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TEST AND EVALUATION OF RAIL FLAW DETECTION TECHNOLOGIES

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by

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13. Abstract

Internal flaws in rail occur as a consequence of the accumulation of fatigue under repeated loading. Inspection of the rail to detect flaws before they progress to complete failure is thus very important. Advanced nondestructive inspection techniques are being pursued to improve rail safety, inspection productivity, and reduce train delays related with delayed action on the repair of non-critical rail flaws.

Evaluations of various types of detector cars operating over known flaws in rail are being conducted at the Transportation Technology Center (TTC) on the Rail Defect Test Facility (RDTF), located on a gauntlet track. The facility was constructed in 1997 for a test program jointly sponsored by the Association of American Railroads and the Federal Railroad Administration (FRA) to provide member roads, the FRA and suppliers with a tool to assess detection technologies over known flaws in a controlled environment. Ongoing and future evaluations of new and emerging technologies are planned for the RDTF and will be conducted with funding from the jointly sponsored test program. Rail flaw data collected during testing will be made available to various program participants to assess improved analytical detection techniques. The test program will continue to sponsor the assessment of new and improved signal processing techniques to improve the reliability of signal interpretation by testing such concepts on the RDTF at TTC.

This report focuses on the RDTF, results from evaluations performed on the RDTF, and future testing of improved and new rail flaw detection technologies planned at TTC.

Additionally, a history of rail flaw detection is provided and a description of typical flaws found in North America, along with information on technology currently used for rail flaw detection.

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EXECUTIVE SUMMARY

Internal flaws in rail occur as a consequence of the accumulation of fatigue under repeated loading. Inspection of the rail to detect flaws before they progress to complete failure is thus very important. Nondestructive inspection techniques are being pursued to improve rail safety, inspection productivity, and reduce train delays with delayed action on the repair of non-critical rail flaws.

Evaluations of various types of detector cars operating over known flaws are being conducted at the Transportation Technology Center (TTC) on the Rail Defect Test Facility (RDTF), located on a gauntlet track. The facility was constructed in 1997 for a test program jointly sponsored by the Association of American Railroads and the Federal Railroad Administration (FRA) to provide member roads, the FRA and suppliers with a tool to assess detection technologies over known flaws in a controlled environment. Ongoing and future evaluations of new and emerging technologies are planned for the RDTF and will be conducted with funding from the jointly sponsored test program. Rail flaw data collected during testing will be made available to various program participants to assess improved analytical detection techniques. The test program will continue to sponsor the assessment of new and improved signal processing techniques to improve the reliability of signal interpretation by testing such concepts on the RDTF at TTC.

This report focuses on the RDTF, results from evaluation performed on the RDTF, and future testing of improved and new rail flaw detection technologies planned. Additionally, a history of rail flaw detection is provided and a description of typical flaws found in North America, along with information on technology currently used for rail flaw detection.

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1.0 INTRODUCTION

The continued increase in axle loads with higher train speeds and less track time available for inspections has made the task of detecting internal and external rail flaws more demanding. The primary focus of rail flaw detection is to assure safe transportation of passengers and commodities through the detection of flaws prior to service disruption.

Detection of rail flaws before they progress to complete failure is important. Based on data from the FRA's 1995 Accident/Incident Bulletin No. 164, track integrity problems such as broken rails, transverse defects, and vertical split heads rank third as the cause of train derailments. An estimate of the annual economic cost for rail flaw inspection is $76.3 million and derailments related to rail flaws is approximately $109 million according to FRA's Accident/Incident Bulletin data . It is estimated that increasing the reliability of detection through process improvements and technology enhancements can help to reduce inspection costs and derailments related to rail flaws by approximately 25 percent for a savings of $46 million annually.

2.0 OBJECTIVES

The railroad industry in cooperation with TTCI and the Federal Railroad Administration (FRA) has been developing and evaluating improved nondestructive evaluation (NDE) technologies for use in rail flaw inspections. NDE technologies being developed include laser ultrasonics, low frequency and remote field eddy current testing, and ultrasonic inspection using electromagnetic acoustic transducers (EMATs). The AAR and FRA have funded a variety of contractors and universities to study the feasibility of various NDE technologies for rail flaw detection. Investigations into flaw propagation and growth are also being studied to determine critical crack sizes. To provide a rational basis to determine remedial action for detected rail flaws, the FRA has initiated the use of fracture mechanics analysis. Rail flaw contractors have continued to increase the capabilities of their inspection systems with the introduction of various transducer arrays to detect flaws throughout the railhead and sections of the web. The development and implementation of computer software to assist in signal interpretation and report generation is also under way. Operator training and retention is a contractor priority in an effort to improve detection reliability and repeatability.

Through efforts being pursued by the railroad industry, along with the FRA, improved reliability and efficiency of rail flaw detection is anticipated.

3.0 RAIL FLAW DETECTION RESEARCH

In cooperation with the regulatory agencies, the railroad industry has taken a proactive approach in addressing rail flaw detection by pursuing improved rail efficiency and economics through the development of maintenance practices that increase rail service life. The AAR has identified track integrity monitoring as a strategic research initiative (SRI) to develop improved rail flaw inspection (SRI No.7). This effort was initiated in 1996 and its objectives include the improvement in reliability and safety of rail operations by developing improved rail flaw detection methods as well as fostering the development of improved rail flaw detector systems. The U.S. Department of Transportation's FRA and Volpe National Transportation Systems Center (VNTSC) have initiated a Rail Integrity Research Program. The focus of the program is on improving railroad safety through the reduction of rail failures and the associated risks of train derailments, while improving railroad economics by developing production or maintenance practices that increase rail service life.[2]

The AAR and FRA are co-sponsoring a test program being performed by TTCI at the Transportation Technology Center (TTC) in Pueblo, Colorado, to assist in the development of rail flaw technology. Through the test program, TTCI has installed the Rail Defect Test Facility (RDTF), with rail containing flaws found during in-service rail flaw inspections performed by AAR member inspection crews or their rail inspection subcontractors. The flawed rail in the test bed is maintained by TTCI and made to the FRA, individual railroads, research organizations, including universities, and equipment manufacturers involved in developing and inspecting rail for flaws.

Rail received by TTCI is evaluated for internal and external flaws using visual, ultrasonic, radiographic and other NDE methods. The flaws found during evaluation have been categorized by type, size, and location and entered into a rail flaw database. The rail installed into the RDTF is entered into another database that lists the source railroad, flaw location in track, size of the flaws at initial installation, and size of the flaws at periodic inspections after installation. The RDTF installation has been a joint effort between the AAR member railroads, the FRA, and TTCI. This track was specifically developed for research and test purposes to enhance technology and verify system capability.

The RDTF is set up as a gauntlet track on the Balloon Loop at TTC. The length of the RDTF is approximately 1890 feet and includes both tangent and curved track. Rail installed into the RDTF ranges from 119-pound to 140-pound rail sections. The rail has been joined using electric flashbutt welding, thermite welding, or joint bars. The majority of the rail is worn and a best effort approach was used in matching profiles when joining one rail to the next. Flaws supplied to date include transverse defects (TD), defective field welds (DFW), vertical split heads (VSH), horizontal split heads (HSH) and bolthole cracks (BHC). The TD's are primarily detail fractures and compound fissures. External flaws supplied to date include shelling, flat spots, slivers, flaking, and chips. Figures 1 and 2 identify tangent and curved sections of the RDTF.

Figure 1. Tangent Section of the Rail Defect Test Facility

Figure 2. Curved Section of Track on the Rail Defect Test Facility

4.0 BENCHMARKING RESULTS ON THE RDTF

The RDTF installation was completed in November 1997, and the first rail flaw inspections were performed over the test track in November and December 1997. The RDTF currently contains over 70 flaws from rail supplied by AAR member railroads. Table 1 lists the flaws currently installed at the RDTF. The track is designed so that the rail sections can be re-positioned as required. The track can also be modified to represent areas of tension and compression to simulate both warm and cold weather inspection environments. These environments are a concern with flaw detection response varying during states of compression or tension. This effect can be easily verified at the RDTF or on other tracks located at TTC. A continued effort is being made to receive and catalog rail with flaws induced during service. The rail is being sent to TTC and will be added to the sample selection on the RDTF.

Table 1. List of Flaws Currently Installed into the RDTF at TTC

Flaw Type	Number of Flaws
Transverse defects	42
Defective Welds	4
Horizontal Split Heads	4
Vertical Split Heads	1
Bolt Hole Cracks	2
Crushed Heads	10
Shells	18

Benchmarking evaluations of six different hi-rail ultrasonic inspection systems were performed between February and May 1998. The evaluations were performed by three North American rail flaw contractors to provide a base line characterization of current capabilities for detection of known flaws on the RDTF located at TTC. The purpose of the benchmark evaluations was to provide a base line for comparison when improvements in the current technology are made or new technologies are introduced.

As stated, the RDTF is an industry tool used to provide consistent evaluation of rail flaw technology over flaws typical to the rail in North American track.

The benchmarking evaluations on the RDTF were performed to determine the capability of the detector systems to find flaws in track. There were 49 flaws used for benchmarking purposes. It should be emphasized that the flawed rail located in the RDTF was supplied by member railroads and are flaws that were found during in service inspections. The flaws included transverse defects with sizes ranging from 3 to 73 percent of the cross sectional head area, horizontal and vertical split heads, bolt hole cracks, and defective welds. The TD's consisted of those located under shells (seven) and those with no apparent surface anomalies (thirty-three). Table 2 lists the flaws used to perform the benchmarking evaluations at TTC.

Table 2. List of Flaws used during Benchmarking Evaluations on the RDTF

Flaws Type	Flaw Size % Head Area or inches (cm)	Number of Flaws
Bolt Hole Crack (BHC)	0.25 & 0.38 (0.64 & 0.97)	2
Defective Weld (DW)	5-15%	4
Horizontal Split Head (HSH)	2 x 1 (5.1 x 2.5) & 3 x 2 (7.6 x 5.1)	2
Transverse Defect (TD)	3 – 10%	17
Transverse Defect (TD)	11 – 20%	9
Transverse Defect (TD)	21 – 40%	9
Transverse Defect (TD)	41 – 80%	5
Transverse Defect (TD)	81 – 100%	0
Vertical Split Head (VSH)	120 (304.8)	1

The benchmarking evaluations have been performed in participation with member railroads, the FRA, the rail flaw detection contractors, and technical staff from TTCI. The detector cars used during the evaluations were all hi-rail vehicles equipped with ultrasonic inspection technology (rail bound detector cars with induction systems have not been evaluated on the RDTF to date). The evaluations were performed under as near to normal car operations as the track would allow. Evaluation speeds were in the range of 4 mph to 7 mph (6.4 km/h to 11.3 km/h), due to the transitions from the various rail sections used to assemble the RDTF. Steps used for the evaluations included:

1. Pretest meeting before all evaluations
    - objectives identified for evaluations
    - schedules determined for evaluations
2. Evaluations performed on the RDTF
    - evaluations performed using normal car operations
    - flaws verified by hand mapping
    - positive hits identified by detection system
    - false hits not recorded during benchmarking
3. Post test meeting after evaluations
    - Findings reviewed from evaluations
    - Consensus established on results
    - participation by suppliers, railroads, and TTCI

The hits (detected rail flaws) were subsequently verified by railroad and TTCI personnel as the detector car and inspection crew identified them. Flaws not detected by the detection systems were identified after the rail flaw run and verified by all participants (Figure 3). Results of the six benchmarking evaluations are identified in Tables 3 and 4. The evaluations are identified as evaluation number 1 (E1) through evaluation number 6 (E6). The detection percentage for each of the six evaluations is shown in Table 5 and includes the number of hits possible and the number of flaws actually detected.

Overall, 72 percent of all known flaws in place were detected in the six benchmarking runs, with a breakdown by defect type as follows:

- The reliability of detecting bolt-hole cracks was 33 percent.
- The reliability of finding defective welds was 54 percent.
- The reliability of finding TDs was 75 percent, with a breakdowns as follows:
  - — 66 percent for TD's 20 percent in size and smaller
  - — 96 percent for TD's 21 percent in size and larger
- The reliability of finding horizonal split heads was 92 percent.
- The reliability of finding the vertical split head was 100 percent.

Figure 3. Flaw Verification Using Ultrasonic Hand Mapping with Participants Observing

Table 3. Results of Benchmarking Evaluations on the East Rail of the RDTF

Flaws		Flaws Detected					
Type	Size	E1	E2	E3	E4	E5	E6
BHC	0.25 in. (0.64 cm.)	Y	N	N	Y	N	N
BHC	0.38 in. (0.97 cm.)	Y	N	N	Y	N	N
TD	3%	N	Y	N	N	N	Y
TD	3%	Y	N	Y	N	N	N
TD	4%	N	Y	N	Y	Y	N
TD	5%	N	Y	N	Y	Y	Y
TD	5%	N	Y	N	N	Y	Y
TD	5%	Y	N	N	N	N	N
TD	6%	N	Y	Y	N	Y	Y
TD	6%	Y	Y	Y	Y	Y	Y
TD	6%	N	N	Y	N	Y	Y
TD	8%	N	N	Y	N	N	Y
TD	14%	N	Y	Y	Y	Y	Y
TD	17%	N	Y	Y	Y	Y	Y
TD	18%	N	Y	Y	N	Y	Y
TD	19%	Y	Y	Y	Y	Y	Y
TD	20%	Y	Y	Y	N	N	Y
TD	23%	N	Y	Y	N	Y	Y
TD	24%	Y	Y	Y	Y	Y	Y
TD	25%	N	Y	Y	Y	Y	Y
TD	30%	Y	Y	Y	Y	Y	Y
TD	33%	Y	Y	Y	Y	Y	Y
TD	40%	N	Y	Y	Y	Y	Y
TD	42%	N	Y	Y	N	Y	Y
TD	45%	Y	Y	Y	Y	Y	Y
TD	48%	Y	Y	Y	Y	Y	Y
TD	68%	Y	Y	Y	Y	Y	Y
TD	73%	Y	Y	Y	Y	Y	Y
DW	5%	N	Y	N	Y	Y	N
DW	6%	N	Y	N	Y	N	N
DW	11%	Y	N	N	N	Y	Y
HSH	3 x 2 in. (7.6 x 5.1 cm.)	Y	Y	Y	Y	Y	Y

Table 4. Results of Benchmarking Evaluations on the West Rail of the RDTF

Flaws		Flaws Detected					
Type	Size	E1	E2	E3	E4	E5	E6
TD	3%	Y	Y	Y	Y	Y	Y
TD	4%	Y	N	N	Y	N	N
TD	5%	Y	N	Y	Y	Y	Y
TD	8%	Y	Y	N	Y	Y	N
TD	8%	N	Y	Y	Y	Y	Y
TD	10%	Y	Y	Y	Y	Y	Y
TD	10%	Y	Y	Y	Y	Y	Y
TD	11%	Y	Y	Y	Y	Y	Y
TD	14%	Y	N	N	Y	N	N
TD	14%	Y	N	N	Y	Y	N
TD	15%	Y	N	N	Y	N	Y
TD	21%	Y	N	Y	Y	Y	Y
TD	22%	Y	Y	Y	Y	Y	Y
TD	25%	Y	Y	Y	Y	Y	Y
DW	13%	Y	Y	Y	N	Y	Y
HSH	2 x 1 in. (5.1 x 2.5 cm.)	Y	Y	Y	Y	Y	N
VSH	120 in. (304.8 cm.)	Y	Y	Y	Y	Y	Y

In Table 5. Flaw Detection Percentage from Benchmarking Evaluations performed on the RDTF at TTC

Evaluation Identification	Actual Hits (49 Possible)	Flaw Hit Percentage
E1	32	65%
E2	36	73%
E3	34	69%
E4	36	73%
E5	38	78%
E6	37	76%

In 1992 a "Recommended Minimum Performance Guideline for Rail Testing" was incorporated as Section 2.2 in to the AREA's *Manual for Railway Engineering*. AREA is now the American Railway Engineering and Maintenance-of-Way Association (AREMA).[3] To paraphrase the introduction from Section 2.2: Rail testing is to be performed reliably and economically. The rail flaw detection system, which includes both the inspection equipment and the operator, strives to identify all rail flaws and must be done at testing speeds compatible with train operations at a price commensurate with the service.

The recommended guideline also states that 100 percent accuracy in testing is not within current capabilities and risk of failure is best controlled using a three-step approach consisting of:

1. Calibration of test cars against standard test specimens in a controlled environment.
2. Regular performance assessments of test cars and operators in regular testing service.
3. Adjustment of rail test cycles to account for reliability of testing.

The introduction to the recommended guideline concludes by suggesting a method to determine the capability of a test car, which is to have a base line of comparison. Having test cars run over a test section of rails containing known flaws best performs the base lining. This process for benchmarking or base lining is what has been performed at TTCI on the RDTF.

In the AREMA recommended guideline labeled Table 2-1, "Minimum Performance Guideline," a reliability ratio for detection of flaws peculiar to rail is shown[5] The recommended guideline identifies two categories of track. Category I includes all main track with annual tonnage equal to or exceeding 3 million gross tons per year (MGT/yr) (2.72 million gross tonne per year), or with train speeds equal to or exceeding 40 mph (64.5 km/h). Category II includes all sidings and track with annual tonnage less than 3 MGT/yr (2.72 million gross tonne per year)and train speeds less than 40 mph (64.5 km/h). Table 6 lists the mean of the detection percentage for detector car performance evaluated on the RDTF. Table 7 compares the reliability ratios from Table 2-1 of the

AREMA manual with the evaluation mean for the benchmarking tests. A graphical comparison of the AREMA recommended guidelines, for Category 1, and the RDTF evaluation mean is depicted in Figure 4. The data shows that evaluations performed on the RDTF are in close agreement with the recommended guidelines. The transverse flaws were the only type of flaws evaluated as they represent the greatest number of flaws in the RDTF. TD's less than 5 percent were not included to provide a direct correlation with the AREMA table. The evaluation mean for the benchmark evaluations was determined as follows:

$$M = \text{\% of all valid flaws found during each evaluation}$$

$$= \frac{\text{Number of verified flaws found during the RDTF evaluations}}{N}$$

where M = evaluation mean and

N = number of hit possibilities in the RDTF

Table 6.RDTF Benchmarking Flaw Hit Percentage (by Size)

Size (%)	Detection %	Possible	Detected
5	54%	24	13
6 to 10	75%	48	36
11 to 15	60%	30	18
16 to 20	79%	24	19
21 to 25	89%	36	32
26 to 30	100%	6	6
31 to 40	92%	12	11
41 to 50	89%	18	16
51 to 70	100%	6	6
71 to 100	100%	6	6

Table 7. Results of Benchmarking Evaluations on the RDTF

Percent Head Area	AREA/AREMA Recommended Guideline Category I/Category II		Evaluation Mean
5 – 10%	65%	55%	68%
10 – 20%	85%	75%	76%
21 – 40%	90%	85%	91%
41 – 80%	98%	95%	93%
81 – 100%	99%	99%	No Samples

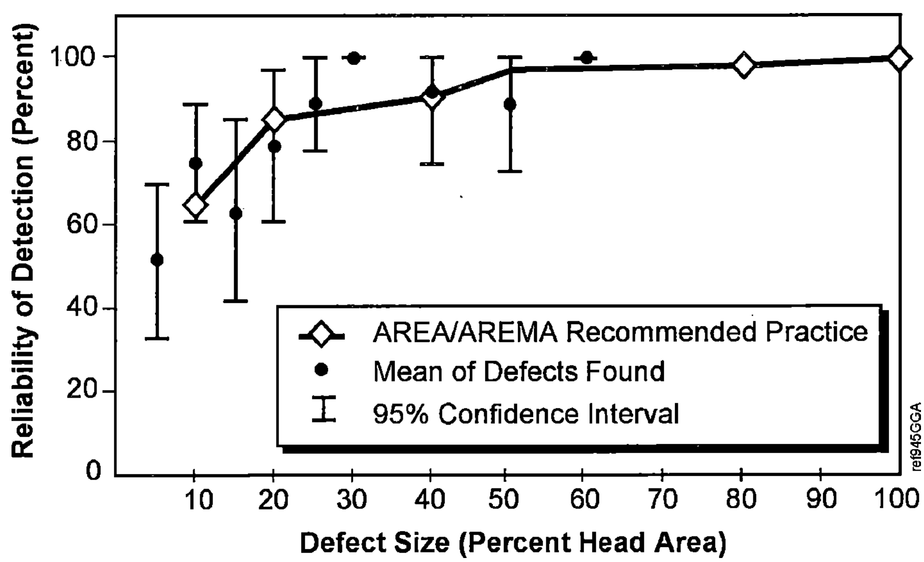

Figure 4. AREMA Recommended Guidelines (Category I) to RDTF Evaluation Mean Comparison

Current efforts in rail flaw detection to include both inspection capabilities and flaw growth characteristics require an emphasis on reliable detection and accurate sizing of flaws. A current waiver relies on the accuracy of flaw sizing and time of year to determine requirements for remedial action.[4] In cold weather or winter conditions, which in North America under the waiver is identified as the time period between November 15 to March 15, the waiver allows a 4-day grace period for flaws less than 20 percent of the cross sectional head area. In warm weather conditions, a 5-day grace period is allowed for flaws less than 25 percent of the cross sectional head area.

The waiver was initiated after a major North American railroad proposed to the FRA a strategy that allows flaws less than a certain critical size to remain in service for a predetermined grace period. The potential benefits of this strategy were identified as increased detector car utilization allowing for the detection of more flaws to include the larger more critical flaws that may go undetected due to inspection stoppage to replace smaller flaws. The waiver was granted after demonstration by the railroad on the accuracy of ultrasonic hand mapping. After hand mapping of the flaws, the defects were broken open to determine the correlation between the ultrasonic sizing and the actual defect size. The FRA in cooperation with VNTSC used various engineering models developed at VNTSC to correlate tests and predict performance in service during flaw growth. The use of the models and the confidence of accurate sizing demonstrations convinced the FRA to grant the waiver. A summary from a presentation given by the VNTSC identifies the following rationale for granting the waiver.[5,6]

- Fracture mechanics analysis of detail fractures provides a rational basis for setting the conditions of the test waiver.
- Simulation modeling of rail flaw detection and removal shows that detector car utilization is increased under this strategy compared to present practice.
- Risk/benefit assessment has shown that this concept is worthwhile.
- Analysis models are continuously developed to reflect the most recent research results.

5.0 FLAW GROWTH RATE STUDY

5.1 FLAW GROWTH RATES

A growth rate study sponsored by the FRA is being performed at TTC's Facility for Accelerated Service Testing (FAST) in an effort to determine growth rates of known transverse flaws in state of the art rail. Under current safety regulations, once flaws of certain sizes are located, they must be removed or otherwise protected. These size limits are based on anticipated growth rates. As the percentage of higher axle loads increase and rail quality advances, the database of flaw growth rates must also be updated. This effort allows for the monitoring of flaw growth rates under controlled conditions at FAST. Results from this study will provide a better understanding of flaw growth rates for transverse flaws of different sizes and orientations. The flawed rail is being supplied to TTCI by the AAR member railroads and rails used in the study are those rails manufactured using current technology and rolling processes. The rails used in the study will be subjected to traffic from heavy axle load conditions at FAST.

The growth rate of detail fractures (DF) in modern rail will be determined by placing rail sections containing DFs with initial sizes on the order of approximately 5 to 20 percent of the Cross Sectional Head Area (CSHA) in track at FAST. The growth of the DFs, due to normal FAST heavy axle load train operations, will be correlated with accumulated tonnage while continually monitoring the longitudinal stress state of the rail. Thus, a change in crack size can be associated with a specific amount of tonnage and longitudinal stress to predict a flaw growth rate. Performing this testing on approximately 10 detail fractures will allow for the determination of an experimentally established-statistically significant growth rate for calculating growth rates in revenue service for safety purposes.

Longitudinal stresses (tensile or compressive) in the rail can greatly affect the propagation rate of an existing crack or flaw. The longitudinal stress state of continuously welded rail can vary greatly during the course of a day due to thermal expansion (or contraction) caused by ambient temperature changes.

5.2 SELECTION

The initial size of the detailed fractures to be tested at FAST will be on the order of 5 to 20 percent of the CSHA. Approximately 10 separate flaws will be characterized. All will be obtained from revenue service. Flaws detected in revenue service which meet the required criteria will be shipped to TTC for an initial screening to document the size, type, and location of the flaw. The test rail will be a minimum of 10-foot long sections containing the identified defect near the center. The initial screening will consist of visual, ultrasonic, and radiographic examination.

5.3 INSTALLATION

Rail sections containing suitable flaws are being installed at FAST in both tangent and curved track. At FAST, the flawed rail will be installed in Sections 01 and 02. At this time, five of the flaws will be tested in Section 01, which is a tangent portion of track with wood ties. The other five samples will be tested in Section 02, which is a 5-degree curve with wood ties. There will be at least one flaw in each of the specified sections of track at any one time until research is completed. The rail sections containing the detailed fractures will be installed using appropriate (standard or premium) thermite welds subsequent to de-stressing of the track.

To ensure safe operation of the train during testing, loose angle bars have been installed around the detailed fractures (Figure 5). The angle bars have had their fishing surfaces machined to reduce contact with the rail during normal operations. The bolts used to apply the joint bars have been tightened and then backed off slightly to maintain support in the event of a rail break without transferring any load during testing. As an added safety measure, a fiber optics rail break detection system has been installed to monitor the continuity of the rail at the flaw location. The fiber optics is an added safety measure that has been implemented under the alternative rail break detection program.

In order to monitor the longitudinal stress state of the continuously welded rail, strain gages have been applied at the two defect sections prior to installation at the designated neutral temperature. The initial longitudinal stress and subsequent changes in strain are being monitored and correlated with flaw growth.

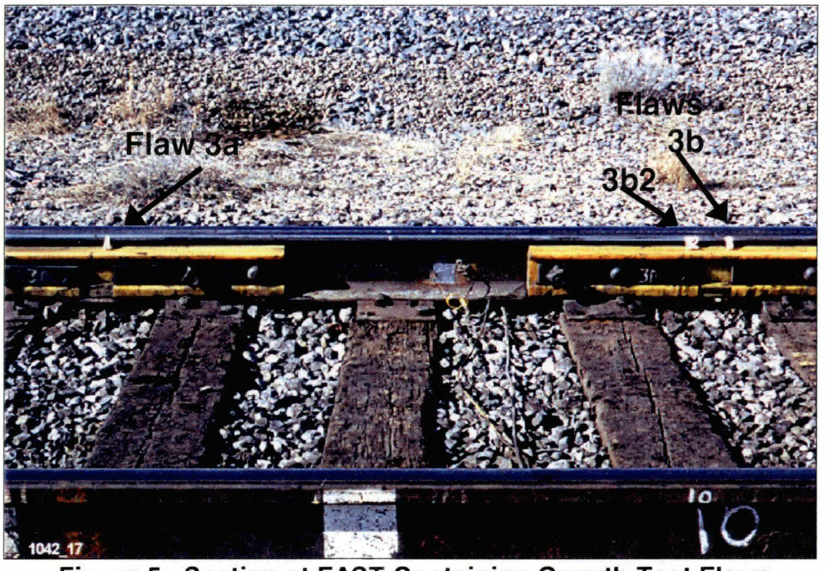

Figure 5. Section at FAST Containing Growth Test Flaws

5.4 MONITORING

The detailed fractures are monitored daily subsequent to normal FAST train operations in order to characterize the change in crack size with tonnage and longitudinal stress. Monitoring consists of visual examination of the rail along with ultrasonic hand mapping of the region. In the event the tonnage accumulated for the day is less than 0.5 MGT, the monitoring is deferred until the following day. However, no more than three days will pass without monitoring independent of tonnage because track longitudinal stresses could affect crack growth. When FAST ceases operation for extended periods, the project engineer determines a suitable measurement repeat period based on daily temperature swing and observed flaw growth rates. The crack will be allowed to propagate until the flaw has grown to approximately 50-percent of the CSHA or until total fracture causes removal from track.

5.5 ANALYSIS

Each detail fracture that grows to approximately 50-percent of the CSHA or totally fractures will be analyzed subsequent to in track monitoring. The specimens that did not totally fracture will be opened to reveal the detailed fracture. All specimens will be visually inspected and documented by a staff metallurgist or metallurgical technician to further characterize the detailed fracture and crack growth. The combination of the data from in track monitoring (crack growth from ultrasonic inspection while accounting for longitudinal stresses) and the visual inspection will allow calculation of detailed fracture growth rate in modern rail. Results from the testing on approximately 10 detail fractures will be supplied to the FRA and VNTSC for use in current flaw growth models.

In October 1998, two transverse defects of approximately 5 percent in size were installed into Section 01 at FAST and monitoring of the flaw growth rate was initiated. The flaws are separated by approximately 4 feet and are positioned at the gage side in the rail. The flaws are located in a 136-pound RE head hardened rail manufactured in 1990. FAST tonnage over the rail section in 1998 was approximately 26 MGT with minimal flaw growth (3 to 5 percent of the CSHA) being observed. Data will continue to be collected during 1999 and a more in depth report containing results of testing will be published at a later date.

6.0 NEW TECHNOLOGIES FOR RAIL FLAW DETECTION

A variety of new technologies are being pursued and evaluated to increase the reliability of rail flaw inspection. These efforts are being performed by the railroads, the various rail flaw detection contractors, the FRA, and the AAR/TTCI in conjunction with various university collaborations. The efforts are focused on new developments in current technologies, the development of new and emerging technologies, the use of computer software and neural networks to enhance signal interpretation, and operator training.

Efforts by TTCI through AAR's Improved Rail Integrity SRI, includes funding and participation in the development of two NDE technologies. The two NDE methods are laser-ultrasonic and eddy-current technologies. The Massachusetts Institute of Technology (MIT) is developing the laser-ultrasonic technology and Karta Technology, Inc. is developing the eddy-current method for adaptation to rail flaw inspection. The two systems are scheduled for evaluation on the RDTF this year.

6.1 MIT RESEARCH (LASER ULTRASONIC)

Research being performed by MIT focuses on a non-contact and remote NDE method for rail flaw detection. MIT is developing laser ultrasonic technology that operates on the same basic physics as conventional ultrasonic technology in that laser UT can be used to produce longitudinal, shear, and surface waves as well as plate and interface waves. Conventional ultrasonics uses piezoelectric transducers (PET) for sound wave generation and requires a coupling medium (couplant) to generate the sound wave into the rail. The laser ultrasonic method is non-contact and does not require a couplant. Laser generation of ultrasound in a material results from a rapid localized heating supplied by the laser pulse optical energy. The thermal expansion of the material produces stress fields that propagate through the material as ultrasound. An advantage of the laser UT method is that it is non-contact and remote so the laser beam can be directed using mirrors and lenses to provide quick scanning of large surfaces and complex wear shapes of the railhead.

In nondestructive applications using laser ultrasound, the generation of sound waves must take place in the thermoelastic regime to avoid damage to the surface of the rail. Lasers require a means for amplification and a means to feed the energy back into the system to build up sustained oscillation. The laser induces the ultrasound through heat shock; which includes heating the body of a surface suddenly causing thermal expansion of the material, which produces mechanical stresses to initiate sound waves. The generation of the heat is between 10 and 20 nanoseconds allowing for the generation of high frequency shock waves in the range of 1 to 30 MHz. The use of higher energy sound generation provides a considerable increase in sound pressure by producing a plasma layer build up on the surface of the test piece. In this range the sound pressures are in the same range as piezoelectric generators and will avoid damage to the surface being inspected.

Phase I of the research being performed at MIT includes determining the feasibility of laser ultrasound for rail flaw detection. A presentation given by MIT in July 1998 provides an overview of their current status in which MIT identifies the methods used to generate the laser UT for the detection of transverse defects in the head of a rail.[7] The rail being used at MIT was supplied by TTCI from rail donated by the railroads for the development of rail flaw technology. The rail section is 136-pound RE containing 11 and 67 percent TD's oriented at 90 degrees from the gage face with no shelling of the railhead.

To confirm the presence of the TD using laser generation, MIT configured a pair of piezoelectric transducers with 45-degree angle wedges to perform through transmission evaluation of the railhead, as Figure 6 shows. A similar set up was then performed using the laser for transmission and a PET for the receiver as Figure 7 shows.

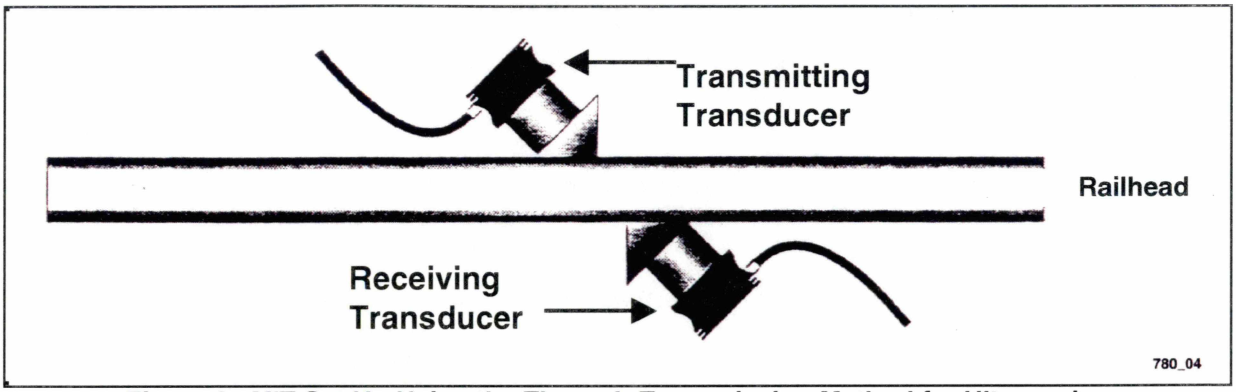

Figure 6. MIT Set Up Using the Through-Transmission Method for Ultrasonic Inspection of a Railhead With Piezoelectric Transducers (Top View)

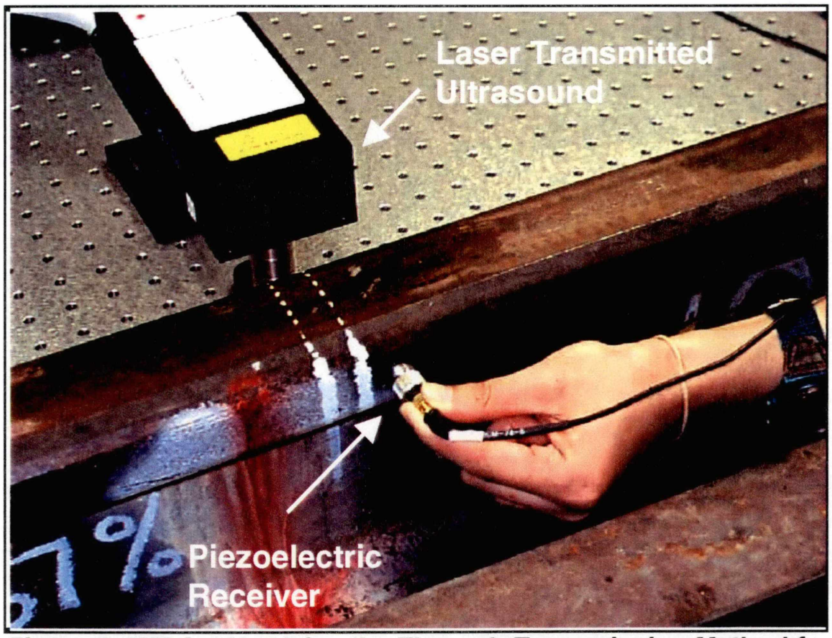

Figure 7. MIT Set Up Using the Through-Transmission Method for Ultrasonic Inspection of a Railhead with Laser Induced Ultrasound and a PET Receiver (Top View)

A radio frequency (RF) signal was used to monitor the waveform established with the PET and the laser UT systems. If a flaw, in this case the TD, is not present, then the signal detected by the receiver will be displayed on the CRT as Figure 8 shows for the PET system and Figure 9 (top) shows for the laser system. When a TD is present the display on the CRT will show a decrease or complete loss of the transmitted signal as Figure 10 shows for the PET system and Figure 9 (bottom) shows for the laser system. The signals generated with the PET and the laser systems are similar showing that laser ultrasound does provide comparable interrogation of the railhead to conventional ultrasonic methods. The primary difference between the UT methods is that the transmitted signal originating in the PET system requires a liquid couplant and contact with the railhead while the signal generated from the laser system does not require either. If the laser technology being developed at MIT proves to be reliable, it will be mounted to a high rail vehicle at TTC and evaluated over known flaws on the RDTF.

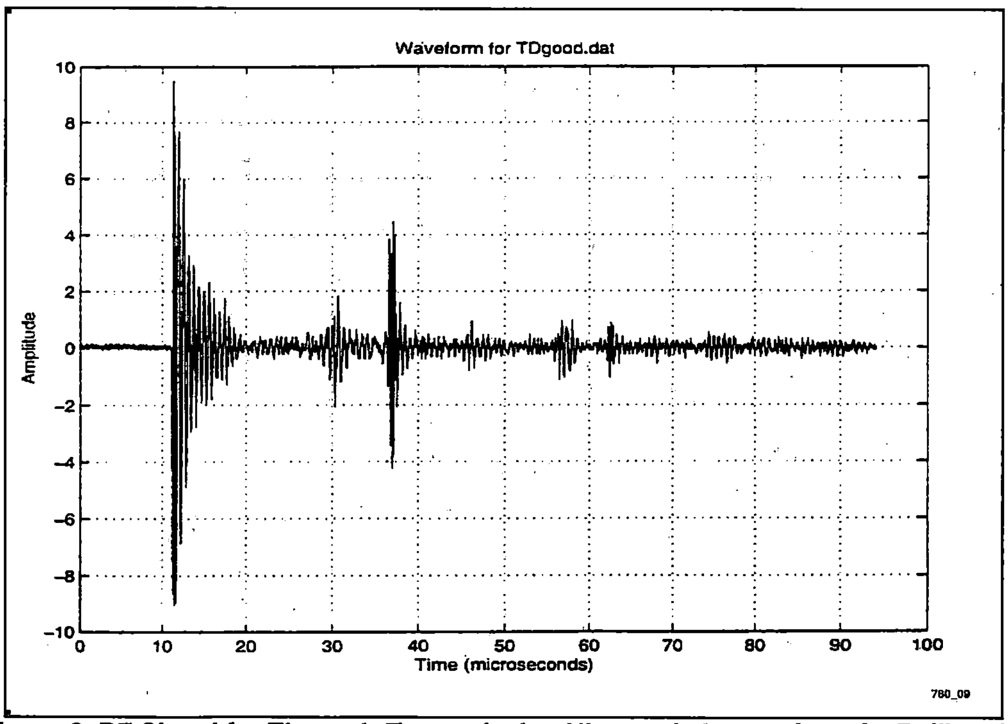

Figure 8. RF Signal for Through-Transmission Ultrasonic Inspection of a Railhead using Piezoelectric Transducers when a Discontinuity is not Present

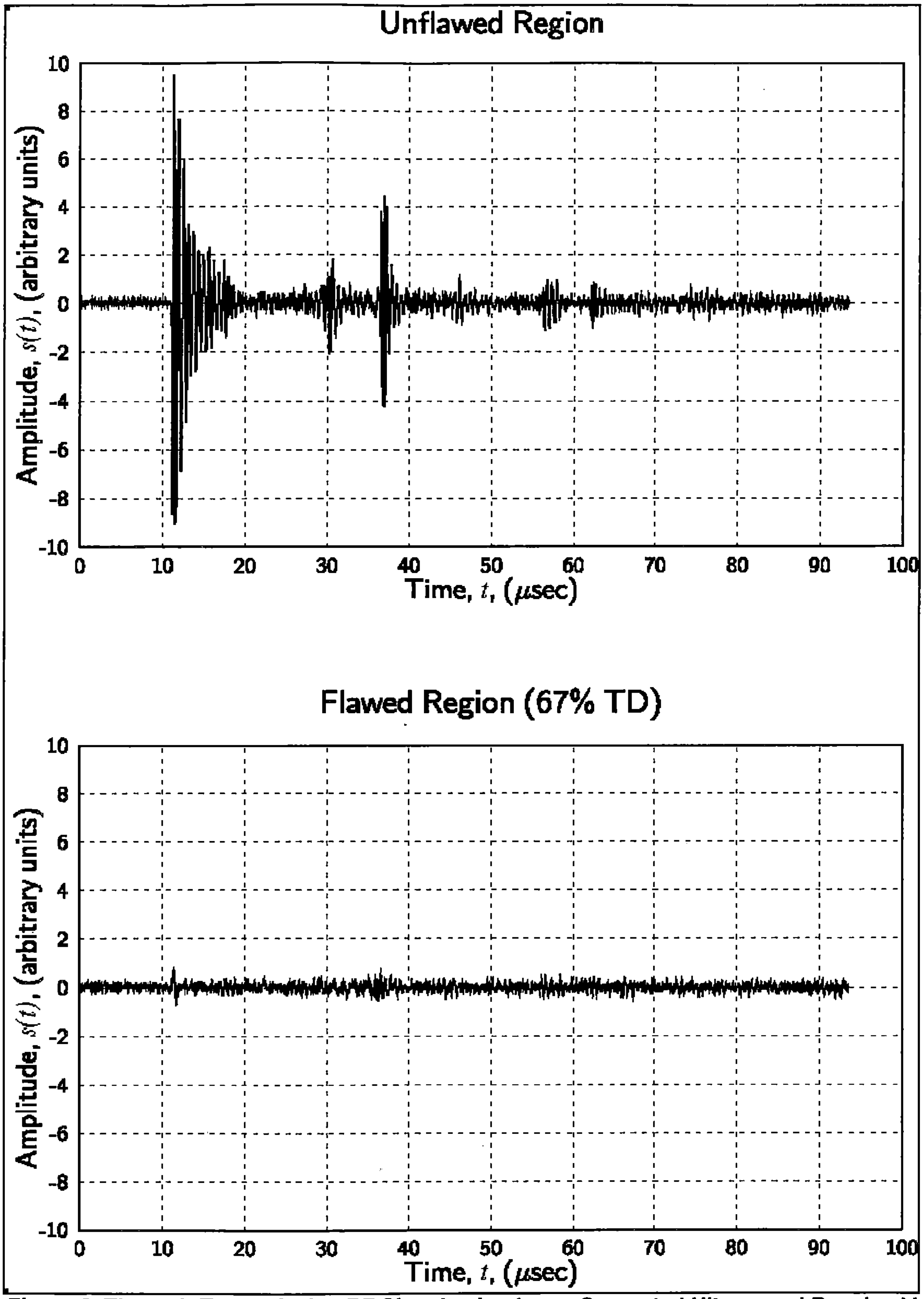

Figure 9. Through-Transmission RF Signal using Laser Generated Ultrasound Received by a Piezoelectric Transducer. Top Figure Shows the Signal When a Flaw is Not Present and the Bottom Figure Shows the Signal When a Flaw is Present.

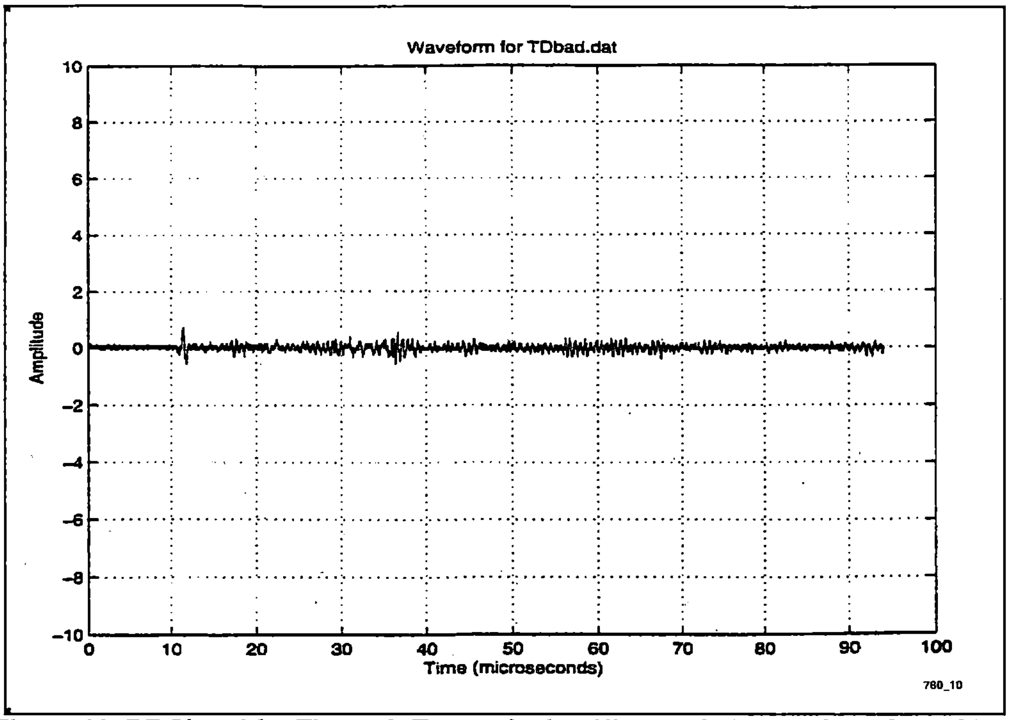

Figure 10. RF Signal for Through-Transmission Ultrasonic Inspection of a Railhead Using Piezoelectric Transducers when a Discontinuity is Present

6.2 KARTA TECHNOLOGY (EDDY CURRENT)

The research being performed by Karta Technology, Inc. focuses on adapting eddy current technology to rail flaw detection. Eddy current is an electrical current induced into a conductor by a time varying magnetic field. Eddy current is used as a nondestructive test method by inducing eddy current flow into a test object. A change in the eddy current flow will occur when variations in the test object cause field fluctuations to be reflected and detected by a nearby coil. Magnetic flux sensors are used to analyze the variations in current flow.[8]

Conventional eddy current techniques are limited by skin effect considerations (the depth of penetration into a conductor decreases as the frequency of the current is increased) and are typically restricted to non-ferromagnetic materials. Karta's approach uses a combination of the remote field eddy current (RFEC) and the low-frequency eddy current (LFEC) methods to address the skin effect and material limitations. RFEC is an electromagnetic NDE method currently used in flaw evaluation of ferromagnetic tubing. LFEC is an electromagnetic method that transmits energy bi-directionally to minimize limitations from the skin effect. The intent is to combine the advantages of both methods to reliably detect flaws in the rail. Figure 11 shows a model of the RFEC/LFEC probe design for transverse crack detection. Comparisons of the two eddy current methods, as identified by Karta, are listed below.[9]

! Low Frequency Eddy Current (LFEC)

- Single coil acts as both sensor and exciter.
- Monitors impedance of coil.
- Skin effect limited to near surface discontinuities.
- Directly applicable to ferromagnetic materials by placing the material under magnetic saturation.
- Signal levels monitored are typically high, making the technique robust.

! Remote Field Eddy Current (RFEC)

- Sensor in remote field of exciter coil.
- Monitors phase of the sensor coil voltage.
- Not limited by skin effect because energy is transmitted bi-directional.
- Works with any conductive material.
- Signal levels detected are typically low, making the technique less robust.

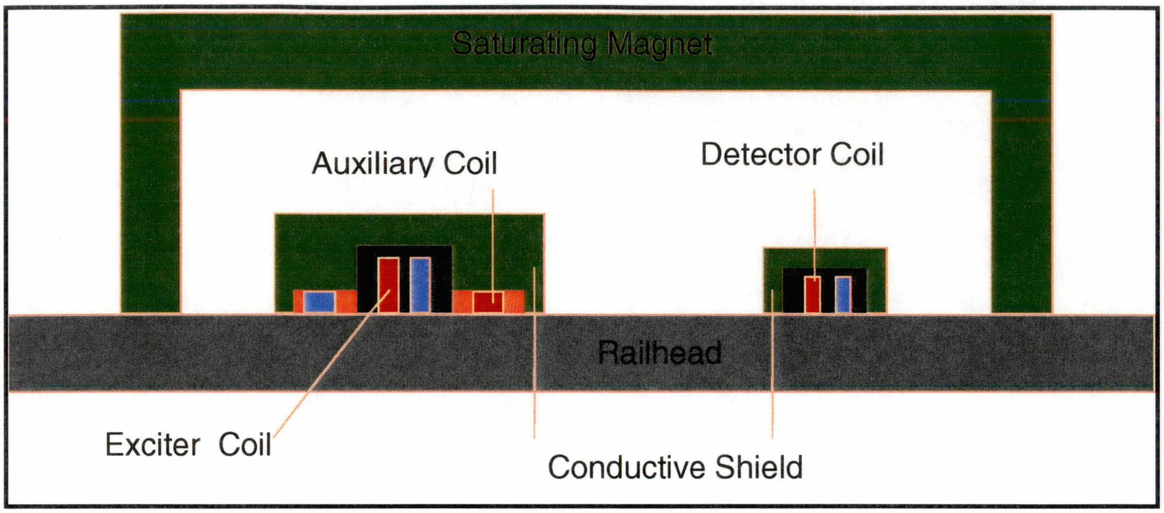

Figure 11. RFEC/LFEC for Transverse Crack Detection

Karta is determining the feasibility of the LFEC and RFEC methods in Phase I of the contract. Phase I includes the design and evaluation of various RFEC-LFEC probes with test equipment already available. The types of probe designs being evaluated by Karta are shown in Figure 12. The probe variations range from the most simple design (pancake coil) to test the feasibility of the eddy current method to slightly more complex probes to include an air-core cylindrical coil, a ferrite-core cylindrical coil, and a ferrite-potcore cylindrical coil. Once a sensor has been developed and optimized for transverse crack detection, it will be evaluated at Karta to determine its capability to detect the transverse flaws located in the rail supplied by TTCI. If it is determined, at the end of Phase I, that the sensors developed can reliably detect transverse defects in the laboratory environment, the sensor selected will be mounted to a hi-rail vehicle at TTC and the eddy current technology will be evaluated on the RDTF.

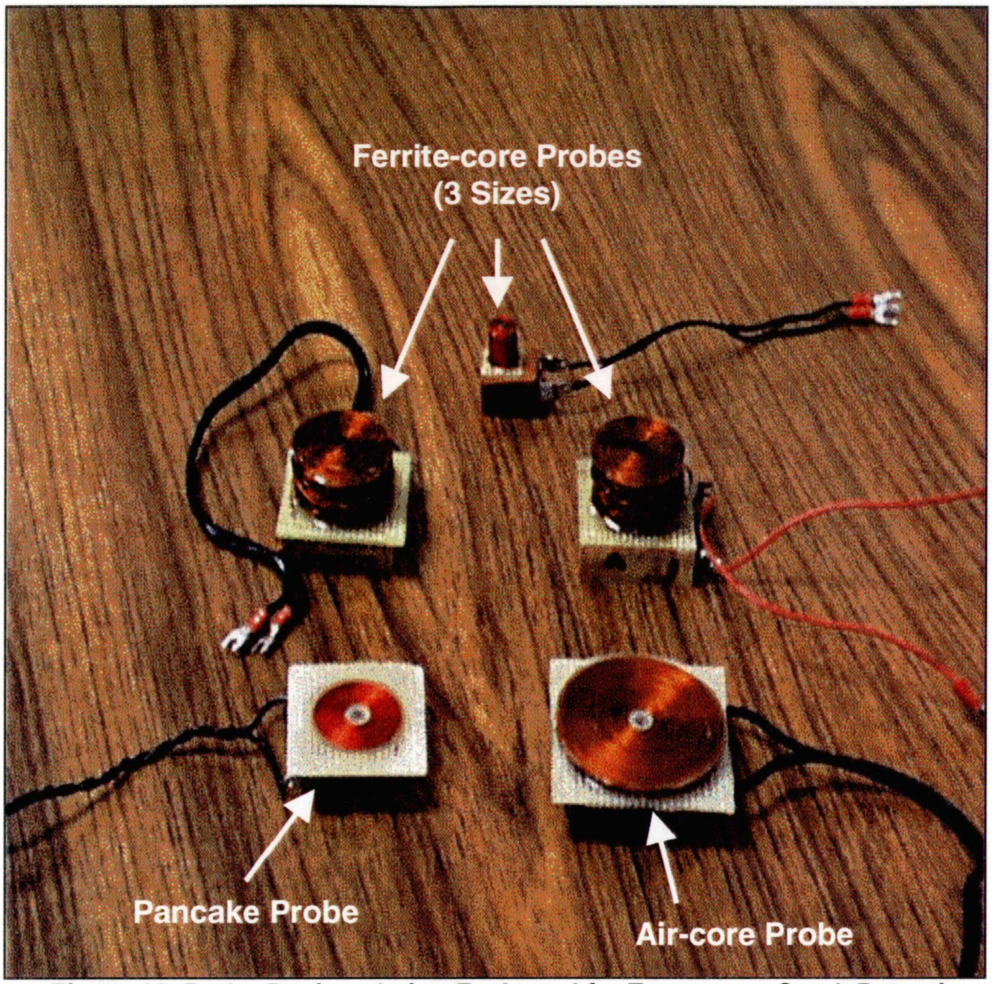

Figure 12. Probe Designs being Evaluated for Transverse Crack Detection

7.0 FUTURE OF RAIL DEFECT DETECTION TECHNOLOGY

The advances introduced to the railroad industry from changes and improvements in technology and regulations are being accompanied by parallel progress in rail flaw detection. The RDTF is an industry tool that can be used to assure continued progress in rail flaw detection. The base line evaluations performed in 1998 will be used to compare results of future evaluations of both current and newly introduced NDE technologies.

The RDTF is scheduled for extension in 1999 through the AAR and FRA joint test program. The railroads are currently assisting TTCI in identifying flaws in rail that will be used to extend the track. The flaws will include transverse defects (with and without shelling or head checks on the surface), horizontal and vertical split heads, web, base, and weld defects. A technical advisory group (TAG) is in place to assist TTCI in the layout and design of the RDTF. The TAG consists of representatives from the member roads and rail flaw detection contractors who are experts in rail flaw detection. The contributions of the TAG will assure that the track extension provides the most useful design for the evaluation of detector cars and inspection personnel.

The FRA sponsored growth rate study will continue at FAST until the end of this year. A rail tension and compression study is also planned on the RDTF to simulate hot and cold weather conditions. This evaluation will be performed to determine the effect rail stress has on detection and sizing of rail flaws.

ACKNOWLEDGEMENTS

The information generated in this report has been compiled through a cooperative effort between the AAR, the TTCI, the railroad industry, and the FRA. Burlington Northern Santa Fe, Canadian Pacific, Conrail, CSX, Norfolk Southern, and Union Pacific supplied test rail and rail flaw evaluation expertise. Herzog, Pandrol Jackson, and Sperry supplied test cars and test personnel for evaluations on the Rail Defect Test Facility. The FRA and the AAR supplied the direction into improving the reliability of rail flaw detection and the funding to construct the RDTF. The industry in general has provided guidance and insight into the advancement of rail flaw detection technology.

A special thanks to the Massachusetts Institute of Technology and Karta Technologies Inc. for their support of sponsored work into the development of technologies designed to improve the reliability of rail flaw detection.

REFERENCES

1. U.S. Department of Transportation, Federal Railroad Administration, Accident/Incident Bulletin No. 164, Calendar Year 1995, August 1996.

2. Sperry Rail Service, *Rail Defect Manual,* 1997.

3. American Railway Engineering Association (AREA), *Manual for Railway Engineering,* Section 2.2 "Recommended Minimum Performance Guideline For Rail Testing," pp. 2-2-4 to 2-2-8, 1997.

4. FRA Docket H-94, Union Pacific Waiver, Relief from Prescribed Remedial Action for Identified "Non-Critical Rail Defects," Washington, D.C., April 1994.

5. Dr. David Y. Jeong, U.S. Department of Transportation, Volpe National Transportation Systems Center, "FRA-Volpe Center Rail Integrity Research Program," UIC/WEC Presentation, July 1998.

6. O. Orringer, Y.H. Tang, D.Y. Jeong, A.B. Perlman, 1999: "Risk/Benefit Assessment of Delayed Action Concept for Rail Inspection," Final Report: DOT/FRA/ORD-99/03.

7. Dr. Shi-Chang Wooh, Massachusetts Institute of Technology, "Rail Defect Detection Sensors for High-Speed Monitoring and High-Reliability Inspection Schemes," UIC/WEC Presentation, July 1998.

8. American Society for Nondestructive Testing, *Nondestructive Testing Handbook* (2nd Ed.), Vol. 10 – Nondestructive Testing Overview, pp. 199-256, 1996.

9. Dr. Gopichand Katragadda, Karta Technology, Inc., "Transverse Crack Detection in Railroad Rails," TTCI Presentation, September 1998.

APPENDIX A

History of Rail Flaw Detection

The prevention of service failures of rail in track has been an ongoing problem for railroad operating companies. Internal flaws occur from the rail manufacturing process coupled with the accumulation of fatigue under repeated loading. Modifications in rail design and metallurgy have extended the wear life of rail. In today's railroad environment, detecting internal and external rail flaws plays a vital role in the maintenance of right away.

Visual inspection of rail is necessary and provides an economical NDE method to find many external flaws and visible indications of internal flaws. But visual inspections do not identify internal flaws or detect all of the external/surface flaws peculiar to rail. It does not provide timely rail inspection (average of 1 mile of track per day) and is dependent upon human interpretation and variability between inspectors.

Internal flaws originating in the head of the rail have been a concern over the years because these type of flaws when undetected can lead to catastrophic failure of the rail. Results of evaluations performed by the U.S. Bureau of Safety of accidents occurring in the early 1900's identified "broken rails" as the cause of several derailments. The study performed on the broken rails revealed a flaw that was entirely internal. The U.S. Bureau of Safety's Dr. Howard described the defect as a "transverse fissure."[1]

A number of private investigations by other railroads to determine the prevalence of transverse fissures in their rails were performed as a result of derailments caused by broken rails. The investigations showed that transverse fissures were wide spread. In 1912 the U.S. railroads requested that the U.S. Bureau of Safety investigate the prevalence and cause of transverse fissures as well as aid in the development of an inspection method to accurately locate and measure the size of hidden flaws in the rail.[1]

In 1915 the Bureau of Standards developed magnetic testing equipment to locate and measure transverse fissures in rail. This system introduced a magnetic flux into the rail and any leakage of that flux was detected using searching coils attached to a sensitive voltmeter. This system of inspection worked well in the laboratory, but field tests determined that the equipment could not differentiate between actual rail defects and strains caused from wheel slippage and/or surface irregularities. Although further efforts were made during this time period, this method could not be adapted to field-testing.[1]

In 1923 Dr. Elmer A. Sperry began developing and building an inspection car to detect transverse fissures in rail. In 1927 Sperry contracted with the American Railway Association (ARA), now the AAR, to build a detector car and provide rail-testing service to the railroads. The inspection system includes energizing the rail with a current and measuring the potential drop with a pair of contacts. This system worked well in the laboratory, but it too had difficulties in distinguishing actual flaws in track. False indications were introduced from rail surface conditions such as dirt, oxide, and scale on the railhead. And despite efforts to develop a practical means to clean the rail, before testing, no solution was found and the method was abandoned.[1]

Dr. Sperry then developed a new principle for rail inspection known as the induction method. The induction method requires a magnetic field to be induced around the rail by passing a heavy electric current of low voltage through the rail. A variation in the magnetic field caused by the transverse fissures is detected by a pair of searching coils set at a constant distance above the surface of the rail detecting the deflection or variation in the field. A current was induced into the coils whenever a change in the field was introduced and the current actuated a series of recording pens on a paper tape thus identifying the presence of a transverse head defect.[1] A detector car using this method was developed jointly by the AAR, E.A. Sperry, the Sperry Development Company, and the New York Central Railroad. After a series of tests, the detector car was officially accepted by the AAR in October 1928.[2]

After the induction system was put into operation, the AAR also developed a magnetic system based on the principal of residual magnetism. W. C. Barnes, engineer of tests for the Rail Investigative committee, and H.W. Keevil, assistant engineer for the AAR invented the detector car. The first car using this process was successfully tested on the Denver and Rio Grande Western Railway in May of 1939. The residual magnetism method works on the principle of distinguishing between two opposite poles using a compass placed near the rail. When a flaw such as a transverse fissure is present in the rail it will set up local magnetic fields with a polarity opposite to that of the rail which is identified with the compass.[2]

Field equipment using the residual method consists of a magnetizing device passed along the rail at a fixed distance from the running surface. Once the rail is magnetized, search coils connected to a recording meter move along the rails and a weak current is induced into the coils by irregularities in the railhead and amplified allowing for a tape record to be produced. A demagnetizing system is also equipped on the detector car to remove any residual magnetism from the rail after evaluation.[2]

Limitations of both the induction and the residual magnetic methods are that they are not capable of satisfactory testing through rail joints due to irregularities (bolts, bolt holes, bars) in the joint area.

Ultrasonic evaluation of the rail was introduced in 1949. Ultrasonic equipment was transported on a motor car and performed manual rail inspections at each joint (hand mapping). By 1959 the ultrasonic inspection equipment was automated and was used for inspections on the New York City subway system. Although the inspection systems were initially designed for detection of transverse fissures, other flaws typical to rail (horizontal/vertical split heads, bolt hole cracks, and weld defects) are also detected using ultrasonic rail flaw detection technology.

Limitations of the ultrasonic method are that the sound waves generated react with each interface they come into contact with. Surface conditions of the railhead may attenuate or completely reflect the sound waves to a level that evaluation for subsurface flaws cannot be adequately performed. An example of this condition would be a transverse defect located under a longitudinal surface flaw such as a shelled rail as shown in Figures A1 and A2.

Technology advancements made in the area of NDE in recent years have generated new efforts into improved reliability of rail flaw inspection. Improvements in signal generation and interpretation from the use of improved electronics and materials, in the NDE equipment, have provided more consistency and repeatability of inspections. The use of different transducer arrays to evaluate more of the railhead, along with the use of computer software to assist in signal interpretation, have provided inspection personnel with tools to improve the evaluation capabilities of the rail flaw inspection system. Research into other NDE methods and/or techniques such as laser ultrasonics, electromagnetic acoustic transducers (EMATs), and eddy current testing are anticipated to enhance the capabilities for defect detection during rail flaw inspection.

The improvement in rail flaw detection technology coupled with other advances in maintenance of way technology will help to increase the efficiency of rail transportation. There have been continuous efforts to develop cleaner rail steels, perform maintenance grinding, and establish rail change out procedures. These efforts and additional developments in detection capabilities continue to be pursued as an effort to increase the reliability and safety of rail transportation.

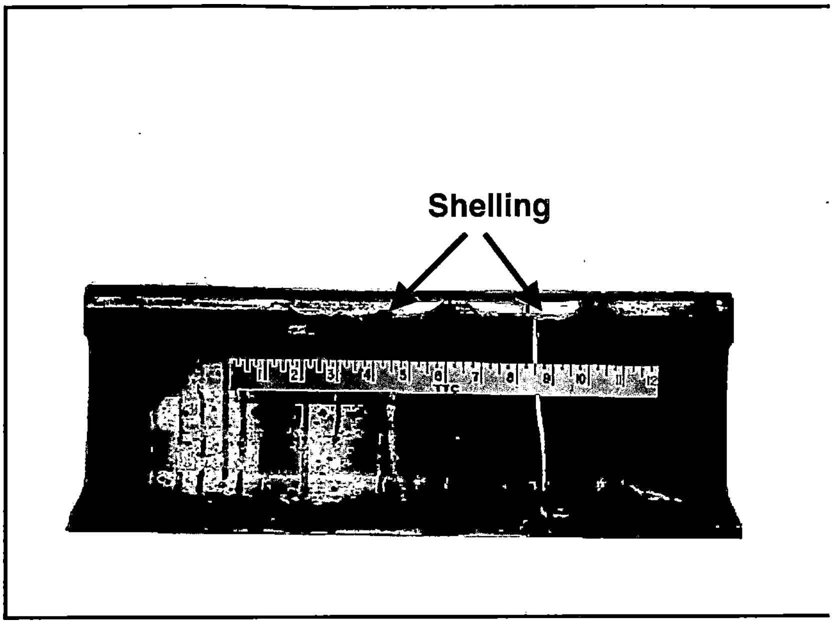

Figure A1. Shelling at the Gage Side of a Railhead from FAST

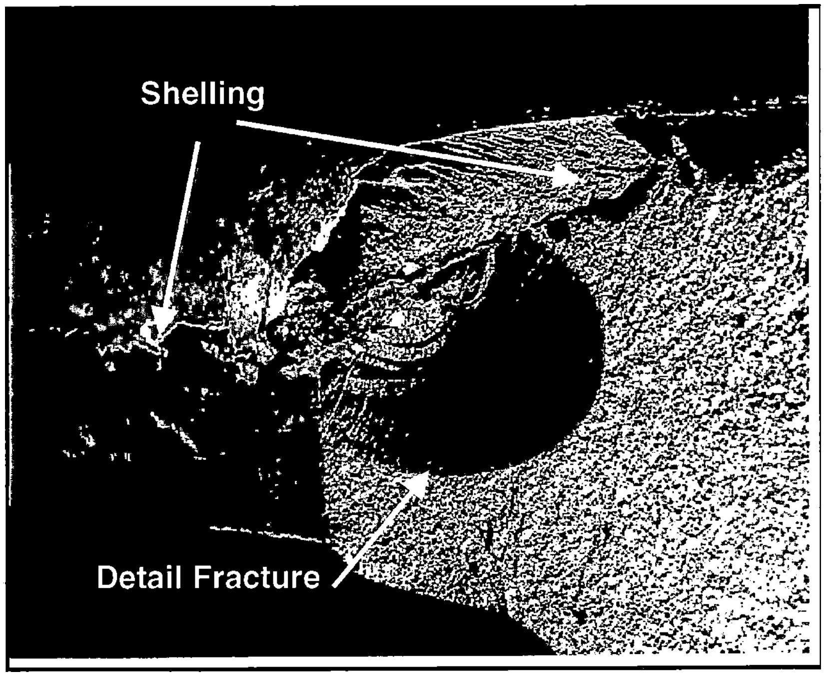

Figure A2. Detail Fracture under a Shell in Rail from FAST

Reference

1. Sperry Rail Service, *Rail Defect Manual*, 1997.
2. Railroad Engineering, Second Edition, William W. Hay, Mgt E., M.S., Ph.D., Copyright 1982 John Wiley & Sons, pgs. 505 – 510.

APPENDIX B

RAIL FLAWS TYPICAL TO NORTH AMERICAN TRACK

Internal flaws in rail occur as a consequence of the rail manufacturing process and the accumulation of fatigue under repeated loading. Rails are subjected to various track conditions that influence the propagation of flaws in the rail. The track may support either passenger trains, freight trains, or a combination of both operating at various train speeds depending on classification of the track. Weather conditions also influence the initiation and growth of rail flaws.

Flaws in the rail can originate in all sections of the rail including the head, web, and base. The flaws can be transverse, vertical, horizontal, or any combination of the three. TDs are found in the railhead and propagate across the head from gage to field, field to gage, or both (depending on initiation site). Vertical and horizontal flaws can initiate in the head, web, or base of the rail and along with the primary orientation of the flaw they will also propagate longitudinally in the rail.

Any flaw, left undetected, can potentially propagate to the point of complete rail failure. Flaws masked by discontinuities at or on the railhead surface can make flaw detection by conventional methods difficult or impossible. Surface discontinuities include shelling (longitudinal separation close to the running surface of the railhead), flaking (scaling or chipping of small slivers occurring on the running surface of gage face of the rail), wheel burns (thermal damage and metal displacement at the railhead surface usually caused from locomotive wheel slippage), and corrugations (railhead surface irregularities that deviate from the regular rail surface profile). Descriptions of typical flaws detected during in track rail flaw inspection, in North America, as defined in Part 213, Subpart A to F of the FRA's *Track Safety Standards* are listed below:[1]

1. **Transverse Fissure:** progressive crosswise fracture starting from a crystalline center or nucleus inside the head from which it spreads outward as a smooth, bright, or dark, round, or oval surface substantially at a right angle to the length of the rail. The distinguishing features of a transverse fissure from other types of fractures or defects are the crystalline center or nucleus and the nearly smooth surface of the development which surrounds it (Figure B1).

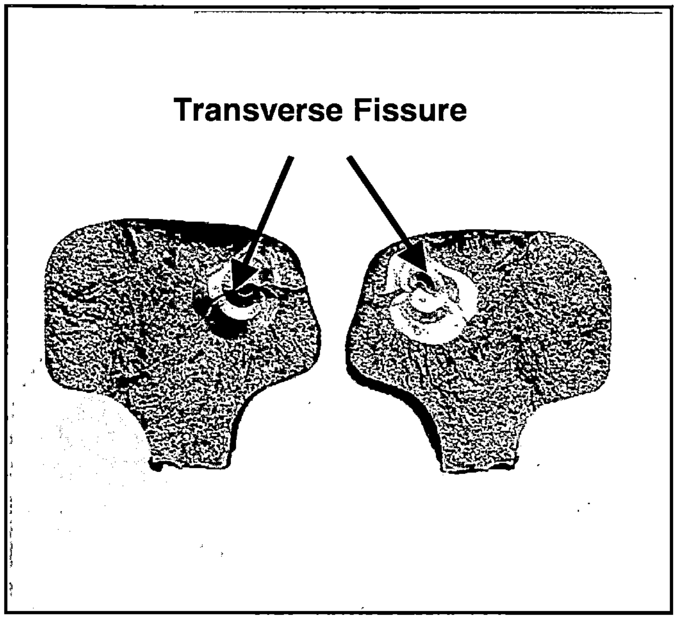

Figure B1. Transverse Fissure Found in Rail at FAST

2. **Compound Fissure:** progressive fracture originating in a horizontal split head which turns up or down in the head of the rail as a smooth, bright, or dark surface progressing until substantially at a right angle to the length of the rail. Compound fissures require examination of both faces of the fracture to locate the horizontal split head from which they originate (Figure B2).

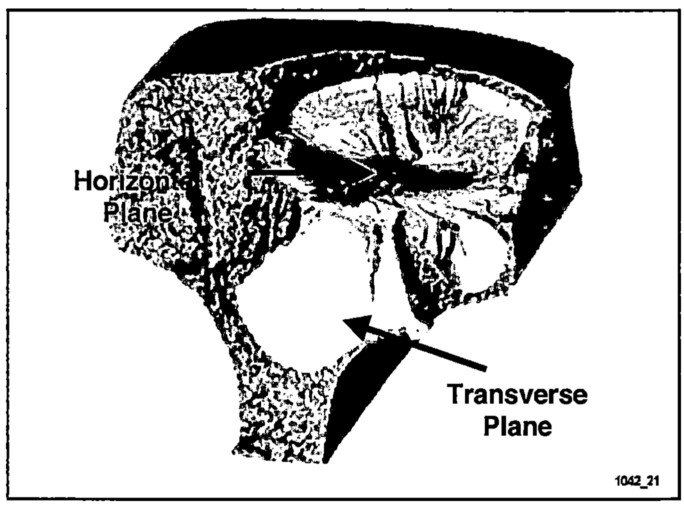

Figure B2. Compound Fissure Showing Horizontal and Transverse Planes (Photo Courtesy of Sperry Rail Service, Rail Defect Manual, 1977)

3. **Horizontal Split Head:** horizontal progressive defect originating inside of the railhead, usually one-quarter inch or more below the running surface and progressing horizontally in all directions, and generally accompanied by a flat spot on the running surface. The defect appears as a crack lengthwise of the rail when it reaches the side of the railhead (Figure B3).

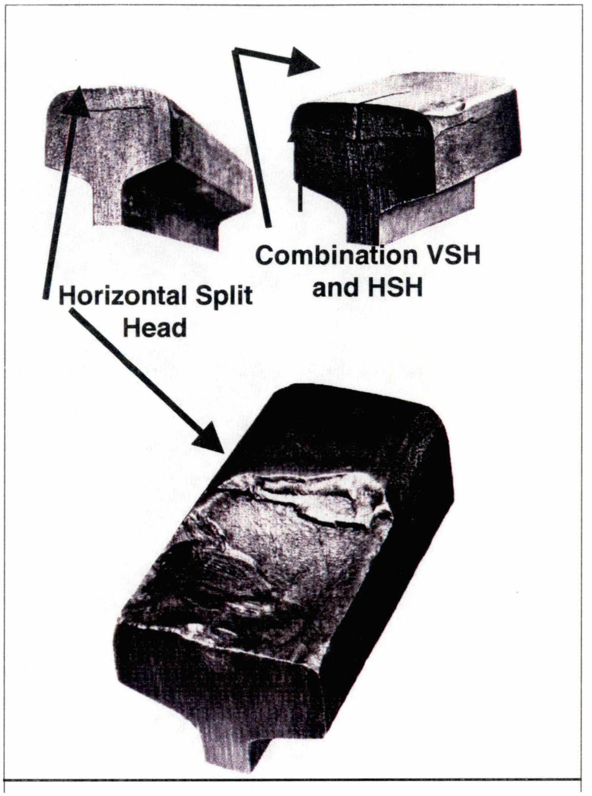

Figure B3. Horizontal and Combination Vertical and Horizontal Split Heads (Photo courtesy of International Union of Railways Catalogue of Rail Defects, 1979)

4. **Vertical Split Head:** vertical split through or near the middle of the head, and extending into or through it. A crack or rust streak may show under the head close to the web or pieces may be split off the side of the head (Figure B4).

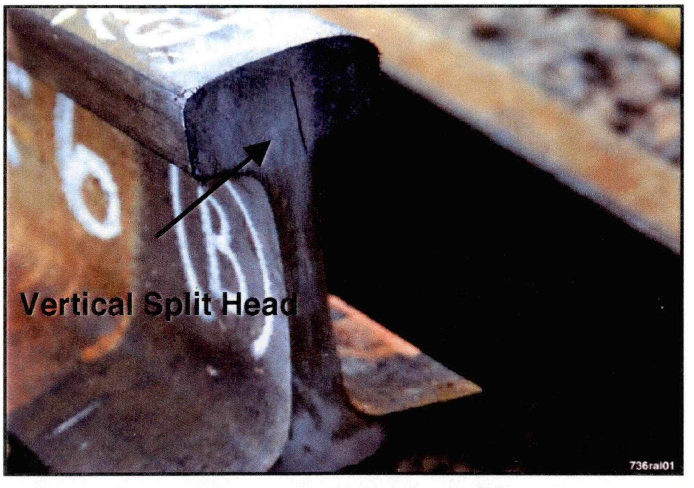

Figure B4. Vertical Split Head in Rail Donated to TTCI for Inclusion into the RDTF

5. **Split Web:** lengthwise crack along the side of the web, extending into or through it (Figure B5).

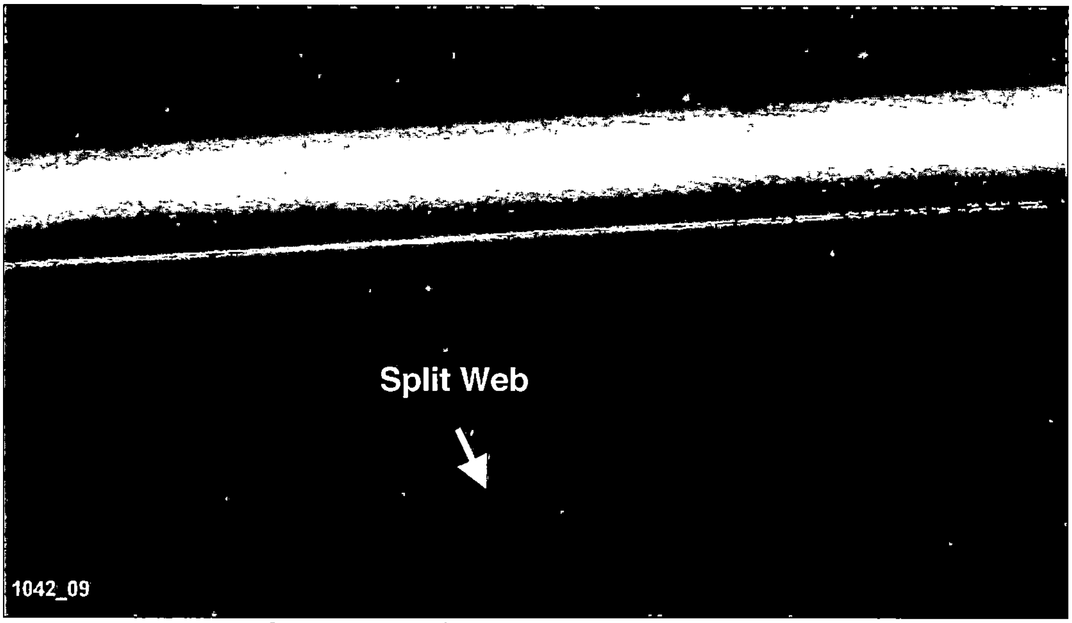

Figure B5. Split Web Running Along the Rail.
(Photo Courtesy of Sperry Rail Service, Rail Defect Manual, 1997)

6. **Piped Rail:** vertical split in a rail, usually in the web, due to failure of the shrinkage cavity in the ingot to unite in rolling (Figure B6).

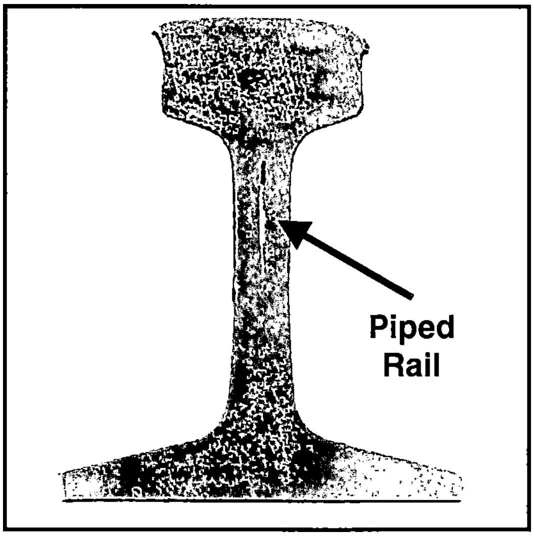

Figure B6. Piped Rail Showing Vertical Separation in the Web of the Rail. (Photo Courtesy of Sperry Rail Service, Rail Defect Manual, 1997)

7. **Broken Base:** any break in the base of the rail (Figures B7 and B8).

8. **Detail Fracture**: progressive fracture originating at or near the surface of the railhead. These fractures should not be confused with transverse fissures, compound fissures, or other defects which have internal origins. Detail fractures may arise from shelly spots, head checks, or flaking (Figure B9).

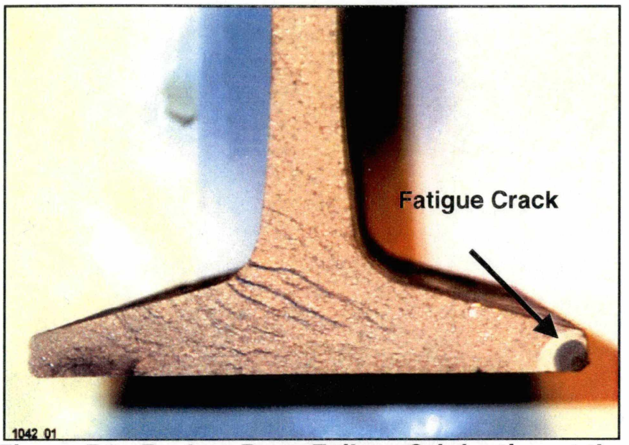

Figure B7. Broken Base Failure Originating at the Corner of the Rail Base

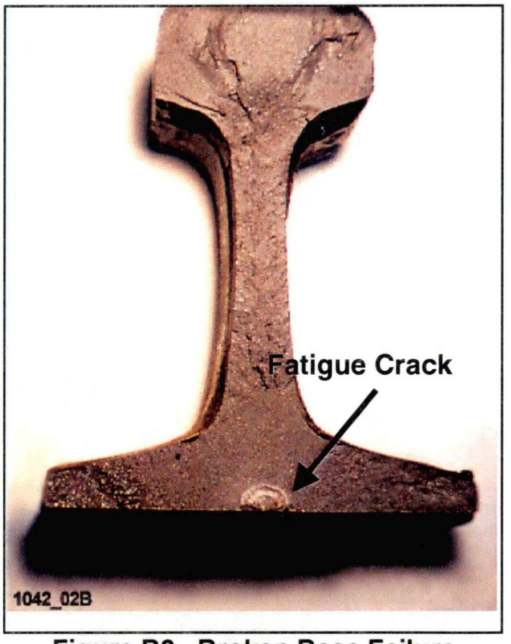

Figure B8. Broken Base Failure Originating at the Bottom Center of the Rail Base

9. **Engine Burn Fracture:** progressive fracture originating in spots where driving wheels have slipped on top of the railhead. In developing downward they frequently resemble the compound or even transverse fissures with which they should not be confused or classified (Figure B10).

10. **Ordinary Break**: a partial or complete break in which there is no sign of a fissure, and in which none of the other defects described in this paragraph (b) are found.

11. **Damaged Rail:** any rail broken or injured by wrecks, broken, flat, or unbalanced wheels, slipping, or similar causes.

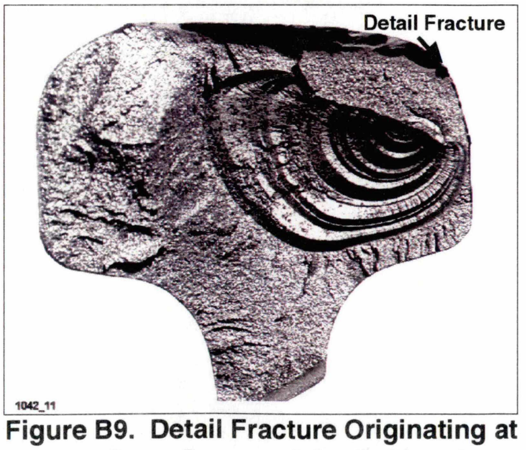

Figure B9. Detail Fracture Originating at the Gage Corner of the Railhead

12. **Flattened Rail:** a short length of rail, not at a joint, which has flattened out across the width of the railhead to a depth of δ inch or more below the rest of the rail. Flattened rail occurrences have no repetitive regularity and thus do not include corrugations, and have no apparent localized cause such as a weld or engine burn. Their individual length is relatively short, as compared to a condition such as head flow on the low rail of curves (Figure B11).

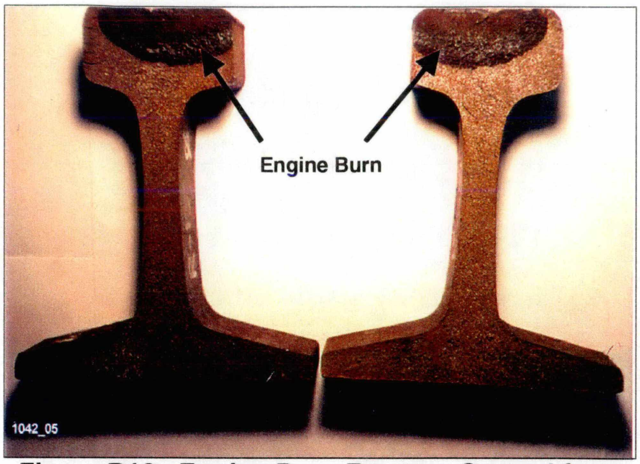

Figure B10. Engine Burn Fracture Caused from Wheel Slippage at the Railhead Surface

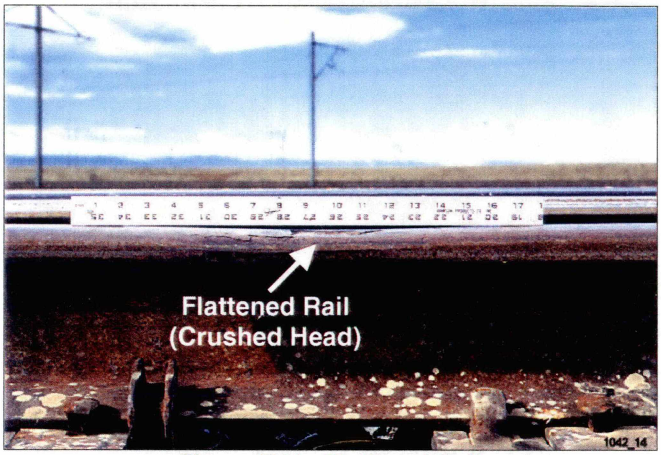

Figure B11. Flattened Rail (Crushed Head) not Associated with the Rail End

13. **Bolt Hole Crack:** a crack across the web, originating from a bolt hole, and progressing on a path either inclined upward toward the railhead or inclined downward toward the base. Fully developed bolt hole cracks may continue horizontally along the head/web or base/web fillet, or they may progress into and through the head or base to separate a piece of the rail end from the rail. Multiple cracks occurring in one rail end are considered to be a single defect. However, bolt hole cracks occurring in adjacent rail ends within the same joint must be reported as separate defects (Figures B12 and B13).

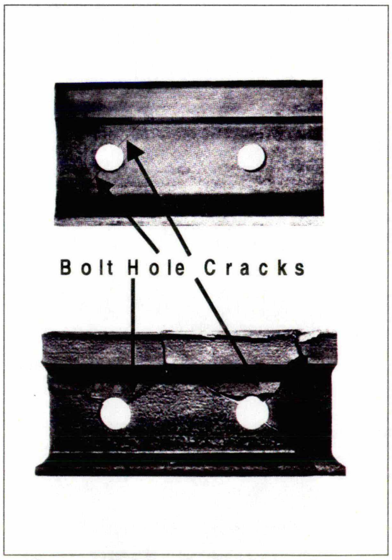

Figure B12. Bolt Hole Cracks Originating at the Holes and Ultimately Turning up and Extending Through the Rail Head (photo courtesy of International Union of Railways Catalogue of Rail Defects, 1979)

14. **Defective Weld**: a field or plant weld containing any discontinuities or pockets, exceeding 5 percent of the railhead area individually or 10 percent in the aggregate, oriented in or near the transverse plane, due to incomplete penetration of the weld metal between the rail ends, lack of fusion between weld and rail end metal, entrapment of slag or sand, under-bead or other shrinkage cracking, or fatigue cracking. Weld defects may originate in the railhead, web, or base, and in some cases, cracks may progress from the defect into either or both adjoining rail ends (Figures B14 through B17).

15. **Head and Web Separation:** progressive fracture, longitudinally separating the head from the web of the rail at the head fillet area (Figure B18).

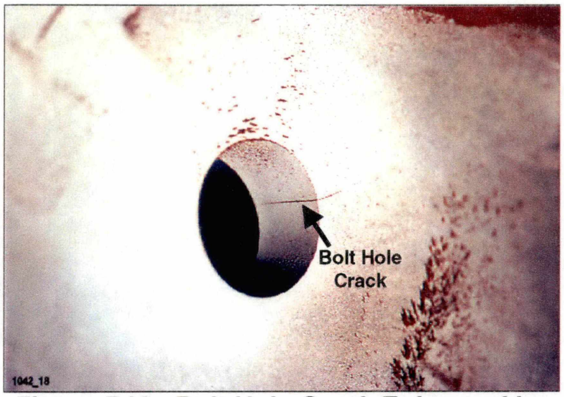

Figure B13. Bolt Hole Crack Enhanced by Magnetic Particle Inspection

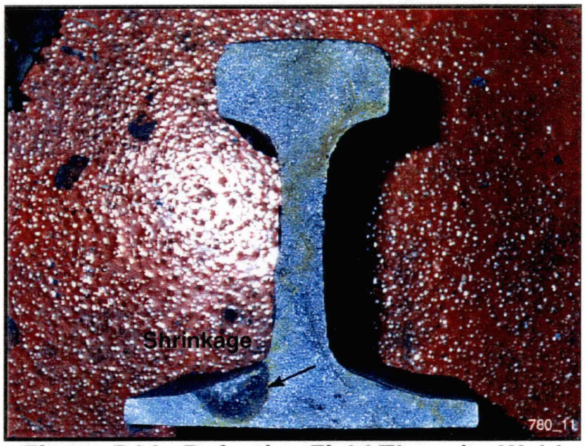

Figure B14. Defective Field Thermite Weld Showing Shrinkage at the Fishing Area between the Web and the Base

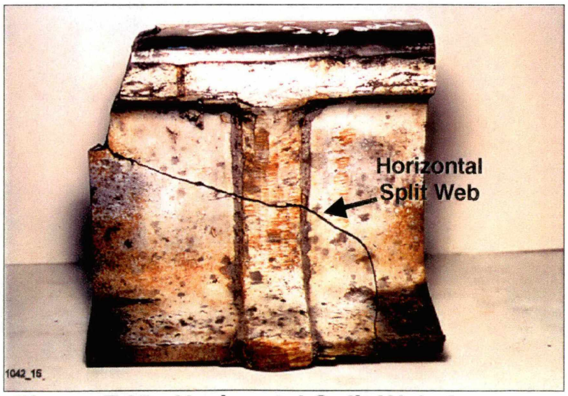

Figure B15. Horizontal Split Web Across a Field Thermite Weld

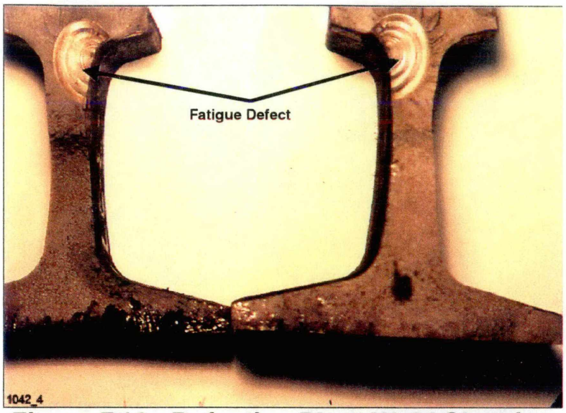

Figure B16. Defective Plant Weld Showing a Transverse Fatigue Defect Originating from a Sharp Corner of the Weld at the Head to Web Transition Area

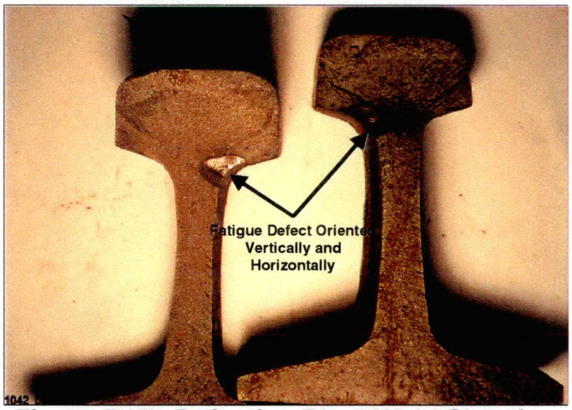

Figure B17. Defective Plant Weld Showing a Horizontal and Transverse Fatigue Defect Located at the Head to Web Transition Area 2

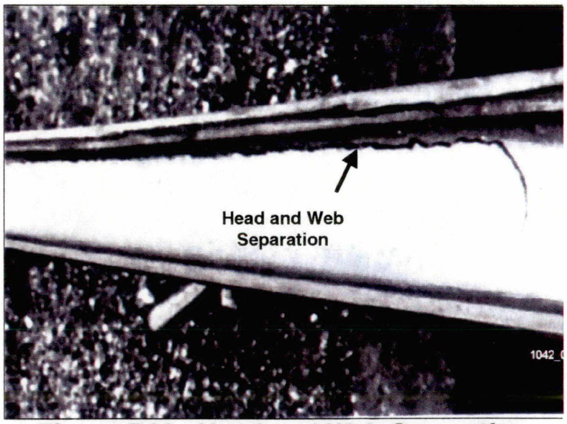

Figure B18. Head and Web Separation Propagating at the Head Fillet Area (Photo Courtesy of Sperry Rail Service, Rail Defect Manual, 1997)

APPENDIX C

RAIL FLAW TECHNOLOGY

Ultrasonic and Magnetic Induction Methods

Technologies currently used for commercial rail flaw detection include ultrasonic and magnetic induction methods. The ultrasonic (UT) system can be used as a handheld portable instrument or installed in either a hi-rail or a rail-bound vehicle. The installation of the UT equipment on a vehicle provides an automated evaluation of the rail at speeds up to approximately 25 mph (40.3 km/h). The detection of a flaw by the inspection vehicle requires follow up evaluation using the handheld UT system to accurately determine type and size of flaws. The magnetic induction method is currently only available on rail-bound vehicles and requires flaw verification with a handheld UT system.

Ultrasonic inspection is the more widely used method and is a nondestructive test that uses acoustic energy in the range of 20 kHz to 25 MHz to evaluate the internal condition of a material. Flaws detected using ultrasonic technology include voids, cracks, inclusions, segregation, laminations, bursts, flakes, and welding discontinuities. The detection of a particular discontinuity is related to the sensitivity, resolution, and noise discrimination of the UT system as well as flaw location and surface condition. Sensitivity is the ability of the instrument to detect the amount of sound energy reflected by the flaw. Resolution is the capability of the instrument to distinguish between flaws that are located close together. Noise discrimination is the ability of the equipment to distinguish between desired signals from a flaw and undesired signals that are of electrical or acoustical origin. The flaws predominantly found in rail and welds, such as fatigue cracks (TD's), inclusions or voids (horizontal or vertical split heads), and welding anomalies make detection using the ultrasonic testing method ideal. Current automated UT systems used in North America allow for reliable rail flaw detection at speeds up to 25 mph (40.3 km/h) depending on track and rail conditions. Limitations of the ultrasonic method include the requirement of a liquid couplant to propagate the sound signal into the rail. Current technology does not allow thorough inspection of the web and base. The signal may be attenuated or reflected by rail surface conditions such as shelling, spalling, and head checking as well as lubrication and debris.

The induction method induces a magnetic field in and around the rail. Any change in the strength or direction of the current will be accompanied by a change in the strength and position of the magnetic field. The variations in the current path are detected by measuring the variation in its magnetic field. Internal separations in the rail will obstruct the flow of current causing a variation in the magnetic field allowing for the detection of flaws particular to rail such as transverse head flaws. The advantages of using this method is that it is not as susceptible to surface debris (dirt/grease) or signal attenuation and reflection due to the orientation of the flaw. Limitations of the magnetic induction system are the inability to evaluate joints (welds), and low reliability to detect head web separations.

The types of systems used for rail flaw detection are primarily hi-rail vehicles with ultrasonic capabilities and rail bound detector cars with ultrasonic and induction capabilities. The hi-rail vehicle is preferred because it provides access to remote locations without impeding other rail operations, due to its ability to set on or off track in approximately 10 minutes. The second most frequently used system is the rail-bound detector car with either induction/ultrasonic or strictly ultrasonic capabilities. The induction/ultrasonic system is unique because it allows for the evaluation of the rail using two NDE methods that augment each other. Use of the induction/ultrasonic system increases the likelihood of detecting a flaw that may go undetected by a single method. Currently efforts are being pursued to adapt the induction-ultrasonic system for use on hi-rail vehicles. It was previously mentioned that although the systems just described are used to detect flaws at speed they are not currently designed to provide accurate identification and sizing of discontinuities. The identification and sizing of the defect is performed through ultrasonic hand mapping. Figures C1 through C7 illustrate typical rail flaw detection vehicles and hand-mapping processes used in North America.

Other ultrasonic rail flaw detection systems are also used in North America for special track inspections, such as tight radius curves, crossover tracks, and miter rails, requiring the use of more portable inspection systems. The portable systems include pushcarts and/or hand operated single rail testing devices. The advantage of using more portable systems is that it frees up the regular test vehicle to perform mobile rail inspection and assures that areas of special track work are inspected. Figures C8 and C9 show portable ultrasonic systems currently available for rail flaw inspection.

Figure C1. Rail Bound Induction/Ultrasonic Detector Car used for Rail Flaw Detection

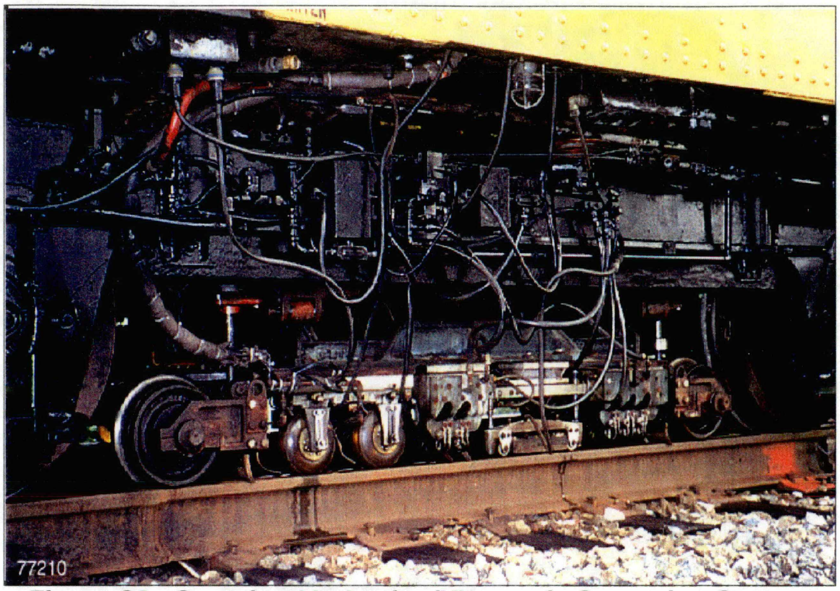

Figure C2. Contained Induction/Ultrasonic Sensoring System on the Detector Car

Figure C3. Hi-rail Ultrasonic Inspection Vehicle Using Roller Search Units for Rail Flaw Inspection

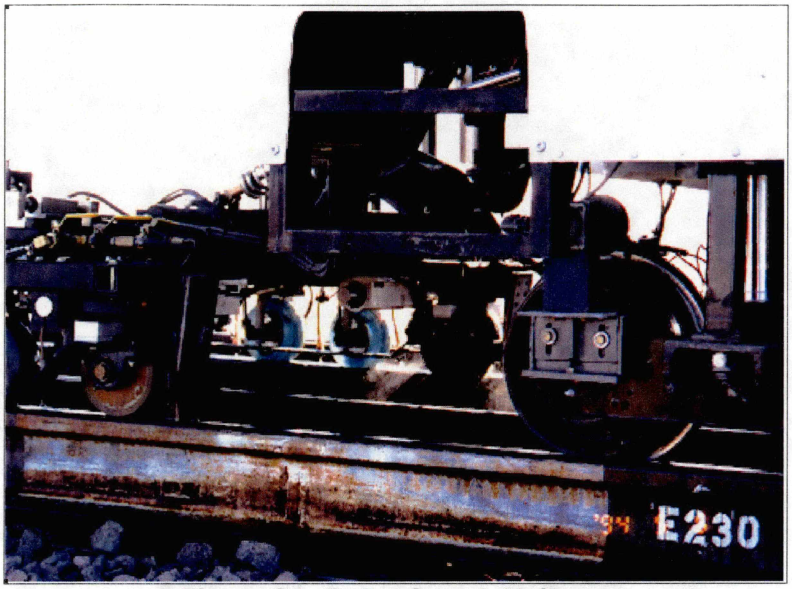

Figure C4. Roller Search Units on Hi-rail Ultrasonic Detector Car

Figure C5. Hi-Rail Ultrasonic Inspection Vehicle Using a Transducer Array Set on a Sled System

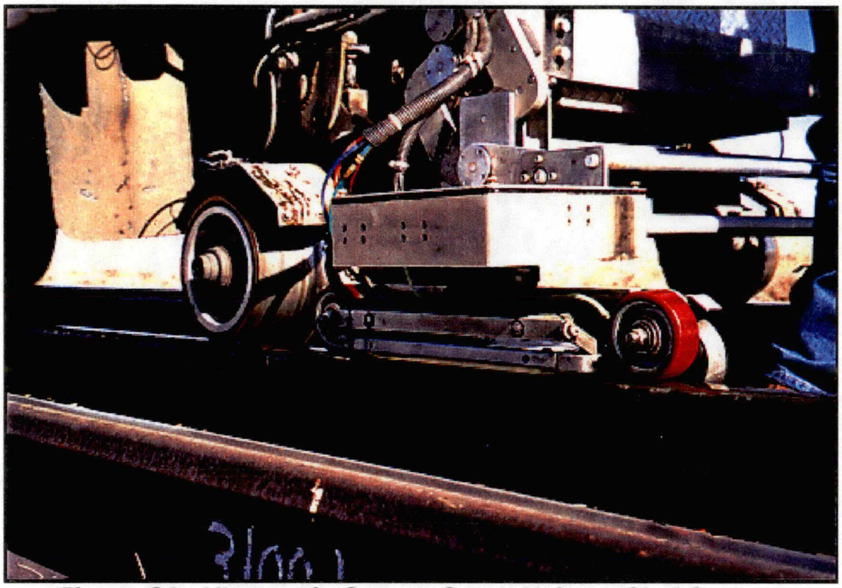
Figure C6. Ultrasonic Sensor Setup Using a Sled System

Figure C7. Ultrasonic Calibration Prior to Hand Mapping of a Rail

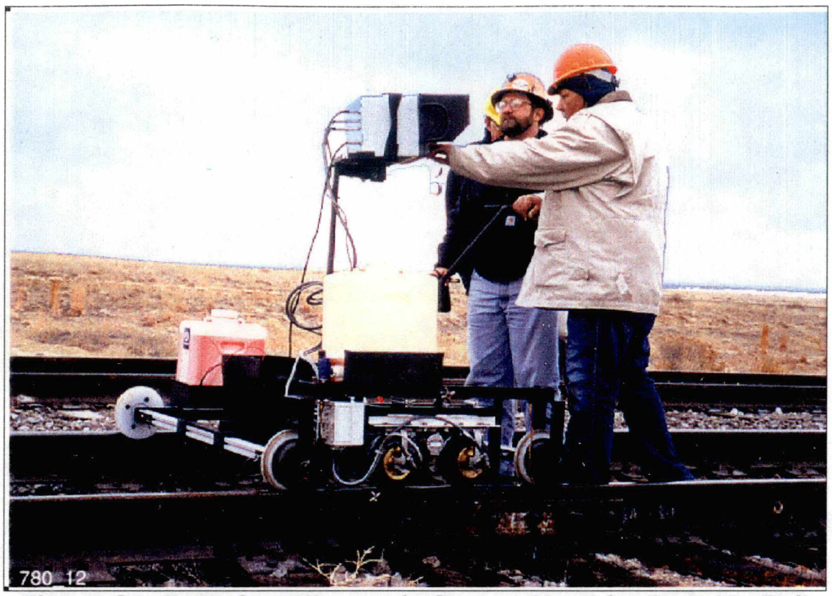

Figure C8. Push Cart Ultrasonic System Used for Portable Rail Flaw Detection

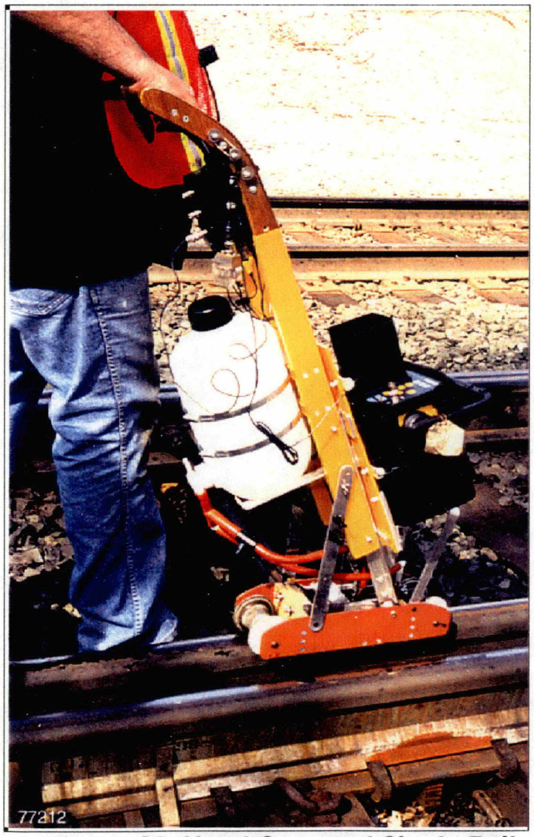

Figure C9. Hand Operated Single Rail Testing Device Used for Portable Rail Flaw Detection

Test and Evaluation of Rail Flaw Detection Technologies, 1999, AAR, G. Garcia, R. Reiff
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