities for oversight in the performance of routine inspection operations.

2. PROBLEMS ASSOCIATED WITH CURRENT PRACTICES

Ordinarily each railroad at an interchange will inspect all cars delivered to it by another road or roads, in order to protect its interests. Where cars tendered for interchange are found by the prospective receiving line to have handling line defects such as slid flat spots, these are ordinarily the responsibility of the delivering line. For this reason, and because Interchange Rules provide (in part) that "cars having defects for which delivering company is responsible must be defect carded when offered in interchange," delivering lines may also in some cases inspect cars to be interchanged.

After an inbound train requiring inspection has stopped, the inspector starts at one end of the train and examines the front of each wheel on that side of the car for defects in the flange, tread, rim and plate. It is also necessary to inspect the tread surface and throat part of the flange to note whether there are any cracks. The back of each wheel on the opposite side of the car should also be inspected for defects in the back face of the flange, the back plate, the hub, or indications of a wheel loose on its axle.

Most wheels are examined visually without use of gauges. This inspection by observation, when diligently done by a competent inspector, calls attention to defects and possible defects. The gauges are then brought into use to determine with certainty the condition of the wheel, and to determine which AAR rule authorizes or requires removal of the wheel from service.

When the entire train or car consist has been examined on one side, it is examined from the other side, following the same procedure followed above.

A car with a defective wheel must be marked bad order and reported so that it will be sent to a repair track. The method and time of reporting must conform to local practice. In some cases, as with trains being inspected at intermediate terminals, the report must be made immediately so the bad order car can be switched out promptly with minimum delay to the train. Usually the report is made to the General Car Foreman or Yardmaster. Telephones, paging devices and portable radio sets are often provided for this purpose. In the case of trains at final terminals or cuts of cars standing in a yard and not made up into a train, it may be permissible to make reports upon completion of the entire inspection.

2.1. Problems with Inspection Practices

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

- Poor Line of Sight

  The wheel defect may not be on a surface of the wheel that falls within the field of vision of the inspector. As was discussed, 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.

2.2. Problems with the Applications of Existing Gauges

When an inspector notices a wheel with a potentially condemning defect, he selects and uses the appropriate condemning gauge to determine if the wheel-set needs to be taken out of service. All of these gauges are subject to significant operator induced measurement error. Some of the potential errors include:

Placing a 34401 or 34401A Condemning Gauge over a flange in a manner that is not simultaneously perpendicular to both the surface of the wheel and the back face of the wheel. Distorting either axis will result in not condemning a wheel for thin flange that would be condemned if the gauge was properly placed on the wheel.

Rocking the Simplified Steel Wheel Gauge forward so that its back face is not flush against the back face of the wheel. Such a distortion could result in missing a high flange.

Twisting the Simplified Steel Wheel Gauge to the side so that it is not perpendicular to the surface of the wheel. Such a distortion could result in a determination that the rim thickness is thicker than it really is. IEM has recently completed a study of the application of the Steel Wheel Gauge (Appendix ___) which showed that the average measurement taken with the Steel Wheel Gauge increases the Rim Thickness measurement by 1/32nd of an inch beyond the actual.

2.3. EFFECTIVENESS OF CURRENT PRACTICES

Most wheel related derailments can be related directly to a failure to properly measure and inspect the wheel. Thus the best guide as to the effectiveness of current measurement and inspection practices can be found in the derailment statistics published annually by the FRA Office of Safety. Over 20% of the damage resulting from derailments caused by car failures is caused by wheel failures. Between 1985 and 1992 over $72,800,000 in derailment caused property damage was attributed to wheel failures. See Figure 1.

TRAIN ACCIDENTS RESULTING MECHANICAL FAILURES								
	1985	1986	1987	1988	1989	1990	1991	1992
Wheel Accidents	92	74	73	95	106	82	75	74
% of Total	16.46%	17.09%	15.87%	18.55%	21.16%	19.29%	18.07%	20.96%
Cost	7,893,788	10,548,283	6,363,482	13,544,918	9,770,097	6,751,470	11,518,700	6,545,187
% of Total	16.59%	25.02%	16.69%	29.13%	22.53%	15.48%	23.93%	26.52%
Total Accidents	559	433	460	512	501	425	415	353
Cost	$47,584,553	$42,162,233	$38,129,194	$46,491,145	$43,355,891	$43,625,552	$48,136,068	$24,676,396
Cost Per Wheel Acc.	$85,802	$142,544	$87,171	$142,578	$92,171	$82,335	$153,583	$88,448

Figure 1

Another reason to begin to focus on the need to improve wheel inspection practices is that wheel accidents are becoming a closer number two cause of accidents. For years bearing related failures were far and away 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 has been dropping while wheel related failures have been a constant. As the following chart shows, there is a slow but significant trend showing accident damage caused by wheel failures has increased

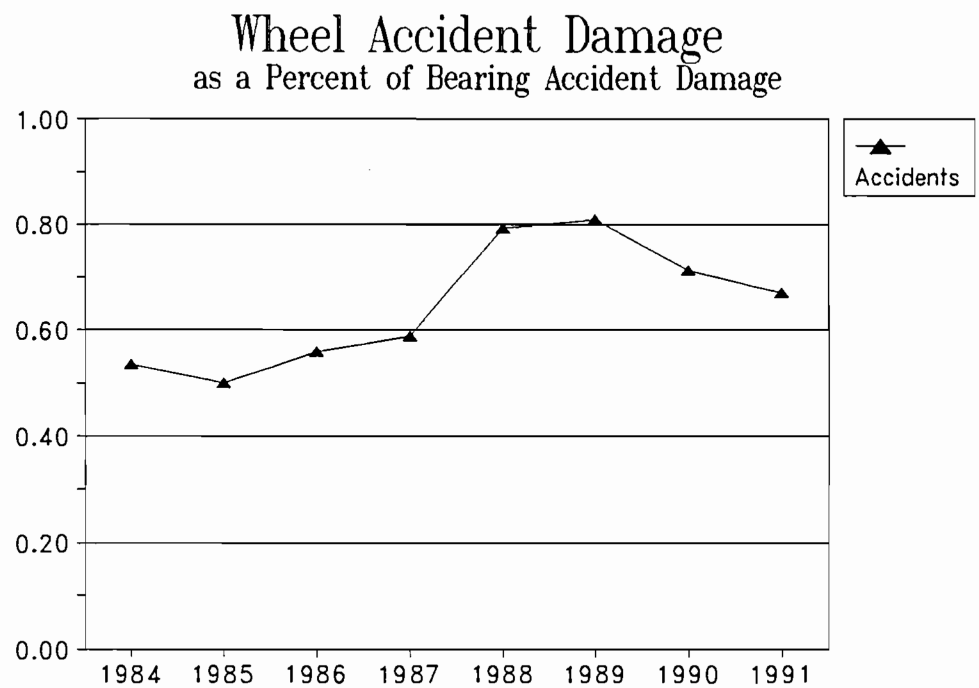


Figure 2

since 1985 compared to damage caused by defective bearings.

2.4. PROBLEM SUMMARY

The freight car fleet is aging, it is carrying heavier loads, and is going faster and farther between inspections. The inspection work force is being reduced. Modern freight car designs are making it more difficult to inspect wheels. The growth of unit train operations is reducing the opportunities available to conduct thorough wheel inspections. Although the overall safety performance of the industry has been improving dramatically, there has not been as great a reduction in the number of wheel accidents. And finally, wheel inspection practices have not changed significantly since the 1920's.

3. PROPOSED SOLUTION: RAIL BASED WHEEL INSPECTION

IEM proposes that the solution to these problems is the development of an automated rail based wheel inspection station. This station would be placed on the rail and would automatically and uniformly inspect every wheel that passed over it. It would incorporate an Automatic Equipment Identification (AEI) reader and would produce a report showing the car number and wheel position of any wheel that exceeded allowable tolerances.

There are three primary benefits that would be derived from such a system. First, every wheel would be uniformly measured leading to a higher quality inspection eliminating those wheel failures which result from inadequate inspections. Second, the automated nature of the rail based gauge could lead to a significant labor savings. Third, a rail based wheel inspection can be performed much more quickly than the traditional walking of the train.

3.0.1. Safety Issues - Derailment Protection

Uniform measurements would eliminate the two major sources of variability in wheel inspections.

A . Uniform Inspections of All Wheels

Unlike existing conditions where car design can result in a less thorough inspection of interior axle wheels, a rail based system would provide the same quality inspection to all wheels.

B . Elimination of Operator Measurement Error

Second, the subjectivity that is a normal part of much of the current practices would be practically eliminated.

These factors would significantly improve the quality of the wheel inspection function and lead to a significant improvement in the safe operation of the railroad.

3.0.2. Cost Effectiveness Issues

A . Automation

Automating parts of the inspection process would provide a relatively cost-effective way to perform the inspections. Although a physical inspection would still be required to perform those inspections that would remain beyond the capabilities of the automated system, the elimination of the need to inspect for high flange, thin rim, and thin flange could provide a significant labor savings.

B . Quality Control

However there is a second financial benefit that would be derived from the improved quality of the wheel inspection process. This benefit would be a reduction in the chance of missing a defect that is the responsibility of the Delivering Line such as a slid flat spot. Missing these defects not only results in a safety hazard but makes the railroad responsible for the cost of repair should the next railroad correctly identify the condition.

C . More Efficient Yard Operations

By placing the rail based wheel gauge on the in-bound track, the wheel inspection would take place at or prior to the arrival of the train in the yard. The provision of a timely a report of cars requiring wheel work would enable the yardmaster to much more efficiently schedule his car movements and maintenance crews leading to an overall reduction in the time the consist of cars remains in the yard.

D . Capturing Unit Train Cars

Since cars in Unit Train operations normally skip yards they are not subject to the same inspection scrutiny as cars more traditional operations. As explained above, the economics and severe time pressures of unit train operations severely restrict the opportunities for the inspection of unit train cars. Consequently, the availability of a "roll-over" gauge which could provide a high quality wheel inspection without the need to stop the train would provide a significant benefit not currently available.

E . Other Benefits

Beyond these initial operational benefits, there is an entire area of benefits that will be derived from the ready access to high quality, low cost wheel inspection wear data. Currently the vast majority of wheels in the nation's rail fleet are simply operated until they are worn to a condemning limit and then they are scrapped or trued. Little thought has been given to effectively implementing preventive maintenance programs for wheels.

A quite different situation exists in the case of captive fleets. With captive fleets, car owners, recognizing that wheel wear is the largest single freight car maintenance expense, devote significant resources to capturing and analyzing wheel wear statistics. This data is then used to project wheel life and to use those projections to schedule preventive maintenance operations.

Similar types of projections are currently impractical with non-captive fleets since the car owners do not see their cars often enough to be able to track their wheel wear on any kind of routine basis.

However, with a rail based wheel gauge, it begins to become practical to collect accurate wheel profile data on an entire fleet of cars without any additional labor expense. This information can then be used in a variety of ways to lower the overall life cycle costs of car ownership.

3.1. THE NEED FOR INTEGRATED WHEEL MEASUREMENTS

In addition to the need for new approaches to inspect railroad wheels for normal wear, there is also a need to develop a common system architecture so that the various different types of rail based inspection devices can be consolidated into a single control unit. For example, at North Platte, Nebraska, the Union Pacific Railroad has a wheel impact detector. It also has a wheel crack detector. The two systems are side by side. However, they each have their own computer controller, their own car identification system, their own power supply and their own communications system. Even the UP engineers express concern about the overlapping of overhead.

However, the problem is more severe than simply the obvious cost of redundant systems. In many cases the effectiveness of each system could be enhanced by increasing its power and capabilities by adding such features as an AEI tag reader and an UMLER interface. However in general operations, neither system standing alone can justify such a cost. Nor is the problem limited to these specific items. The acoustic bearing detector system's operation could also be enhanced by a real time interface with UMLER to help differentiate between different size wheels.

SECTION II

SYSTEM SPECIFICATIONS

4. SYSTEM SPECIFICATIONS - FUNCTIONAL REQUIREMENTS

Based on the changes taking place in the national rail industry and an analysis of the data presented in the FRA's Office of Safety annual Accident/Incident Bulletin that there is a real need for a comprehensive rail based, wheel inspection station.

To determine the final design for the proposed system, we will look at three items:

- What is needed

  What must the system be capable of doing in order to make a significant contribution to the industry?

- What is possible

  What are the limits of existing technologies in terms of their ability to meet these performance requirements?

- What it will be

  What system results from matching the desired to the possible?

4.1. SPECIFICATION DEVELOPMENT

There are a great many factors that need to be incorporated into the process of deriving a set of system specifications. Some of these are:

- Application

There are several different markets and applications for rail based wheel measurement technology and each has its own unique set of requirements.

- Distribution of Defects

  Why do wheels get condemned? What are the trends?

- Safety Issues

  Which wheel defects cause derailments?

- Market Preferences

  What is the current view of the market? What capabilities does the market want?

- Speed Requirements

  What are the minimum train speeds that the system will have to handle?

- Cost/Benefits

  What savings can be accrued from the use of the technology and what expense could that justify?

- Reliability

  What are the performance targets in terms of defective wheels correctly identified and false alarms?

- Environmental Constraints

  What environmental stresses will the system have to survive?

- Service Requirements

  How long does the system have to operate without servicing?

4.1.1. Application / The Type of Service

There are four general classifications to the overall market place. These are general freight, unit train operations, locomotive operations and passenger car or transit operations. Each has significantly different requirements for each performance criteria for the system.

A . General Freight

General freight operations are the most demanding of all. Here the broadest variety of defects would have to be identified, under the worst environmental conditions and at the highest speeds.

B . Unit Train

In unit train operations, there is a much greater degree of uniformity in wheel type, train speed can be controlled, and the wheels can be seen on a regular routine basis.

C . Locomotive Operations

Here the wheel quality is among the worst in terms of built-up grease and limited access to the wheel. However, the range of wheel defects is limited and train speeds can be restricted to under 5 MPH.

D . Passenger Car

Here wheel quality is among the highest eliminating much of the range that the inspection system would have to cover in the freight world. However, the allowable tolerances are tighter and condemning many wheels which would be perfectly acceptable in the freight world.

4.1.2. Distribution of Defects

Another approach to establishing a set of specifications for the system is to look at the overall distribution of wheel condemnations to see which defects are most common.

Following are two tables (Figures 3 and 4). The first lists all the condemnations recorded by the American Association of Railroads for the period of 1988 - 1992. The second eliminates those condemnations not related to a specific wheel defect and sorts the remaining list by frequency of condemnation. Here we can see that over 90% of all wheel condemnations are due to just eight defects: Thin Flange, Shelled Tread, High Flange, Wheel Not Reappliable

DFCT # TYPE OF DEFECT	1988	Percent	1989	Percent	1990	Percent	1991	Percent	1992	Percent	Total	Percent
3 MISSING	257	0.05%	265	0.05%	270	0.05%	107	0.02%	69	0.01%	968	0.04%
7 OBSOLETE MATERIAL	780	0.15%	436	0.08%	394	0.07%	1203	0.23%	3130	0.59%	5943	0.23%
8 WRONG NOT STANDARD	52	0.01%	58	0.01%	88	0.02%	56	0.01%	42	0.01%	296	0.01%
11 REMOVED GOOD CONDITION	191950	37.55%	183534	35.35%	199916	36.49%	193684	36.85%	177715	33.67%	946799	35.98%
23 GOVERNMENT REG. REQ'MT'	46707	9.14%	61607	11.87%	60875	11.11%	55900	10.64%	42720	8.09%	267809	10.18%
25 OWNER'S REQUEST	512	0.10%	3303	0.64%	2425	0.44%	755	0.14%	542	0.10%	7537	0.29%
31 FIRE OR HEAT DAMAGE	122	0.02%	56	0.01%	110	0.02%	46	0.01%	29	0.01%	363	0.01%
60 FLANGE THIN	50247	9.83%	44730	8.62%	40736	7.44%	35907	6.83%	36448	6.91%	208068	7.91%
62 FLANGE VERTICAL	34	0.01%	133	0.03%	132	0.02%	45	0.01%	36	0.01%	380	0.01%
64 FLANGE HIGH	27173	5.32%	27921	5.38%	29166	5.32%	29594	5.63%	31105	5.89%	144959	5.51%
66 FLANGE CRACKED OR BROKEN	526	0.10%	444	0.09%	495	0.09%	436	0.08%	280	0.05%	2181	0.08%
68 RIM CRACKED OR BROKEN	3241	0.63%	1740	0.34%	9036	1.65%	1418	0.27%	1181	0.22%	16616	0.63%
69 THERMAL CRACKS 2W-MW	19	0.00%	0	0.00%	95	0.02%	127	0.02%	90	0.02%	331	0.01%
70 RIM THIN, SP IN HAZMAT	NA	0.00%	NA	0.00%	NA	0.00%	3337	0.63%	16581	3.14%	19918	0.76%
71 RIM SHATTERED	312	0.06%	289	0.06%	371	0.07%	320	0.06%	295	0.06%	1587	0.06%
72 RIM SPREAD	106	0.02%	118	0.02%	128	0.02%	104	0.02%	121	0.02%	577	0.02%
73 RIM THIN	3295	0.64%	3914	0.75%	4547	0.83%	7508	1.43%	15570	2.95%	34834	1.32%
74 THERMAL CRACKS	3125	0.61%	6834	1.32%	8586	1.57%	10951	2.08%	8277	1.57%	37773	1.44%
75 TREAD SHELLED	32898	6.44%	37243	7.17%	39058	7.13%	44955	8.55%	49592	9.40%	203746	7.74%
76 TREAD BUILT-UP	10883	2.13%	11624	2.24%	10517	1.92%	9686	1.84%	9299	1.76%	52009	1.98%
77 TREAD GROOVED	3645	0.71%	3067	0.59%	2538	0.46%	2457	0.47%	2058	0.39%	13765	0.52%
78 TREAD SLID FLAT	20355	3.98%	23402	4.51%	24460	4.47%	22792	4.34%	20631	3.91%	111640	4.24%
79 TREAD SLID FLAT W/ WEAR	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
80 SCRAPE, DENT, GOUGE	3341	0.65%	3501	0.67%	3737	0.68%	2657	0.51%	2377	0.45%	15613	0.59%
81 WHEEL OUT OF GAGE	53	0.01%	75	0.01%	28	0.01%	42	0.01%	103	0.02%	301	0.01%
83 CRACKED OR BROKEN PLATE	163	0.03%	166	0.03%	155	0.03%	141	0.03%	78	0.01%	703	0.03%
84 HOLE IN PLATE	1	0.00%	5	0.00%	5	0.00%	4	0.00%	2	0.00%	17	0.00%
85 WHEEL LOOSE	38	0.01%	35	0.01%	52	0.01%	101	0.02%	59	0.01%	285	0.01%
86 BIG BORE	114	0.02%	70	0.01%	20	0.00%	61	0.01%	0	0.00%	265	0.01%
87 INSUFF. HUB WALL	12	0.00%	5	0.00%	2	0.00%	3	0.00%	1	0.00%	23	0.00%
88 SUB SURFACE DEFECT	10	0.01%	7	0.01%	2	0.00%	1	0.00%	0	0.00%	20	0.00%
89 OVERHEATED WHEEL	2887	0.56%	NA	0.00%	NA	0.00%	NA	0.00%	NA	0.00%	2887	0.11%
90 MATE WHEEL SCRAPPED	83480	16.33%	82801	15.95%	86799	15.84%	78920	15.02%	85463	16.19%	417463	15.86%
91 WROUGHT STEEL PRIOR TO 1939	13	0.00%	14	0.00%	19	0.00%	30	0.01%	17	0.00%	93	0.00%
98 WHEEL NOT REAPPLIABLE	24855	4.86%	21771	4.19%	23044	4.21%	22256	4.23%	23894	4.53%	115820	4.40%
TOTAL	511206		519168		547806		525604		527805		2631589	

Figure 3 - AAR Reported Wheel Defects 1988 - 1992

DFCT # TYPE OF DEFECT	1988	Percent	1989	Percent	1990	Percent	1991	Percent	1992	Percent	Total	Percent	Cum Prcnt
60 FLANGE THIN	50247	26.58%	44730	23.39%	40736	20.35%	35907	18.22%	36448	16.42%	208068	20.82%	20.82%
75 TREAD SHELLED	32898	17.40%	37243	19.48%	39058	19.51%	44955	22.81%	49592	22.35%	203746	20.38%	41.20%
64 FLANGE HIGH	27173	14.37%	27921	14.60%	29166	14.57%	29594	15.01%	31105	14.02%	144959	14.50%	55.70%
98 WHEEL NOT REAPPLIABLE	24855	13.15%	21771	11.38%	23044	11.51%	22256	11.29%	23894	10.77%	115820	11.59%	67.29%
78 TREAD SLID FLAT	20355	10.77%	23402	12.24%	24460	12.22%	22792	11.56%	20631	9.30%	111640	11.17%	78.46%
76 TREAD BUILT-UP	10883	5.76%	11624	6.08%	10517	5.25%	9686	4.91%	9299	4.19%	52009	5.20%	83.66%
74 THERMAL CRACKS	3125	1.65%	6834	3.57%	8586	4.29%	10951	5.56%	8277	3.73%	37773	3.78%	87.44%
73 RIM THIN	3295	1.74%	3914	2.05%	4547	2.27%	7508	3.81%	15570	7.02%	34834	3.49%	90.93%
70 RIM THIN, SP IN HAZMAT	NA	0.00%	NA	0.00%	NA	0.00%	NA	0.00%	16581	3.14%	19918	1.99%	92.92%
68 RIM CRACKED OR BROKEN	3241	1.71%	1740	0.91%	9036	4.51%	1418	0.72%	1181	0.53%	16616	1.66%	94.58%
80 SCRAPE, DENT, GOUGE	3341	1.77%	3501	1.83%	3737	1.87%	2657	1.35%	2377	1.07%	15613	1.56%	96.15%
77 TREAD GROOVED	3645	1.93%	3067	1.60%	2538	1.27%	2457	1.25%	2058	0.93%	13765	1.38%	97.52%
25 OWNER'S REQUEST	512	0.27%	3303	1.73%	2425	1.21%	755	0.38%	542	0.24%	7537	0.75%	98.28%
7 OBSOLETE MATERIAL	780	0.41%	436	0.23%	394	0.20%	1203	0.61%	3130	1.41%	5943	0.59%	98.87%
89 OVERHEATED WHEEL	2887	1.53%	NA	0.00%	NA	0.0%NA	NA	0.00%	NA	0.00%	2887	0.29%	99.16%
66 FLANGE CRACKED OR BROKEN	526	0.28%	444	0.23%	495	0.25%	436	0.22%	280	0.13%	2181	0.22%	99.38%
71 RIM SHATTERED	312	0.17%	289	0.15%	371	0.19%	320	0.16%	295	0.13%	1587	0.16%	99.54%
3 MISSING	257	0.14%	265	0.14%	270	0.13%	107	0.05%	69	0.03%	968	0.10%	99.63%
83 CRACKED OR BROKEN PLATE	163	0.09%	166	0.09%	155	0.08%	141	0.07%	78	0.04%	703	0.07%	99.70%
72 RIM SPREAD	106	0.06%	118	0.06%	128	0.06%	104	0.05%	121	0.05%	577	0.06%	99.76%
62 FLANGE VERTICAL	34	0.02%	133	0.07%	132	0.07%	45	0.02%	36	0.02%	380	0.04%	99.80%
31 FIRE OR HEAT DAMAGE	122	0.06%	56	0.03%	110	0.05%	46	0.02%	29	0.01%	363	0.04%	99.84%
69 THERMAL CRACKS 2W-MW	19	0.01%	0	0.00%	95	0.05%	127	0.06%	90	0.04%	331	0.03%	99.87%
81 WHEEL OUT OF GAGE	53	0.03%	75	0.04%	28	0.01%	42	0.02%	103	0.05%	301	0.03%	99.90%
8 WRONG NOT STANDARD	52	0.03%	58	0.03%	88	0.04%	56	0.03%	42	0.02%	296	0.03%	99.93%
85 WHEEL LOOSE	38	0.02%	35	0.02%	52	0.03%	101	0.05%	59	0.03%	285	0.03%	99.96%
86 BIG BORE	114	0.06%	70	0.04%	20	0.01%	61	0.03%	0	0.00%	265	0.03%	99.98%
91 WRT STL PRIOR TO 1939	13	0.01%	14	0.01%	19	0.01%	30	0.02%	17	0.01%	93	0.01%	99.99%
87 INSUFF. HUB WALL	12	0.01%	5	0.00%	2	0.00%	3	0.00%	1	0.00%	23	0.00%	100.00%
88 SUB SURFACE DEFECT	10	0.01%	7	0.00%	2	0.00%	1	0.00%	0	0.00%	20	0.00%	100.00%
84 HOLE IN PLATE	1	0.00%	5	0.00%	5	0.00%	4	0.00%	2	0.00%	17	0.00%	100.00%
79 TREAD SLIT FLAT W/ WEAR	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	100.00%

Fig. 4 - Reported Whl Defects 1988-92 Defective Wls Only

(generally a combination of thin rim and thin flange), Slid Flat, Built-up tread, Thermal Cracks, and Thin Rim.

4.1.3. Safety Issues

Another perspective emerges when the wheel accident data is broken down into the type of wheel defect that caused the accident (Figure 5). Here we can see that worn flanges are the single greatest cause of train derailments. Then there is a 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, however, they 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. If crack detection could be built into the system, it would not only eliminate the greatest number of accidents but the most severe accidents as well.

Distribution of Wheel Accidents by Cause

	84	85	86	87	88	89	90	91	92	TTL	%
Worn Flange	42	35	20	18	28	25	29	23	27	247	31%
Broken Rim	16	19	15	8	19	20	9	9	8	123	15%
Broken Plate	14	10	11	11	15	12	17	14	11	115	14%
Other causes	12	8	8	14	10	21	7	13	8	101	13%
Loose Wheel	16	6	12	5	8	8	3	4	4	66	8%
Broken Flange	16	4	5	4	5	4	6	5	2	51	6%
Damaged Flange or Tread	6	3	0	9	5	5	1	3	13	45	6%
Thermal Cracks	4	3	2	2	2	3	3	2	0	21	3%
Broken Hub	2	3	1	2	2	4	3	2	1	20	2%
Worn Tread	7	1	0	0	1	4	4	0	0	17	2%

Figure 5

4.1.4. Market Preferences

At the earliest stages of product development, market preferences are skewed by the market's limited view of the capabilities of the proposed system. At this stage, unrealistic demands are freely mixed in with practical concerns regarding the implications of the system on operating systems and practices. Nevertheless, as part of the Phase I effort, IEM conducted several studies utilizing direct mail, telephone interviews and face to face interviews to ascertain the market's perception of the minimum necessary requirements of the system.

The responses represented a broad range of views. On the one hand, some responses indicated that if the system did not completely eliminate the need for visual inspection of the cars, it would have no value whatsoever. On the other hand, this view was more than balanced by a practical view that all the system needed to do initially was to perform a basic inspection for normal flange and rim wear at relatively low speeds.

From this research various market segments and cost/benefit product profiles emerged. For example, a system could be initially installed as part of the 92 day inspection for locomotives. Then as the capabilities of the system improved over time in terms of additional defects identified and increased operating speeds, the application could be expanded to include unit freight trains and ultimately general freight operations. A system similar to the locomotive 92 day inspection system would also have applications in the Unit Freight world and in transits.

One consistent view was that existing systems for crack detection are inadequate. While relatively few wheels are actually condemned for cracks, a dominant proportion of wheel caused train accidents and derailments are caused by cracked and broken wheels. Consequently, any system that could efficiently, reliably, and correctly identify potentially catastrophic wheel cracks at at least moderate speeds would have a tremendous value to the freight industry.

4.1.5. Speed Requirements

The RR industry has adopted the philosophy that faster is better. One RR stated that they would be willing to pay several million dollars for a comprehensive wheel inspection station capable of reliably measuring wheels on the main line at 60 MPH. However, they also acknowledged that such a system was not currently feasible and that a 20 MPH capability would be more than adequate for virtually all freight car operations approaching yards and that 5 to 10 MPH would be adequate for locomotive operations. This response was typical.

The speed requirement for the system is a function of several interdependent factors. These include:

- the location of the inspection station,
- the price of the system, and, to a lesser extent,
- the lead time required to process the information.

These factors are, in turn, impacted by the type of service that the system is measuring.

A. General Freight

The optimal location for a Rail Based Wheel Gauge assigned to measure car wheels of cars in general freight operations would be on the in-bound track three to five miles outside of the yard. The reason that the measurement station could not be closer to the yard is that the first few miles of track immediately outside of the yard are very often used in conjunction with train movements in the yard. The problem, report several RR officials, is that double or overlapping defect reports would be generated should the same car pass over the measurement station several times as a function of train movements in and about the yard.

Assuming that this is a valid concern, a location at least three miles from the throat of the yard would be required. At such a location, it would not be practical to require the train to drop below a 20 MPH operating speed.

Another reason for locating the device outside of the yard is that the yardmaster needs as much lead time as possible to incorporate reports about potential wheel problems into his decisions regarding how to process the train once it gets into the yard and how to schedule his maintenance crews.

B . Unit Train

Since most Unit Trains bypass traditional yards, the best location to capture them would be on the main line. Here the speed requirement is in the 50 - 60 MPH range. However, depending on the price of the system and overall utility of the system, it may be practical to install the device at the terminal locations. At such locations a 3 - 5 MPH capability would be adequate.

C . Locomotive Operations

The most practical location for the device in locomotive operations would be at the in-bound track to the 92 day inspection facility. Here a 3-5 MPH capability would be adequate. Lead time issues are not a major concern here however they remain significant. For example, if a locomotive coming in for a 92 day inspection is found to have a wheel requiring a change or a true, the sooner that knowledge is incorporated into the maintenance schedule for that locomotive the better.

D . Passenger Car

There are two different locations where the device might be located in transit operations. If the device was to be used for a daily inspection, it would have to be located on the in-bound track to the storage yard. Here an operating speed capability of at least 10 MPH would be required. The speed requirement is dictated by the fact that this track can become congested at peak travel times and slower speeds would unacceptably disrupt operations. On the other hand, if the application of the device was restricted to one class of service such as high speed operations, it might be able to be located on a track with less congestion allowing for slower speeds.

Another possible location in transit operations would be at the wash facility. Here an operating capability of 3 MPH would be adequate.

4.1.6. Cost/Benefits

A . Safety

As we have seen, wheel failures have consistently been the number 2 cause of mechanical failures in the rail industry. With the gradual replacement of friction bearings with roller bearings, the number of bearing related failures has been dropping while the damage caused by wheel failures has remained relatively constant. Consequently there is an increasingly powerful incentive for the industry to address wheel failure rates.

B . Labor Savings

In the locomotive market approximately 4 hours per year are spent measuring the wheels of each locomotive. A low speed flange and rim wear measurement device could eliminate this labor cost. A similar savings could be realized in the Unit Train and Transit markets.

C . Equipment Utilization / Maintenance Scheduling

By locating a rail based wheel inspection station on the in-bound track of a maintenance facility, it will be possible to identify the need to perform any required wheel maintenance such as wheel truings and/or change-outs early in the inspection process. This capability could reduce equipment down-time leading to an approximate 10% increase in equipment utilization.

4.1.7. Reliability

The issue of reliability is a two headed monster. While the inspection system must reliably pick up close to 100% of the defective wheels, its utility degrades rapidly if it reports too many false alarms. Consequently additional testing will have to be performed to establish condemning limits which are appropriately restrictive.

4.1.8. Environmental Constraints

In the development of the hand held Electronic Wheel Gauge, IEM has learned a great deal about the rigors of the railroad environment. Many of these lessons are being applied to the development of the Rail Based Wheel Gauge. Fortunately, the opportunities to protect the gauge from environmental fouling are much greater with the Rail Based Wheel Gauge since the design is not constrained by serious size, weight, or power constraints, appropriate environmental safeguards can be built into the system.

Many of the environmental issues for a Rail Based Wheel Gauge are similar to those faced by such well established technologies such as hot box detectors by Servo Corp. Some of these factors are as follows:

- harsh environment - dust, grease, dirt, etc.,
- temperature variations - from -50C to +60C,
- high humidity - rain, snow, and
- lightning.

5. MEASUREMENT SPECIFICATIONS - SELECTED WHEEL DEFECTS

5.1. CONDEMNING LIMITS - SELECTED DEFECTS

An analysis of wheel condemnations by condemning defect shows that high flange, thin flange, shelled tread, slid flats, wheel not reappliable, built-up tread, and thermal cracks and thin rim account for over 90% of all wheel condemnations for normal and abnormal wear.

In our analysis we will look primarily at flange and rim wear related defects, identify the measurements needed to identify those defects and propose some basic operational requirements for the gauge. The treatment of thermal cracks will be covered in Section 6.2. However we will also address the specifications pertaining to vertical flange, and loose, or out of gauge wheels.

The theory behind the establishment of these operational specifications is that the Rail Based Wheel Gauge will not satisfy AAR requirements for the condemnation of defective wheels but will rather identify potentially defective wheels which will then be carefully inspected and condemned through the use of conventional hand held gauges. Therefore, the Flagging or Condemning Limits set into the Rail Based Wheel Gauge shall be slightly more conservative than the AAR Condemning Limits since the cost of missing a wheel dramatically exceeds the cost of unnecessarily measuring a marginal wheel.

5.1.1. Normal Wear

Flange wear is the most basic form of wheel wear. Several types of flange defects may develop due to wear, any one of which requires condemnation of the wheel. A flange may wear so thin that it is liable to break or derail due to tracking improperly through switches. It may wear vertical so that it creates hazardous levels of lateral stresses at curves. Or, it may become high relative to the tread, so that it extends too far below the top of the rail resulting in a derailment due to its riding up on a frog or breaking from striking ballast, track work, etc. The defects and methods of gaging them are described below.

A . **Thin flange. AAR Why Made Code 60.**

Flanges on wrought or cast steel wheel worn 15/16 inch thick or less as measured by the wheel defect gauge as shown in Fig. 6 are defective due to the thin flange.

Operational Specification.

For the Rail Based Wheel Gauge to simulate the operation of the Wheel Defect in the Condemnation of Thin Flange Wheels, it is necessary to establish a valid flange thickness measurement at a point on the flange 3/8ths of an inch above the wheel tread surface. However, abnormal wheel wear patterns may result in a "double flange" condition which will result in a wheel failing the

Wheel Defect Gauge test even though it exceeds a thickness of 15/16ths at a point 3/8ths inch above the tape line.

Therefore, to establish a final operating specification for the Rail Based Wheel Gauge, it would be first necessary to conduct a study of a large sample of wheels condemned under Code 60 to determine what the lowest flange thickness finger reading using the Standard Steel Wheel Gauge was. Such a study could be conducted under Phase II of this SBIR program through cooperation of the AAR and/or one or more Class I RR's.

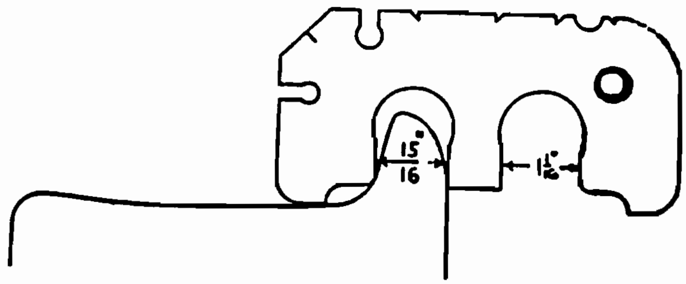


Figure 6 - AAR GO/NOGO GAUGE

The readings provided by the Standard Steel Wheel Gauge share a known reference point - the tape line of the wheel. Given a reliable reference point, these readings have the benefit of showing the maximum flange thickness at a point 3/8ths of an inch above the surface of the wheel which can still be condemned by the Wheel Defect Gauge.

Nevertheless, the overall accuracy of the Rail Based Wheel Gauge should be within 1/2 unit on the Flange Thickness scale of the Standard Steel Wheel Gauge which averages to 0.02 inches.

B . Vertical flange, AAR Why Made Code 62.

Cases of properly-gaged vertical flange are rare. When testing for this condition, the wheel defect gauge must be held vertical. The edge of the gauge which is below the 1-inch notch, must touch the flange. The limit point of the gauge above the 1-inch notch also must touch the flange in order to class the wheel as defective for vertical flange. If there is the slightest clearance at this point, the wheel is not defective. If light can be seen between the surface above the notch and the flange, or if thin tissue paper can be slid between the surface and the flange, the wheel is not defective. Often wheels which are very close to a vertical flange condition will clearly fail the thin flange test and be condemnable for that reason. AAR billing rules require that wheels which are both vertical and thin be condemned as thin flange symbols and not for vertical flange.

Operational Specifications

While Vertical Flange is a defect that is, for all practical purposes subsumed by Thin Flange, it still remains a concern for some prospective customers, especially transit customers. In fact, there is a growing body of evidence that flange angle may be a more important variable in flange related derailments than flange thinness due to its impact on wheel rail dynamics. However, since there has been no convenient way to measure flange angle, it has not been tracked. IEM recommends that the Rail Based Wheel Gauge develop a capacity to measure "flange angle" in addition to flange thickness. The specific dimensions of this flange angle measurement have yet to be developed but could be derived from the flange profile data gathered by the proposed system.

C . **High flange, AAR Why Made Code 64**

The maximum height for steel wheel flanges in service is 1-1/2 inches above the approximate center of the tread as measured with the steel wheel gauge or simplified steel wheel gauge. These gauges are designed so that when applied to wheels of acceptable flange height, with the point on the tread center and the notches against the back face of rim, there will be clearance between the gauge and the apex of the flange. If the clearance is zero, or if the point cannot be brought to rest on the tread, the flange is too high. It is somewhat of a misnomer to consider high flanges as a flange wear condition since high flanges result from tread wear.

Operational Specifications

The condemning limit should be the same as the AAR limit, ie 1.5 inches. The overall accuracy of the Flange Height measurement should be within 1/32nd of an inch.

D . **Thin rim. AAR Why Made Code 73**

The AAR requires that a 33" wheel be removed from service with a rim thickness of 3/4" inch rim or less and that a 28", 36", and 38" wheel be removed with a rim thickness of 7/8" or less. Wheels failing to show sufficient metal when measured for thin rim with the AAR steel wheel gauge or simplified steel wheel gauge must be removed from service to comply with the Interchange Rules. The measurement is made with the tip of the gauge on the tread and the calibrated mark flat against the back face of the rim. If the 3/4 inch or 7/8 inch mark falls below the measuring point of the wheel (where the back face joins the back rim fillet) the wheel rim is too thin. The minimum for passenger train cars and locomotives is 1 inch.

Operational Specification

Since it is not feasible for the Rail Based Wheel Gauge to differentiate between wheels which should be condemned at the various different rim thicknesses on a real time basis, it is prudent to flag all wheels with a rim thickness of 7/8 inch or less and then query the UMLER system to determine which wheels were on which cars on a batch mode basis after the train has left the inspection location. Measurement Accuracy should be within 1/16th".

5.1.2. Other Defects

A . Loose or Out of gauge. Why Made Code 85

Any wheel showing evidence of movement on the wheel seat or oil seepage on the back plate from inside of wheel fit is considered a loose wheel and is condemnable under Why Made Code 85. Another indication of a loose wheel may be back-to-back measurement out-of-gage 52 15/16 inch minimum to 53 3/8 inch maximum. Out of gauge wheels are condemnable under Why Made Code 81.

Operational Specifications

Out-of-gage wheels within 1/32nd of an inch of either limit should be flagged for inspection. Measurement Accuracy should be within 1/32nd of an inch.

5.1.3. Tread Abnormalities

There are a number of tread defects including flat spots, out of round conditions, built-up tread, and shelled tread, that are currently being correctly identified by high speed rail impact or acceleration detection technologies.

A . Slid-flat. AAR Why Made Code 78. And Out of Round. AAR Code 72

Fig. 7 shows the method of gaging a slid-flat spot on the tread of a cast-steel or wrought-steel car wheel. The notches on the gauge that measure the condemning dimensions of a single flat spot are shown in the figure. If a flat spot on a freight car wheel measures two inches or over in length, or if there are two or more adjoining flat spots each 1-1/2 inches or over in length, the wheel is defective. The car should be sent to the repair track so the pair of wheels can be removed and replaced. A slid-flat spot on a wheel ordinarily is accompanied by a similarly-sized spot on the mate wheel. The mate wheel is automatically condemnable regardless of length of flat spot.

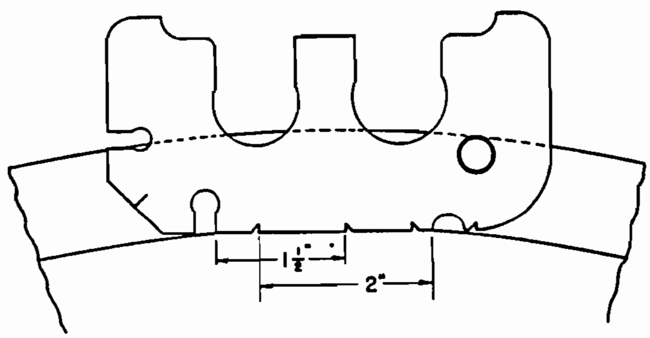


Figure 7 - Measuring Slid Flats

The question often arises whether two slid-flat spots are "adjoining," for purposes of applying the rule for condemning wheels with 1-1/2-inch adjoining flat spots. The correct interpretation is that the spots are adjoining if they actually run into one another.

A slid-flat is a wheel condition for which the handling line is responsible.

A wheel shall be judged Out of Round if it is tagged by a wheel impact detector as having and impact of 70 kips or more and is subsequently found to have and out of round condition as verified by an AAR approved gauge or 50 mils or more.

Operational Specifications

The conventional approach to identifying slid flat wheels used by rail resident systems is to monitor the increased impact or vibration caused by the presence of a flat spot hitting the rail. These systems are only effective at speeds exceeding 20 mph, beyond the limits of this system. However, IEM is developing an alternative approach to the slow-speed rail-based identification of slid flat and Out of Round wheels. This approach calls for the installation of an array of sensors to monitor changes in apparent flange height around the circumference of the wheel. If the difference between the high and low flange height exceeds the 50 mil tolerance for out of round wheels, IEM will recommend that the wheel be tagged for closer inspection.

B . **Shelled tread, AAR Why Made Code 75.**

When the shell or spall is 3/4 inch in length and in width or larger and the shells or spalls are more or less continuous around the periphery of the wheel or whenever any shell or spall is 1 inch or more in length and in width, the wheel must be removed from service. See Figure 7.

Operational Specifications

More work needs to be done to relate AAR condemnable shells to a set of readings for an overall surface regularity sensor.

5.2. MEASUREMENT REFERENCE POINTS

By definition, the reference point is the basis against which a measurement system functions. There are three factors which require that a special emphasis be placed on reference point issues in the development of Rail Based Wheel Gauge. In addition to the general principal that any deviation in the relationship between the reference point and the measured object can seriously distort the measurement accuracy and reliability, the Rail Based Wheel Gauge will have to face two specific factors. First, the gauge must operate in the stresses of locomotives and car axle loads potentially in excess of 100 tons. Second, the measurements in question, especially the flange thickness measurement, are very sensitive to slight deviations in reference points. Third, the time constraint placed on the measurement and vibration that normally accompanies the movement of a train place additional stresses and pressures on the system.

The most logical reference point for a Rail Based Wheel Gauge would seem to be the rail head itself. However, IEM sees a number of potential problems in choosing this course.

First, the rail can move in a variety of ways that are somewhat independent of the wheel. Since even slight movements of the rail relative to the wheel can create potentially large errors, the validity of a rail mounted sensor system has been called into question. Second, the size of the various sensors and their related packaging require that the gauge be mounted not on the rail but on a larger platform such as a tie or a concrete platform next to the tie. Third, the mounting of the sensors on the rail could potentially weaken the rail and exacerbate problems with rail head movement.

While it may be possible to overcome some or all of these problems through the manufacture of a very strong, rigid rail segment, IEM is not yet prepared to state that the rail head will be able to serve as a reliable reference point for the Rail Based Wheel Gauge. Therefore, IEM recommends that the initial design of the gauge incorporate, as a reference floor, a concrete platform adjacent to the rail.

Thus, for the proposed wheel measurement system, the primary reference point is the railway tie/instrumentation floor and the secondary reference point is the rail itself (wheel rail contact).

For any consistent set of measurements, it is necessary not to have any changes in the reference points from the time the system is calibrated to the time the system is used day after day.

Any change in the reference points should be accounted for if it happens over time due to normal wear (also called diurnal changes) or for any other reason such as load variation under speed (also called dynamic changes). While some of the changes that normally occur in the relationship between the wheel and the track base can be factored out through careful operating constraints (slow speeds, straight track segment, etc.) and mechanical engineering (special heavy duty rail segment, guide rail, etc.) other factors such as changes in the back-to-back distance of the wheels in the wheelset (wheel gauge) can not be factored out and will have to be accommodated through the flexibility and operating range of the various sensors being used to perform the wheel measurements.

Prior to proposing a system to compensate for the potential reference point changes, we will first present a discussion of the various types of stresses that the system will likely encounter along with a discussion of the impact of those stresses and a set of proposed responses to the impacts.

5.2.1. Why Do Reference Points Change

The following discussion will cover various reasons for the reference point changes. The discussion will cover changes in load, normal wear and tear on the rail, truck hunting, and a variety of wheel defects such as changes in wheel gauge.

A . **Load Variation causing Rail Deflection**

The vehicle/track load variations can be subdivided in a number of load change frequency bands.

The first and more relevant of these load variation bands is the low frequency band from 0 to 15 Hz. This includes static load, car body bounce (pitch, roll, yaw) and truck frame resonance. Table 1 covers the actual frequencies for various car types. Load variations also produce higher variation frequency bands such as axle loading or unloading at higher speeds (45 mph or higher). However, higher frequency bands are not discussed as the proposed system will operate at low speeds (under 10 mph) thus permitting a system designer to average out higher frequency bands (please see any reference on adaptive filtering to learn more about the averaging technique).

Also, at slow speeds where the proposed system will operate, the dynamic load effects and some of the higher band responses are minimal.

Another reason for rail deflection is the lateral component of load. This can cause the rail to deflect as much as 0.25 inch. Figure 8 illustrates the lateral deflection of rail.

The system has to account for such lateral deflection in order to accurately measure the wheels. A typical vertical wheel/rail load of 10k lb (Figure 9) can produce rail deflection around 0.1 inch.

While there can be movement in the secondary reference point (the rail), it is more important not to have any movement in the primary reference point (tie

Car Type	Gross Weight, lb.	Natural Frequency, Hz Bounce	Pitch	Roll	Twist
LPG Tank Car	86,320	4.4	5.8	0.8	-
	217,540	3.2	4.2	0.9	-
100T Covered Hopper Car	59,000	5.8	7.4	1.0	-
	262,500	3.3	5.7	0.7	-
	256,060	2.8	4.3	1.1	-
80T Open-Top Hopper Car	51,980	5.2	5.2	1.7	4.8
	204,700	3.0	3.9	1.3	4.0
89 Container Car	62,540	8.0	12.5	2.2	9.5
100T "Bathtub" Coal Cars	54,700	5.7	5.7	0.9	4.0
	272,640	2.8	4.9	0.9	-
-With C-PEP-	271,580	3.1	4.9	1.3	-

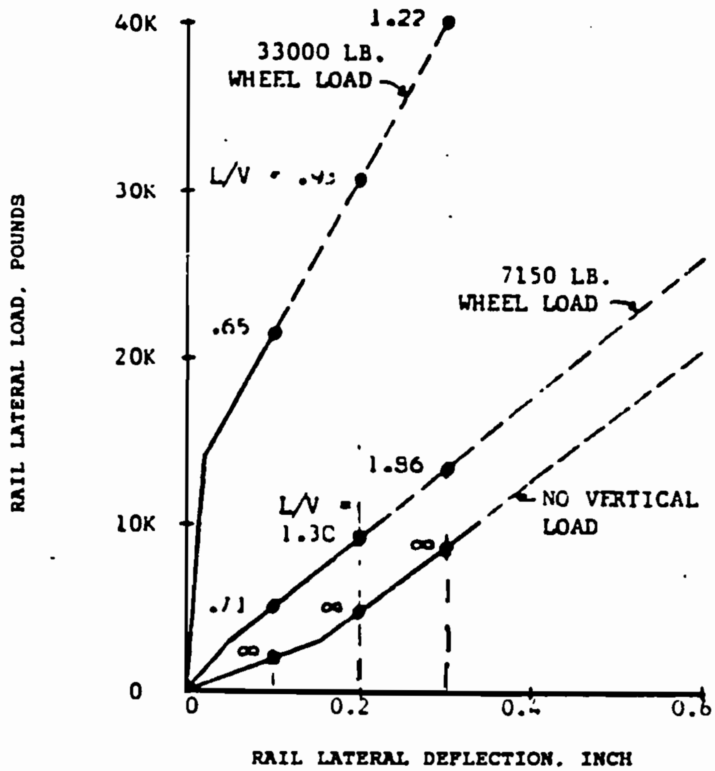
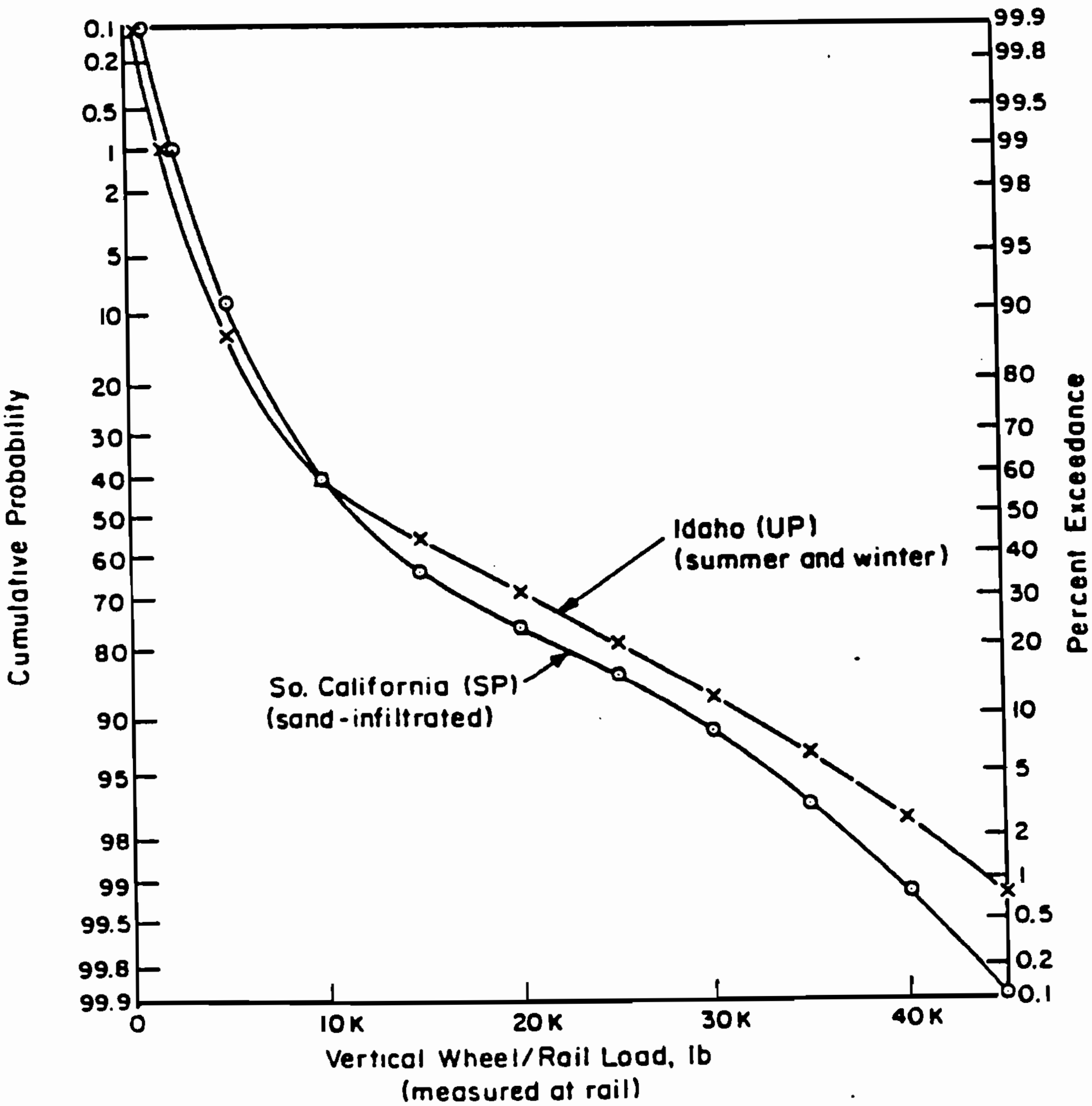


Figure 8 - Rail Lateral Deflection Characteristics



CUMULATIVE PROBABILITY LEVELS OF PEAK WHEEL/RAIL LOAD UNDER MIXED FREIGHT TRAFFIC AS DERIVED FROM TIE PLATE LOAD MEASUREMENTS

Figure 9 - Vertical Wheel/Rail Load

plate or instrumentation base) - at least relative movement (e.g. transmitted vibration) between the instrumentation and base.

The final system design needs to incorporate a number of measures to account for any and all movement in both the primary and secondary reference points.

5.2.2. Reference Degradation Under Use

The secondary reference point (the rail) can change with a variety of possible degradations in the rail. Some of these degradations are:

- track alignment geometry
- track gauge deterioration
- rail head corrugation
- rail head shelling
- rail head wear
- rail surface plastic flow
- wheel burn
- track surface geometry

While these types of degradation are not uncommon on main line track, IEM does not consider them to be serious obstacles to the reliable operation of the Rail Based Wheel Gauge since a more rugged special rail segment will be used as part of the proposed system and a set of calibration and maintenance procedures will be developed to ensure that the part of the track that is being used for instrumentation will be kept in excellent condition.

A. Truck Hunting

Freight trucks shift from side-to-side with the axle perpendicular to the gauge line. Additionally, trucks skew so that the axles are at an angle instead of perpendicular to the gauge. This is evident when walking between the rails - the inside of one rail will appear polished and the inner rail head somewhat worn. Opposite the polished area, the rail head is peened over indicating the angle tread (1.5 degrees) is pressing on the inside rail head. This condition disappears only to repeat at a distance down the track - however, the opposite rail is now polished. A cyclical condition exists as the truck hunts and skews. It is difficult to see how, under high speed operations where truck hunting is most severe, accurate measurement could be made under this condition.

Truck hunting or axle hunting refers to the lateral movement of either of the two for a variety of reasons such as the designed clearance between the flange and the rail at the time of wheel truing and normal subsequent wheel wear. Although hunting is primarily speed related and happens above say a speed of 45 or 50 MPH,(P. 669 Railway Eng.), as we will see from the discussion of Wheel Set Movement, the proper system design should accommodate as much as +/- 1.5 inches for lateral movement without degrading wheel measurement quality. The +/- 1.5 figure is derived from a combination of the maximum variances in wheel back to back measurements and the maximum variation in flange thickness from a freshly trued wide flange wheel to a worn thin flange.

Lateral movements beyond the 1.5 inch limit can be eliminated by using special track segment as part of the system.

B . Wheel Set Movement/Location on the Track

The location of a wheel set with respect to track can vary as much as +/-1.5" from the optimum location. This number is arrived at by considering five factors:

- gauge tolerance

  The distance between the tracks can vary as much as half an inch. But for the instrumented track segment we can assume that the track is accurately calibrated.

- Rail deflection

  Lateral loads can cause irreversible rail deflection as much as 1/4 ". In our case, we can ignore this deflection just as gauge tolerance.

- Back to back tolerance

  The distance between the back to back face of the wheels can vary as much as 3/8". For our discussion purposes, we assume that this distance has to be accounted for in the calculations.

- Wear tolerance

  Fully worn out wide flange wheels can provide lateral movement of up to 3/4". Truing tolerance - some railways like to true their wheels so that the flange is as close to the rail as possible. Others like to provide some gap between flange and the wheel. The potential of such variation can be as much as 3/8".

Considering all of the above factors, the total wheel movement can be as much as +/-1.5". Any working design will have to accommodate this lateral movement.

5.3. WHEEL DEFECTS THAT CAN EFFECT WHEEL MEASUREMENTS

Following are some of the common wheel defects that can effect the final wheel measurements:

- brake shoe metal deposit on rim
- flat spots and out of round condition on wheels
- chipped flange
- deformed flange by hitting a frog
- shelling,
- spalling,
- shattering, and
- broken wheel rim (P. 116, Anthology)

These conditions are unavoidable. A possible solution is to install multiple measuring heads to acquire more than one measurement on the wheels.

5.3.1. Poor Wheel and Track Contact (P.657-660, 665, Railway Engineering)

While the design of the Rail Based Wheel Gauge may eliminate or compensate for most of the normal variations in the distance between the wheel and the measurement sensors, certain abnormal conditions such as poor wheel/rail contact may still result in defective wheel measurements. For example, on a three axle truck it is possible that one of the wheels will not make contact at all. If such a situation arises, there will be potential of inducing error in wheel reference. Also, the wheels do not make contact where a severe flange forces on one side of axle causes the other side to elevate (P. 348, Anthology).

Additionally, rocking motion of cars can result in slight to substantial wheel lift. Harmonic rocking cars have shown wheel lift of several inches in the past, generally relating to specific speed range and joint spacing. There is a recent proliferation of high center-of-gravity cars that are vulnerable to rocking and wheel lift.

SECTION III

TECHNOLOGY EVALUATION

6. EXISTING SYSTEMS TEST & EVALUATION

6.1. WHEEL IMPACT DETECTORS

Over the past several years, the railroad industry has changed the way it identifies and condemns wheels with tread abnormalities. The new approaches use a performance based set of condemnation criteria to supplement existing dimensional criteria. Stated more simply, the industry found that the existing criteria for the condemnation of slid flat wheels was resulting in the condemnation of some wheels that caused only minor damage to track and car structures while at the time allowing some severely out of round wheels not condemnable as flat to remain in service.

These wheels have been found to cause considerable damage primarily to tracks but to car components as well. As a result of these findings, a number of railroads have installed wheel impact detectors and the AAR has developed a condemnation criteria based on the severity of the impacts caused by the defective wheel. Two such impact detectors exist. The first is a Rail Load Measurement System; the second is a Rail Mounted Acceleration Detector. Both technologies have been found to be effective is certain circumstances.

The AAR conducted a series of performance evaluation tests of these systems in August of 1991 using a large assortment of wheels obtained on loan from the six major North American Railroads. Defects present included slid flats, shells, spalls, out-of-round condition, and tread buildup. The defective wheels were mounted under 70, 100, and 125 ton cars.

6.1.1. Rail Load Measurement Systems

IEM's evaluation of the Rail Load Measurement System was based on a series of reports and tests conducted by AAR and market interviews. The AAR report number R-829 (178 pages) covers the extensive testing conducted on the Rail Load Measurement System.

The AAR test results show that the impact load detector system has the capacity to identify high

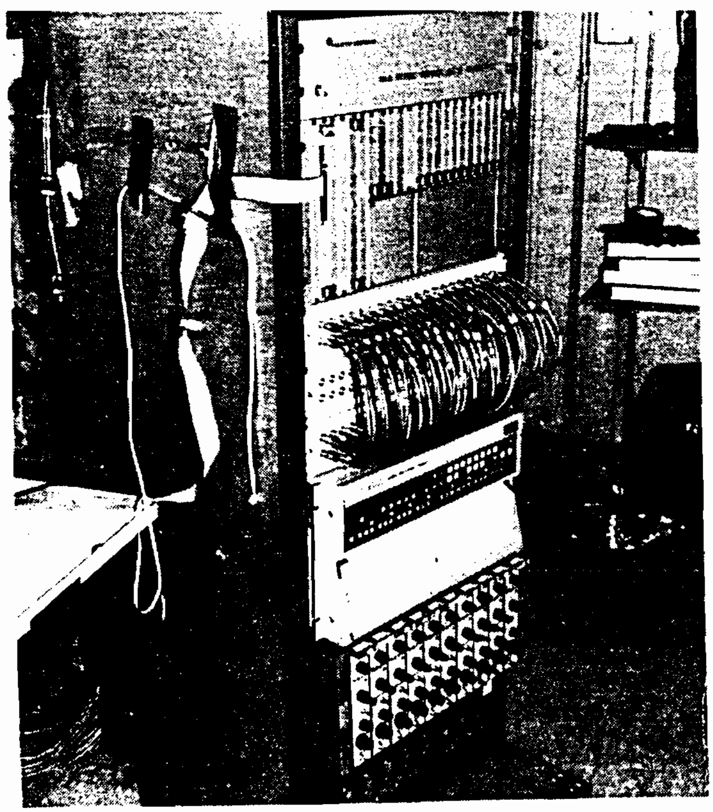


Figure 10 - Impact Load Detector Electronic System Console

SPEED (MPH)	IMPACT LOAD (KIP)		
	MEAN	STD	REPEAT.
20	37.9	3.1	EXCELLENT
30	38.4	3.4	EXCELLENT
40	40.5	3.5	EXCELLENT
50	42.1	3.4	EXCELLENT
60	46.1	4.5	EXCELLENT
65	52.4	7.2	GOOD

Figure 11-Impacts & Repeatability for Gd Whls @ Var. Spds

SPEED (MPH)	IMPACT LOAD (KIPS)			LOW READINGS REMOVED		
	MEAN	STD	REPEAT.	MEAN	STD	REPEAT.
20	67.5	14.9	FAIR	74.9	6.1	GOOD
30	88.9	22.1	POOR	99.6	11.1	FAIR
40	107.6	31.5	V.POOR	121.9	16.6	POOR
50	113.2	36.1	V.POOR	132.6	15.9	POOR
60	120.0	36.3	V.POOR	137.0	19.8	POOR
65	117.7	37.2	V.POOR	138.8	20.8	POOR

Figure 12 - Impacts for OOR WHeel with 140 Mil Deep Divot

impact load producing wheels as well as to distinguish between defective and round wheels (Figure 11). However, the detector system does occasionally underestimate the peak impact load if the prominent defect lands outside the influence zone of the strain gauges (Figure 12). The variability in impact load measurements increases with defect depth and speed. The results also show that a higher percentage of high impact producing flat and out-of-round wheels are identified at load threshold levels set at 50,000 to 90,000 lbs. The optimum train speed at which maximum detector coverage is achieved appears to be near 40 mph, for most defects. Based on impact studies, the system is not recommended to be used at speeds above 60 MPH. Also, at speeds below 20-30 MPH, the detector's ability to detect defects is compromised, therefore the detector usage is not recommended at slow speeds either.

At the optimum train speed of 40 MPH, excellent repeatability is achieved for 2-2.5" flats; good repeatability for 3-3.5" flats, and fair to poor repeatability for slid flats larger than 4.0". Similarly, fair repeatability results from out-of-round wheels with radial runouts ranging from 0.05 to 0.10", while poor repeatability is obtained for those with depths greater than 0.10". Personal interviews with Union Pacific and other users of the impact detector system indicated that the system performed reliably and did not break down often. Existing customers of the system were happy with the overall performance of the system.

6.1.2. Impact Acceleration Detectors

The AAR also tested this system (Figure 13) and found that it had several benefits. These include:

- High Durability,
- Ease of installation,
- High Reliability in that it reliably differentiated between defective and non-defective wheels at speeds above 20 MPH.

Its effectiveness and reliability did not change significantly as a function of car loading.

IEM's evaluation of the Wheel Impact Acceleration Detector was based on a series of reports and tests conducted by AAR and market interviews. The AAR report number R-852 (156 pages) covers the extensive testing conducted on the Wheel Impact Acceleration Detector.

Test results show that the impact acceleration detector system has the capacity to identify high impact acceleration producing wheels as well as to distinguish between defective and round wheels. (Figure 12) However, the detector system occasionally underestimates or overestimates the peak acceleration or the transmission of the acceleration from one rail to the other rail through the tie, this detector falsely identifies a good wheel on the other side of an axle as a bad wheel. The variability in the impact acceleration measurements increase with defect depth and speed. The results also show that a higher percentage of high impact producing flat and out-of-round wheels are identified at acceleration threshold levels set at 100 to 250 g. The optimum train speed at which

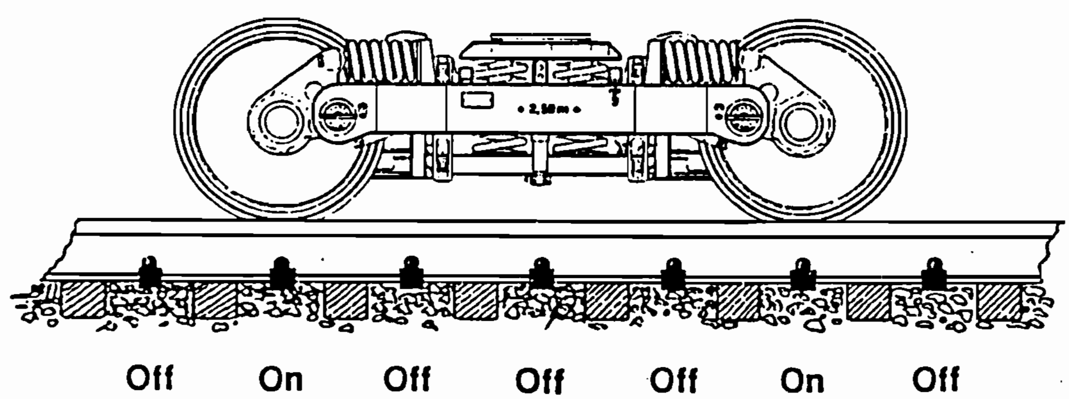


Figure 13 - Data Sampling for Wheels over the Detector

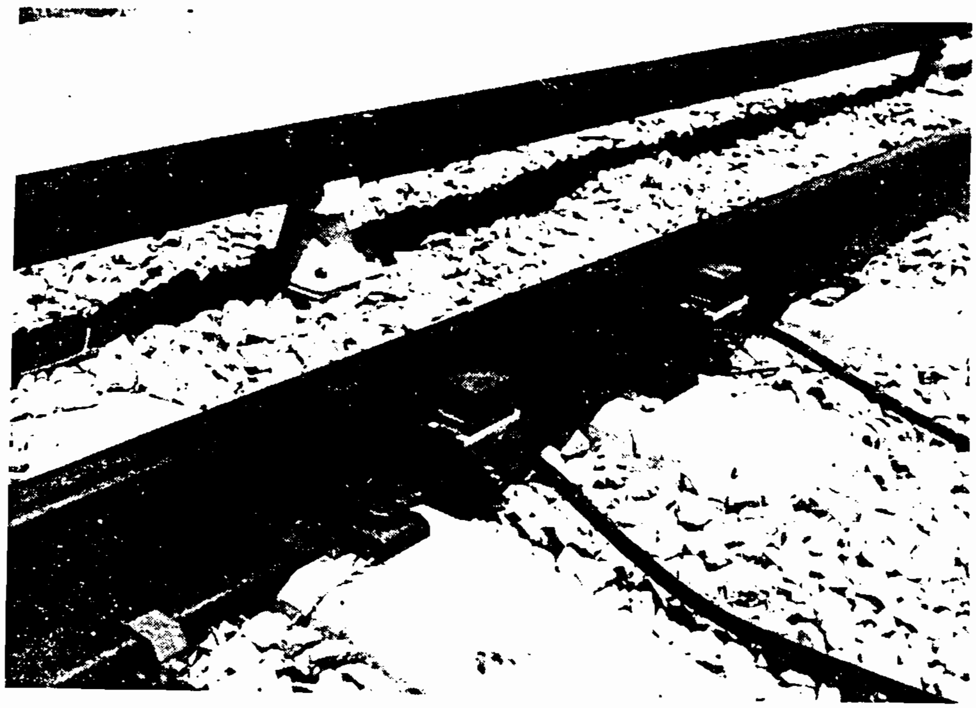


Figure 14 - Accelerometers & Wheel Sensors

SPEED (MPH)	IMPACT ACCEL. (G)		REPEA.	OUTLIER POINTS REMOVED		
	MEAN	STD		MEAN	STD	REPEA.
20	28.6	9.4	EXCEL.	27.9	4.9	EXCEL.
30	34.7	5.9	EXCEL.	34.7	5.9	EXCEL.
40	44.3	8.6	EXCEL.	44.3	8.6	EXCEL.
50	61.4	15.6	EXCEL.	61.4	15.6	EXCEL.
60	79.9	25.4	GOOD	78.5	19.7	EXCEL.
65	97.7	73.5	FAIR	89.8	23.7	EXCEL.

Figure 15- Acceleration & Repeatability Gd Wl @ Var Spds

SPEED (MPH)	IMPACT ACCEL. (G)		REPEA.	HIGH READINGS REMOVED		
	MEAN	STD		MEAN	STD	REPEA.
20	172.04	232.88	V. POOR	138.88	38.7	GOOD
30	272.26	273.45	V. POOR	234.6	92.5	POOR
40	344.24	141.82	V. POOR	327.49	84.11	POOR
50	435.30	220.39	V. POOR	406.20	99.19	POOR
60	497.20	273.82	V. POOR	447.00	104.21	POOR
65	578.21	352.71	V. POOR	501.8	193	V. POOR

Figure 16 - Impact Acceleration OOR Whl with 140-mil Divot

maximum detector coverages is achieved appears to be near 40 mhp for most defects.

The test data also show that occasionally impact accelerations above 100 g can result from the operation of "good" wheels at train speeds above 60 mph. Therefore, operation of wheel impact acceleration detector systems in a high speed corridor is not recommended at impact alarm levels below 100 g. At 20 and 30 mph, the extent of coverage to identify out-of-round wheels is compromised, because this type of wheel defect shows a strong speed sensitivity. As a result, utilization of the detector system is not recommended on track with low speed traffic.

At the 100 g acceleration threshold level, detector reliability was found to be excellent at 40 mph. At this threshold level and at this speed, the probability of detecting slid flats greater than 2", and out-of-round wheels with radial runouts greater than 0.05 inches was better than 88%. At the 200 g impact acceleration

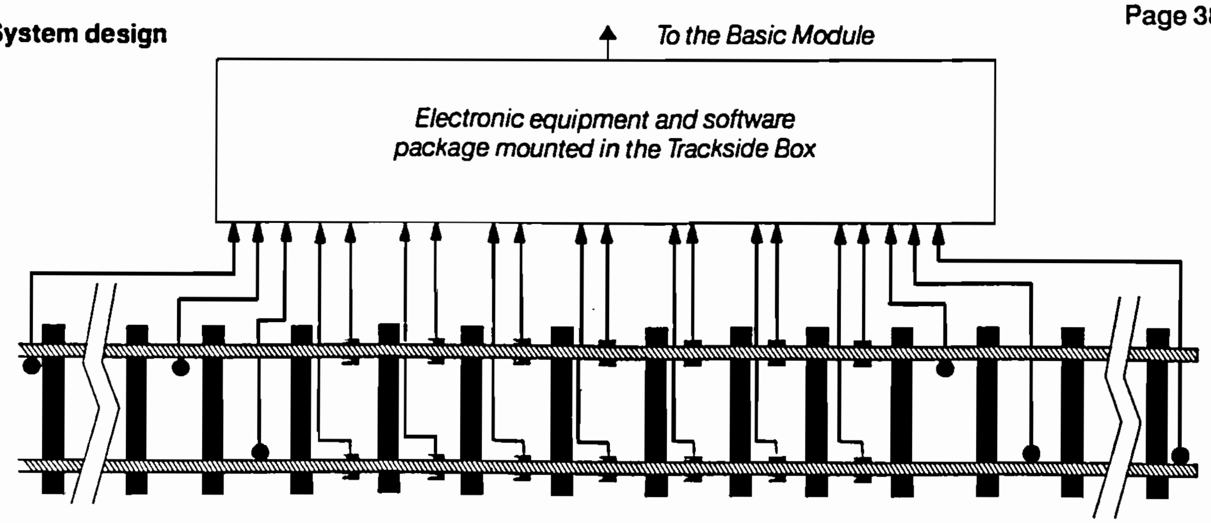


Fig.17 - Seven Accelerometers & 3 Wheel Triggers per Rail

threshold, the probability of detecting wheels with slide flat greater than 2" is 80% and it is 100" for slid flats greater than 4". At this alarm level, the probability of detecting small to medium out-of-round wheels is about 35% and for radial run-outs greater than 0.10 inches is about 65%.

6.2. WHEEL CRACK DETECTORS

The key problem with crack detection is the need for a clear definition of what size cracks have to be removed. On a typical RR wheel, the small cracks start from 2 mil size up to 10 mils. Based on some of the studies conducted by a variety of researchers, 5-7 mil cracks should prompt wheel removal. However, a typical wheel with 5-7 mil cracks will also have quite a few 2-3 mil thermal cracks. These cracks show up as echoes in the returned signal when an attempt is made to detect them using ultrasonic technology. The net effect is that the signal returned has a lot of echoes resulting poor signal to noise ration making larger cracks difficult to detect.

To make the crack detection problem even more difficult, residual stress states in the wheel alters/attenuates the signal return. For example, one RR concluded that when a wheel does not provide any return signal, the wheel was so bad that it should be removed from service immediately. This premature conclusion result in large numbers of wheels removed from service.

One of the problems with existing approaches to crack detection is that they are trying to implement the technology at main line speeds. IEM believes that a more realistic goal for wheel crack detection would be to incorporate it into a low speed system (under 10 MPH). The system would have to be able to measure residual stress and crack depth. Such a system will be useful in a classification yard or on a hump. As we explain elsewhere in the document, there is a tradeoff between price and speed. The slower the train speeds that a system can handle, the more units a railroad will require and the less they are going to be willing to pay on a unit price basis.

Since the high speed approach does not seem to function satisfactorily at preset, IEM believes that a low speed, low price system is currently feasible. Such a system will utilize a carbon fibre read head which can be replaced quickly. Optimum technology based on the state of the art will be Electromagnetic Acoustic technology. Based on the difficulties that such systems are currently experiencing, IEM does not intend to incorporate Crack Detection into the initial working prototype of the Rail Based Wheel Inspection Station. However, we do expect to incorporate it into subsequent models as the technology matures.

6.2.1. EMAT Systems

The EMAT system was evaluated and tested by IEM at NIST Laboratory at Boulder, Co in conjunction with Ray Schram and Van Clark. This EMAT implementation is similar to the Hamburg, Germany EMAT system in principle. However, the system is in early prototype stage and needs further development. The prototype worked fairly well in recognizing the test wheel for a pre-specified crack in the wheel. The prototype repeatedly identified the crack when the wheel was rolled over the test system.

The EMAT system demonstrated several advantages over other ultrasonic approaches. The main advantage is the fact that the system uses a non-contact sensor and does not require a couplant to operate. Non-contact sensors result in higher reliability over contact systems and virtually no wear over time. However, the system has to operate through a 10-20 mil air gap requiring a lot of

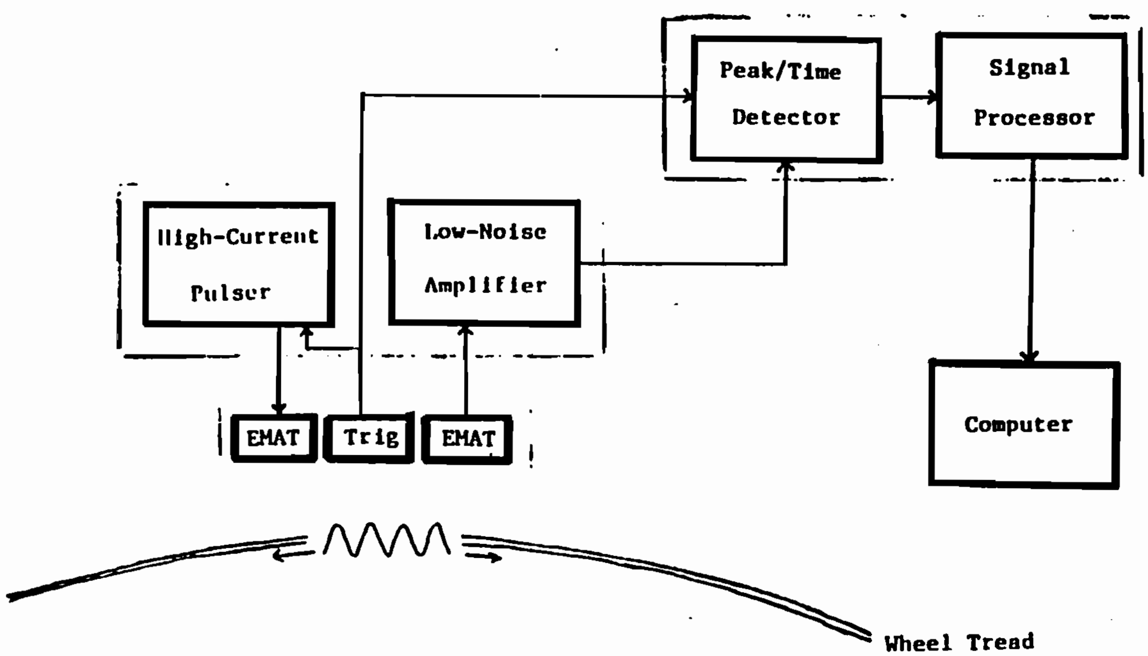


Figure 18 - Functional Layout - EMAT System

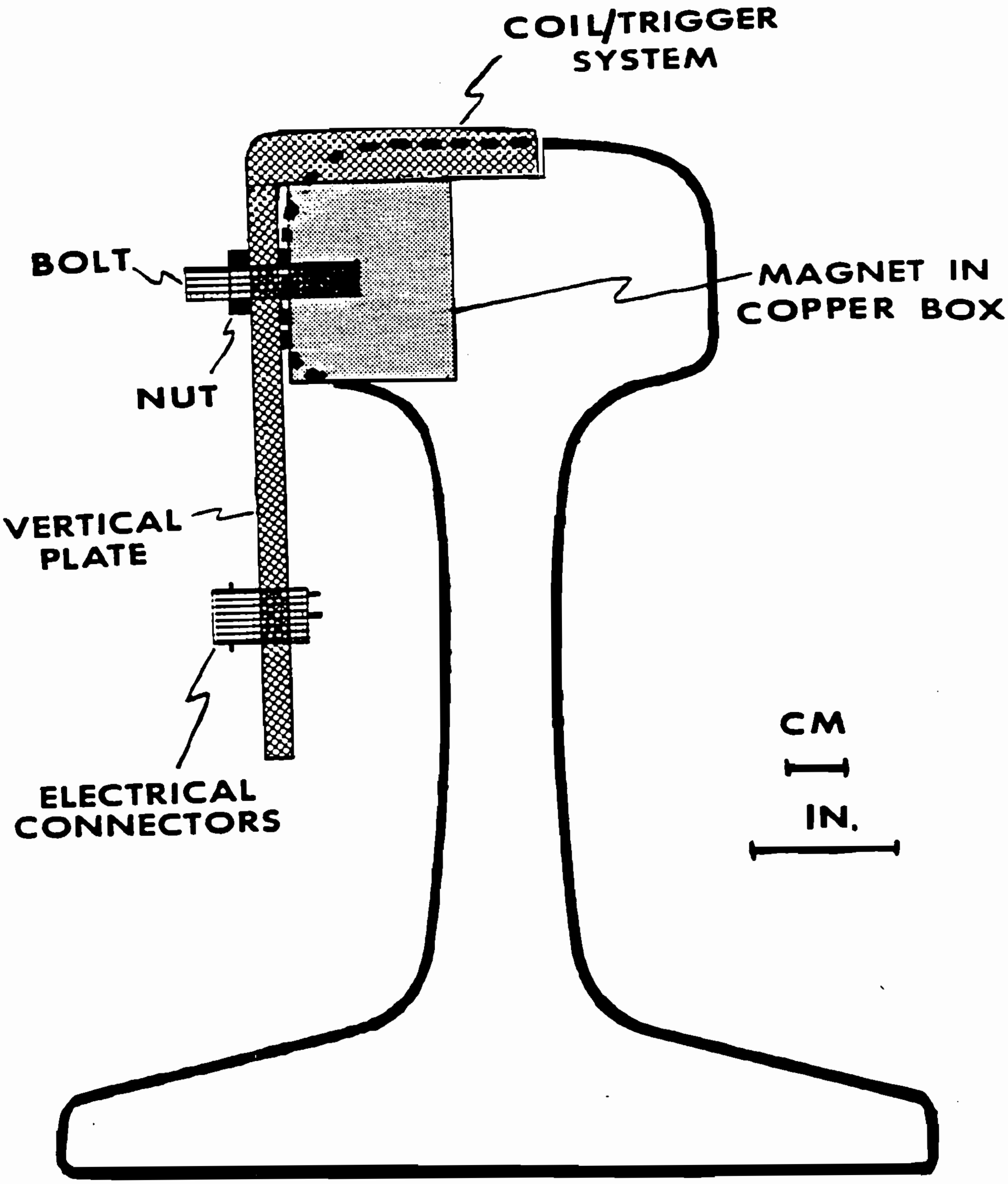


Figure 19 Schematic Drawing of NIST EMAT System

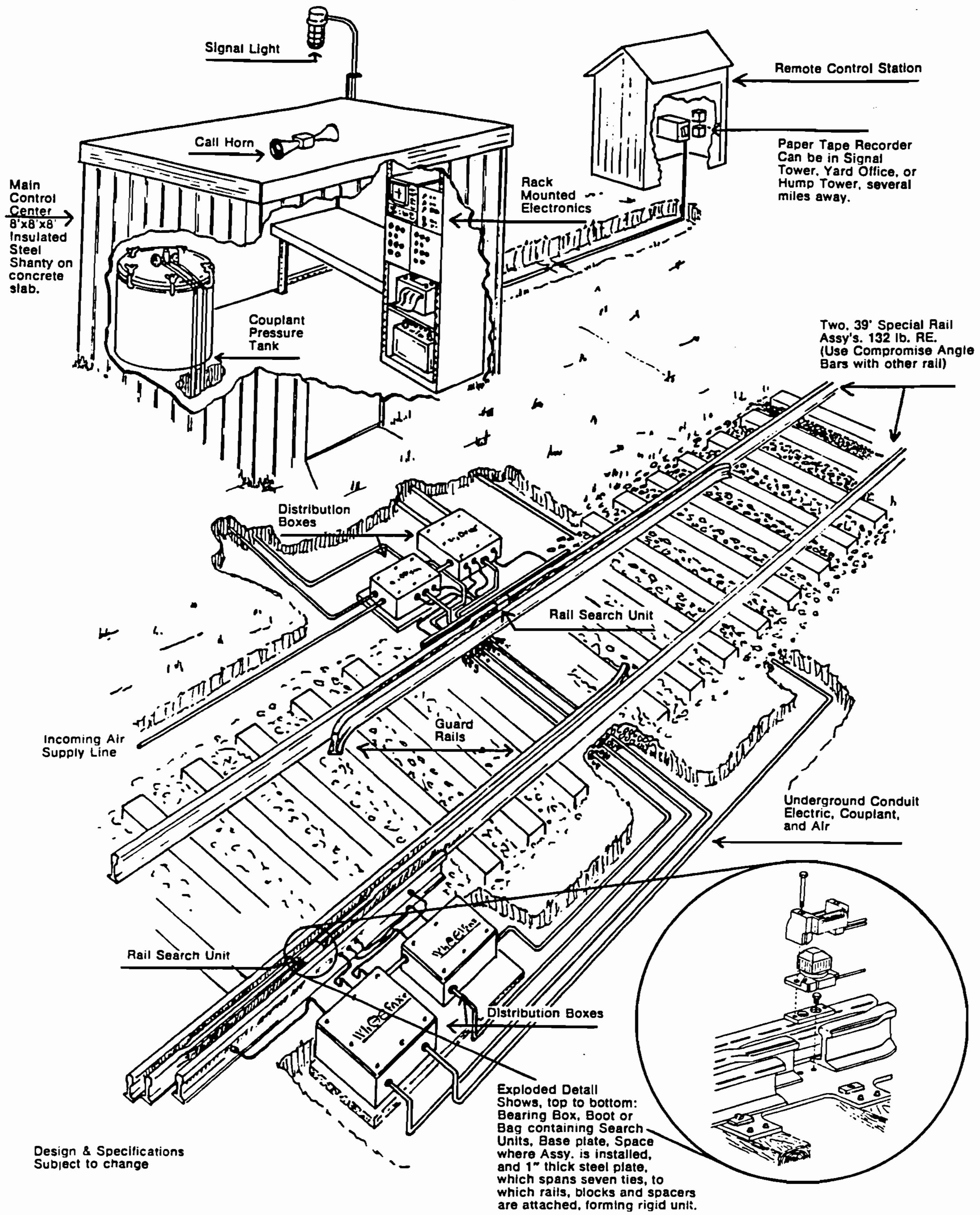
EMAT power and which complicates signal processing. The prototype system used a contact sensor for slow speed operation. Significant further development in the prototype has to take place before the system can be used for real life testing.

6.2.2. UltraSonic Systems (Fax Corporation)

The leading ultrasonics based system on the market is from the Fax Corporation located in Danbury, Ct. The system is based on the ultrasonic flaw detection principle. Several of these systems have been installed in the field.

IEM conducted its testing and evaluation on one of the recent installations at Union Pacific at North Platte. The installation is dormant at present due to severe technical problems. Union Pacific reported problems with the basic capability of the system to recognize cracks. Even at low speeds, the system was not able to recognize cracks with any repeatability. The rubber boots used around the ultrasonic transducers failed frequently. The transducer did not produce good signal from the wheels. The net result is high rate of false positive indications, and unreliable system. Both of these problems have large scale impact on the system. Unfortunately, this approach also require use of couplant between the wheel and the sensor. IEM does not believe that this approach will be preferred over other approaches considering all the factors even if all the bugs are worked out.

EXAMPLE OF A TYPICAL WHEELFAX® INSTALLATION



Design & Specifications Subject to change

7. EXISTING TECHNOLOGIES ANALYSIS

There are two main categories of technologies available for measuring wheel profile: Contact and Non-contact technologies.

Contact technologies refers to measurement techniques where a probe makes physical contact with the object being measured. Such an effort for wheel measurement was tried by Wheel Checkers and failed because of excessive wear, accuracies and maintenance.

The latter are more pertinent to this discussion and are covered in more detail. In our review we will look at the following non-contact technologies:

- Ultrasonics
- Infrared Lasers
- Visible Light Systems
- Magnetic
- X-Rays, Microwave and other

A preliminary review of these technologies quickly results in the elimination of all but Ultrasonics and Infrared Lasers. Please see IEM Patent Number 4,904,939 (Appendix ___) for a detailed discussion of a magnetic rim thickness sensor and other non-contact sensors used to measure railroad wheel profile.

IEM tested several of these technologies including ultrasonic sensors and laser sensors both on bench top and test track layouts.

7.1. Ultrasonics:

The ultrasonic technologies work on the basis of emitting a high frequency (around 25K to 250K HZ) sound signal and measuring the phase shift or return time for first echo from the closest object. Sensor heads are generally available in narrow beam for sharp focus point or wide beam models.

Appendix ___ includes product literature on the TMS 1000 Ultrasonic Array. This literature provides a good description of the application of this technology to industrial measurement problems.

ADVANTAGES

The advantages of this technology are medium to low resolution (0.001 inch to 1 inch), medium to long stand off distances (few inches to few feet), and cost - ultrasonic sensors tend to be durable and inexpensive.

DISADVANTAGES

These are namely significant variation of sound velocity with temperature,

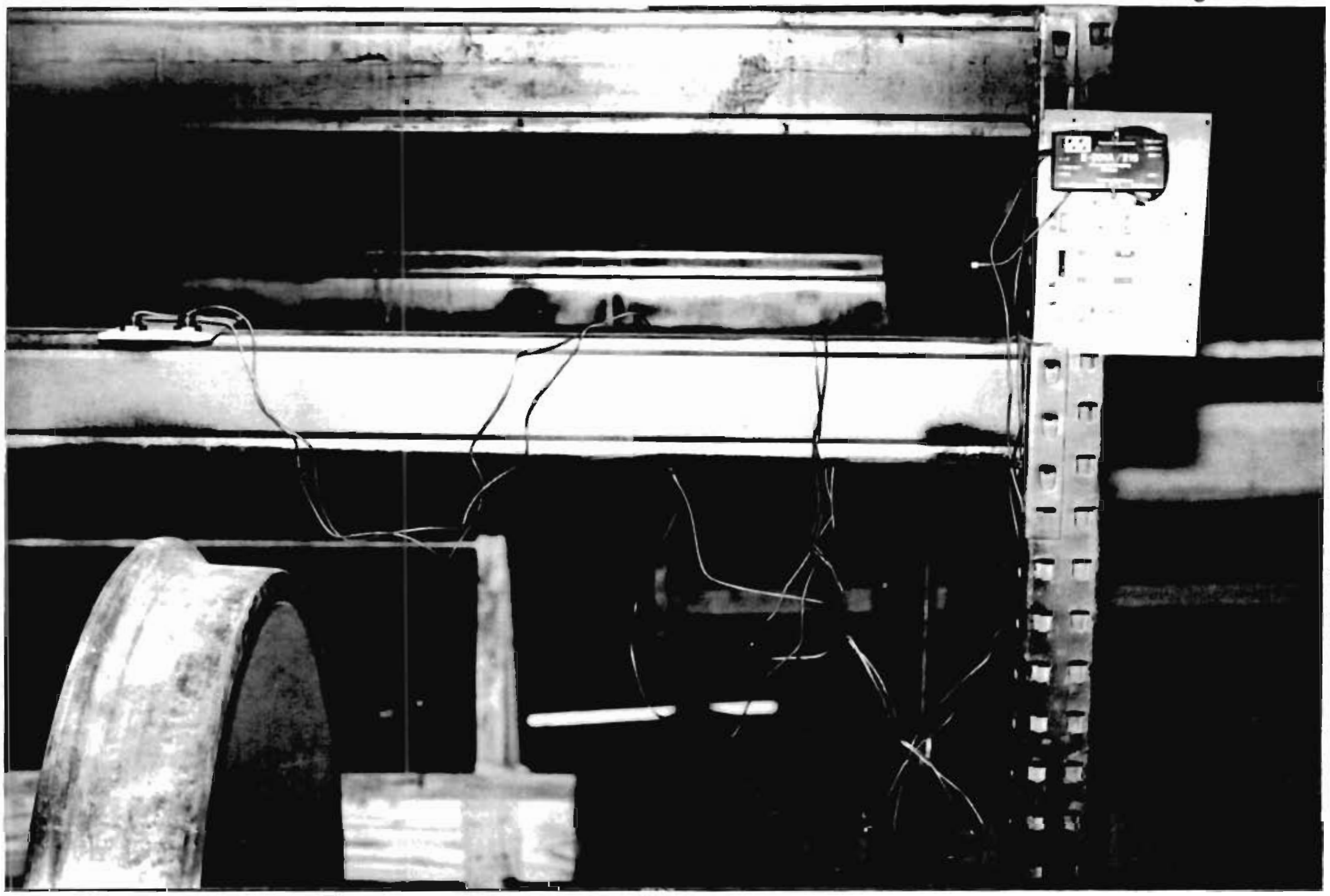


Figure 20 - IEM Test Track Showing Ultrasonic Whl Detector

large focus point even for narrow beam (no minor lobes) sensors, slow speed, poor immunity to ambient noise.

APPLICATIONS

While the variation of sound speed can be accommodated if proper temperature compensation techniques are applied, the large focus point makes this technology practically useless for very well defined measurements such as flange thickness. Since the flange thickness measurement is very sensitive to the measurement point, an extremely narrow focus point is required, effectively eliminating ultrasonic sensors as a viable technology for this measurement.

On the other hand, one can take advantage of the large focus in measurement distance or height if the object being measured moves laterally. Therefore, this technology can be used for flange height measurement or rim thickness measurement if:

- Proper filtering is applied to cancel ambient noise.
- Proper temperature compensation techniques are applied to accommodate

changes in ambient temperature which affect ultrasonic measurement accuracy.

There are a number of sensors available to make these measurements. Two such systems are IEM's ultrasonic thickness/height measurement system and Servo's acoustic system. The Servo system, operational in the field for several years, is similar in technology except that it operates in an audible frequency range (200 to 20K-Hz).

7.2. Infrared Laser Systems:

The infrared laser systems work on the basis of sending out an infrared laser beam (generally from 1mW to 10mW power range) and measuring the reflected response from the object using opto-triangulation, diffraction grating, or opto-array scanning techniques.

IEM tested several laser scanners and found that this technology produced the overall best results.

The IEM testing program included developing a mechanically driven laser sensor (Figure 21) to determine the ability of the technology to respond apropriately to RR wheel surfaces. Using this device we tested for accuracy, repeatability, and resolution. We found that with appropriate software mean-

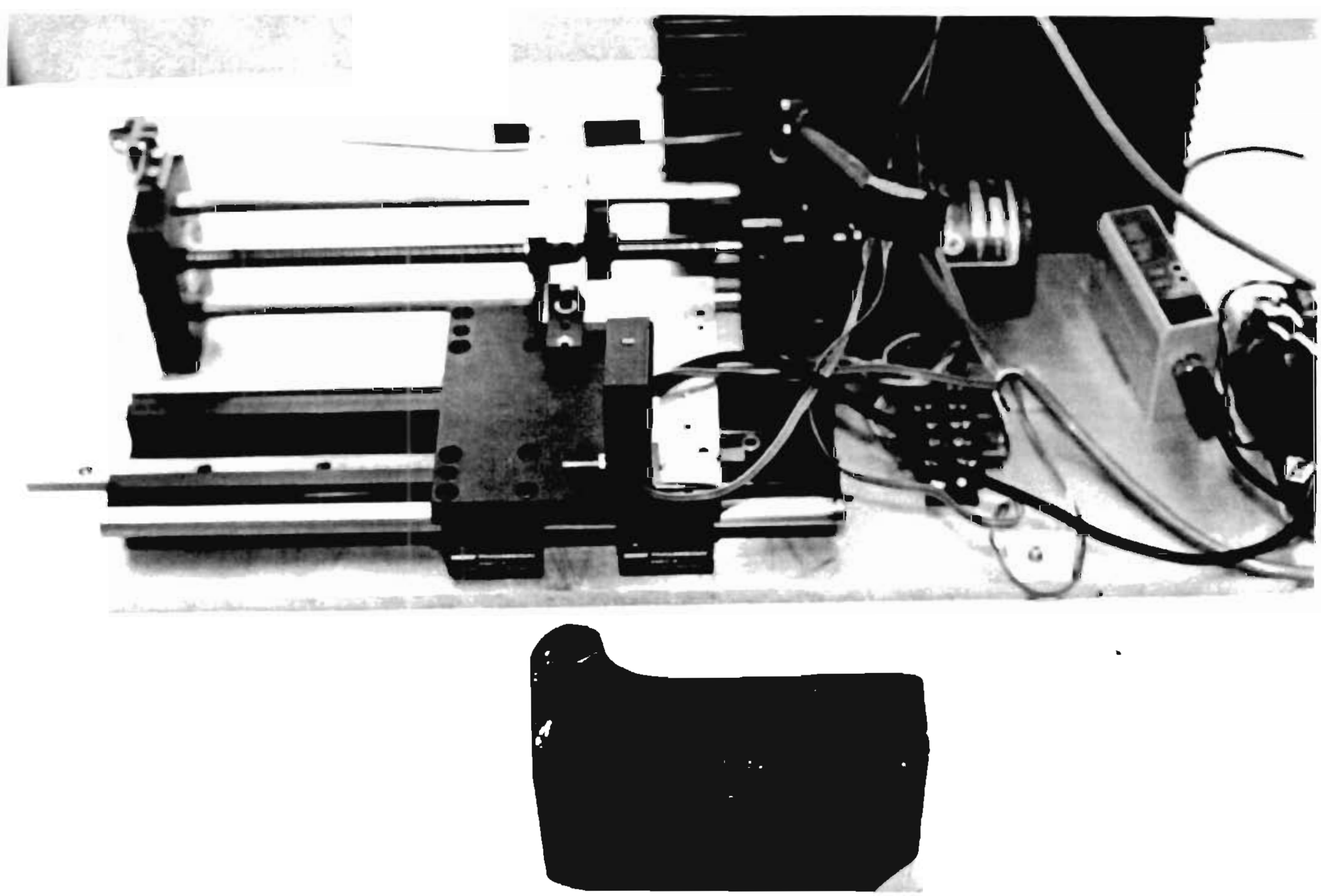


Figure 21 - IEM Test of Mechanically Driven Laser

ingful measurements in the one to two mil range were achieved. However, although this device demonstrated the feasibility of the use of laser sensors to measure the wheels, it is a slow speed device, not suitable for our application.

We then tested two laser scanner technologies. The choice of laser scanning technology was mandated by the need to reduce the measurement time to under one second. The first involved bouncing the laser beam off a rotating mirror. This technique did achieve the desired results. The second was a solid state scanner utilizing a piezoelectric diode. This second approach is preferred to the motorized mirror approach for its durability.

Using this device we were able to take a number of high resolution scans of actual railroad wheel segments. Figures 22, 23,and 24 show scans of flange profile, tread surface and reference groove respectively. Note that these scans are actual raw numbers prior to the application of data smoothing. IEM has developed a number of proprietary algorithms for the translation of raw scan data into a set of standard railroad dimensions including flange thickness, flange height, rim thickness and distance from reference groove location.

Appendix ___ describes the "Optocator" gauge probe, an alternative system. The description gives a good brief technical overview of the application of infrared lasers to non-contact measurements.

ADVANTAGES

The advantages of this technology are precise measurement point, down to one millimeter or less (based on beam width), medium to high resolution available (better than 1 millimeter), normal stand-off (few inches), ambient light noise immunity through proper modulation-demodulation techniques, medium cost, and proven technology.

Such sensors have proven accuracies and reliability for years. IEM has tried a number of sensors and has designed its own sensors.

DISADVANTAGES

The primary disadvantage of this technology is the need to keep the systems clean. There are a number of air purge systems available for such application. When installed properly, air purge systems keep the dirt away from the sapphire lenses. Additionally, mechanical shutter systems can be installed to keep the unwanted dirt away.

There is a second disadvantage to the laser scanner technology and that is cost. There is no off the shelf laser scanner that meets our targets for ruggedness, speed, cost, and applicability. We believe that the technology works but that we will have to develop our own laser scanner to achieve our performance targets.

Another approach which we tested involved the use of "laser curtains" especially for the flange height and rim thickness sensors. This would involve an array of lasers sensors which would be directed across the wheel. Each sensor would provide a single GO/NOGO measurement regarding the presence of location of metal in its path. While this approach is capable of handling very

Figure 22 - Laser Scan of Flange Profile (Partial)

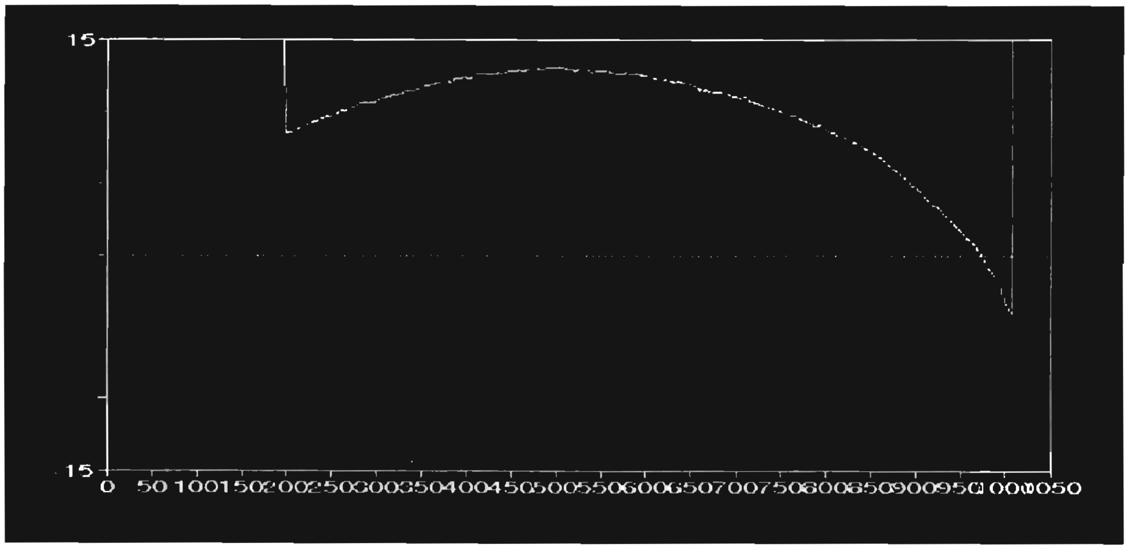


Figure 23 - Laser Scan of Block

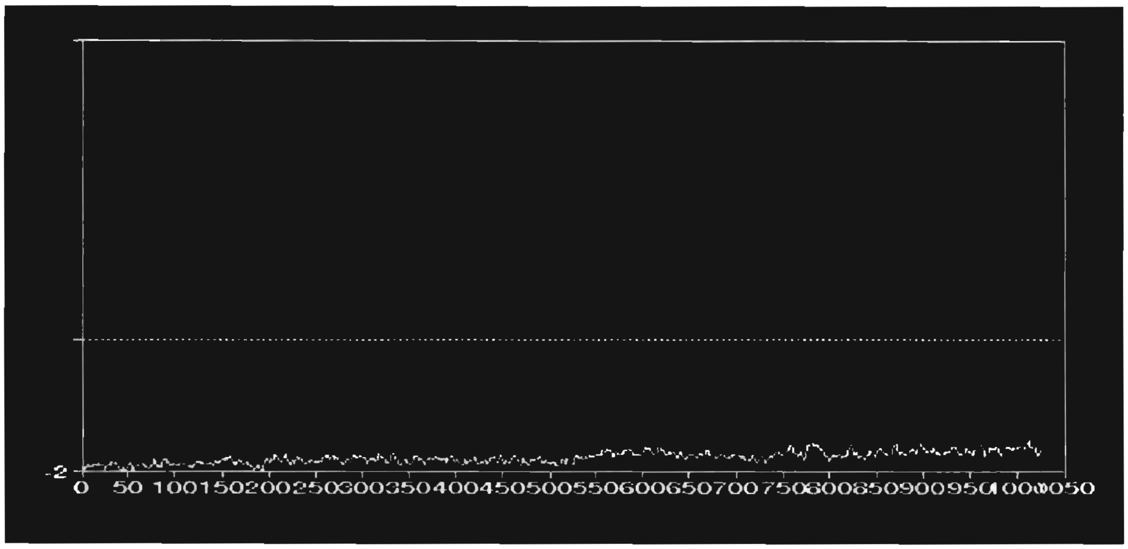
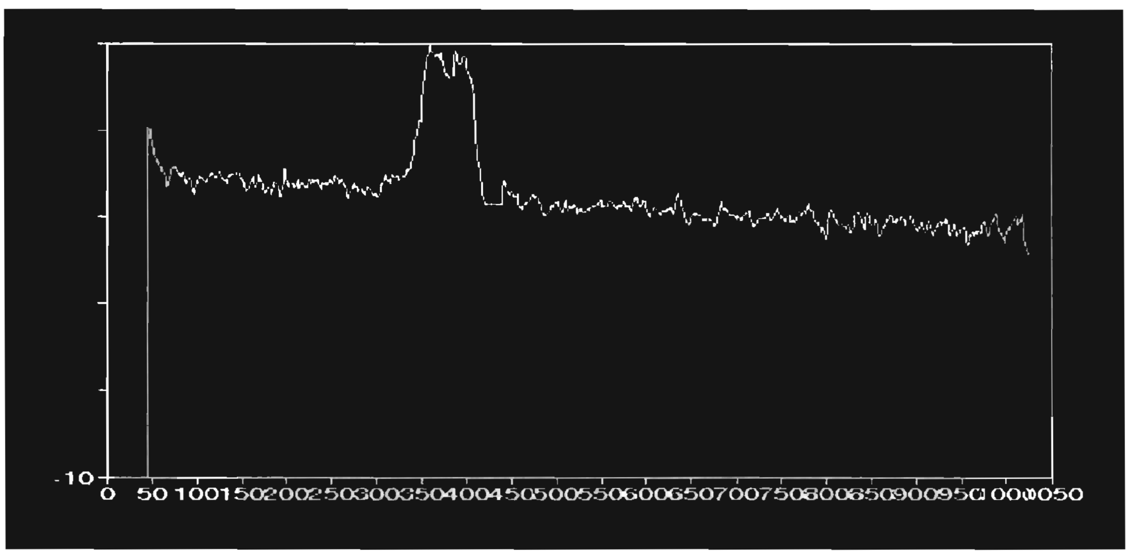


Figure 24 - Laser Scan of Reference Groove



high train speeds, its high cost limits its utility for the next phase of development.

APPLICATIONS

The infrared Laser Systems can be used to perform all three of the primary measurements including Flange Thickness, Flange Height, Reference Groove location and Rim Thickness.

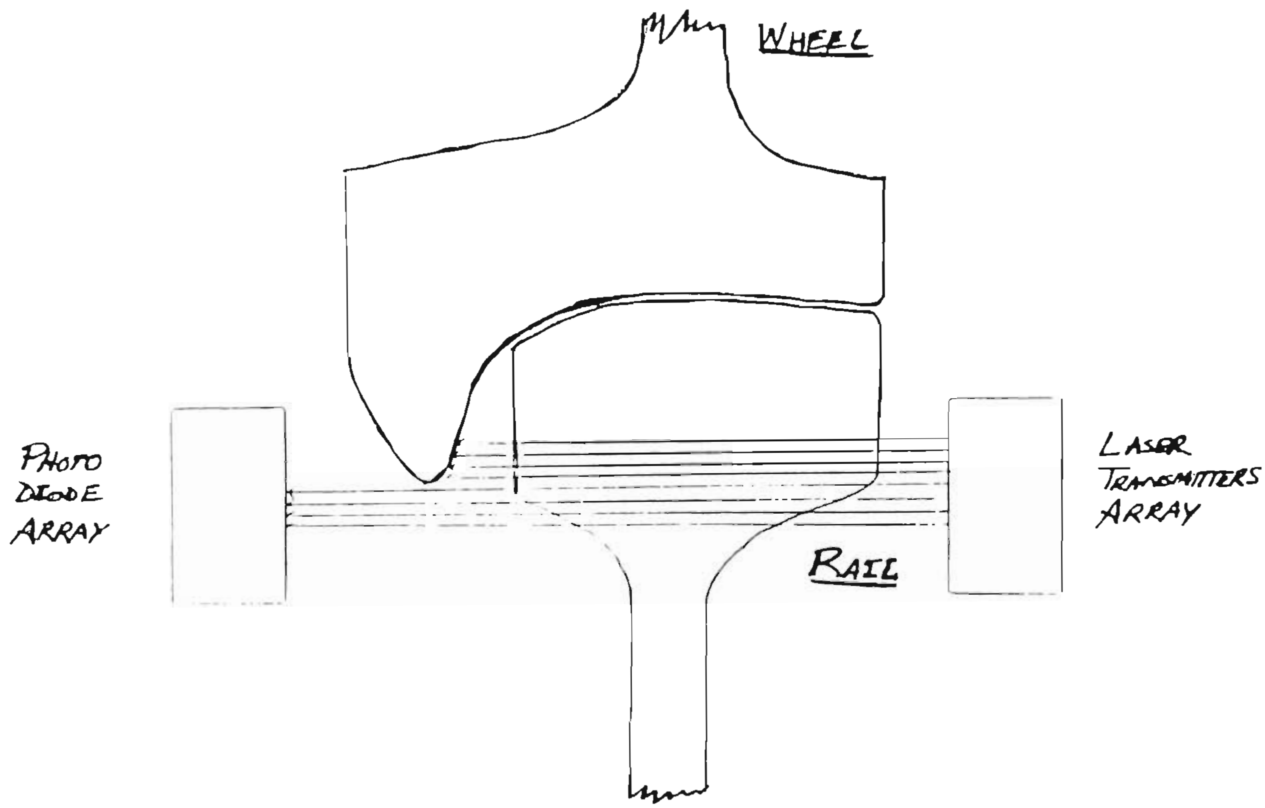


Figure 25 - Illustration of Laser Curtain Concept

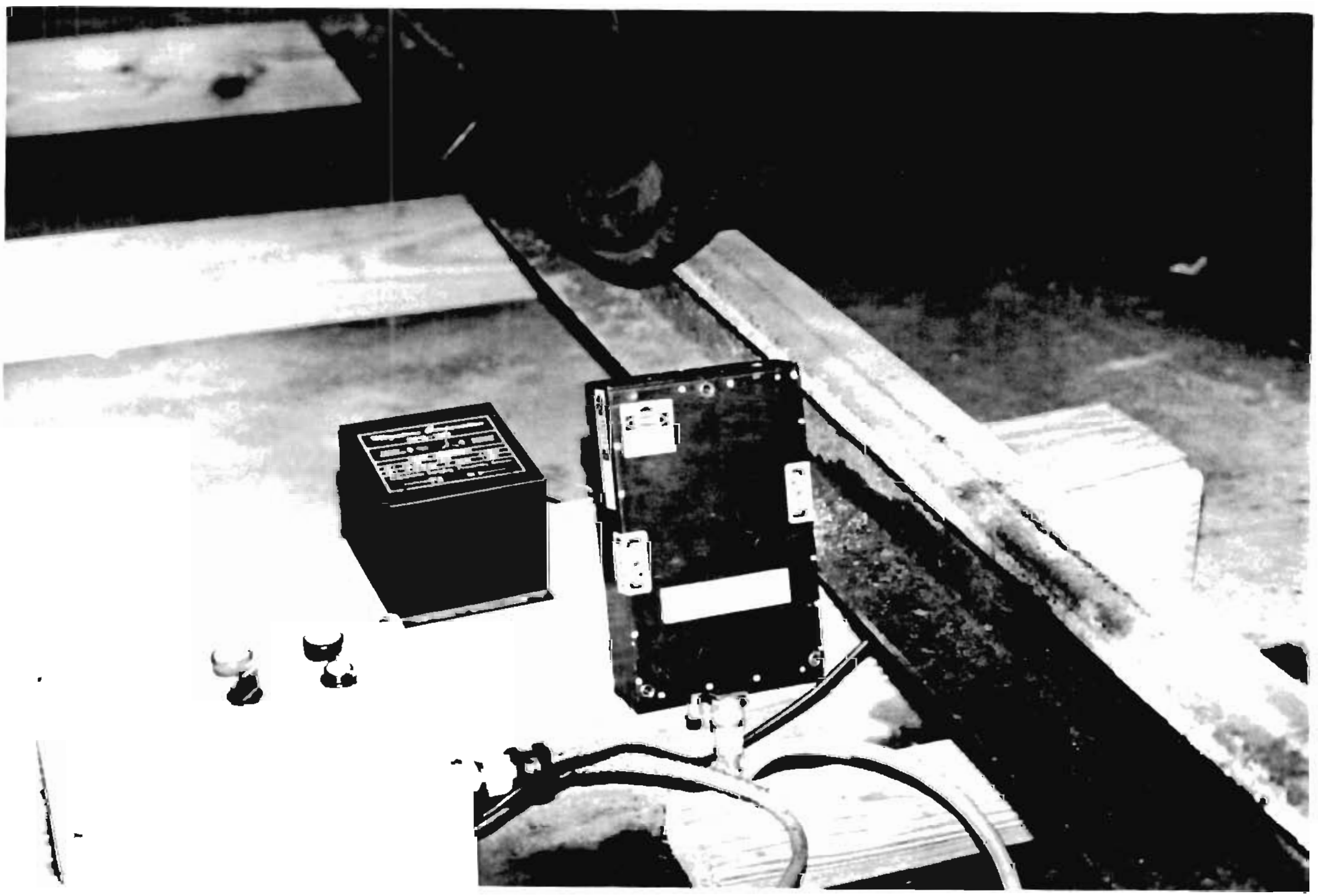


Figure 26 - Piezoelectric Laser in Flange Profile Config.

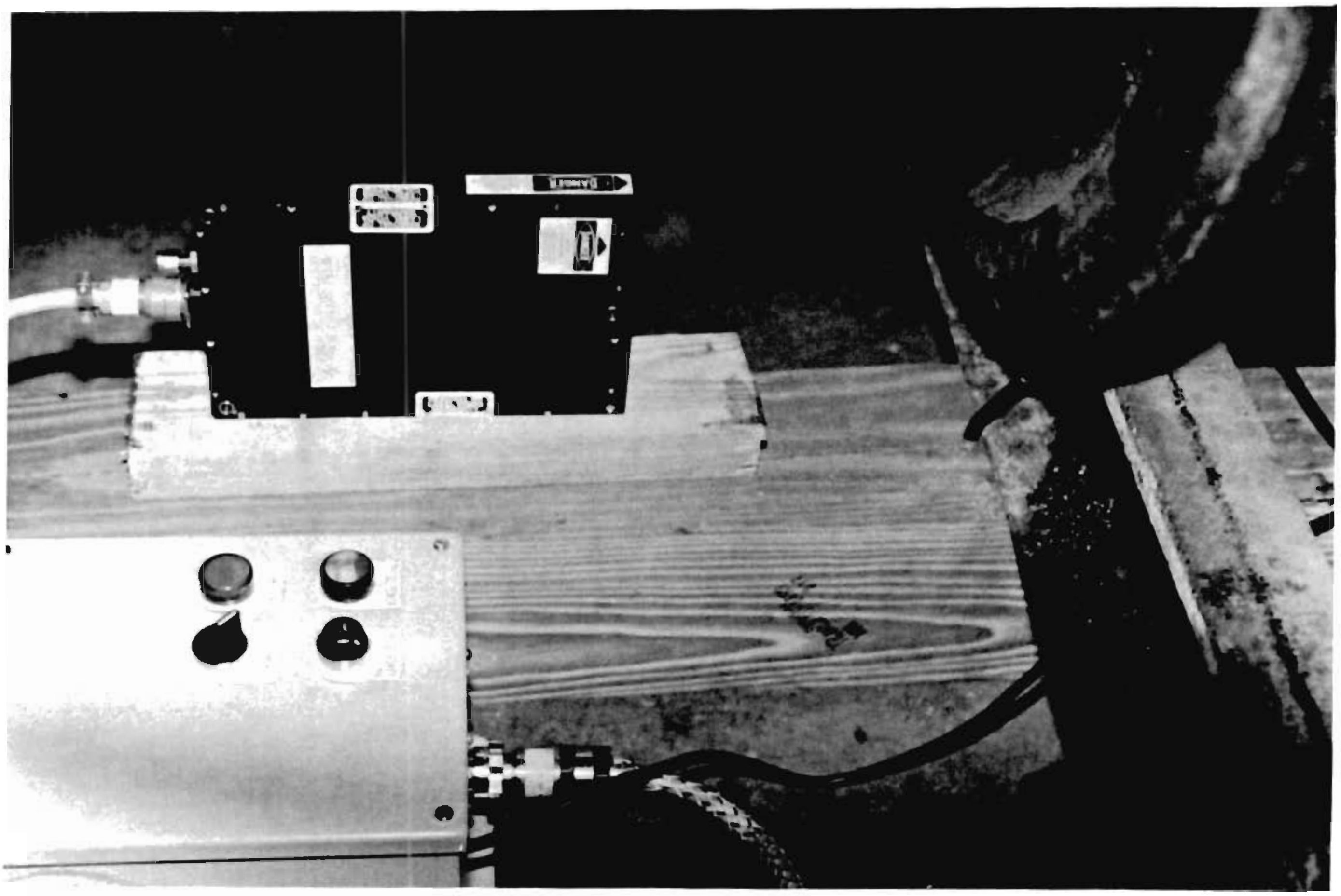


Figure 27 - Piezoelectric Laser in Rim Thickness Config.

7.3. Visible Light

Visible light systems refer to the optical systems such as light sources and associated detection methods such as cameras and video frame grabbers that operate in the visible light spectrum.

Visible light systems have poor ambient light immunity and reflection characteristics. Though a slit light source of very high intensity can be used to overcome the reflection problem, ambient light noise still remains an issue. Modulation-demodulation incorporated into conventional light systems can improve light noise immunity.

Although visible light systems have been shown to be able to perform the required measurements, no significant advantages have been identified relative to laser light systems.

IEM performed a number of experiments using a pair of high speed cameras assisted by a slit light assembly (Patent Pending) illuminating the wheel from under the wheel. The image of the wheel being measured is captured as the wheel passes over the cameras. After the train has gone past the measurement station, software data smoothing and image analysis is done by the computer. The lateral movement of the wheels can be accommodated in the software analysis as the image analysis software searches the entire image obtained by the cameras.

ADVANTAGES

None relative to laser technologies.

DISADVANTAGES

In our work we found a number of disadvantages to this approach. Given the problems of contrast and resolution we concluded that in order to acquire images at 10 MPH or higher speeds, the cameras would have to be very fast. Also, the image quality can be susceptible to the ambient light conditions and deterioration in the clarity of the protection window. Therefore we have concluded that reliance on visible light technology as a primary approach is not warranted at this time.

APPLICATIONS

Can be used for all three measurements.

7.4. Magnetic

Magnetic sensors are of the magnetic proximity type and work over a small distance from the metal being measured.

Also, the finest focus point/magnetic beam width of such largest possible distance sensors is too wide for flange thickness and flange height measurement. IEM has designed a proprietary rim thickness sensor that works for rim thickness measurement very accurately. However, this sensor can only work in close proximity of the wheels and is not capable of meeting the need to accommodate wheel movements of +/-1.5 inches.

7.4.1. Axle Counter

One application of Magnetic Sensors is the axle position indicator. The position indicator will be wheel reluctance activated and consist of a permanent magnet mounted on one side and a sensitive magnetic pick up on the other side of the wheel As soon as the wheel passes through this mechanism, the magnetic pick up will indicate a peak in induced current. Using some wave shaping electronics, the pulse can be used to trigger the rest of the measurement.

7.5. X-ray Systems

X-ray systems work very well for profile measurement and inspection but are very expensive and bulky. Also, these systems do not lend themselves to harsh environment usage because of their imaging techniques.

If, however, the underlying system design gets broadened to incorporate wheel crack detection, X-ray technology may come into play.

7.6. Microwave Technology

Microwave technology does not lend itself to any measurement where precise focus point has to achieved. More complicated and expensive, microwave technology can be used for flange height and possibly for rim thickness readings. However, the relatively high cost of this technology when compared to magnetics or ultrasonics make it a poor candidate for final consideration.

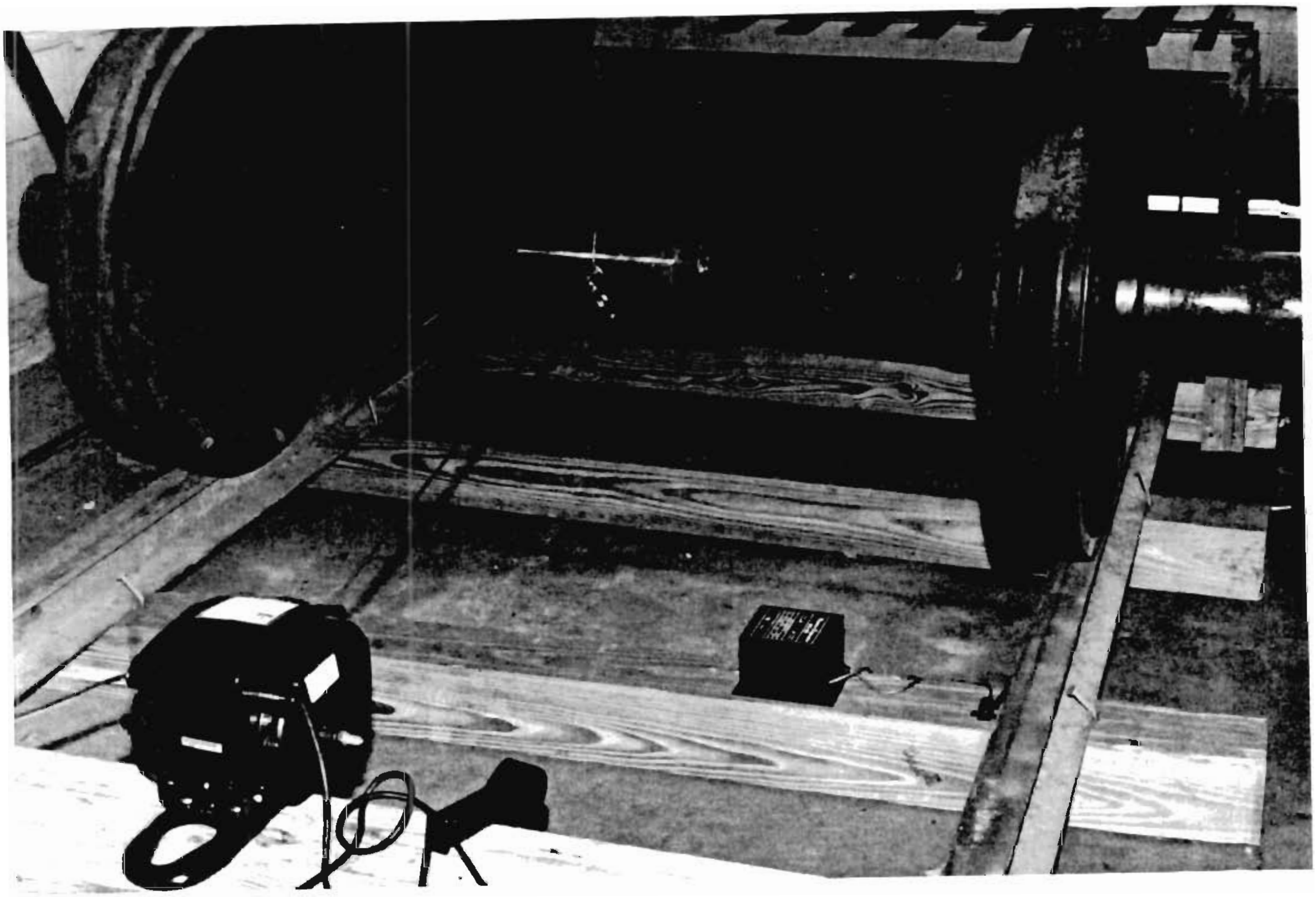


Figure 28 - IEM Test Track

SECTION IV

PRELIMINARY FEASIBLE SYSTEM DESIGN

8. PROPOSED TRACK MOUNTED SYSTEM

Any design of a new technology necesserily requires decisions balancing trade-offs between competing goals. The trade-offs inherent in the Automated Wheel Inspection Station design are bewteen system cost, reliability, functionality, and train speed. For example, the industry would prefer a highly reliable, multi-function ie comprehensive, high speed system. Some industry leaders have indicated a willingness to pay in excess of $1,000,000 for such a system. However, given the state of the available technology, such a system is not a currently viable option.

At this point, it is much more reasonable to create a limited function, low speed system that is both low cost and highly reliable. Then as the technology matures, additional functions can be added and/or allowable train speeds can increase. To achieve this goal, IEM recommends the development of a slow speed, relatively inexpensive laser based system to perform flange profile and rim thickness measurements.

We believe that based on our analysis of wheel defects, wheel related accidents and the capabilities of the existing relevant technologies, the such a product will have the ability to stand on its own as a valuable contribution to rail technology. Needless to say as additional capabilities become implemented, the value of the system will increase. We will now present a development plan for our Phase II product

8.1. IDENTIFIABLE WHEEL DEFECTS

IEM's proposed solution involves a set of sensors that will perform five sets of wheel measurements:

- flange thickness,
- flange height,
- rim thickness,
- reference groove location, and
- wheel gauge.

Other wheel defects will be added to the system later on in the product development. Some of these include cracks and the tread defects of flats, shells, and spalls.

8.2. OPERATING SPEED CAPABILITIES

The proposed system will be capable of performing reliable measurements at speeds of up to ten miles per hour initially. As the product matures, it may be possible to increase the operating speeds of the system.

8.3. ENVIRONMENTAL CONSTRAINT PARAMETERS

The system proposed by IEM will incorporate a number of electro-mechanical features to work in the harsh environment. The sensors will have a structural baffle built around them to keep dust or snow from directly getting into already sealed sensors. The front face of all the sensors will incorporate an air purge system to keep their measurement faces clean. As product development progresses, it may become apparent that there is a need for auto - shut off windows in front of the sensors' heads.

Temperature variations can be worked around by providing appropriate temperature compensation circuits. Where such circuits are not available, IEM will consider environmentally controlled chambers.

Rails located outside in a yard are good candidates for lightning attacks. Any electronics attached to the rails or in the neighborhood of rails have to address the high voltage spikes in excess of thousands of volts. To resolve this problem, IEM proposes to use well grounded sensor enclosures and preferably grounded independent of the rail using their own metal rods. Also, all of the rail mounted electronics and power supply will have to be isolated from the main controller boards. The total system power will also have to be isolated from the main power input. Proper surge protection schemes will also have to be incorporated into the system.

8.4. SERVICE REQUIREMENTS

The railroad environment is one of the harshest of all industrial environments. Combining the full range of environmental stresses with extraordinary levels of vibration and impact, the railroad environment requires close to military specifications. At the same time, regardless of the durability of the system components, things will break. Therefore, a fundamental principle must be to make as much of the system as possible field serviceable by technicians in the Signals and Communications departments. This means making all system components easily replaceable and providing clear, straight forward service manuals.

8.5. TARGET PRICE REQUIREMENTS

The target price of the system will directly depend on the ultimate performance capabilities of the system. One railroad reported a willingness to pay several million dollars for a system that would operate on the main line at high speeds and incorporate a broad variety of wheel and truck defects. At the same time, as the train speed capabilities of the system are reduced, the number of systems required by a single organization will have to increase and the unit price will have to come down.

IEM recommends the early development of a relatively low speed device in the $100,000 and under range.

8.6. DATA DISPLAY & STORAGE

The basic operation of the proposed system is to alert inspectors to defective wheels so that the existing labor force can be used more efficiently. To achieve this goal, the system will have to incorporate a car identification capability such as AEI or an alternative video approach and will have to display the information in a printed report in a train master's or maintenance supervisor's office. The report should be close to real time and should include the car identification, the wheel position and the suspected defect.

8.7. SYSTEM CONFIGURATION

IEM's track mounted system consists of three key pieces: the control unit, the track mounted measurement units, and the data processing unit.

As shown in the figure on the following page, the control unit is mounted adjacent to the track in an environmentally controlled chamber. The data processing unit is located inside the shop for convenient access to the reports and other monitoring information. The measurement units are mounted on a reinforced concrete platform immediately adjacent to the track.

The heart of the system is IEM's proprietary measurement technology. This technology is "non-contact" in nature and does not wear out over time. The measurement unit houses three sensor sub systems that measure flange height, flange thickness, reference groove location, gauge, and rim thickness. The measurement unit also houses track wear and train lateral movement compensation systems. The proposed technologies have proven to work in harsh industrial environments in other electronic gauges.

The measurement unit which is mounted on a reinforced concrete platform scans the wheels as the train passes by and stores the data on each wheel in system RAM for analysis and report generation after the train has passed over the scanner. The reports include, among other information, a listing of wheels which are out of safety specifications and should be condemned for safety reasons.

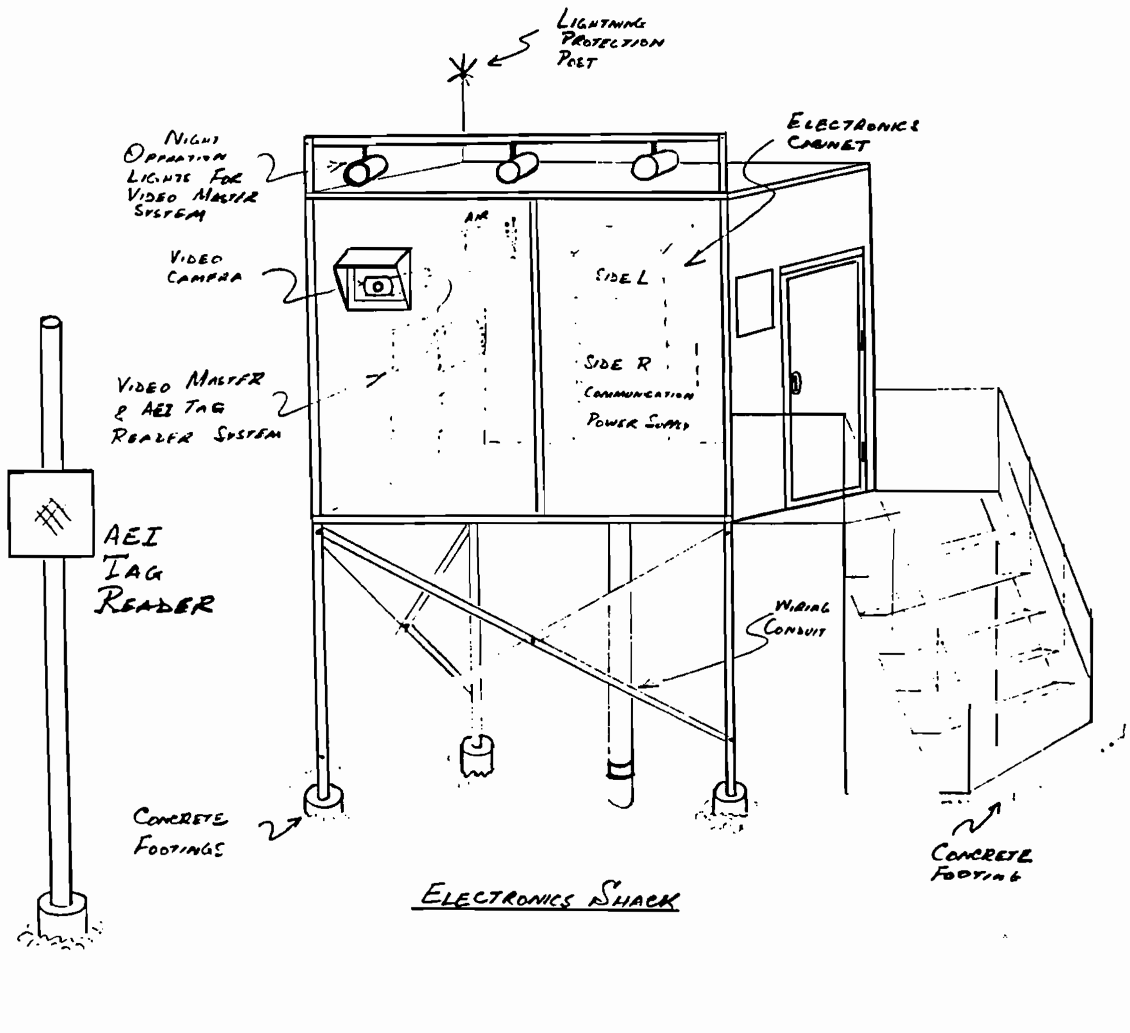


Figure 29 - IEM System Design

The Rail Based Wheel Gauge will be used to efficiently and accurately take the above mentioned wheel measurements. These readings are used to determine if the train has any wheel which should be condemned. The Rail Based Wheel Gauge points out all the wheels which are out of specifications for flange height and wheel gauge as defined by the American Association of Railroads (AAR). This report can also be used to initiate confirmation flange thickness and rim thickness measurements using the 34401 gauge. Since condemnable limits on rim thickness vary as a function of initial wheel diameter, it will be necessary to have an interface to the AAR's UMLER system to determine if a given rim thickness is condemnable or not.

The primary focus of this system is pre screening of the entire train wheel sets for a more stringent measurement check if found necessary.

8.7.1. The Laser Scanner

The laser scanner will consist of a modulated laser source operating at 40K-Hz. The laser source will be modulate to avoid ambient light interference. The optical detector will only recognize responses coming back from the modulated light source. All other responses will be ignored.

The laser light source will also automatically adjust its intensity to accommodate for variations in surface reflectivity. The intensity of the laser beam will be adjusted using an automatic gain control arrangement. However, in all cases, the intensity will stay under Class I allowable limits.

The reflection from the surface will be digitized using a linear array of photo diodes. The reflection will be converted to a final value directly proportional to the distance between the sensor and the object using triangulation schemes.

For this application, we need to scan the surface of the wheel very rapidly as we take profile measurements. The surface of the wheel is scanned using a high speed piezoelectric scanner built in to the optical part of the scanner. The solid state piezoelectric scanner has several advantages over conventional scanners which tend to operate at lower speeds and have moving parts. The solid state scanners operate at very high speed and contain no moving parts.

Beside the laser scanner sensor, the profile measurement system will incorporate a wheel detector. The wheel detector technology is very well developed based on electromagnetic technology and we will be using a standard off-the-shelf wheel detector.

As the data becomes available from the scanner, the data will be digitized using a high speed analog to digital convertor. The converted data will be manipulated to produce profiles information and stored in the computer. The digitized profile will be used to produce the appropriate wheel profile dimensions.

8.7.2. The Software

The software for this system will be divided into the following functional blocks. The dimensions block will be responsible for converting the XY coordinate profile into wheel profile information. The XY profile first has to go through the data smoothing algorithm for possible data correction. As the laser scanner is based on the reflected light from the surface, it will occasionally, "Drop Out" of the XY profile. Such points will have to be smoothed out using "Spline Fit" or other data smoothing techniques.

Once the data is smoothed, the data is processed through the dimensional block to produce measurements. Please refer to the listing in Appendix ___ to see the details on the "C" program used to smooth profiles and extract dimensional information. As the system will be subject to wear over time, the system will allow for automatic recalibration using a calibrated wheel segment. However, the need for automatic calibration will be once or twice a year depending on the usage. The present design works on the two dimensional data and extracts wheel profile dimensions. Therefore, irrespective of the location of the profile features within the two dimensional space, the features can still be extracted without sacrificing accuracy.

The end use will be allowed several levels of interface with the system. Next to the system shack, the user will have access to all the data using a PC as the user interface device. As the dimensional numbers are extracted from the profile information, the numbers will be stored in the computer's memory for further access and review. Also, the system will allow remote information access using a high speed modem and a Video Master's (VMS) System where not only the exception reports will be displayed, but also information on the train number, car number, axle number and speed of the train will be displayed. Please see Appendix ___ for more information on the VMS.

The RBG will also allow remote diagnostic and remote calibration using a modem interface.

8.8. System Description

The system (See Figure 30) consists of two laser scanners and a powerful computer controller. One scanner would measure rim thickness, the other - flange profile. From the output of these two devices we can derive the following measurements: rim thickness, flange thickness, flange height, and flange slope. Additionally, we hope to be able to develop our own tread defect technology that would be able to detect shells, flats, etc. And we have signed a cooperative research agreement to acquire the rights to a crack detection methodology that may well work at relatively slow speeds on transit wheels. Our goal is to create what will ultimately become an integrated rail based wheel inspection station. However, the first step that we are taking is the development of the profile measurement component.

Here is a brief description of the device under development.

8.8.1. Rim Thickness

The proposed rim thickness subassembly consists of a laser scanner sensor placed parallel to the rim. The laser in the scanner is turned on under computer control one step at a time to sense the presence of metal and then advanced. The number of steps that detect the presence of metal is directly proportional to the rim thickness reading. The laser diode in the scanner is excited with a modulated signal (signatured to avoid interference by ambient light) and the reflected response from the wheel is looked at by a linear detection array to define the rim thickness edge. The arrangement will have several advantages over conventional video detection systems:

- Fast response time (better than 1 mili-second)
- Resilient to ambient light problems and better noise immunity
- Reproducible at a reasonable cost.

8.8.2. Flange Profile

The flange profile assembly consists of a laser scanner placed adjacent to the rail. It will scan the wheel profile from a point on the back face of the rim to the taping line. This measurement data will be calibrated by matching it against the rim thickness data. The scan data will be intelligently analyzed using principles developed as a part of IEM's Wheel Profilometer Gauge. The software will interpret the wheel scan and will derive the flange thickness, flange height, and flange slope numbers.

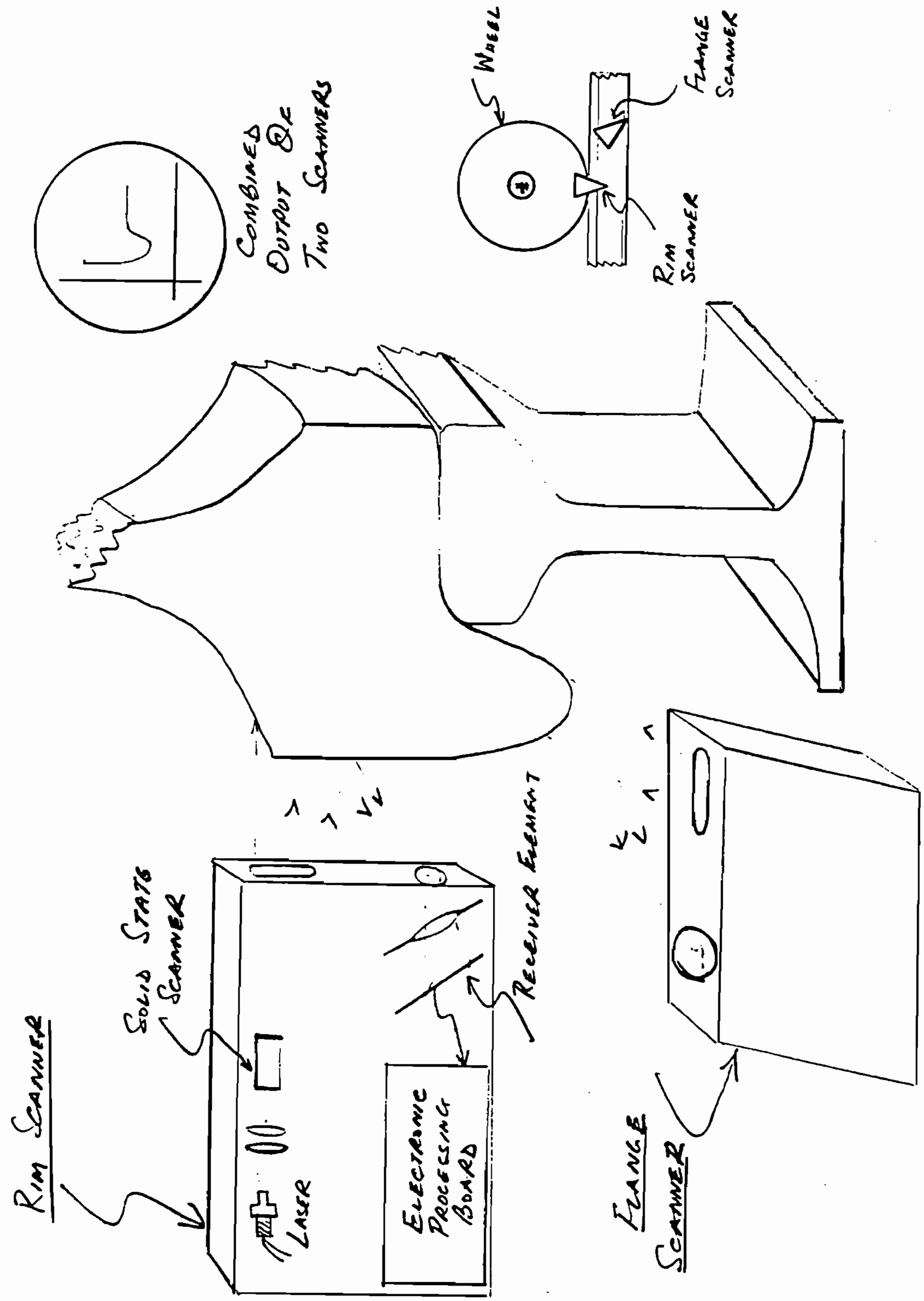


Figure 30 - Conceptual Design of Rail Based Gauge

9. TRACK MOUNTED WHEEL INSPECTION STATION - PROPOSED SPECIFICATIONS

MEASUREMENT ACCURACY (targeted at comparable to SWG)

Flange Thickness:	1/64"
Flange Height:	1/32"
Rim Thickness:	1/16"

MEASUREMENT RANGE (same as SWG)

Flange Thickness:	0.75" to 1.60" (for NF & WF)
Flange Height:	0.9" to 1.60"
Rim Thickness:	0.60" to 3.5"

MEASUREMENT TIME

Total time for each wheel will not exceed 100 mili-seconds

MEMORY SPECIFICATIONS

16 Mega Byte, 80 Nano Second Virtual Drive

80 Mega Byte local hard disk drive

1.44 Mega Byte program and utility disk drive

CONTROLLERS

Main Local Processor will be Intel 386 at 33 M-Hz

Other local processors will be Intel 8031 at 10 M-hz

Remote Processor may be added if needed

SYSTEM COMMUNICATION

RS-422 at 19.2 K-Baud

TEMPERATURE

-30C to 70C for all the electronics

BATTERY

All electronics will be surge protected and assisted with UPS.

10. OTHER ISSUES

IEM has several patents pending covering this technology and approach. Any other patents arising out of this developmental effort will also be owned by IEM. Therefore, IEM will retain the right to all the technology associated with this project and its usage in other possible applications.

APPENDIX A

Meeting Schedule

M E M O R A N D U M

TO: File

FROM: Richard Arthur

RE: SBIR Meetings

DATE: June 15, 1994

The following face-to-face interviews took place to research the Rail Based Wheel Gauge:

Date:	January 12, 1994
Attendees:	Richard Arthur, IEM Terry Tse, CONRAIL Paul Steets, CONRAIL
Topic:	Rail Based Wheel Gauge CONRAIL reports mixed views withing the organization regarding the proper location of the rbwg. The Car Maintenance Department wants to locate it within the yard. Others prefer a location just outside the throat of the yard. CONRAIL agreed to work with us in the future in the development of this product.
Date:	January 12, 1994
Attendees:	Richard Arthur, IEM George Binss, AMTRAK
Topic:	Rail Based Wheel Gauge AMTRAK sees a pressing need for a rail based wheel inspection station to support the aggressive equipment utilization goals of thier high speed rail initiative.
Date:	January 24, 1994
Attendees:	Zahid Mian, IEM Richard Arthur, IEM Don Gray, Federal DOT
Topic:	DOT Priorities for future R & D

Date:	January 24, 1994
Attendees:	Zahid Mian, IEM
	Richard Arthur, IEM
	Scott Keegan, Norfolk Southern RR
	Bob Blank, Norfolk Southern RR
	Hayden Newell, Norfolk Southern RR
	Charlie Scott, Norfolk Southern RR
	Bob Rolph, Norfolk Southern RR
	Tim Ward, Norfolk Southern RR
	John McKiernan, Norfolk Southern RR
	Pat Reidy, Norfolk Southern RR
	Art Lettril &, Norfolk Southern RR
	John Sigler , Norfolk Southern RR
Topic:	Rail Based Wheel Gauge

NS believes that the best approach to building this gauge is to start simple and build a slow speed rim and flange gauge for locomotive inspections.

NS sees a growing problem with the inspection of unit trains, the fastest growing component of thier fleet.

Date:	January 25, 1994
Attendees:	Richard Arthur, IEM
	Tom Guins. AAR
Topic:	Rail Based Wheel Gauge

Confirmed that impact detectors only catch 80% of high impact wheels.

Date:	January 25, 1994
Attendees:	Richard Arthur, IEM
	Ed Gregorman, APTA
	Paul Lennon, APTA
Topic:	Transit Interest in RBWG

They were both very interested in invited me to present a paper at the Rapid Transit Conference Annual Meetings.

Date:	February 10, 1994
Attendees:	Richard Arthur, IEM
	Bill Peterman, CP Rail
	Sydar Belgin, CP Rail
	Abe Aronian, CP Rail
Topic:	RBWG

CP would want a very comprehensive system.

Date:	February 22, 1994
Attendees:	Zahid Mian, IEM Richard Arthur, IEM Ron Swearengen, Swearengen Enterprises Jack Close, Heartland Railway Supply Mike Wall, Union Pacific Railroad Bob Cartwright, Union Pacific Railroad J M Santamaria, Union Pacific Railroad N Vargason, Union Pacific Railroad J. Magner, Union Pacific Railroad
Topic:	RBWG

The Union Pacific is very interested in a gauge that could reduce the time spent measuring locomotive wheels. Additionally, they would like assistance in improving their existing installations of crack detection equipment. They agreed to work with us in the development of the RBWG.

APPENDIX B

Proposed Software Communications Protocol

APPENDIX A
EXTENDED MESSAGE Formats - Version 1

General Format: **[header] { message stream } [tail]**

All data is expressed in ASCII. All transmitted hexadecimal data are the ASCII representations of the hexidecimal values.

Header Format: **[header] = [STX] [version] [nchar]**

field name	[STX]
size (char)	1
type	constant
description	02H

field name	[version]
size (char)	1
type	character
description	Provides interface version number for future expansion and compatibility, starting with "1".

field name	[nchar]
size (char)	4
type	hexchar
description	total characters in message stream (hex count)
special values	ffff = text data (of undetermined length) in message, look for special tail indication for end of data.

Tail Format: **[Tail] = [cksum switch] [cksum] [ETX]**

special values	ffff,ETX indicates end of data for text files.

field name	[cksum switch]
size (char)	2
type	hexchar
description	indicates that cksum field is active
special value	ff = cksum <u>does</u> <u>not</u> have to be checked.

field name	[cksum]
size (char)	2
type	hexchar
description	2's complement of the 8-bit sum of all the binary equivalents of ASCII characters in message stream.
special value	ff when combined with ff above closes the undetermined length, text file declared in header.

field name	[ETX]
size (char)	1
type	constant
description	03H

General format of message streams:

{ message stream } = [mtype]{ message fields }

Field Descriptions found among different message types:

field name	[mtype]
size (char)	1
type	upper case alpha
description	Identifies message type, establishes record structure.

field name	[d]
size (char)	1
type	char
description	Delimiter to separate data within a record (e.g. comma, dash, space, or tab).

field name	[d2]
size (char)	2
type	char
description	Delimiter to separate data within a record (normally CR/LF characters).

type description	timestamp [MSB] [ ] [ ] [ ] [LSB] Data is sent in order, from MSB to LSB. All values are the ASCII representations of the hexidecimal. Assume leading zero's to pad message.

Message 'T': **Train Data**

The train data consists of the following fields:
[mtype][d2][date/time][d][TrnOD][dir][d][naxles][d][alarms][selft][d][TotTime]

field name	[mtype]
size (char)	1
type	constant
description	'T'

field name	[date/time]
size (char)	10
type	decimal
description	date and time train arrived at site (24 hr. format)

field name	[TrnOD]
size (char)	2
type	hexchar
description	(train of day) train number after midnight

field name	[dir]
size (char)	1
type	char
description	1 = left to right; 0 = right to left.

field name	[naxles]
size (char)	3
type	hexchar
description	total number of axles in train

field name	[alarms]
size (char)	2
type	hexchar
description	alarm count (' ' = no alarms)

field name	[selft]
size (char)	2
type	char
description	2 characters indicating system status

field name	[TotTime]
size (char)	6
type	timestamp (hexidecimal)
description	total time (in msecs) TRAIN PRESENT signal was engaged for train.

Message 'A': **Axle Data**
The axle data consist of the following fields:
[mtype] { axle records }

field name	[mtype]
size (char)	1
type	constant
description	'A'

record name	axle record
size (char)	12 per record, up to 1023 records
structure	[d2] [axle number] [d] [axle timestamp]
description	provides the timestamp for axle events

field name	[axle number]
size (char)	3
type	hexchar
description	assigns a number value to an axle event

field name	[axle timestamp]
size (char)	6
type	timestamp (hexidecimal)
description	Time of axle event since TRAIN PRESENT signal was engaged.

Message 'E': **Event (or Exception) Data**

The event data consist of the following fields:
[mtype] { Event records }

field name	[mtype]
size (char)	1
type	constant
description	'E'

record name	Event record
structure	[d2][Event axle number][d][Event type][d][Event label][d][event time]
size (char)	31 per record, up to approx. 100 records
description	Provides a description of significant events (typically, an alarming axle).

field name	[Event axle number]
size (char)	3
type	hexchar
description	Assigns an axle number value to the event or alarm.

field name	[Event type]
size (char)	1
type	char
description	Describes type of event or alarm.

field name	[Event label]
size (char)	16
type	character
description	A string of characters used to describe the event on the screen.

field name	[Event time]
size (char)	6
type	timestamp (hexidecimal)
description	Time of event since TRAIN PRESENT signal was engaged.

NOTE: This message may require further revision to allow more complete car information to be conveyed with the basic axle alarm data. The device creating the alarm may also be one reading the car tag and/or counting the cars.

Message 'S': **Train Summary**

The Train Summary data message provides a means for one detector system to send text data through another system for display at a remote location without the intermediate system taking an active part in processing or handling the information. This data message consists of the following fields:

[mtype] {summary text }

field name	[mtype]
size (char)	1
type	constant
description	'S'

field name	{ summary text }
size (char)	undetermined
type	character
description	Train data to be stored and displayed upon command from the remote destination.

Message 'D': **Detail Train Data**

The Detail Train data message provides a means for one detector system to send text data through another system for display at a remote location without the intermediate system taking an active part in processing or handling the information. This data message consists of the following fields:

[mtype] { detail text }

field name	[mtype]
size (char)	1
type	constant
description	'D'

field name	{ detail text }
size (char)	undetermined
type	character
description	Train data to be stored and displayed upon command from the remote destination.

Message 'N': **No Train**

The No Train command comsists of one field:

[mtype]

field name	[mtype]
size (char)	1
type	constant
description	'N'

Message 'Q': **Status Request**

The Status Request command consists of one field:
[mtype]

field name	[mtype]
size (char)	1
type	constant
description	'Q'

Message 'L': **Last Message**

The Last Message command consists of one field:
[mtype]

field name	[mtype]
size (char)	1
type	constant
description	'L'

APPENDIX C

Market Research Questionaire - Formats

Transit

Locomotive

Freight Car

Freigh Fleet

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Topics to be covered for the Locomotive Market

I. Overview

In locomotive applications, a "rollover" gauge could provide flange thickness, flange height, rim thickness and distance from reference groove measurements. This system would have to be able to handle speeds of up to 5 mph and would be installed in a sheltered area such as a service center, wheel truing facility or barn.

To keep costs down, it may make sense to **not** include inspections for other defects such as cracks, shells, flats, etc. These inspections would continue to be performed by the federal man as a normal part of his other duties. By eliminating the need to take wheel measurements, this system would improve locomotive throughput and reduce manpower requirements by saving 15 - 30 minutes per locomotive per 92 day inspection.

There could be two performance levels for the device. The first could simply produce a GO/NOGO report flagging and reporting on any wheel that failed to meet a user specified wear limit or wheel diameter matching limit. The resolution of the gauge at the margin of the wear limits would have to be +/- 1/32nd(?) of an inch.

The second performance level would be for gauges that would be used to (1) provide data directly to a Simmons-Stanray Wheel Truing Machine and/or (2) a locomotive wheel management system. This gauge would have to have a resolution across the entire measurement range of +\- 1/64th of an inch. It would also benefit from an AEI tag reader so that it could store and subsequently report on wheel measurements by locomotive number.

International Electronic Machines Corporation
71 Fourth Street, Troy, New York 12180-3901 (518) 273-2445 (800) 724-1062 FAX (518) 273-2446

II. Required Measurements

To determine the most cost-effective set of system requirements for the gauge, we need to look at three areas:

A. Train delays by defect

B. Wheel Maintenance Activities by defect including:
   1. Trues
   2. Change-outs

C. Best judgement regarding necessary and desirable capabilities of the system.

D. For each of the following AAR Wheel Defects, we need to determine the number of train delays and wheel trues/change-out caused by the defect. On the following table please indicate the actual number of train delays (DEL) attributed to each defect for a designated time period such as 1993, the number of Trues (TRU) and the number of change-outs (CHG).

			DEL	TRU	CHG
1.	60	Thin Flange	[ ]	[ ]	[ ]
2.	62	Flange Vertical	[ ]	[ ]	[ ]
3.	64	Flange High	[ ]	[ ]	[ ]
4.	66	Flange Cracked or Broken	[ ]	[ ]	[ ]
5.	68	Rim Cracked or Broken	[ ]	[ ]	[ ]
6.	71	Rim Shattered	[ ]	[ ]	[ ]
7.	72	Rim Spread	[ ]	[ ]	[ ]
8.	73	Rim Thin	[ ]	[ ]	[ ]
9.	74	Thermal Cracks	[ ]	[ ]	[ ]
10.	75	Tread Shelled	[ ]	[ ]	[ ]
11.	76	Tread Built-Up	[ ]	[ ]	[ ]
12.	77	Grooved Tread	[ ]	[ ]	[ ]
13.	78	Tread Slid-flat	[ ]	[ ]	[ ]
14.	80	Scrape etc > 1/8 inch	[ ]	[ ]	[ ]
15.	81	Wheel Out of Gauge	[ ]	[ ]	[ ]
16.	83	Cracked or Broken Plate	[ ]	[ ]	[ ]
17.	84	Hole in Plate	[ ]	[ ]	[ ]
18.	85	Wheel Loose	[ ]	[ ]	[ ]
19.		Out of Round	[ ]	[ ]	[ ]
Other standard wheel defects					
20.		Subsurface Cracks	[ ]	[ ]	[ ]
21.		Stress Conditions	[ ]	[ ]	[ ]
22.		Wheel Skew	[ ]	[ ]	[ ]
23.		Hot Wheel	[ ]	[ ]	[ ]
24.		Wheel Diameter Variation	[ ]	[ ]	[ ]

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E. Best Judgement

We also need to determine how important it is for the gauge to identify each of the following defects. We have provided selections for (1) required for the gauge to be useful (REQ), (2) desirable - meaning that the ability of the gauge to identify the defect would enhance the value of the gauge (DES), not necessary meaning that the ability of the gauge to identify the specified defect would **not** have a substantial impact on the value of the gauge (NN).

			NEC	DES	NN
1.	60	Thin Flange	[ ]	[ ]	[ ]
2.	62	Flange Vertical	[ ]	[ ]	[ ]
3.	64	Flange High	[ ]	[ ]	[ ]
4.	66	Flange Cracked or Broken	[ ]	[ ]	[ ]
5.	68	Rim Cracked or Broken	[ ]	[ ]	[ ]
6.	71	Rim Shattered	[ ]	[ ]	[ ]
7.	72	Rim Spread	[ ]	[ ]	[ ]
8.	73	Rim Thin	[ ]	[ ]	[ ]
9.	74	Thermal Cracks	[ ]	[ ]	[ ]
10.	75	Tread Shelled	[ ]	[ ]	[ ]
11.	76	Tread Built-Up	[ ]	[ ]	[ ]
12.	77	Grooved Tread	[ ]	[ ]	[ ]
13.	78	Tread Slid-flat	[ ]	[ ]	[ ]
14.	80	Scrape etc > 1/8 inch	[ ]	[ ]	[ ]
15.	81	Wheel Out of Gauge	[ ]	[ ]	[ ]
16.	83	Cracked or Broken Plate	[ ]	[ ]	[ ]
17.	84	Hole in Plate	[ ]	[ ]	[ ]
18.	85	Wheel Loose	[ ]	[ ]	[ ]
19.		Out of Round	[ ]	[ ]	[ ]
Other standard wheel defects					
20.		Subsurface Cracks	[ ]	[ ]	[ ]
21.		Stress Conditions	[ ]	[ ]	[ ]
22.		Wheel Skew	[ ]	[ ]	[ ]
23.		Hot Wheel	[ ]	[ ]	[ ]
24.		Wheel Diameter Variation	[ ]	[ ]	[ ]

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III. Cost/Benefit Considerations

How can we quantify the benefits of the proposed system? and how would the RR capture these savings? We see four areas of savings. They are improved safety, reduced labor costs, faster through-put of locomotives through the 92 day inspection, and a variety of benefits that may accrue from more frequent inspections. To determine the value of each of these benefits, we need to try to quantify the savings to be derived from each area. We have tried to identify specific areas of savings to be quantified.

A. Improved safety
   1. accidents and derailments prevented
      a. list accident histories for past ___ years as a function of specific wheel defects.

B. Reduced labor costs
   1. How much savings could be generated by eliminating the labor required to measure the wheels during 92 day inspections?
      a. number of inspections per year ___ inspections
      b. time spent measuring wheels ___ minutes/inspection
      c. fully loaded cost/labor hour $___ hour

C. Faster through-put
   1. How much savings could be generated by reducing the locomotive down time attributed to standard wheel inspections during 92 day inspections?
      a. number of inspections per year ___ inspections
      b. time spent measuring wheels ___ minutes/inspection
         (1) fully loaded cost/locomotive hour $___ hour

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D. More frequent inspections

1. The rail based wheel gauge will provide a low cost, high quality wheel inspection. Because the cost per inspection will be reduced, railroads may want to conduct wheel inspections more frequently than the current 92 day standard. More frequent measurement will, in turn, create the ability to run locomotives closer to a wheel wear condemnation limit. This could result in more efficient wheel management leading to a variety of savings.
   a. would more frequent inspections enable the railroads to extend wheel life by running the wheels closer to the fra condemning limit prior to a true/change-out?

E. More efficient use of the wheel truing machine

1. would the elimination of the need to re-measure the wheels at the wtm increase utilization and cost-effectiveness of the wtm?
2. would having more accurate and more timely data regarding wheel truing requirements improve the scheduling and thus the through-put at the wtms?
3. would the complete profile data produced by a rail based system provide more efficient wheel trues than the three point measurement taken by the finger gauge?
   a. this point rests on the theory that the existing finger gauge does not provide enough data to accurately determine the amount of metal that needs to be removed in order to efficiently restore the profile. IEM believes that the most accurate method of determining the required depth of cut would be to scan the profile of the wheel and superimpose this wheel scan over the desired profile. By working with the entire profile instead of the simplistic flange thickness measurement, we could easily and efficiently optimize cut depths. It may be possible to provide a scan of the cross section of the wheel as part of the RBWG. This scan could be used to determine not only traditional flange thickness measurements but optimal cut depths as well.

4. How can we quantify these savings?

F. Therefor what price both in terms of one time costs and annual maintenance could be justified by these savings?

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IV. Market Size

A. How many yards conduct 92 day inspections?
   1. __________ yards.

B. What are the projections for the next 20 years regarding the number of yards conducting 92 day inspections?
   1. __________ yards.

C. What is the best location within the yard for this device?

1.	By wheel truing machine?	Yes [ ]	No [ ]
2.	By throat of the yard?	Yes [ ]	No [ ]
3.	By Pre-inspection building?	Yes [ ]	No [ ]
4.	By locomotive wash facility?	Yes [ ]	No [ ]
5.	______________________________?	Yes [ ]	No [ ]

D. How many units would the RR require within each yard and system-wide?
   1. Within each yard __________
   2. System-wide __________

V. Other

A. Would the RR be able to ensure that the RBWG was located within a shelter?
   1. If not, could a shelter be built?

B. If it was necessary to clean the wheels prior to measurement/inspection, what technologies exist to perform this task.

C. Where do the rr's project that their AEI readers will be in their locomotive yards?

VI. Technological considerations

A. Are there any truck designs in active use or in contemplated use that would restrict line of sight access to the back face of the wheel from a location between the tracks?

B. To what extend will the advent of slip/slide systems elimination the need to conduct wheel diameter matching?

Completed by ______________________________
Title ______________________________
Organization ______________________________
Phone ______________________________
Date ___/___/___

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Topics to be covered for the Freight Market

I. Overview

International Electronic Machines Corporation (IEM) is under contract with the US DOT to produce a plan for the development of an integrated rail based wheel inspection station. We believe that the technologies currently exist that will enable us to create a system that would combine profile measurement, with slow speed out of round and flat spot detection, and crack detection capabilities.

This system will be capable of detecting virtually all of the standard AAR wheel defects. The proposed system would inspect all the wheels automatically as the train passed by. Any wheel that approached an AAR condemning limit would result in a signal be sent to a central dispatching or switching system resulting in that car being automatically routed to a rip track where it could be more closely inspected using traditional means. The two primary expected savings would be in the reduction of workload in the area of train inspections along with more efficient car movements within the yard.

In the course of our investigation we plan to test and evaluate a variety of technologies to determine their practical capabilities in the harsh railroad environment. We also plan to investigate, in detail, the potential impact of the system on train operations. This investigation will encompass the areas of:

A. Technology
   1. What are the real world capabilities of the various technologies?
   2. How can the out-put of the system interface with existing train operations?
B. Operational Issues
   1. How will this system change the way a RR yard operates?
   2. How would such a system interface with railroad switching systems?
   3. What skills and capabilities will be required on the part of the railroad to operate and maintain the system?
C. Cost/Benefits
   1. What product features and capabilities will be required to ensure that the product meets a real need of the industry?
   2. What features would be desirable
   3. What are the practical limits on the cost of the system?
      a. One time capital costs?
         (1) for the system
         (2) to install
      b. Operating costs?
   4. What are the tradeoffs in terms of cost and performance from both a technological and marketing perspective?

The attached survey attempts to address some of the cost/benefit issues. We need to develop a clear understanding of how the RBWG would be used by the railroads and what value specific features would provide.

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II. Required Measurements

To determine a set of cost effective design parameters for the RBWG, we need to identify the most expensive wheel defects that currently exist. There can be three ways of identifying these defects. First is the number and cost of derailments associated with each type of wheel defect. Second, would be the number of wheel condemnations by type of defect. Third, the best judgement of railroad professionals regarding necessary and desirable capabilities of the system.

A. For each of the following AAR Wheel Defects, we need to determine:
   1. the number and cost of derailments caused by the defect.

			NMBR	COST
a.	60	Thin Flange	____	$______
b.	62	Flange Vertical	____	$______
c.	64	Flange High	____	$______
d.	66	Flange Cracked or Broken	____	$______
e.	68	Rim Cracked or Broken	____	$______
f.	71	Rim Shattered	____	$______
g.	72	Rim Spread	____	$______
h.	73	Rim Thin	____	$______
i.	74	Thermal Cracks	____	$______
j.	75	Tread Shelled	____	$______
k.	76	Tread Built-Up	____	$______
l.	77	Grooved Tread	____	$______
m.	78	Tread Slid-flat	____	$______
n.	80	Scrape etc > 1/8 inch	____	$______
o.	81	Wheel Out of Gauge	____	$______
p.	83	Cracked or Broken Plate	____	$______
q.	84	Hole in Plate	____	$______
r.	85	Wheel Loose	____	$______
s.		Out of Round	____	$______
Other standard wheel defects				
t.		Subsurface Cracks	____	$______
u.		Stress Conditions	____	$______
v.		Wheel Skew	____	$______
w.		Hot Wheel	____	$______

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B. Wheel Condemnations by Defect

			NMBR
1.	60	Thin Flange	____
2.	62	Flange Vertical	____
3.	64	Flange High	____
4.	66	Flange Cracked or Broken	____
5.	68	Rim Cracked or Broken	____
6.	71	Rim Shattered	____
7.	72	Rim Spread	____
8.	73	Rim Thin	____
9.	74	Thermal Cracks	____
10.	75	Tread Shelled	____
11.	76	Tread Built-Up	____
12.	77	Grooved Tread	____
13.	78	Tread Slid-flat	____
14.	80	Scrape etc > 1/8 inch	____
15.	81	Wheel Out of Gauge	____
16.	83	Cracked or Broken Plate	____
17.	84	Hole in Plate	____
18.	85	Wheel Loose	____
19.		Out of Round	____
Other standard wheel defects			
20.		Subsurface Cracks	____
21.		Stress Conditions	____
22.		Wheel Skew	____
23.		Hot Wheel	____

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C. Best judgement.

We also need to determine how important it is for the gauge to identify each of the following defects. We have provided selections for (1) required for the gauge to be useful (REQ), (2) desirable - meaning that the ability of the gauge to identify the defect would enhance the value of the gauge (DES), not necessary meaning that the ability of the gauge to identify the specified defect would not have a substantial impact on the value of the gauge (NN).

			NEC	DES	NN
1.	60	Thin Flange	[ ]	[ ]	[ ]
2.	62	Flange Vertical	[ ]	[ ]	[ ]
3.	64	Flange High	[ ]	[ ]	[ ]
4.	66	Flange Cracked or Broken	[ ]	[ ]	[ ]
5.	68	Rim Cracked or Broken	[ ]	[ ]	[ ]
6.	71	Rim Shattered	[ ]	[ ]	[ ]
7.	72	Rim Spread	[ ]	[ ]	[ ]
8.	73	Rim Thin	[ ]	[ ]	[ ]

a. Would the system have to differentiate between the 3/4 inch Condemning limit for all wheels except 28, 36, & 38 inch wheels and the 7/8 inch Condemning limit for 28, 36, & 38 inch wheels.

(1) 3/4 & 7/8 [ ]
(2) Just 3/4 [ ]
(3) Just 7/8 [ ]

b. Would the RR be able to query UMLER to determine the wheel type?

(1) Yes [ ]
(2) No [ ]

			NEC	DES	NN
9.	74	Thermal Cracks	[ ]	[ ]	[ ]
10.	75	Tread Shelled	[ ]	[ ]	[ ]
11.	76	Tread Built-Up	[ ]	[ ]	[ ]
12.	77	Grooved Tread	[ ]	[ ]	[ ]
13.	78	Tread Slid-flat	[ ]	[ ]	[ ]
14.	80	Scrape etc > 1/8 inch	[ ]	[ ]	[ ]
15.	81	Wheel Out of Gauge	[ ]	[ ]	[ ]
16.	83	Cracked or Broken Plate	[ ]	[ ]	[ ]
17.	84	Hole in Plate	[ ]	[ ]	[ ]
18.	85	Wheel Loose	[ ]	[ ]	[ ]
19.		Out of Round	[ ]	[ ]	[ ]
Other standard wheel defects					
20.		Subsurface Cracks	[ ]	[ ]	[ ]
21.		Stress Conditions	[ ]	[ ]	[ ]
22.		Wheel Skew	[ ]	[ ]	[ ]
23.		Hot Wheel	[ ]	[ ]	[ ]
24.		Wheel Diameter Variation	[ ]	[ ]	[ ]

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III. Cost/Benefit Considerations

A. In determining the value of the RBWG for the industry, we are concerned with three questions.
   1. What specific savings will the RBWG generate?
   2. How can the RR achieve these savings?
   3. How can we quantify these savings?

B. What Savings will the RBWG generate?

   1. Improved safety
      a. accidents and derailments prevented
         (1) list accident histories for past ___ years caused by specific wheel defects.

   2. Reduced labor costs
      a. To what extent would the elimination of the requirement to inspect wheels reduce manpower requirements in the yard.
         (1) would for example, the availability of a rail based wheel gauge change the way cars are inspected in the yard?
            (a) Yes [ ]
               i) How ______________________________
               ____
               ____
            (b) No [ ]
         (2) How many inspectors are employed as train walkers?
            (a) Number of inspectors __________
         (3) What functions do they perform other than wheel inspections?
               ____
               ____
               ____
      b. Could these functions be performed more efficiently?
         (1) either by incorporating them into the rbwg or
               i) Yes [ ]
               ii) No [ ]
         (2) Having the inspection process return to the visual procedure of having an inspector inspect the cars at the hump as they passed by instead of walking the train?
               i) Yes [ ]
               ii) No [ ]
   3. Increased wheel billings?
         (1) Yes [ ]
            (a) Best guess on how much ________
         (2) No [ ]
   4. Therefor what price both in terms of one time costs and annual maintenance could be justified by these savings?

      a. $______________

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IV. Technological considerations

A. What is the optimal location for such a system?
   1. By the Hump [ ]
   2. At the throat of the yard [ ]
   3. Slow speed main line [ ]
   4. High speed main line [ ]

B. What are the necessary and desirable speed requirements for each type of operation?

	Neces.	Desirable
1. By the Hump	______ MPH	______ MPH
2. At the throat of the yard	______ MPH	______ MPH
3. Slow speed main line	______ MPH	______ MPH
4. High speed main line	______ MPH	______ MPH

C. To what extent would a rr be willing to adjust this speed to enhance the operation of the gauge? ____________________________
____
____
____

D. If the device was located in a train yard, what is the optimal location for the device in the yard? ____________________________
____

   1. Where do the rr's project that their AEI readers will be with respect to the throat of the yard? ____________________________
   ____

E. How much lead time does the yard switching system require to rout a car to a rip track? _____ minutes.

F. Would the rr be able to construct a shed to shelter the system?
   1. Yes [ ]
   2. No [ ]

G. What is the range of axle loads faced by the system?
   1. _____ tons to _____ tons.

H. Are there any truck designs in active use or in contemplated use that would restrict line of sight access to the back face of the wheel?
   1. No [ ]
   2. Yes [ ] Describe ____
   ____

I. How much time is available on a daily and weekly basis to perform maintenance on the system in Hump operations?
   1. Daily _______ hours
   2. Weekly _______ hours.

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V. Market Size

A. How many humps are in active operation at your railroad?
   1. __________ hump yards.

B. What are the projections for the next 20 years regarding the number of humps in active operations?
   1. __________ hump yards.

C. What proportion of your train operations do not pass over Humps?
   _____ %.

D. How is this expected to change over the next 20 years?

   Will go to _____ %.

E. What impact would such a system have on operations which do not use Humps?
   1. ____
   ____
   ____
   ____
   ____
   ____
   ____
   ____
   ____
   ____

   2. How many locations at your railroad ____________________

Completed by ____________________ Organization ____________________
Title ____________________ Phone ____________________
Date ___/___/___

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Applications of the Rail Based Wheel Gauge for Private Car Fleets

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I. Overview

International Electronic Machines Corporation (IEM) is under contract with the US DOT to produce a plan for the development of an integrated rail based wheel inspection station. We believe that the technologies currently exist that will enable us to create a system that would combine profile measurement, with slow and/or moderate speed out of round and flat spot detection, and crack detection capabilities.

This system will be capable of detecting virtually all of the standard AAR wheel defects. The proposed system would inspect all the wheels as the cars entered an inspection facility or terminal location. Any wheel that approached an AAR condemning limit or an in-house "watch" limit, would be listed on an automatically generated wheel inspection report which would list all defects by car, axle, and wheel position. Alternatively, all inspection data could be recorded into a wheel management system which would subsequently generate a list of wheels needing to be changed out. If the inspection station was located at a remote location from the maintenance facility, the data could be automatically sent via modem to the maintenance shop.

In the course of our investigation we plan to test and evaluate a variety of technologies to determine their practical capabilities in the harsh railroad environment. We also plan to investigate, in detail, the potential savings generated by the proposed system. This investigation will encompass the areas of:

A. Technology
   1. What are the real world capabilities of the various technologies?
   2. How can the out-put of the system interface with existing yard operations?

B. Operational Issues
   1. How will the system change the way a fleet of cars is managed?
   2. What skills and capabilities will be required to operate and maintain the system?

C. Cost/Benefits
   1. What product features and capabilities will be required to ensure that the product meets a real need of the industry?
   2. What additional features would be desirable?
   3. What are the practical limits on the cost of the system?
      a. One time capital costs?
         (1) for the system
         (2) to install
      b. Operating costs?
   4. What are the tradeoffs in terms of cost and performance from both a technological and marketing perspective?

The attached survey attempts to address some of these issues. We need to develop a clear understanding of how the RBWG would be used and what value specific features would provide.

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II. Required Measurements

To determine a set of cost effective design parameters for the RBWG, we need to identify the most expensive wheel defects that currently exist. There can be three ways of identifying these defects. First is the number and cost of derailments associated with each type of wheel defect. Second, would be the number of wheel condemnations by type of defect. Third, the best judgement of railroad professionals regarding necessary and desirable capabilities of the system.

A. For each of the following AAR Wheel Defects, please indicate:

1. the number and cost of derailments caused by the defect in your fleet for the past five years.

			NMBR	COST
a.	60	Thin Flange	____	$________
b.	62	Flange Vertical	____	$________
c.	64	Flange High	____	$________
d.	66	Flange Cracked or Broken	____	$________
e.	68	Rim Cracked or Broken	____	$________
f.	71	Rim Shattered	____	$________
g.	72	Rim Spread	____	$________
h.	73	Rim Thin	____	$________
i.	74	Thermal Cracks	____	$________
j.	75	Tread Shelled	____	$________
k.	76	Tread Built-Up	____	$________
l.	77	Grooved Tread	____	$________
m.	78	Tread Slid-flat	____	$________
n.	80	Scrape etc > 1/8 inch	____	$________
o.	81	Wheel Out of Gauge	____	$________
p.	83	Cracked or Broken Plate	____	$________
q.	84	Hole in Plate	____	$________
r.	85	Wheel Loose	____	$________
s.		Out of Round	____	$________
Other standard wheel defects				
t.		Subsurface Cracks	____	$________
u.		Stress Conditions	____	$________
v.		Wheel Skew	____	$________
w.		Hot Wheel	____	$________

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B. Wheel Condemnations by Defect

For each of the following AAR Wheel Defects, please indicate: the number and cost of wheel condemnations caused by the defect in your fleet for the past five years.

			NUMBER IN-HOUSE	NUMBER CLASS I
1.	60	Thin Flange	____	____
2.	62	Flange Vertical	____	____
3.	64	Flange High	____	____
4.	66	Flange Cracked or Broken	____	____
5.	68	Rim Cracked or Broken	____	____
6.	71	Rim Shattered	____	____
7.	72	Rim Spread	____	____
8.	73	Rim Thin	____	____
9.	74	Thermal Cracks	____	____
10.	75	Tread Shelled	____	____
11.	76	Tread Built-Up	____	____
12.	77	Grooved Tread	____	____
13.	78	Tread Slid-flat	____	____
14.	80	Scrape etc > 1/8 inch	____	____
15.	81	Wheel Out of Gauge	____	____
16.	83	Cracked or Broken Plate	____	____
17.	84	Hole in Plate	____	____
18.	85	Wheel Loose	____	____
19.		Out of Round	____	____
Other standard wheel defects				
20.		Subsurface Cracks	____	____
21.		Stress Conditions	____	____
22.		Wheel Skew	____	____
23.		Hot Wheel	____	____

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C. Best judgement.

We also need to determine how important it is for the gauge to identify each of the following defects. We have provided selections for (1) required for the gauge to be useful (REQ), (2) desirable - meaning that the ability of the gauge to identify the defect would enhance the value of the gauge (DES), not necessary meaning that the ability of the gauge to identify the specified defect would not have a substantial impact on the value of the gauge (NN).

			NEC	DES	NN
1.	60	Thin Flange	[ ]	[ ]	[ ]
2.	62	Flange Vertical	[ ]	[ ]	[ ]
3.	64	Flange High	[ ]	[ ]	[ ]
4.	66	Flange Cracked or Broken	[ ]	[ ]	[ ]
5.	68	Rim Cracked or Broken	[ ]	[ ]	[ ]
6.	71	Rim Shattered	[ ]	[ ]	[ ]
7.	72	Rim Spread	[ ]	[ ]	[ ]
8.	73	Rim Thin	[ ]	[ ]	[ ]

a. Would the system have to differentiate between the 3/4 inch Condemning limit for all wheels except 28, 36, & 38 inch wheels and the 7/8 inch Condemning limit for 28, 36, & 38 inch wheels.

(1) 3/4 & 7/8 [ ]
(2) Just 3/4 [ ]
(3) Just 7/8 [ ]

			NEC	DES	NN
9.	74	Thermal Cracks	[ ]	[ ]	[ ]
10.	75	Tread Shelled	[ ]	[ ]	[ ]
11.	76	Tread Built-Up	[ ]	[ ]	[ ]
12.	77	Grooved Tread	[ ]	[ ]	[ ]
13.	78	Tread Slid-flat	[ ]	[ ]	[ ]
14.	80	Scrape etc > 1/8 inch	[ ]	[ ]	[ ]
15.	81	Wheel Out of Gauge	[ ]	[ ]	[ ]
16.	83	Cracked or Broken Plate	[ ]	[ ]	[ ]
17.	84	Hole in Plate	[ ]	[ ]	[ ]
18.	85	Wheel Loose	[ ]	[ ]	[ ]
19.		Out of Round	[ ]	[ ]	[ ]
Other standard		wheel defects			
20.		Subsurface Cracks	[ ]	[ ]	[ ]
21.		Stress Conditions	[ ]	[ ]	[ ]
22.		Wheel Skew	[ ]	[ ]	[ ]
23.		Hot Wheel	[ ]	[ ]	[ ]
24.		Wheel Diameter Variation	[ ]	[ ]	[ ]

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III. Cost/Benefit Considerations

A. In determining the value of the RBWG for the industry, we are concerned with three questions.
   1. What specific savings will the RBWG generate?
      a. In improved safety?
      b. In fewer change-outs by Class I roads?
      c. In more efficient maintenance and inspection operations?
      d. In extended wheel life?
      e. In improved fleet utilization?
   2. How can the your organization achieve these savings?
   3. How can we quantify these savings?

B. What Savings will the RBWG generate?
   1. Improved safety
      a. accidents and derailments prevented
         (1) list accident histories for past five years caused by specific wheel defects.
   2. Given the number and distribution of change-outs by Class I roads listed above in Section II B, what savings would you expect to achieve by reducing your change-outs by Class I roads due to the improved quality and consistency of the wheel inspections generated by the RBWG?
      a. ______________________________
      ____
      ____
      ____
   3. More Efficient Maintenance and Inspection Practices
      a. To what extent would the elimination of the requirement to inspect wheels reduce manpower requirements in your inspection and maintenance procedures?
         (1) How ______________________________
         ____
         ____
         (2) How many inspectors are employed as train walkers?
            (a) Number of inspectors ____________
         (3) What functions do they perform other than wheel inspections?
         ____
         ____
         ____
      b. Could these functions be performed more efficiently?
         (1) either by incorporating them into the rbwg or
            i) Yes [ ]
            ii) No [ ]
         (2) Having the inspection process return to the visual procedure of having an inspector inspect the cars at a fixed location as they passed by instead of walking the train?
            i) Yes [ ]
            ii) No [ ]

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4. Extended Wheel Life
   a. To what extent would the higher quality of the inspections generated by the RBWG allow you to run closer to the AAR condemning limit resulting in a longer effective wheel life?______________________________

   b. To what extent would the lower cost of the wheel inspections provided by the RBWG allow more frequent inspections and thus allow you to lower your in-house condemnation limits and thus extend wheel life? __________

5. What impact do existing failures of your wheel inspection process have on creating avoidable unscheduled maintenance?

6. Would an automated wheel inspection process as a very first step in your scheduled maintenance program improve the scheduling of your wheel work and thus lead to faster throughput in your maintenance program?
   a. Yes [ ]
      (1) How ______________________________
   b. No [ ]

C. Therefor what price both in terms of one time costs and annual maintenance could be justified by these savings?
   1. Capital
      a. $____________
   2. Operating
      a. $____________/year

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IV. Technological considerations

A. Should the device be designed to operate at the slow speeds of yard operations or for high speed main line operations?
  1. Slow speeds [ ] ____-_____ MPH
  2. High speeds [ ] ____-_____ MPH

B. If the system needs to be designed for high speed operation, what are the necessary and desirable speeds which it should be able to handle?
  a. Necessary ___ MPH
  b. Desirable ___ MPH

C. To what extent would a rr be willing to adjust this speed to enhance the operation of the gauge? ______________________
____

D. If the device was located in a train yard, what is the optimal location for the device in the yard? ______________________
____

E. Would the system have access to an existing AEI reader or would it have to have its own reader to determine the car number?
  1. An AEI tag reader is available [ ]
  2. An AEI reader would have to be added [ ]

F. Would the your operation be able to construct a shed to shelter the system?
  1. Yes [ ]
  2. No [ ]

G. What is the range of axle loads in your operation?
  1. ____ tons to ____ tons.

H. Are there any truck designs in active use or in contemplated use that would restrict line of sight access to the back face of the wheel?
  1. No [ ]
  2. Yes [ ] Describe ______________________________
____
____

I. How much time is available on a daily and weekly basis to perform maintenance on the system in Hump operations?
  1. Daily ______ hours
  2. Weekly ______ hours.

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V. Market Size

A. Where would you locate a RBWG?

1. Plant [ ]
2. Mine [ ]
3. Maintenance facility [ ]

B. How many units of the RBWG would you require for your operation?

____

Completed by _______________________ Organization ____________________
Title _______________________ Phone ____________________
Date ___/___/___

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APPENDIX D

Proposed Cooperative Research Agreement with NIST

CRADA Identification Number:
Collaborator:
Collaboration Project Title:

Appendix A
The Research Plan

NIST requires the information listed below. The company name, address and the project title are needed for public disclosure. The Collaborator may consider the information in items 6, 7, 9 and 10 proprietary. If the Collaborator wishes any of the information in items 6, 7, 9, or 10 kept proprietary, the Collaborator should label the information "PROPRIETARY INFORMATION" and place the information on a separate page. NIST must be willing to accept this information as proprietary.

1. Collaboration Project Title (Please provide a brief project title that NIST may use for public disclosure and management reporting.): EMAT RR Wheel Crack & Stress Technology Transfer

2. Collaborator Eligibility. In order to assure compliance with section 2 of the Federal Technology Transfer Act of 1986 (15 U.S.C. 3710a), the Collaborator must provide the following information to NIST (please check the appropriate box):

[X] Collaborator certifies that it is not subject to the control of any foreign company or government, and agrees to notify NIST within thirty days should it become subject to the control of a foreign company or government at any time during this agreement; or

[ ] Collaborator acknowledges that it is subject to the control of the following foreign company or government (if a company, please specify nationality):

____
Company Name, Country/Government

Collaborator certifies to NIST that it is incorporated under the laws of one of the states or territories of the United States; and that it has a manufacturing presence in the United States; and that the foreign government listed above permits United States agencies, organizations, or other persons to enter into cooperative agreements and licensing agreements.

3. Collaborator Participation in NIST's Advanced Technology Program. NIST will enter into CRADAs with recipients of awards from the Advanced Technology Program ("ATP"). However, as a general policy, NIST will not accept, under CRADAs, contributions of ATP funds from ATP recipients. Collaborator hereby states that: (Please check the appropriate box.)

[X] Collaborator is not a recipient of ATP funds.

[ ] Collaborator is a recipient of ATP funds, and the research to be conducted under this CRADA is part of the ATP project.

[ ] Collaborator is a recipient of ATP funds, and the research to be conducted under this CRADA is not a part of the ATP project.

CRADA Identification Number:
Collaborator:
Collaboration Project Title:

4. **NIST's Principal Investigator (include mailing address and telephone number):**

Ray Schram
NIST
Boulder, Co
(303) 497-3232

5. **Collaborator's Principal Investigator (or Principal Contact, include telephone and mailing address):**

Zahid Mian
IEM Corporation
71 Fourth Street, Troy NY
(518) 273-2445 Ext. 11

6. **Proposed Duration and starting date for the CRADA:** 1 Year, 6/14/94

7. **Collaborator Equipment, Facility, and/or Funds Contributions:** Instrumentation and Sensor Lab, Test Track Simulator, $10,000 in personnel time

8. **NIST Personnel, Services, Facilities and/or Equipment Contributions:**

9. **Collaborator's Project Team (please list):**

Name	Telephone
Zahid Mian	
Richard Arthur	All personnel at
Bill Peabody	(518) 273-2445
Peter Hays	

10. **The Research Project:**

(Please describe the research project. The description should: 1) state the project's objectives, and 2) detail the research approach sufficiently to permit your management chain to review the proposed collaboration. A brief description, usually one page, is usually sufficient.)

This project involves technology improvement and transfer to commercial sector of RR EMAT-based wheel crack and stress detection technologies.

APPENDIX E

Market Literature - Automatic Equipment Identification System

APU 102

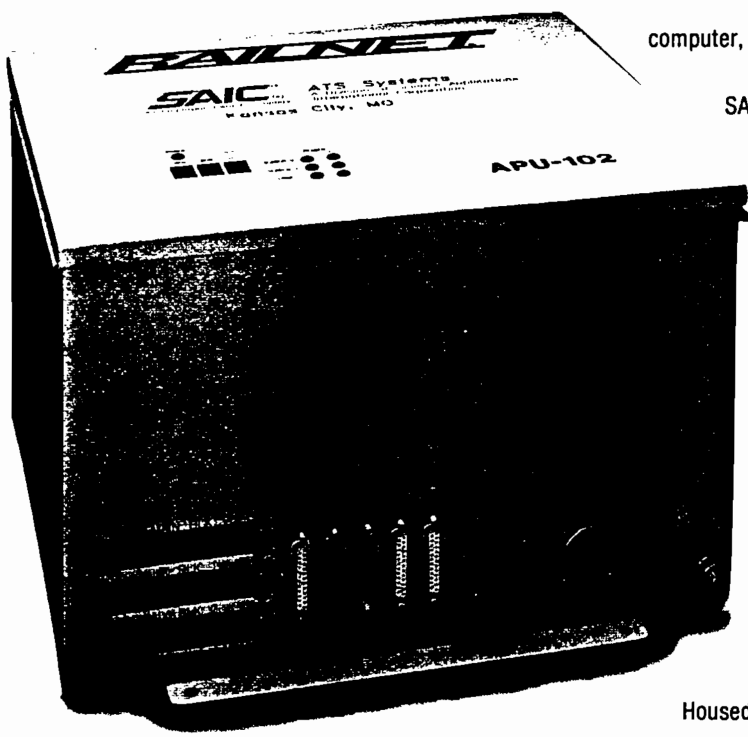
AUTOMATIC EQUIPMENT IDENTIFICATION CONTROLLER

FEATURES

- Provides a "clean list consist" for tagged and untagged equipment
- Provides a double track interface and tag disqualifier logic that eliminates tag multipathing problems
- Provides the ability to download new code or change the system parameters via modem or the local port
- Provides a password protected menu driven user interface to communicate with the system, including on-line help for all menu selections
- Transmits "train consists" and maintenance reports to multiple locations upon inquiry, or automatically
- Performs extensive system diagnostics, automatically or upon request
- Provides a non-volatile "mini remote support" mode that allows the system to be completely regenerated from scratch remotely
- Provides full control and remote access to the Amtech reader logic board(s)
- Controls and performs the Amtech "check tag" test sequence
- Expandable to support up to two internal and two external AI-1200 readers and up to eight external AR-2200 RF units
- Standard communications protocol such as TCP/IP and Xmodem can be integrated to the system architecture to meet customer requirements

SAIC's RAILNET APU-102 is designed to identify equipment by reading electronically coded Amtech tags mounted on locomotives, railcars, trailers, end-of-train units, and other rolling stock. It stores all tag data, including time and date, train direction, and speed through the AEI site. Information is stored by train sequence and can be reviewed through remote or local access.

The APU-102 is based on the industry standard IBM-AT class central processing unit configured on the STD bus platform. This configuration allows the utilization of a wide base of off-the-shelf interface products to meet hardware and software requirements. The system incorporates the STD bus computer, Amtech reader logic board, SAIC wheel detector interface board, DC power supply, modem, and mother board. Connected to an Amtech AR2200 RF unit, the system can identify vehicles, read transponders, and generate "clean consists" at train speeds up to 79 mph. Housed in a ruggedized enclosure, the APU-102 conforms to AAR specifications for equipment identification.



APU 102

AUTOMATIC EQUIPMENT IDENTIFICATION CONTROLLER

SPECIFICATIONS

Processor
Standard: 80486 @ 25 MHz
Optional: Currently available "State-of-the-Art"

CPU Memory
Standard: 512 KB
Optional: 1MB, 2MB

Solid-State Disk
Standard: 1MB (33-100 car trains)
Optional: 2 to16 MB (Up to 528-100 car trains)

Reader Unit
Standard: Amtech model AI-1200 reader module (Qty 2 for APU-102D)
Optional: Amtech model AR-1301 STD bus reader module

External RS-232 Serial Ports
Standard:
#1 Local port
#2 Amtech reader 1 Aux port
#3 Amtech reader 2 Aux port (If installed)
#4 Double track communications
#5 Defect detector, scale

Modem
Standard: Internal 2400 baud V.22 MNP-5
Optional: 9600 baud

Telephone Ports
Standard: 2 RJII (Software selectable)
Optional: Per customer requirements

Input Ports
Standard: 6-Opt-Isolated (Active Low)
Optional: STD bus card expandable per customer requirements

Output Ports
Standard: 6 (Active Low/High/Open Collector)
Optional: STD bus card expandable per customer requirements

Alarms
Standard: AC power fail
Optional: Per customer requirements using opto-isolated inputs

Watchdog Circuit
Standard:
Watchdog circuit located on STD bus COM4
Restarts the computer automatically if hardware or software fails

APU-102 Software
Standard: Railnet APU-102 single and double track for railcar, locomotive, EOT

APU Host Interface
Standard: Host interfaces and maintenance reporting currently supported are:

TCS	Union Pacific
COMPASS	Burlington Northern
EDI-160	Contrail
EDI-160	Southern Pacific
EDI-160	Canadian Pacific

Idle Power Requirements
15.36 Watts 24 VDC @ 640ma

Train Presence Power Requirements
28.8 Watts 24 VDC @ 1200ma

Dimensions
13.5" x 16.5" x 10.5" (HWD)

Weight
31 lbs

Temperature Range
-40C to 70C

Humidity
95%, non-condensing

OPTIONS

Standard Software Interfaces:

Dynamic Tags
Reads and performs specialized decoding and reporting options based on the data within the tag

AEI Intermodal
Interfaces and controls multiple readers to read single and double stack containers in addition to standard engine, railcar, and EOT tags

Railnet Video Hybrid
Utilizes the SAIC-designed "REDI" (Railnet External Data Interface) to interface the APU-102 to a video hybrid system. The APU-102 performs its standard tasks in addition to providing the video system with proper tag placement data that allows the hybrid system to send only the pictures of untagged equipment.

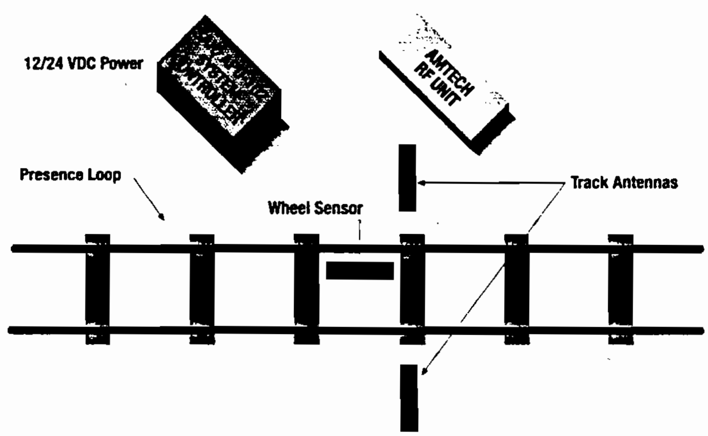
Defect Detection System Interface
Utilizes "REDI" to interface APU-102 to defect detection systems. The APU-102 performs its standard functions in addition to providing the defect detection system with proper tag placement data and then appends the host report with the wheel defect data.

Coupled-in-Motion Scales
Utilizes a standard ASCII interface and time correlation to properly place the correct acquired weight with the appropriate tagged or untagged equipment

Car Dumper Interface
Utilizes software to acquire and decode tags in a real-time environment and sends data to a host

Real-Time Event Alarms
Time stamps a real-time event or alarm condition provided by a contact closure and correlates it with the proper equipment and tag data

Basic APU-102 Configuration



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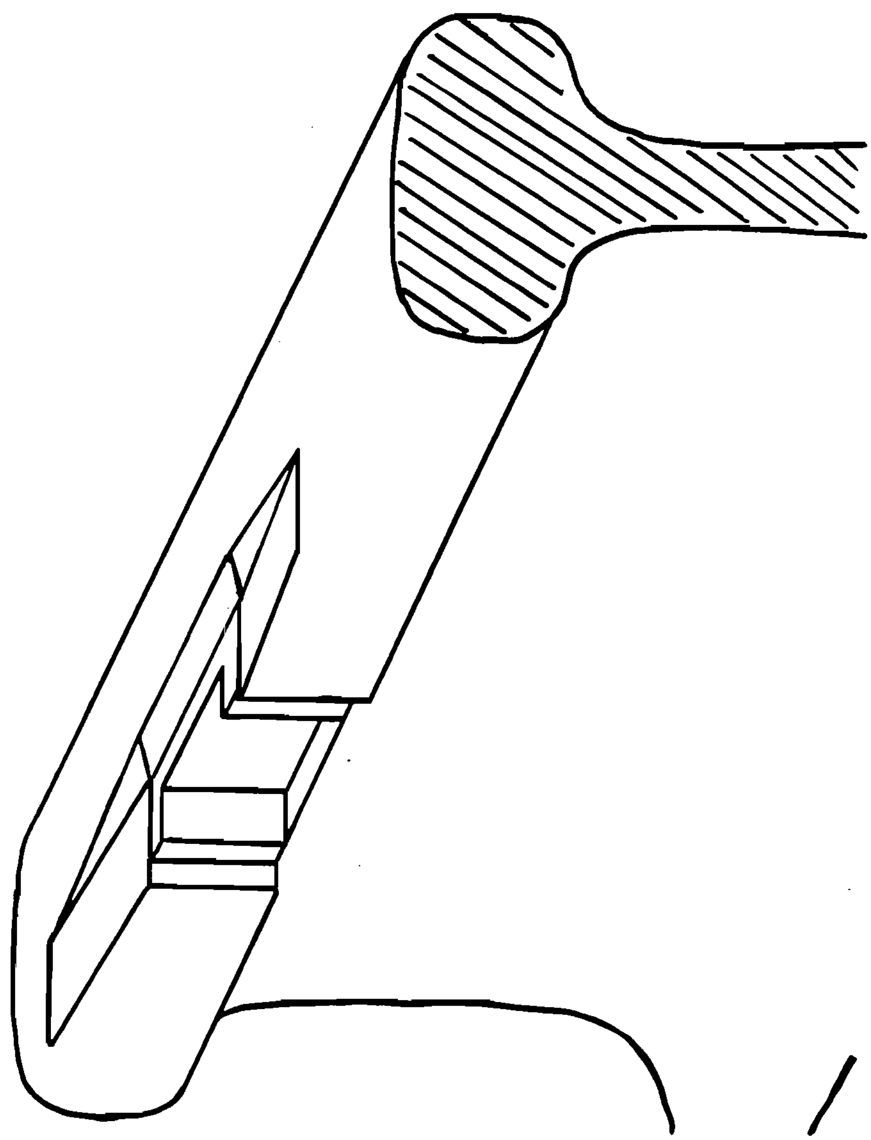
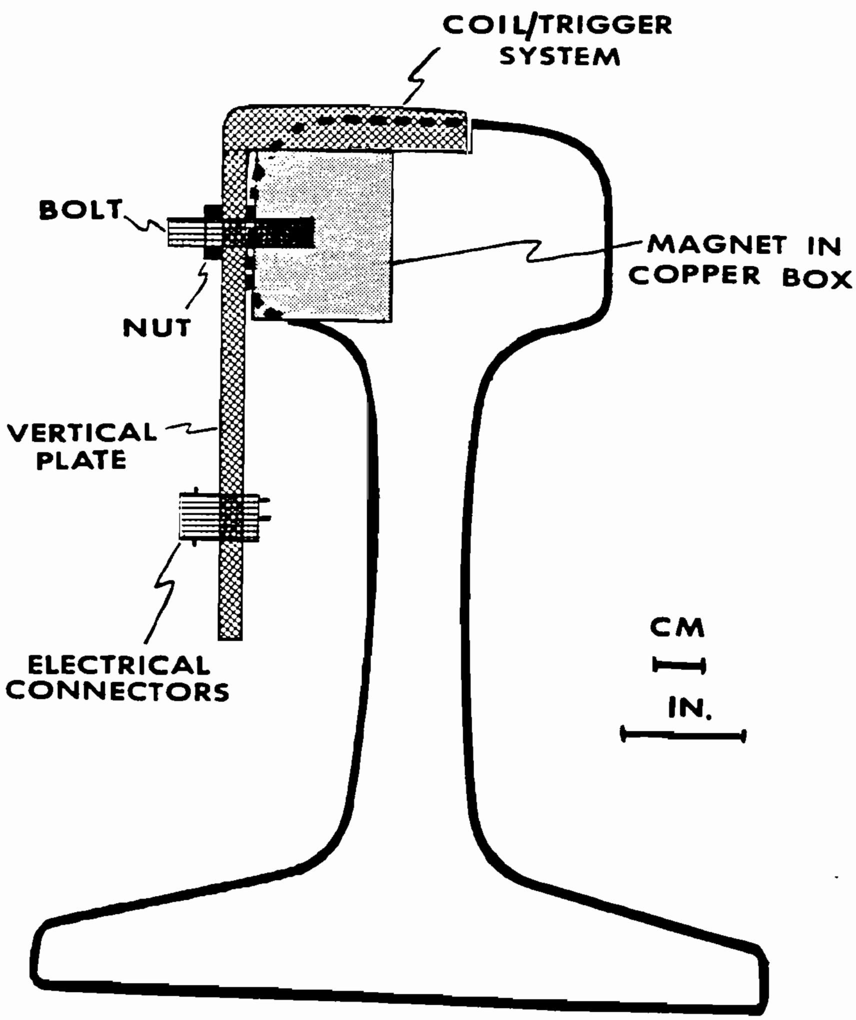
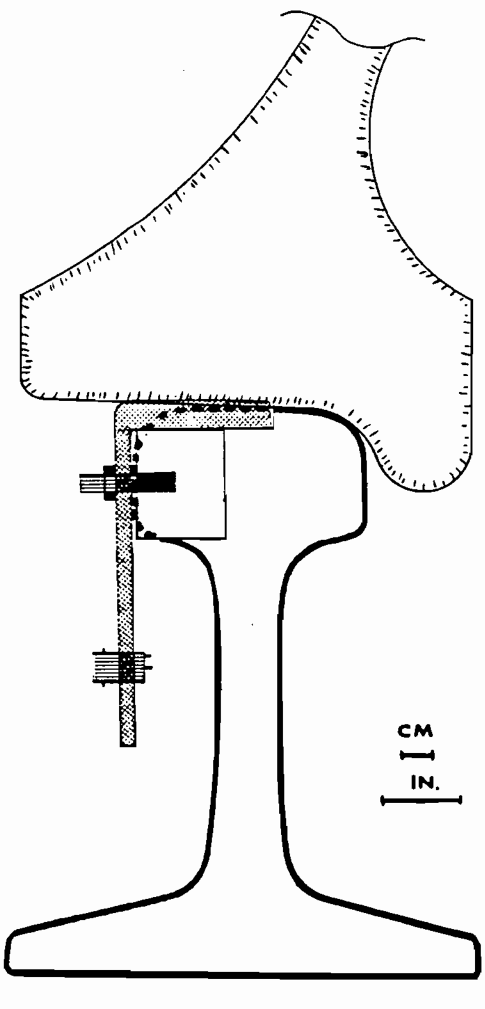
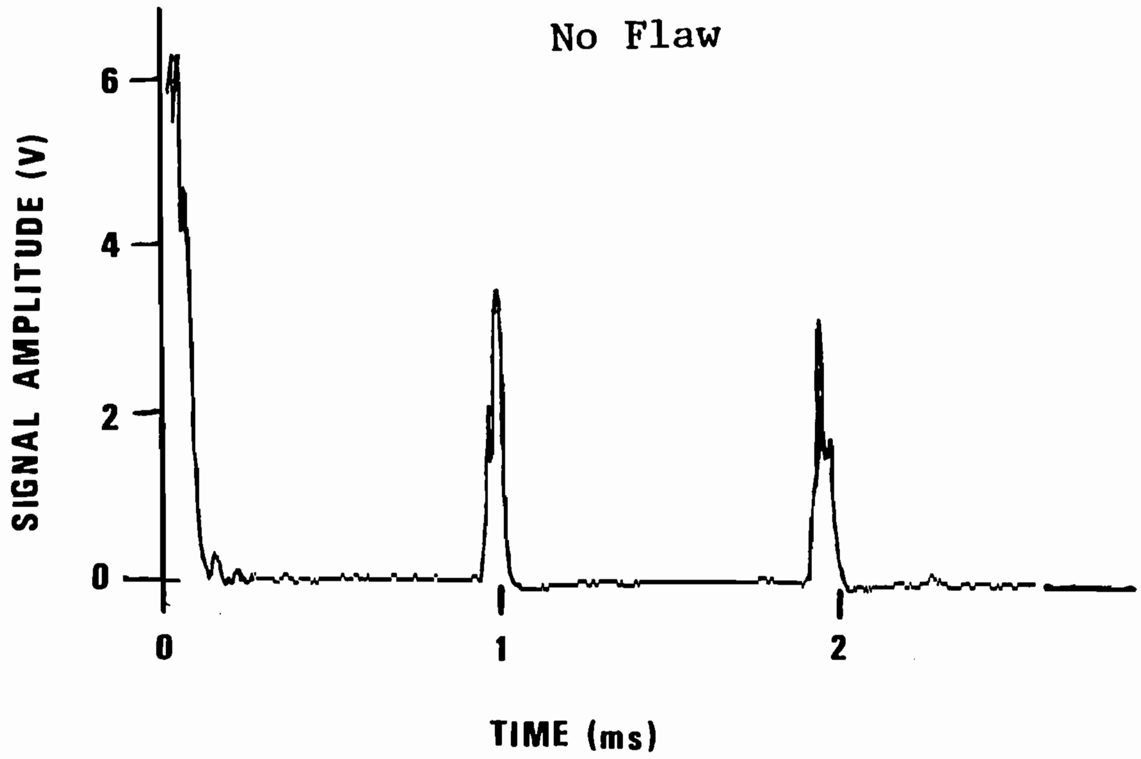
APPENDIX F

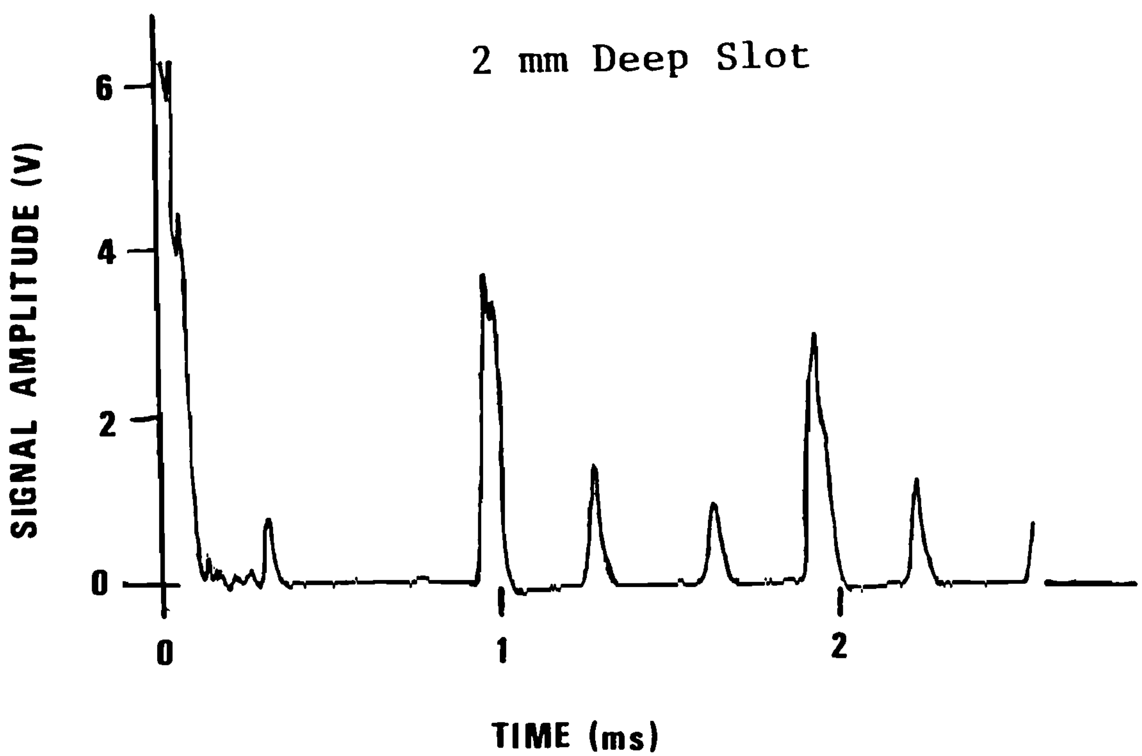
Sample Illustrations NIST EMAT System


BC
VERT
PL
ELE
CON


COIL/TRIGGER SYSTEM
BOLT
NUT
MAGNET IN COPPER BOX
VERTICAL PLATE
ELECTRICAL CONNECTORS
CM
IN.

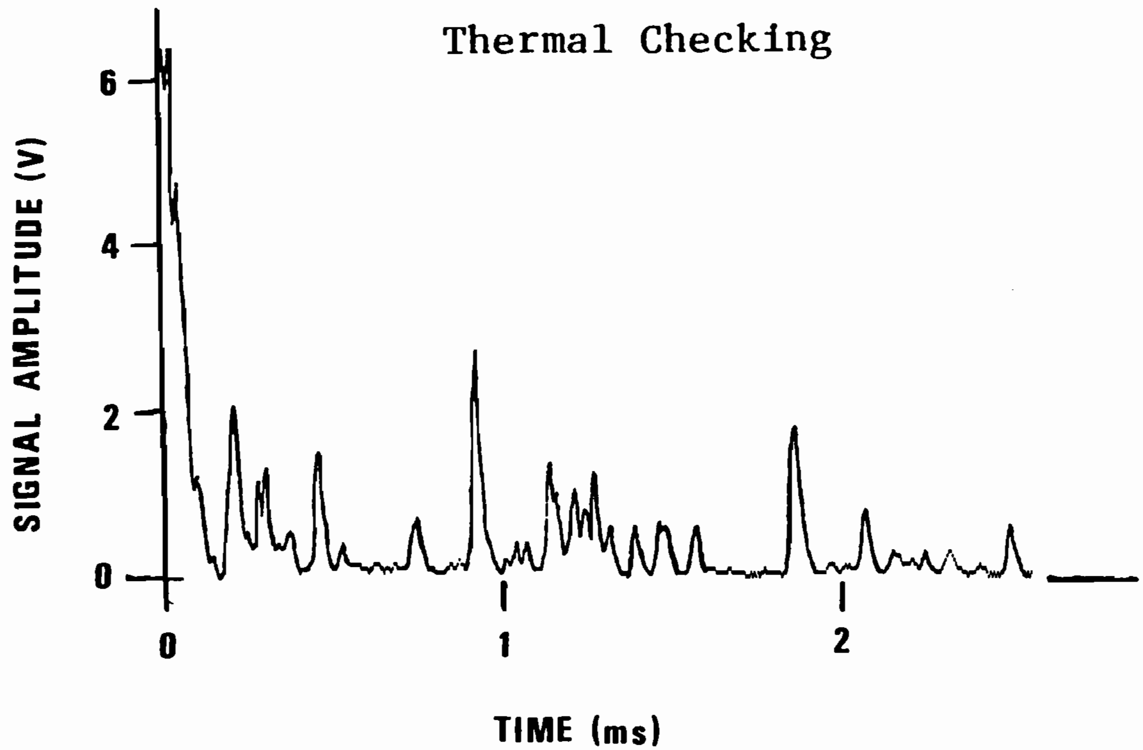

CM
IN.

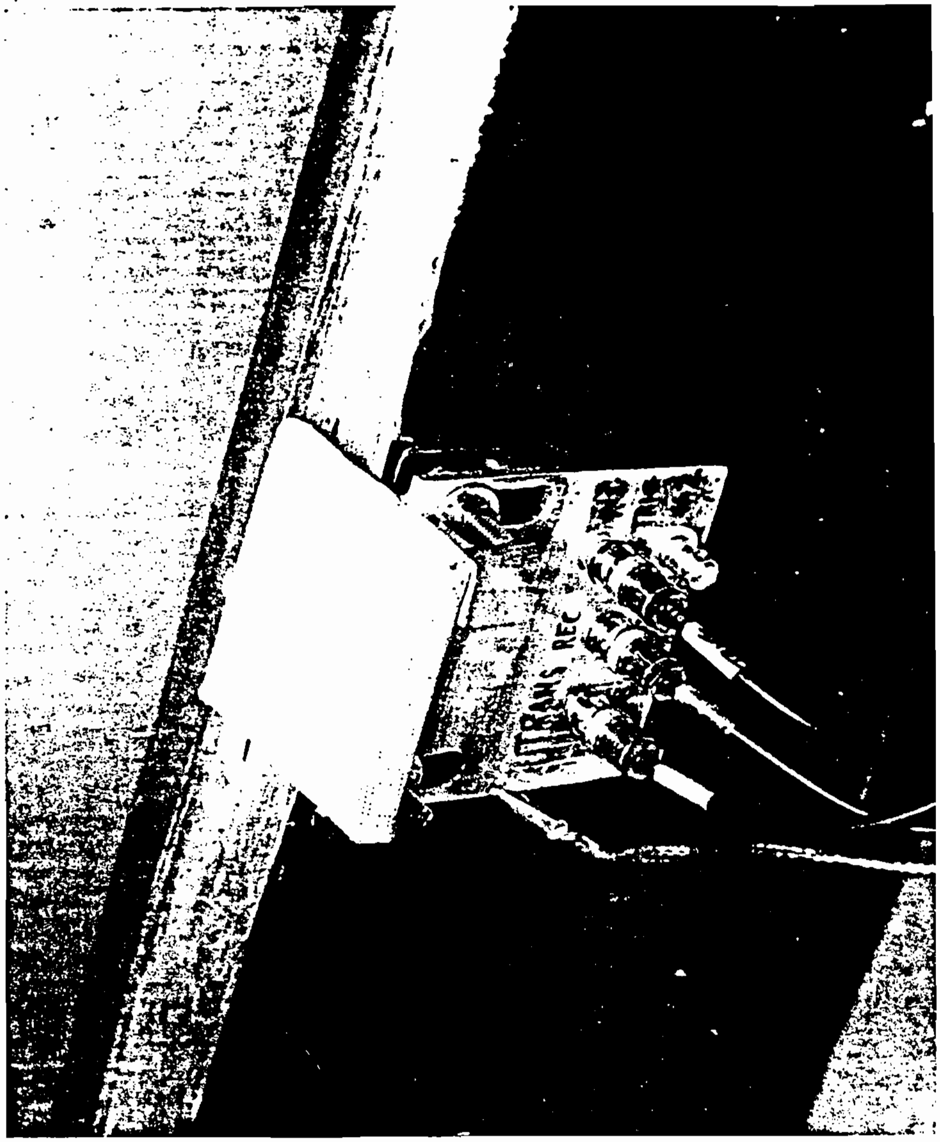

No Flaw
SIGNAL AMPLITUDE (V)
6
4
2
0
0
1
2
TIME (ms)

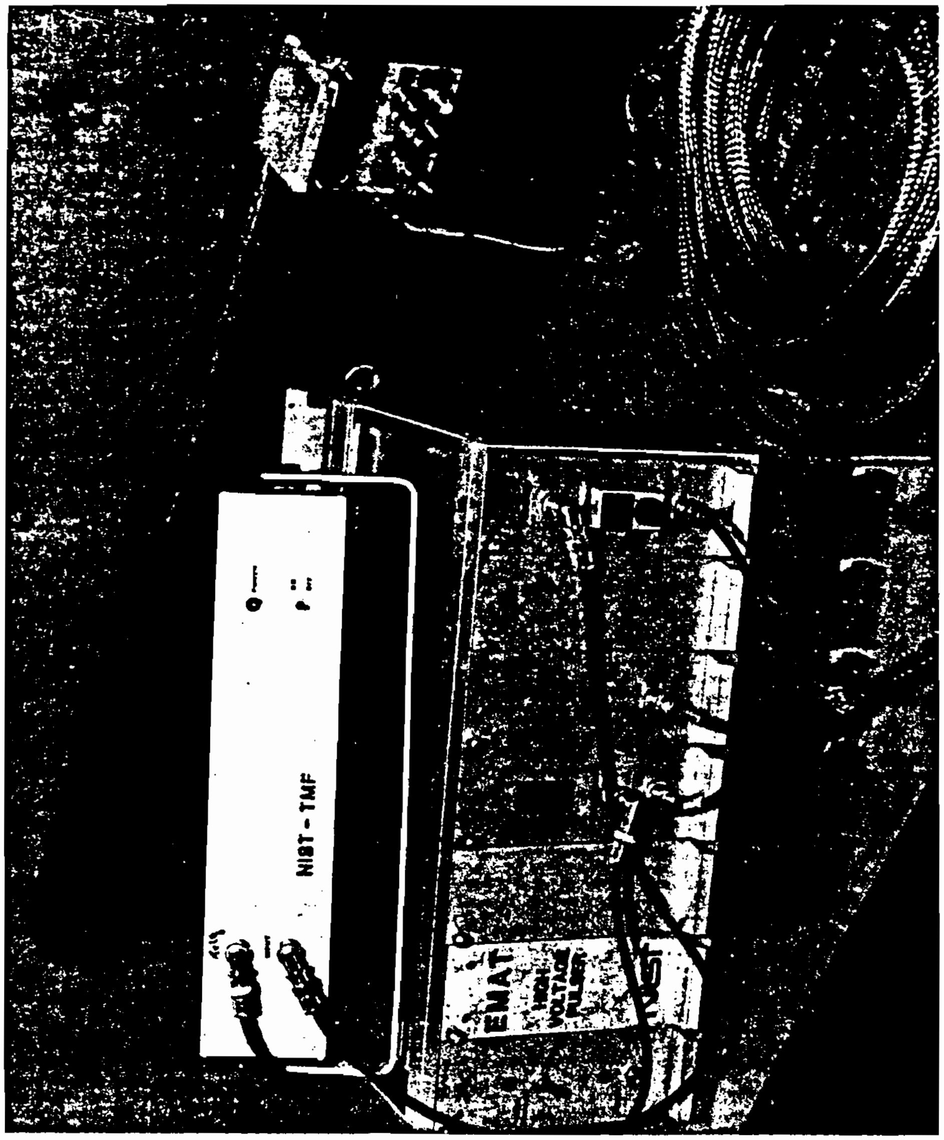


Thermal Checking

Thermal Checking






NIST - TMF
EMAT

APPENDIX G

Electronic Wheel Gauge/Steel Wheel Gauge Comparison

COMPARISON OF THE ELECTRONIC WHEEL GAUGE
AND
THE FINGER GAUGE IN AAR BILLING

In the past four years, IEM has conducted eight studies comparing measurements taken with the IEM Electronic Wheel Gauge and the Standard Steel Wheel Gauge at various wheelshops and rip tracks throughout the United States.

The purpose of these studies has been to determine what, if any, impact the Electronic Wheel Gauge would have on AAR Bills. The results, summarized in the following table shows that measurements taken with the Steel Wheel Gauge tend to overstate wheel size by an average of 1.7 sixteenths of billable material per wheelset. This error comes from five factors:

First, operators very often will tilt the steel wheel gauge when they actually determine the rim thickness. This tilting can increase the apparent size of the rim by one sixteenth or more.

Second, operators tend to remove the gauge from the wheel when they take the flange thickness measurement. This action very often causes the flange finger to get pushed out slightly increasing the apparent size of the wheel.

Third, the 3Read Software built into the IEM Gauge automatically helps the operator identify the most worn part of the wheel.

Fourth, operators sometimes make very large and costly measurement errors.

Fifth, all the contact points of the IEM Gauge are manufactured out of extremely hard steel so it is not subject to the same wear and tear as a finger gauge.

The IEM Electronic Wheel Gauge will not take a measurement unless the Gauge itself determines that it is properly placed on the wheel. It then prompts the operator to take three readings and clearly displays the most worn flange and rim readings. The features, built into the design of the IEM gauge, result in significantly more accurate wheel readings and equally significant savings for the railroad.

Study	Sample Size (# of Wheelsets)	Savings (# of billable 16ths/wheelset)
Eastern Wheelshop I	74	2.1
Eastern Rip Track I	20	4.5
Eastern Wheelshop II	74	2.2
Eastern Wheelshop III	70	1.0*
Western Wheelshop I	72	1.8
Field Test I	160	1.3
Western Rip Track I	47	1.0
Western Wheelshop II	39	1.7
Total	556 Wheelsets	1.7 Sixteenths

Value of 1.7 sixteenths of service metal at $32/16th = $54.

*IEM believes that this study significantly understated the actual measurement differences since the railroad conducting the study did not include flange measurements and ignored all rim differences of less than 2 16ths.

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