TP 13611E

DEVELOPMENT OF A MOBILE INSPECTION SYSTEM FOR RAIL INTEGRITY ASSESSMENT

Prepared for
Transportation Development Centre
Safety and Security
Transport Canada

by
Tektrend International

June 2000

TP 13611E

Development of a Mobile Inspection System for Rail Integrity Assessment

by
Ahmad Chahbaz, Vice-president R&D
Tektrend International

June 2000

This report reflects the views of the author and not necessarily those of the Transportation Development Centre.

As the accepted measures in the railway industry are imperial, this report does not use metric measures.

Un sommaire français se trouve avant la table des matières.

Transport Canada | Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No. TP 13611E	2. Project No. 8980	3. Recipient's Catalogue No.
4. Title and Subtitle Development of a Mobile Inspection System for Rail Integrity Assessment		5. Publication Date June 2000
		6. Performing Organization Document No.
7. Author(s) Ahmad Chahbaz		8. Transport Canada File No. ZCD2450-D-635-2
9. Performing Organization Name and Address Tektrend International Inc. 2113A St-Regis Dollard des Ormeaux, Quebec H9B 2M9		10. PWGSC File No. XSD-6-02773
		11. PWGSC or Transport Canada Contract No. T8200-6-6577/001/XSD
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 800 René Lévesque Blvd. West Suite 600 Montreal, Quebec H3B 1X9		13. Type of Publication and Period Covered Final
		14. Project Officer R. Nishizaki

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

Program developed in collaboration with CP Rail System and CN North America

16. Abstract

The primary objective of the **Development of a Mobile Inspection System for Rail Integrity Assessment** project was to develop a rail test vehicle with an Electromagnetic Acoustic Transducer (EMAT) probe carriage designed for real-time testing of rails. In addition, an inspection procedure coupled to the hardware and software was developed. The resulting RailPro system can detect, locate and validate rail defects, thus helping to prevent catastrophic events and reduce maintenance time.

Preliminary assessment of the detection capabilities of the system was conducted over an evaluation track in Montreal. Results were interpreted as B-scan images and A-scan waveforms, which were observed in inspection cabin of the customized RailPro vehicle. The tests proved that the system, together with inspection procedures, EMAT sensors and automated interpretation techniques, is an efficient and reliable inspection approach. All tasks within the scope of this project were developed in close relationship with Canadian National and Canadian Pacific to ensure that the system meets marketable requirements.

The system uses bulk and guided stress waves generated by couplant-free EMAT probes. In addition, EMATs for various types of defect were designed and manufactured to selectively solicit and extract information from the inspected rails. In the final stage, recognition techniques were developed to analyse the accumulated signals collected during the rail inspection.

17. Key Words Rail inspection, EMAT, ultrasonic, shear waves, rail defects	18. Distribution Statement Limited number of copies available from the Transportation Development Centre E-mail: *tdccdt@tc.gc.ca*

19. Security Classification (of this publication)	20. Security Classification (of this page)	21. Declassification (date)	22. No. of Pages	23. Price
Unclassified	Unclassified	—	x, 31	Shipping/ Handling

Transports Canada / Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada TP 13611E	2. N° de l'étude 8980	3. N° de catalogue du destinataire
4. Titre et sous-titre Development of a Mobile Inspection System for Rail Integrity Assessment		5. Date de la publication Juin 2000 6. N° de document de l'organisme exécutant
7. Auteur(s) Ahmad Chahbaz		8. N° de dossier - Transports Canada ZCD2450-D-635-2
9. Nom et adresse de l'organisme exécutant Tektrend International Inc. 2113A, boul. St-Regis Dollard des Ormeaux, Québec H9B 2M9		10. N° de dossier - TPSGC XSD-6-02773 11. N° de contrat - TPSGC ou Transports Canada T8200-6-6577/001/XSD
12. Nom et adresse de l'organisme parrain Centre de développement des transports (CDT) 800, boul. René-Lévesque Ouest Bureau 600 Montréal (Québec) H3B 1X9		13. Genre de publication et période visée Final 14. Agent de projet R. Nishizaki

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

Programme élaboré en collaboration avec le Réseau CP Rail et le Canadien National

16. Résumé

L'objectif premier du projet **Développement d'un système mobile de contrôle des rails** était de mettre au point une voiture d'auscultation des rails équipée d'une sonde à transducteurs électomagnéto-acoustiques (EMAT, *electromagnetic acoustic transducer*) pour le contrôle des rails et l'interprétation des données en temps réel. Une procédure d'inspection, couplée au matériel et au logiciel du système, a également été élaborée. Le système résultant, baptisé RailPro, détecte, situe et caractérise les défauts dans les rails, aidant ainsi à prévenir les accidents et à réduire le temps de maintenance.

Le nouveau dispositif, monté sur la voiture d'auscultation, a été soumis à des essais sur voie à Montréal, aux fins d'une évaluation préliminaire des capacités de détection du système. Les données s'affichaient sous forme de présentations du type A et du type B dans la cabine de contrôle de la voiture RailPro. Les essais ont révélé que le système, soit les procédures d'inspection, les capteurs EMAT et les techniques d'interprétation automatisées, constitue une méthode de contrôle efficace et fiable. Toutes les tâches prévues dans le cadre du projet ont été réalisées en étroite collaboration avec le Canadien National et le Canadien Pacifique, de façon que le système soit bien accordé aux besoins du marché.

Le système utilise des ondes de contrainte de volume et guidées générées par les sondes EMAT, lesquelles sont exemptes d'agent couplant. De plus, une gamme d'EMAT correspondant à divers types de défauts ont été conçus et fabriqués, qui peuvent solliciter les rails de façon sélective. À la dernière étape du projet, des techniques de reconnaissance ont été mises au point pour l'analyse de la masse de signaux accumulés au cours des essais.

17. Mots clés Contrôle des rails, EMAT, ultra-sons, ondes de cisaillement, défauts dans les rails	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires. Courriel : *tdccdt@tc.gc.ca*

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	—	x, 31	Port et manutention

CDT/TDC 79-005
Rev. 96

Canada

ACKNOWLEDGMENTS

Tektrend International wishes to acknowledge the co-operation and support of Roy Nishizaki from the Transportation Development Centre, Safety and Security, Transport Canada; Al Wilson, Dave Boshart and Robert de Vries from Canadian Pacific; Richard Maltby, Jim Horbay, Norm Noiles and André Pigeon from Canadian National; and Jovite Grondin and Frank Lalonde from Railway Safety, Transport Canada.

EXECUTIVE SUMMARY

This report describes research and development work performed under the project entitled **Development of a Mobile Inspection System for Rail Integrity Assessment** conducted by Tektrend International Inc. The project was funded jointly by Canadian Pacific, Canadian National North America, the Transportation Development Centre and Tektrend International.

Our main objective was to develop a rail test vehicle with an electromagnetic acoustic transducer (EMAT) probe carriage designed for real-time testing of rails. Over the course of our research and development, we also developed an inspection procedure coupled to the system hardware and software. The resulting RailPro system can detect, locate and validate rail defects, thus helping to prevent catastrophic events and reduce maintenance time. The RailPro system uses bulk and guided stress waves generated by couplant-free EMAT probes for integrity assessment of rails. In addition, the EMATs for various types of defect were designed and manufactured at Tektrend to selectively solicit and extract the information available from the inspected rails. In the final stage, recognition techniques were developed to analyse the accumulated signals collected during the rail inspection.

Our work also includes preliminary test results obtained with the inspection vehicle. The detection capabilities of the system were assessed over an evaluation track at the Canadian National (CN) Taschereau Yard in Montreal. Results were interpreted as B-scan images and A-scan waveforms, which were observed in the inspection cabin of the vehicle on an LCD display. The tests proved that the system, together with inspection procedures, EMAT sensors and automated interpretation techniques, is an efficient and reliable inspection approach. The project was successful in addressing all the theoretical, mechanical, software and detectability problems.

SOMMAIRE

Ce rapport décrit les travaux de recherche et de développement réalisés dans le cadre du projet Développement d'un système mobile de contrôle des rails, confié à Tektrend International Inc. Le projet a été financé par le Canadien Pacifique, le Canadien National, le Centre de développement des transports et Tektrend International.

Notre principal objectif était de développer une voiture d'auscultation des rails équipée d'une sonde à transducteurs électromagnéto-acoustiques (EMAT, electromagnetic acoustic transducer) pour le contrôle des rails et l'interprétation des données en temps réel. Les travaux de R-D ont en outre débouché sur une procédure d'inspection couplée au matériel et au logiciel du système. Le système de contrôle des rails peut détecter, situer et caractériser les défauts dans les rails, aidant ainsi à prévenir les accidents et à réduire le temps de maintenance. Le système RailPro utilise des ondes de contrainte de volume et guidées générées par les sondes EMAT, lesquelles sont exemptes d'agent couplant, pour évaluer l'intégrité des rails. De plus, Tektrend a conçu et fabriqué une gamme d'EMAT correspondant à divers types de défauts, qui peuvent solliciter les rails de façon sélective. À la dernière étape du projet, des techniques de reconnaissance ont été élaborées pour l'analyse de la masse de signaux accumulés au cours des essais.

Le rapport comprend également les résultats des essais préliminaires du véhicule d'auscultation. Les capacités de détection du système ont été soumises à des essais sur voie au triage Taschereau du Canadien National (CN), en banlieue de Montréal. Les données s'affichaient sous forme de présentations du type A et du type B dans la cabine de contrôle de la voiture RailPro. Les essais ont révélé que le système, soit les procédures d'inspection, les capteurs EMAT et les techniques d'interprétation automatisées, constitue une méthode de contrôle efficace et fiable. Les travaux ont été couronnés de succès en ce qu'ils ont permis de surmonter toutes les difficultés théoriques et mécaniques posées par le système de même que les problèmes reliés au logiciel et aux capacités de détection.

Contents

LIST OF FIGURES

LIST OF TABLES

1. WORK DESCRIPTION

1.1. PURPOSE

The main objectives of this project were:

- to develop an easily implemented and integrated mobile system for reliable and effective rail inspection with an Electromagnetic Acoustic Transducer (EMAT) probe carriage designed for real-time testing of rails;
- to develop inspection procedures coupled to the hardware and software with the ability to detect, locate and validate rail defects in order to help prevent catastrophic events and reduce maintenance time;
- to develop advanced signal processing techniques for defect recognition and analysis.

1.2. TECHNOLOGY AREA

The RailPro system developed uses bulk and guided stress waves generated by couplant-free EMAT probes for integrity assessment of rails. EMATs for various types of defects were designed and manufactured at Tektrend to selectively solicit and extract the information available from the inspected rails. Defect recognition techniques were also developed and integrated into the system to analyze the accumulated signals collected during the rail inspection.

1.3. APPLICATION DOMAIN

Current methods of automated rail inspection use technologies that have been in place for several decades. However, increasing demands for safety and the industry's need to minimize costs of both inspection and failure call for research and development to pursue advances in science and technology which have occurred in non-destructive testing. Thus, the application of a combination of system control elements, EMAT probes and intelligent interpretation will help to improve the effectiveness of rail inspection.

2. RESEARCH & DEVELOPMENT RESULTS

2.1. WORK OVERVIEW

Within the scope of this project, a rail test vehicle with two EMAT (Electromagnetic Acoustic Transducer) probe carriages designed for real-time testing of rails was developed. A non-destructive inspection procedure, including hardware and software, with the ability to detect, locate and validate rail defects, was also developed. The RailPro system uses bulk and guided stress waves generated by couplant-free EMAT probes.

Preliminary assessment of the detection capabilities of the system was conducted over an evaluation track at Canadian National (CN) Taschereau Yard in Montreal. Results were interpreted as B-scan images and A-scan waveforms, which were observed in the inspection cabin of the vehicle on an LCD display. The tests proved that the system, together with inspection procedures, EMAT sensors and automated interpretation techniques, is an efficient and reliable inspection approach. All tasks within the scope of this project were developed in close relationship with CN and CP to ensure that the system specifications meet marketable requirements.

2.2. TECHNICAL BACKGROUND

Feasibility tests were conducted prior starting the project. The results obtained showed that non-destructive testing of rails with EMAT probes is a potentially powerful tool for the rail transport industry. An overview of these results is available in TP 12914E, "Assessment of Rail Defect Inspection Technology" (prepared by D. Robert Hay, Vasile Mustafa, Ahmad Chahbaz, John R. Hay and Julie Gauthier, November 1996).

2.2.1. INSPECTION WITH ULTRASONIC WAVES

Waves in a solid material can be either longitudinal, where particle oscillation is in the direction of propagation, or transverse, where oscillation is perpendicular to the direction of propagation. Velocity depends on the type of wave and on the propagation medium. Typically, these waves are generated using piezoelectric transducers, which require a coupling agent between the material and the oscillating transducer. However, in metallic materials EMAT transducers can also be used, requiring no coupling. Moreover, EMAT transducers can efficiently generate SH waves, where the polarization of the wave remains parallel to the material surface even when the ultrasonic beam is propagated at an angle. The SH mode generated by EMAT diminishes the number of spurious echoes by eliminating mode conversion.

2.2.2. DEFECT CHARACTERIZATION

Ultrasonic bulk waves are mechanical vibrational waves that propagate in elastic media. These waves are three-dimensional and are attenuated rapidly in thick materials. A wave pulse travelling in the material will be reflected at a discontinuity if there is an impedance change in the material. This reflected energy can be detected by a properly placed transducer. The time interval (time-of-flight) between the transmitted and reflected pulses is a measure of the distance of the discontinuity from the surface.

When a normal beam transducer is used for both sending and receiving the ultrasonic pulse, the technique is referred to as the pulse-echo method. The distance of the flaw from the surface is calculated as

$$d = \frac{vt}{2}$$

where t is the pulse transit time and v is the velocity of the wave in the material, either longitudinal or transverse. With an angle beam transducer, the incident angle should be considered when determining the distance from the flaw. Both EMAT and piezoelectric transducers can function in the pulse-echo mode. When two independent transducers are used at a fixed distance while the transmitted pulse between them is monitored, the method is called through transmission or pitch-and-catch. With this method, signal attenuation is used as a measure of the presence and extent of a defect.

2.2.3. Sensor Development

The use of ultrasound for rail inspection is current practice; however, for the RailPro system the rail will be inspected with ultrasound generated with EMATs instead of the commonly used piezoelectric transducers. The principles of operation of EMATs and the basis for this choice of transduction method are described below.

2.2.4. EMAT Principles

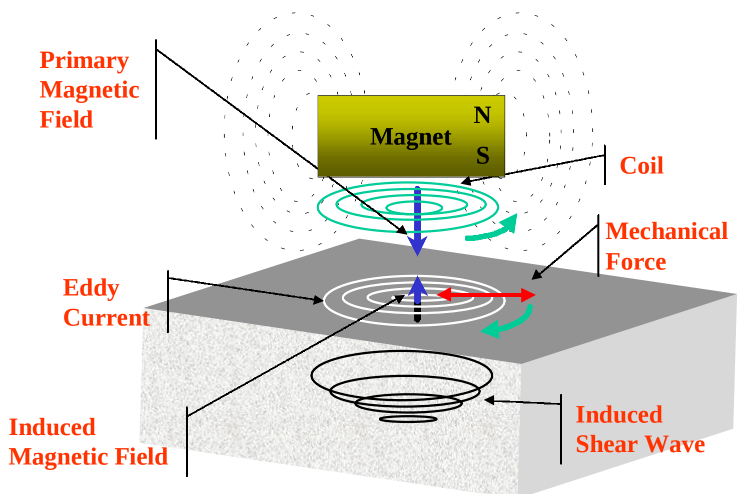


Figure 1 Typical EMAT configuration for bulk wave generation

EMATs are acoustic probes that need no physical contact with the inspected specimen. They can generate and receive ultrasonic waves in conductive or magnetic materials. EMATs can excite several types of ultrasonic waves based on the coil-magnet configuration.

The physical principles of EMAT operation are based on the principle of Lorentz force, which is caused by the interaction between the magnetic flux and the electric current, induced through the eddy current coil (see Figure 1). Ultrasonic waves are generated with an EMAT by driving its coil with high-voltage radio-frequency bursts. These bursts of current introduce eddy currents into the surface of the specimen. The eddy currents then interact with the static magnetic field perpendicular to the coil surface, producing a unidirectional shearing force. The reverse process occurs in the receiving stage: the resulting eddy current is inductively picked up by the same coil in the pulse-echo mode or the receiver in the pitch-and-catch arrangement. Different coils and magnet configurations can be used to generate different types of elastic waves.

2.3. System Components

The complete system comprises the hardware and software modules as shown in **Table 1**. All the modules were developed under the project under various headings, namely Transportation System, Ultrasonic Probes and System Instrumentation, Transducer Carriage Assembly, and Software and Automated Interpretation. Each of these tasks is detailed below.

Table 1 RailPro inspection system hardware and software modules

Hardware	Software
EMAT transducers	**User interface**
Transducer carriage and deployment mechanism	**Transducer carriage deployment**
Ultrasonic data acquisition instrumentation	**Ultrasonic data acquisition**
System host computer	**Data interpretation**
Positioning system	**Display and reporting**
Communications	**Positioning system**
Host vehicle	**Communications**

2.4. Transportation System

2.4.1. Task Goal

To perform the desired rail inspection, a transport system for all the electronics and ultrasonic probe instrumentation was required. This aspect of the project consisted of outfitting a mobile high-rail vehicle with the necessary equipment for automated rail inspection. The challenge was to design and develop a mechanism to carry the EMAT probes along the rail surface when the vehicle is operated on rails but which could be retracted to allow normal vehicle operation off rails.

Figure 2 Integrated mobile inspection system

2.4.2. Achievements

A) <u>High-Rail Vehicle</u>

The high-rail truck is a Ford model F-350 pickup truck with 4-wheel drive, automatic transmission, and a load capacity of one ton. The truck has been modified using a standard high-rail conversion whereby the tires provide traction. Additional front and rear axles with railway wheels guide the truck on the rails. The entire inspection system is contained inside the truck cabin; there is no need for external power or control. The truck is shown in Figure 2, and a drawing with the overall dimensions (in inches) in Figure 3, showing the rail clearance required with the inspection mechanism retracted.

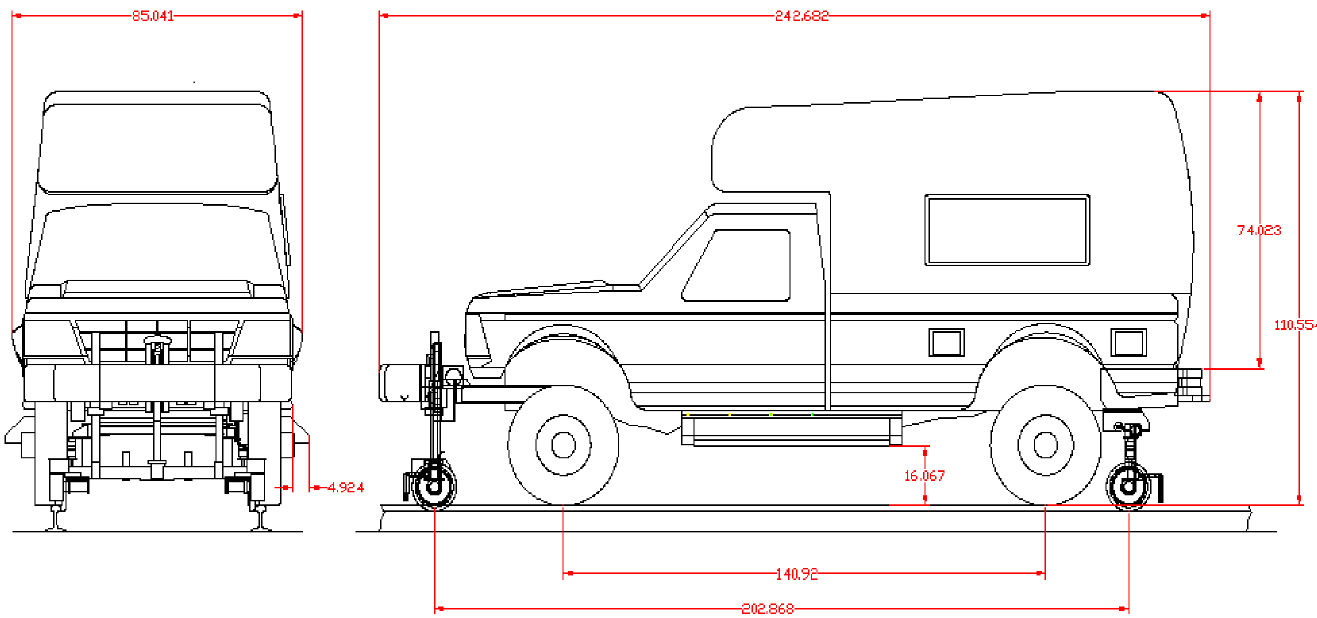


Figure 3 Overall dimensions (in inches) of the inspection vehicle

B) <u>CABIN</u>

A fibreglass cabin insulated with blown foam houses the components of the inspection system, namely the electronics, the computers, the inspection material and working space to accommodate an operator (see Figure 4). The cabin is high enough for the operator to stand up, and the layout is designed to include space for 19" equipment racks and all other electronic equipment. The cabin also features side, back and front windows. The cabin is not permanently mounted on the truck and can be removed.

Figure 4 Cabin workspace for system operation

C) <u>UTILITIES</u>

Two transducer carriages, controlled by pneumatic actuators, were designed and built. A 15-gallon compressed air tank bracketed inside the cabin powers the pneumatic system. The tank is filled by compressor under the hood. This compressor is belt-driven and can deliver up to 12 CFM at 100 psi. The inspection system requires 3400 W, which is supplied by a 24 V alternator mounted inside the cabin. The alternator charges a set of four 12 V 85A/H batteries located in containers in the back cabin. Two battery-driven 24 V DC input inverters are also located in the back cabin, and directly feed the inspection electric system. They have 1800 W continuous output at 120 V and 60 Hz. Special care is taken to prevent electrical shortages between each side of the rail.

2.5. Ultrasonic Probes and System Instrumentation

2.5.1. Task Goal

Our objectives under this task were to design EMAT probes for the detection of specified types of major defects in railroads and to develop specifications for the instrumentation required to drive the EMAT probes.

The target defects and the transducers used to detect them are shown in Table 2.

Table 2. Defect detection methods

DEFECT TYPE	EMAT TEST METHOD
Transverse fissure	90° SHEAR (0°SR)
Compound fissure	90° SHEAR (0°SR)
Detail fracture from shelling	90° SHEAR (0°SR)
Detail fracture from head check	90° SHEAR (0°SR)
Engine burn fracture	90° SHEAR (0°SR)
Welded burn fracture	90° SHEAR (0°SR)
Horizontal head split	0° SHEAR (0°SR)
Vertical head split	0° SHEAR (0°SR)
Head and web separation	0° SHEAR (0°SR)
Split web	0° SHEAR (0°SR)
Piped rail	0° SHEAR (0°SR)
Square or angular break	90° SHEAR (0°SR)
Defective weld	35° and 70° SHEAR
Bolt hole crack	35° SHEAR
Surface cracks	Surface/Rayleigh waves

2.5.2. Achievements

A) EMAT Probes

The ensemble of transducers required was defined in previous study and documented in the Design Manual. Two ultrasonic methods, pulse-echo and pitch-and-catch, are used to detect and characterize the discontinuities. The system uses angle beam, normal beam and surface wave inspection. Transducers used to detect all target defects were described in **Table 2**. The choice of transducer reflects the current configuration and shows the defects to be detected by each transducer set.

The EMAT probes in the system function in the pulse-echo mode or in both the pulse-echo mode and the pitch-catch mode. Positioning of the transducers within this assembly was investigated to determine the design trades required to optimize the inter-transducer spacing of pitch-and-catch pairs with respect to detectability, and to balance the magnetic forces of the EMAT probes.

The pitch-and-catch mode requires a fixed distance separation between the receiver and emitter. The system contains two pitch-and-catch tandems, the Rayleigh waves pair and the SH 90° waves pair. For the SH 90° tandem to inspect the railhead, a separation of 12" was established as the most effective. One single EMAT in the inspection tool is used to generate a 70° SH wave and a 90° SH wave. The same EMAT probe designed to generate 90° SH waves was configured to induce 70° SH waves in the rail head.

The two other EMATs, the 0° SH radially polarized and the 35° shear wave, work independently. However, the transducers are separated with respect to the others to balance the strong magnetic attraction between the rail and the transducer, and to avoid overlap of echoes entering the receiving gates. The key design and performance specifications for each EMAT are:

- coil configuration and dimension;
- spatial periodicity (λ_S) when applicable;
- number of periods when applicable;
- wavelength (λ);
- track width;
- track spacing;
- thickness of PCB material;
- operating frequency;
- transmitter-receiver distance for pitch-catch configuration.

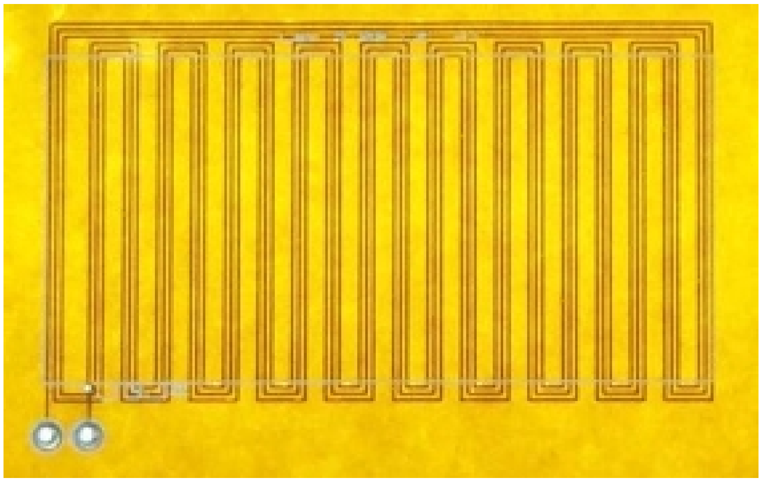


Figure 5 Coil used for generation of shear vertical waves

Each EMAT probe consists of a flat coil (see Figure 5) printed (wound or on a Kapton sheet) and a single or set of permanent magnets made of sintered Neodymium-Iron-Boron (NdFeB) stacked over the coil. The magnet is shielded from the coil by a copper foil inserted between the coil and the magnet(s). A layer of foam material is also inserted to allow the coil to follow railhead surface irregularities. With a polymer tape, PCB material and foam, the magnet lift-off is about 0.1" from the rail. When the coil is printed on the bottom side of the PCB material, coil lift-off corresponds to the polymer tape thickness of 0.007". Figure 5 illustrates a multi-wire meander line coil used to generate shear waves at a 35° angle.

Table 3 lists the probes used and their detection tasks. Table 4 shows some of the EMAT parameters that have already been established during system design.

Table 3. EMAT probes for rail inspection

Probe	Function	Detection task
SR 0°	Transmitter – Receiver	HSH, VSH, SW, HW, BHC
SV 35°	Transmitter – Receiver	BHC, DWF, DWP
SH 90°	Transmitter – Receiver	VSH, TD, DWF, DWP
SH 90°	Receiver	
Rayleigh	Transmitter – Receiver	Surface defects
Rayleigh	Receiver	

Table 4. EMAT probe parameters

Probe	Configuration	λ_S	λ	Frequency	Coil Area	T/R distance
SV 35°	Meander line	0.15"	0.1"	1.4 MHz	1" x 2"	N/A
SR 0°	Circular	N/A	0.08"	1.6 MHz	1.5" dia.	N/A
Rayleigh	Meander line	0.12"		1 MHz	1" x 2"	8"
SH 90°	PPM	0.25"		~0.4 MHz		10"

B) Instrumentation

A complete inspection system was designed and developed (see Figure 6). The system requires many electronic components, and where possible, commercially available components were used. Where this was not possible, or not cost-effective, special-purpose components were designed and fabricated. An eight-channel ultrasonic pulser-receiver system was designed and built.

The data acquisition system was successfully designed to support 12 real-time acquisition channels. Each channel represents a high-power tone burst pulser/receiver card with adjustable voltage output (400-1800 Vpp). Figure 7 shows the pulser/receiver unit. The receiver units on the system have excellent linearity, fast recovery form overload, and a good signal-to-noise ratio. Filters were also designed and manufactured to reduce the noise and to limit the high-end signal response.

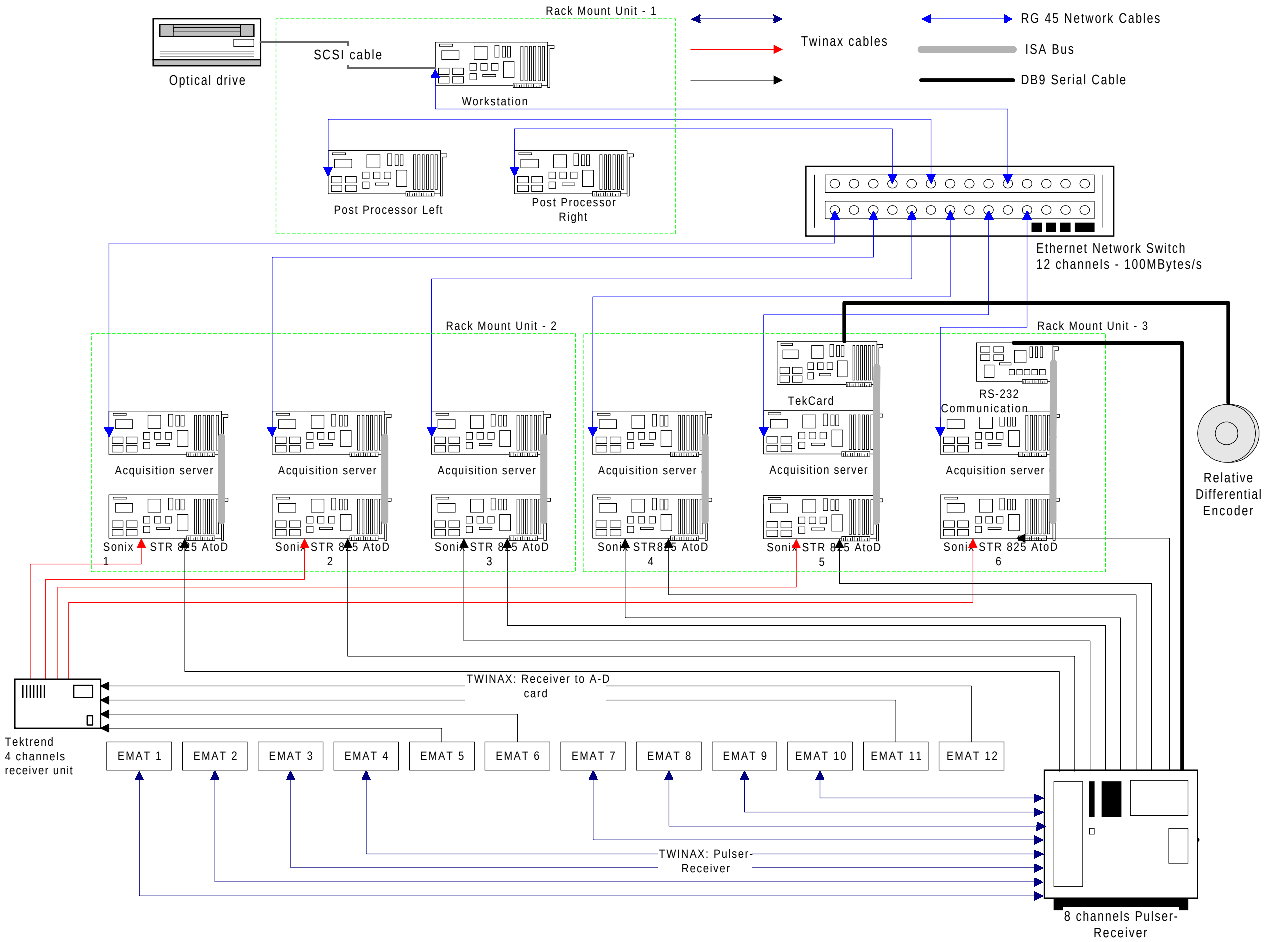


Figure 6 Complete instrumentation diagram for rail inspection tool

Figure 7 Pulser/receiver unit

2.6. Transducer Carriage Assembly

2.6.1. Task Goal

To transport the EMATs along the rail surface for defect inspection, a transducer carriage system was designed and installed under the inspection vehicle. This carriage consists of an enclosure, the transducer assembly and of two levels of pneumatically-activated articulations.

2.6.2. Achievements

A) <u>Enclosure</u>

The enclosure consists of a galvanized steel box containing the entire carriage mechanism and the transducer assembly (Figure 8). This box is fastened to the truck frame by a set of specially designed brackets. The enclosure has two roles. When closed, it provides a dry protection box in which the transducer assembly is retracted and safely stored, allowing the truck to roll on regular roads. When open, it serves as a structural member, maintaining the position of the transducer assembly on the rails. All of the electrical wiring and the pneumatic tubing connects to the enclosure through a quick-connect fitting.

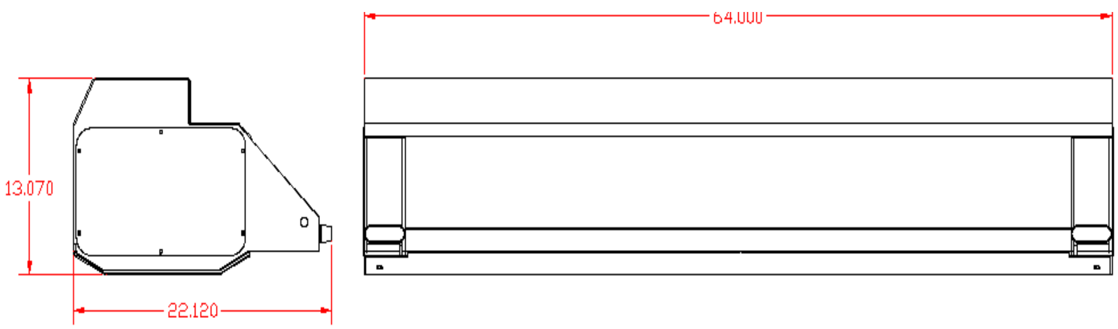


Figure 8 Transducer assembly enclosure dimensions (retracted)

The enclosure incorporates a truck step inserted in the design to reinforce the base and to act as a structural member to which some components are attached. The step conceals the base system and increases the storage volume in the enclosure without blocking access to the truck.

To deploy the inspection system, two doors located at the bottom of the enclosure are opened by pneumatic cylinders. Hinges are located on the sides of the base (interior and exterior). The open doors hide and protect the articulation system. Once the doors open, the two mechanisms forming the transducer carriage are automatically lowered to rail level using pneumatic actuation.

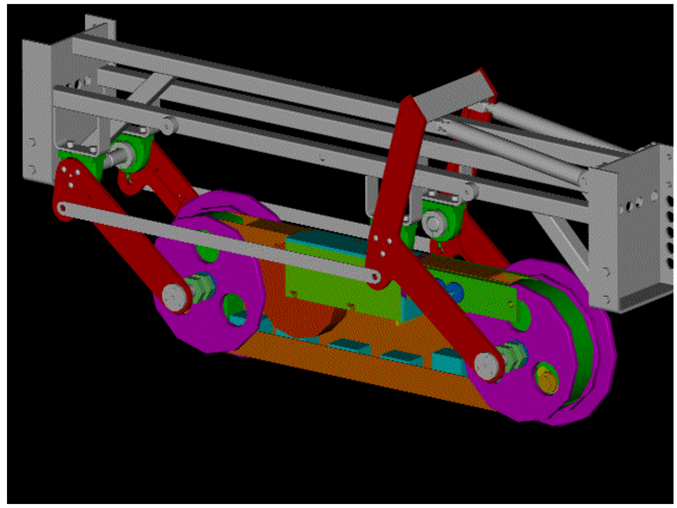


Figure 9 Transducer carriage and holder

B) ACTIVATED ASSEMBLY

Carriage component positioning is provided on three orthogonal axes: the longitudinal axis, which is defined by the rail orientation; the vertical axis; and the transverse axis, which is parallel to the ground but perpendicular to the rails. The main carriage members are displaced pneumatically and the carriage pressure on the rail is also provided by compressed air. The activation of these various mechanisms is performed though a series of pneumatic actuators and cylinders controlled via a Programmable Logic Controller (PLC). Operation of the inspection carriage is fully automated and performed from the cabin by computer push buttons that activate the PLC. The carriage is shown in Figure 9, while Figure 10 provides a clear view of the deployment mechanism.

Figure 10 Transducer deployment mechanism

C) TRANSDUCER ASSEMBLY

The transducer assembly is the part of the system that holds the EMATs and is brought into contact with the rail surface. The assembly also contains a winding mechanism with a polymer tape which is used as a protective layer between the transducers and the rail surface. Flanged wheels are placed at both ends of the assembly to guide it along the gauge side of the rail and to maintain the transducers over the centre of the head (see Figure 11).

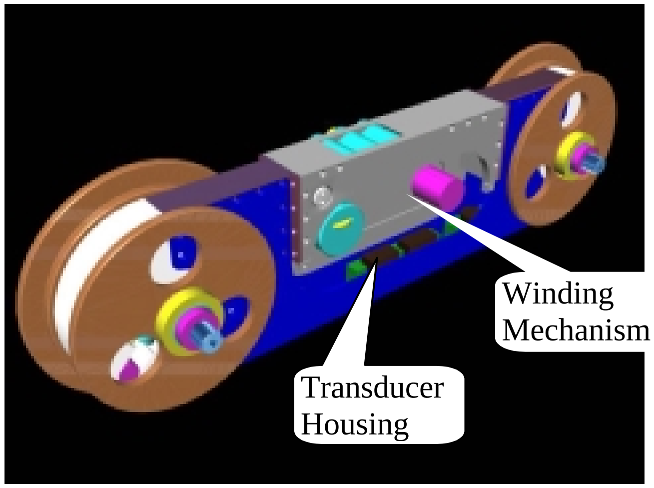


Figure 11 Transducer assembly enclosure dimensions (retracted)

2.7. Software and Automated Interpretation Development

2.7.1. Task Goal

The developments under this task include the specification, design and development of the software responsible for data acquisition, data analysis (intelligent algorithms) and data management. The software functions were identified as follows:

- system set-up and hardware control (local network, odometer, carriage, keyboards, digitizers, and so on);
- data acquisition (UT signals, rail features, milepost);
- data interpretation and defect automatic classification;
- data display (real-time and play-back);
- data management (storage, report edition, analysis).

2.7.2. Achievements

As mentioned in the instrumentation section, pyramidal hardware architecture was designed to support high-speed data acquisition and management (see Figure 12). This architecture is composed of nine computer stations distributed at three levels and communicating via IPX/Ethernet connections.

- Level 1: six acquisition servers
- Level 2: two post-processor stations
- Level 3: one RailPro station

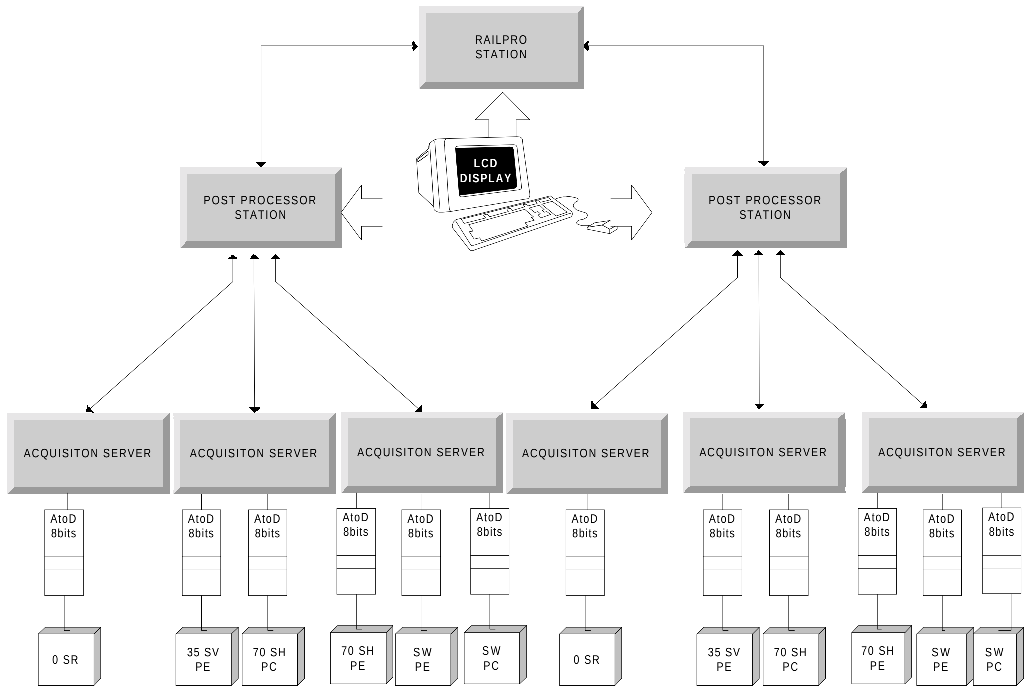


Figure 12 Hardware pyramidal architecture

Table 5 summarizes the allocation of the developed software modules on the distributed levels.

Table 5. Function allocation on the different stations

Functions/Station	RailPro	Post-Processor	Acquisition Server
System set-up and hardware control (UT instrumentation)			**X**
System set-up and hardware control (carriage, keyboards)	**X**		
Data acquisition: UT signals, odometer			**X**
Data acquisition: rail features, milepost	**X**		
Data interpretation and defect automatic classification	**X**	**X**	
Data display (real-time and play-back)	**X**	**X**	
Session management (data and set-up storage, report edition, analysis)	**X**		

A) <u>LEVEL 1: ACQUISITION SERVERS</u>

At the bottom level of the pyramid, multi-channel signal acquisition servers have been developed. These servers perform real-time acquisition and real-time data analysis through the use of thresholding and signal gating. Each server manages one or several acquisition channels, including a digitizer card and a pulser-receiver channel.

B) <u>LEVEL 2: POST-PROCESSORS</u>

Two post-processor stations are included. These post-processors embed hybrid classification routines for flaw classification. This simplifies the inspector's workload by reducing the amount of data that must be analyzed in order to assess the condition of the rails.

Data Analysis

Post-processing and signal analysis algorithms were designed and tested. These algorithms were integrated into the software to form the heart of the post-processor.

Processing of the collected data includes the following steps:

- signal pre-processing, noise filtering and signal pre-selection (Figure 13, Figure 14);
- flaw detection and clustering (Figure 15);
- feature and parameter extraction;
- data mapping and fusion (Figure 16);
- automatic classification.

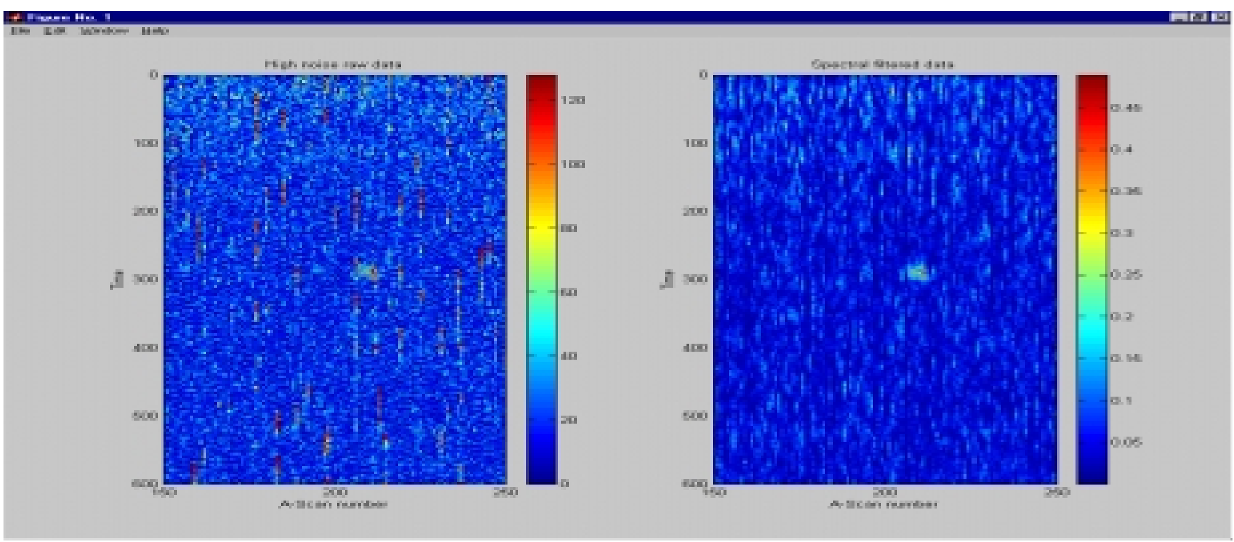


Figure 13 Noise filtering

The mapping and fusion algorithms are still being tested. This task consists of developing a 2D or 3D virtual environment in which the data collected from each acquisition channel is presented for defect interpretation and assessment. Such mapping of the data takes into account the angle of propagation of the propagated waves, the probe positions along the rail, the channel from which wave was recorded, the wave arrival time, and finally, when possible, the direction of the collected signal (since EMATs have forward and backward wave emission).

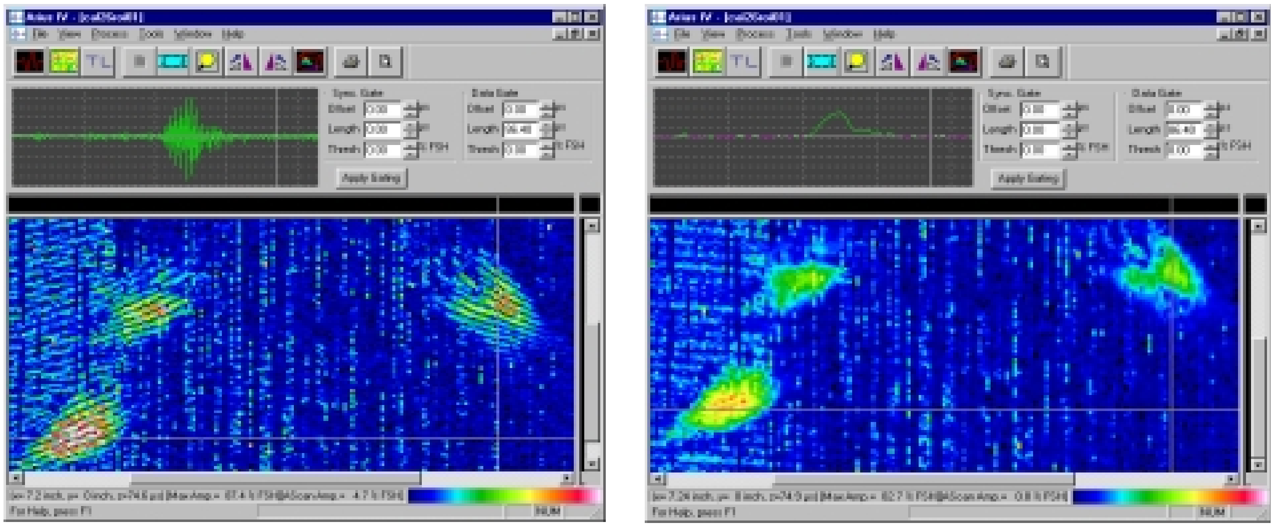


Figure 14 Noise filtering and signal pre-selection

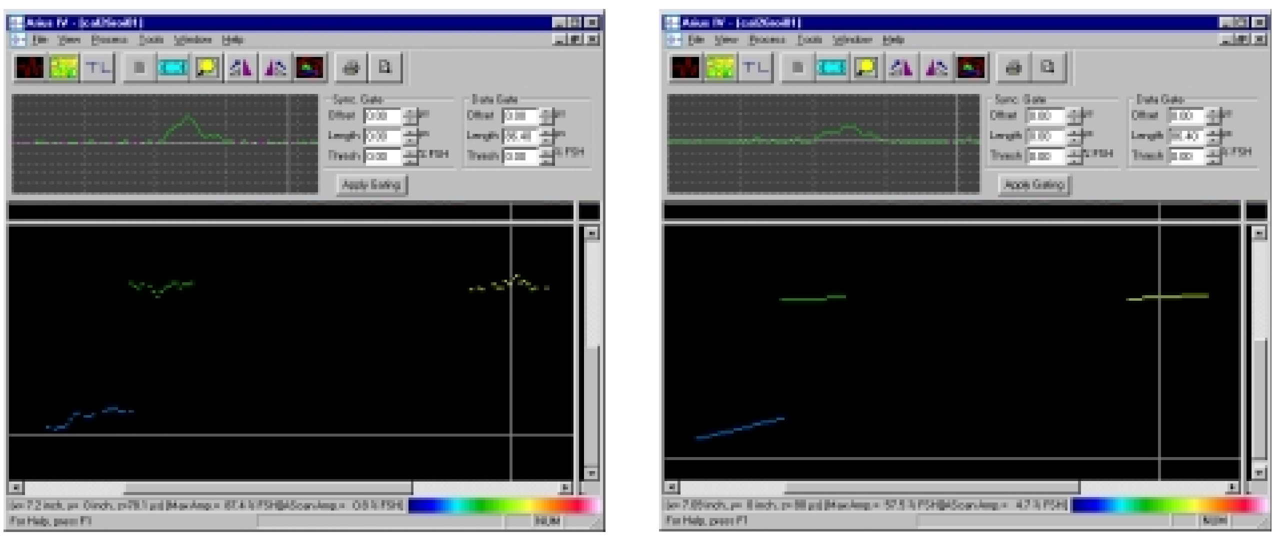


Figure 15 Flaw clustering

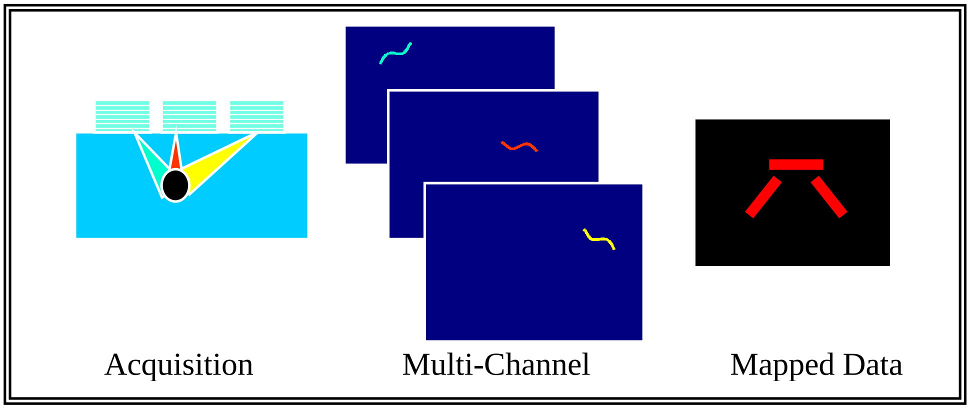


Figure 16 Multi-sensor data mapping and fusion

Network Communication Higher Layers

To manage the link and ensure layer communication (acquisition servers, post-processors and RailPro workstation), network development was required. The link, as shown in Figure 17, allows us to manage the multi-channel acquisition (graphical user interfaces, set-up functions, data management and lower level network communications).

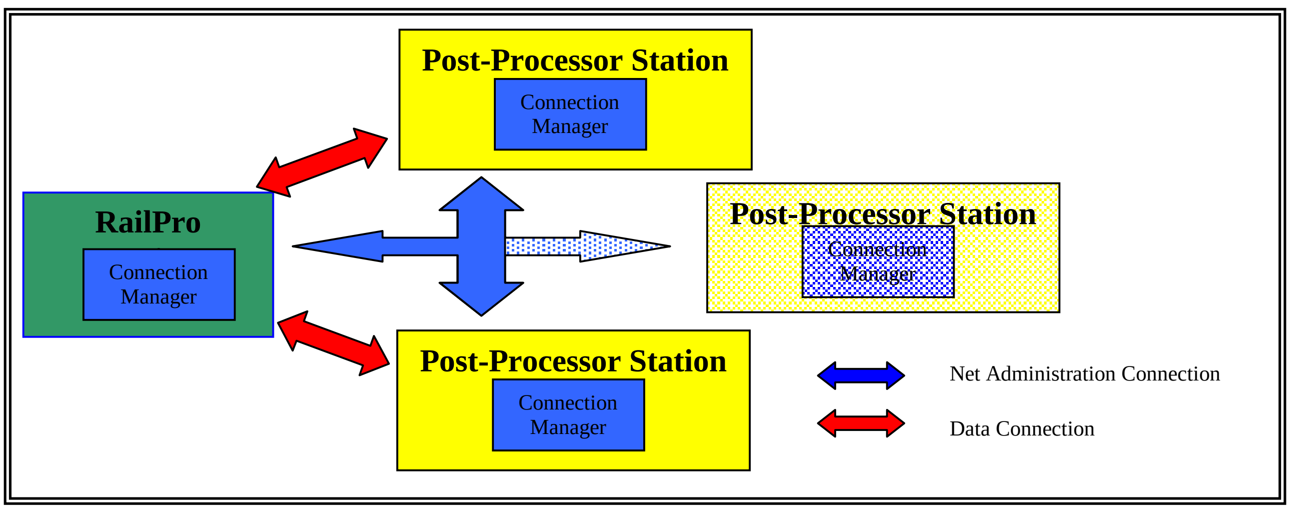


Figure 17 Developed and implemented network communication

C) LEVEL 3: RAILPRO WORKSTATION

The RailPro workstation manages the inspection session and all interactions with the user through a dedicated graphical user interface that provides the user with a simple and effective means of interacting with the rail inspection system. The interface provides the user with the following information and/or capabilities:

- pre-inspection calibration;
- alarm conditions and general rail condition;
- position/geographical information;

- defect status;
- post-inspection reporting;
- manual override;
- real-time and playback strip chart display of indications, anomalies, user comments, rail features, milepost and carriage velocity;
- data management;
- session management;
- report generation and connection with Excel software.

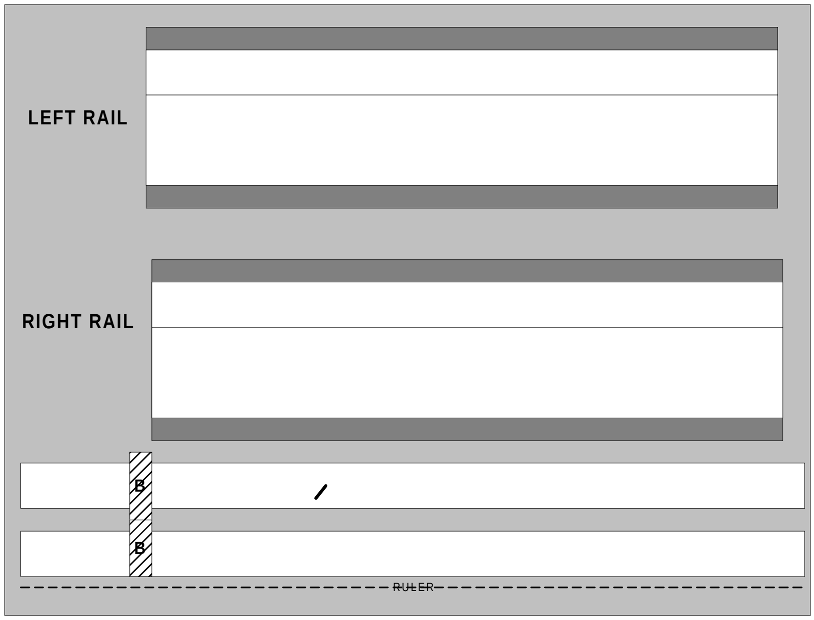


Figure 18 Data display channel

Figure 18 shows the data display screen that is activated when the user presses the Start Inspection button. The top panels show the two rail sections in a B-scan (B-scan with indication representation). These two frames are a magnification of a region in which an indication of a possible defect was found. When a new indication (defect or not) is detected, the corresponding rail section is refreshed in the top section of the display. In the bottom section, the rails are scrolled continuously in strip chart mode and all information recorded by the system, including rail features, milepost, velocity of carriage and indications, is displayed. With two scrolling cursors, one for each rail on the bottom section, the user can magnify a region of interest. Once selected, this portion is replotted in the top section. As soon as a new indication is found, the top section is refreshed.

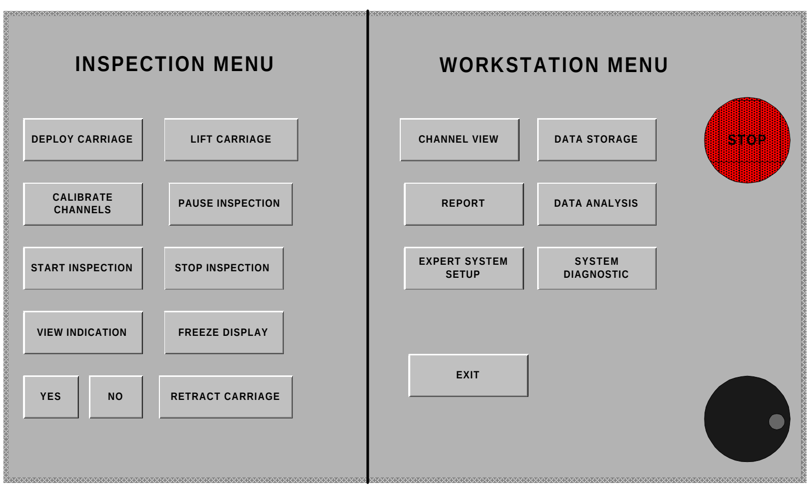
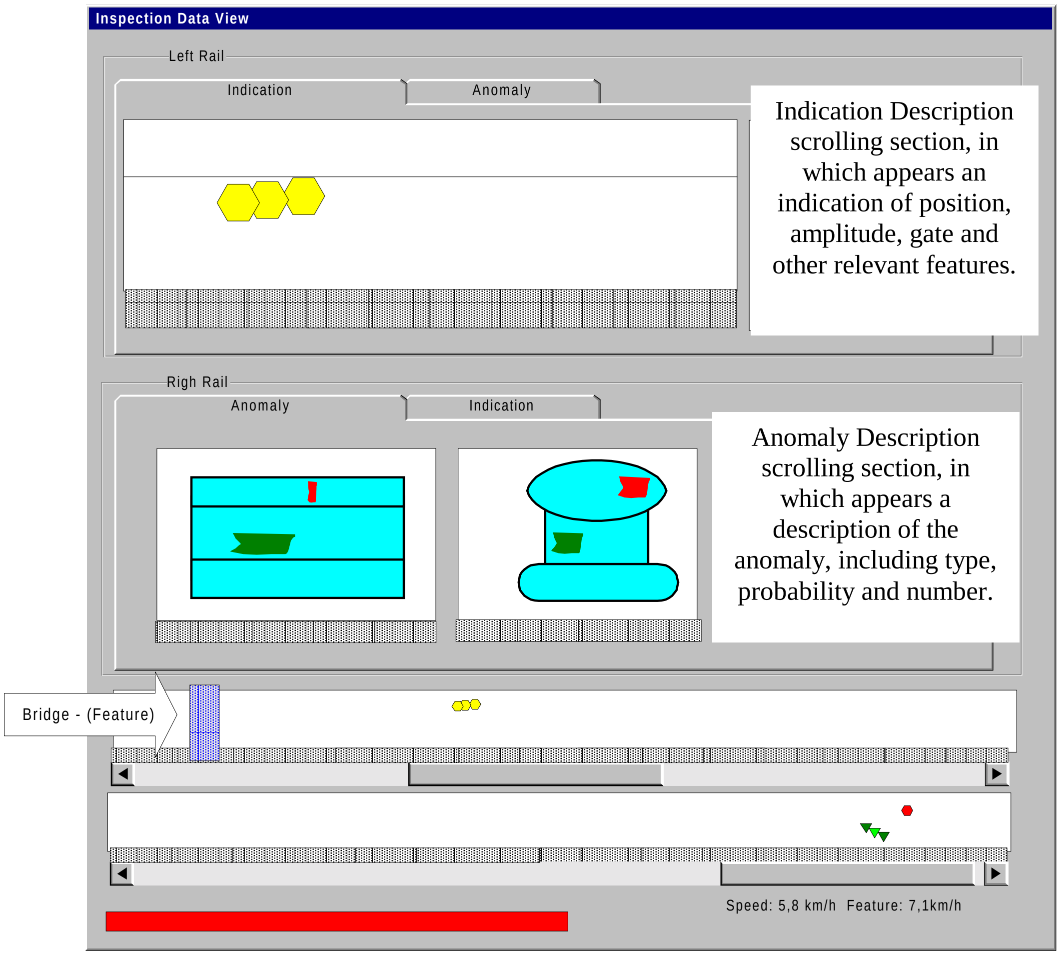


Figure 19 Main system control, set-up and management interface

The main system interface is shown in Figure 19. Communication between the software and the inspector is maintained through a dedicated keyboard with predefined functions. This keyboard, similar to a video station interface, is divided into two main sections: the inspection section and the workstation section. The visual keyboard also has an emergency stop button, a track ball and



a full alphanumeric pad. This alphanumeric keyboard and the trackball (mouse or wheel) address and simplify more complex software functionality.

Figure 20 Interpretation panel

The top section in Figure 20, the interpretation panel, is a magnification of the region where indications were found and computed as anomalies. As soon as a new indication (defect or not) is detected, the corresponding rail section is refreshed in the top section of the display. For each rail, the inspector can either watch a magnified view of indications, complete with synthetic feature display, or an anomaly view, showing data resulting from expert-system indications analysis. Indications considered to be part of the same anomaly are grouped for flaw sizing.

Flexible display of data on each channel are displayed in the window illustrated in Figure 21. Multiple instances of this window can be opened simultaneously for each channel.

Channel View Display

Several of these windows can be opened simultaneously via the display channel button on the RailPro keyboard. In this view, the area of inspection can be seen as an A-scan. The refreshment rate corresponds to the rate of data collection. Instrumentation parameters, including gate length and threshold, for the pulser/receiver and the digitizer can also be set from this menu.

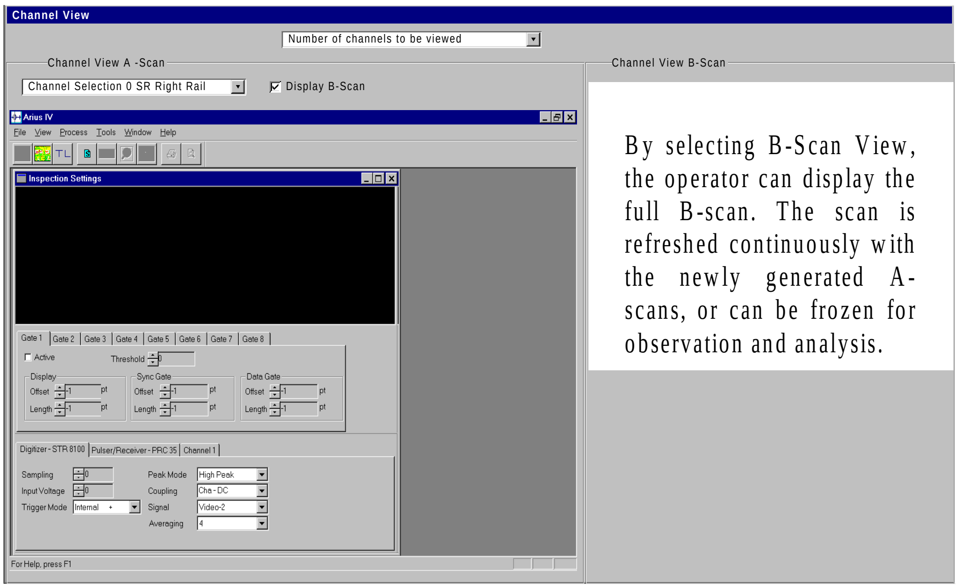


Figure 21 Channel view

2.8. TEST INSPECTION RESULTS

2.8.1. TASK GOAL

Under this task our objective was to compile a comprehensive library of well-known defects to be used for inspection system design and development. Rail samples with defects were made available to Tektrend by CN North America. These samples represent a significant set of rail defects that were inspected in detail by Tektrend.

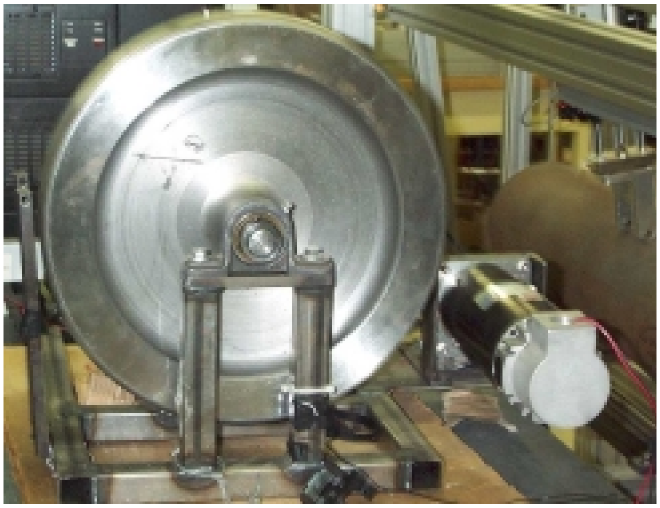


Figure 22 Flywheel used for dynamic tests in the laboratory environment

2.8.2. ACHIEVEMENTS

A) TESTS ON LABORATORY SAMPLES

Laboratory dynamic tests were performed using a 15½" diameter steel flywheel with a machined defect through the thickness of its inner section (see Figure 22). These tests were performed to establish the dynamic noise and the ability of the EMAT probes to detect defects at high-speed inspection. This set-up also permitted testing of the polymer strip used to protect the EMAT coil and ensure reduced friction with the railhead.

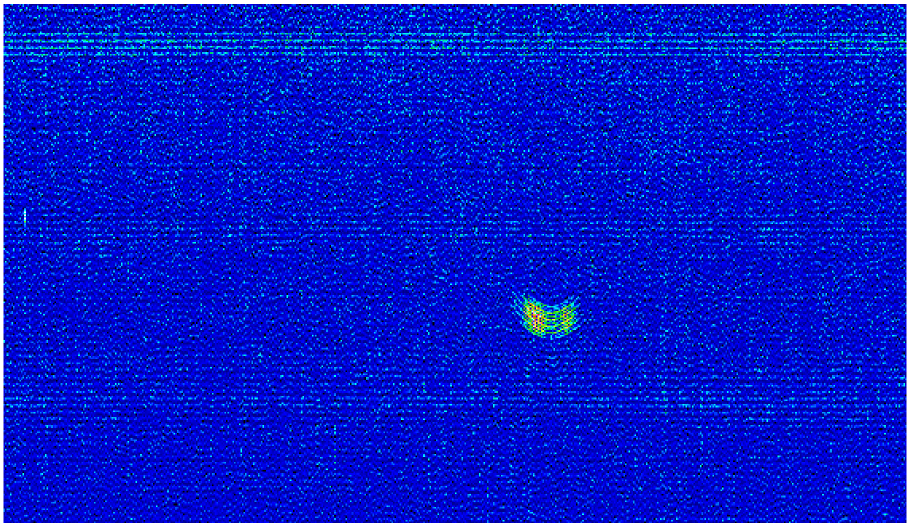


Figure 23 RF B-scan of defect on flywheel with speed of 5 mph

Tests were performed at different speeds up to 10 mph. In all cases, the defects were easily detected. The scan in Figure 23 was performed using a 0° shear EMAT at a 2.4 MHz frequency with an acquisition rate of 1.7 kHz.

B) <u>CALIBRATION RAILS</u>

The detection capabilities of the system were assessed over the 150-foot evaluation track at CN Taschereau Yard in Montreal. These tracks are specially designated for system test calibration and have been prepared with defects of various types. During these tests, different EMAT configurations were used to evaluate their detection performance from 3 mph to 6 mph. **Table 6** describes the 12 defects known to be in the track and the type of probes used to detect them with the RailPro inspection system. Figures 24 – 30 are examples of the A- and B-scans collected.

Table 6 Test calibration defects

Defect Number	Defect Name	Defect Acronym	Main Detection Transducer	Secondary Transducer Detection	Position	Dimensions
1	Horizontal Split Head	**HSH**	0^0 SR	80^0 SH	Rail head 1/2" from top of rail	1/16" milled slot, 2" long
2	Bolt Hole Crack	**BHC**	35^0 SV	0^0 SR	Rail web 45^0 from top of bolt hole	1/16" machined slot, 1/2" long
3	Vertical Split Head	**VSH**	80^0 SH	0^0 SR	Rail head Gauge side	Cut and reweld 6" long
4	Defective Weld (in flash butt weld)	**DW**	80^0 SH	0^0 SR 35^0 SV	Rail head 5/8" from top – 20^0 from web head separation	Flat bottom hole drill 1/4" x 2-3/16"
5	Split Web	**SW**	0^0 SR	35^0 SV	Rail web ½ thickness of web	Milled slot 2" long
6	Vertical Split Head	**VSH**	80^0 SH	0^0 SR	Rail head Field side	Cut and reweld 6" long
7	Bolt Hole Crack	**BHC**	35^0 SV	0^0 SR	Rail web 225^0 from top of bolt hole	1/16" machined slot, 1/2" long
8	Defective Weld (in thermit weld)	**DW**	80^0 SH	0^0 SR	Rail head 5/8" from top - 20^0 from web head separation	Flat bottom hole drill 1/4" x 2-3/16"
9	Head and Web Separation	**HW**	0^0 SR	35^0 SV	Head and web interface	2" milled slot ½ thickness of web
10	Transverse Defect	**TD**	80^0 SH	0^0 SR	Rail head	Machined slot 1/16" x 1/2"
11	Bolt Hole Crack	**BHC**	35^0 SV	0^0 SR	Rail web 315^0 from top of bolt hole	1/16" machined slot, 1/2" long
12	Bolt Hole Crack	**BHC**	35^0 SV	0^0 SR	Rail web 135^0 from top of bolt hole	1/16" machined slot, 1/2" long

The results are displayed as B-scan images, and observed in the inspection cabin on an LCD display. The horizontal axis on the B-scans corresponds to the displacement along the rail tracks and the vertical axis corresponds to the time-of-flight (or distance) across the head rail section.

DEFECT #1: HORIZONTAL SPLIT HEAD DETECTED WITH TX 0°

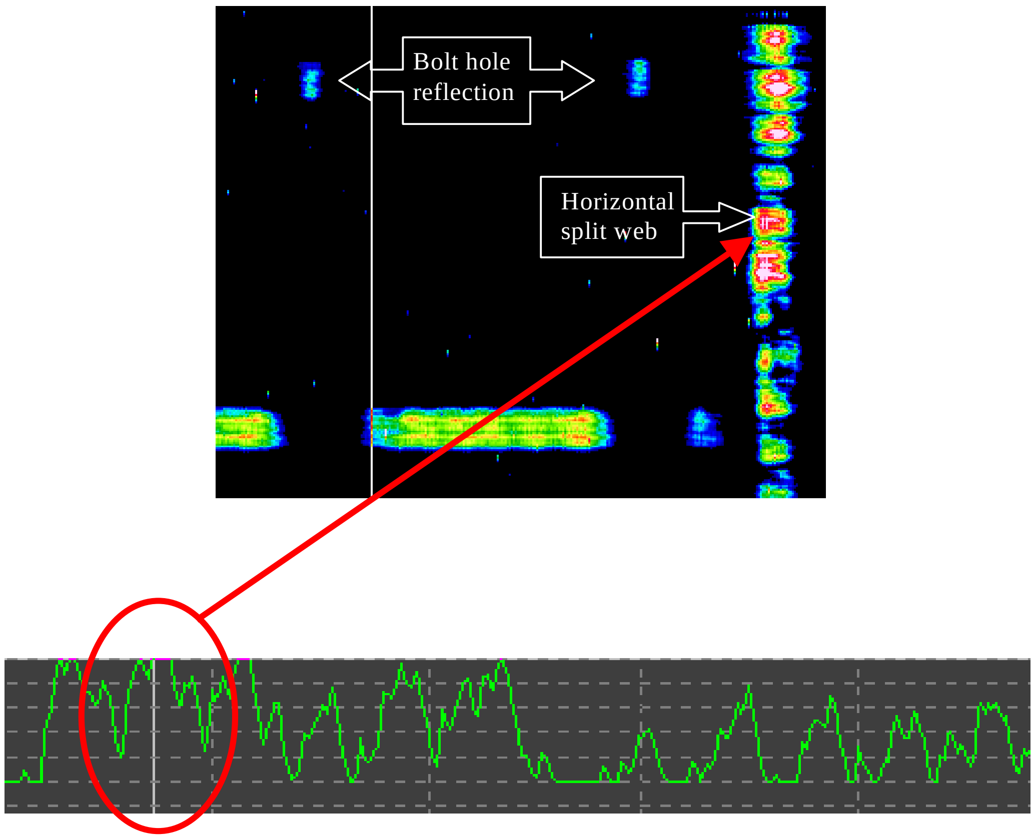


Figure 24 B-scan and corresponding A-scan of HSH #1

DEFECT #2: BOLT HOLE CRACK DETECTED WITH TX 0°

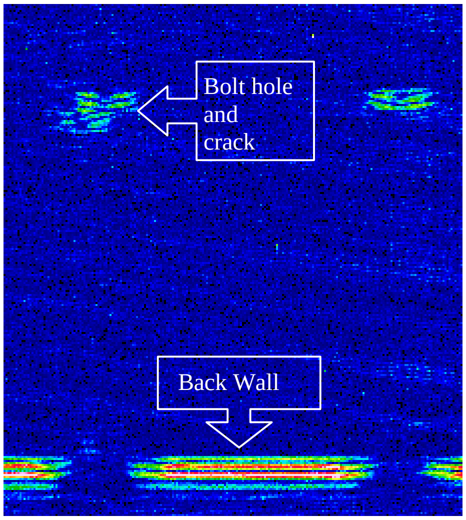


Figure 25 B-scan of BHC #2

DEFECT #5: SPLIT WEB DETECTED WITH TX 0°

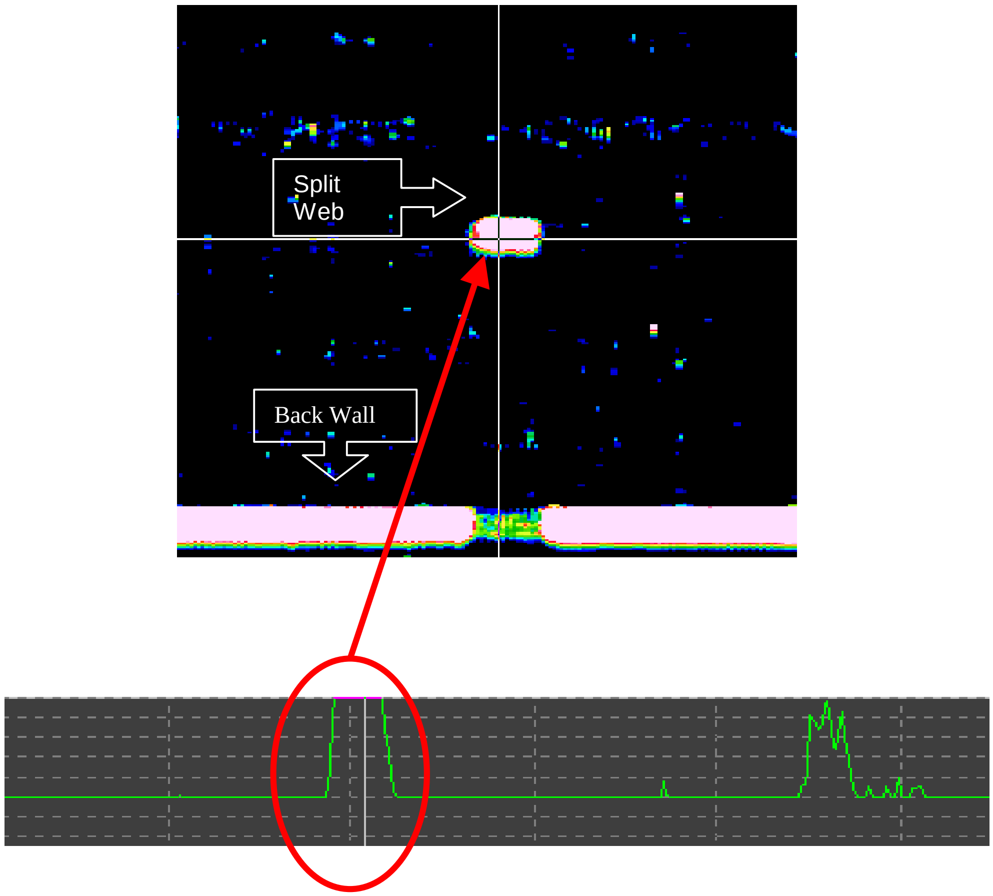


Figure 26 B-scan and corresponding A-scan of SW #5

DEFECT #6: VERTICAL SPLIT HEAD DETECTED WITH TX 0°

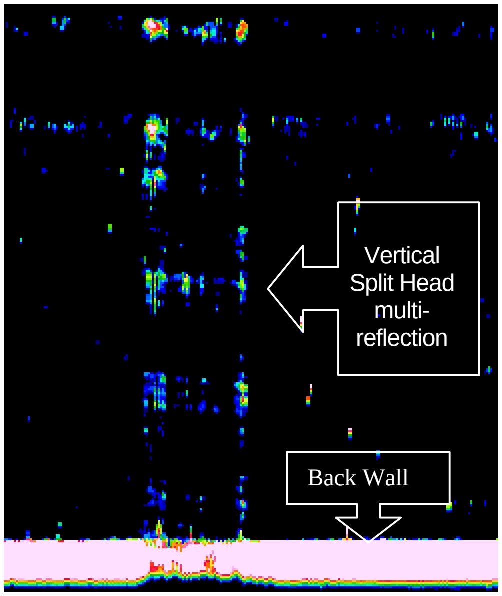


Figure 27 B-scan of VSH #6

DEFECT #7: BOLT HOLE CRACK DETECTED WITH TX 35°

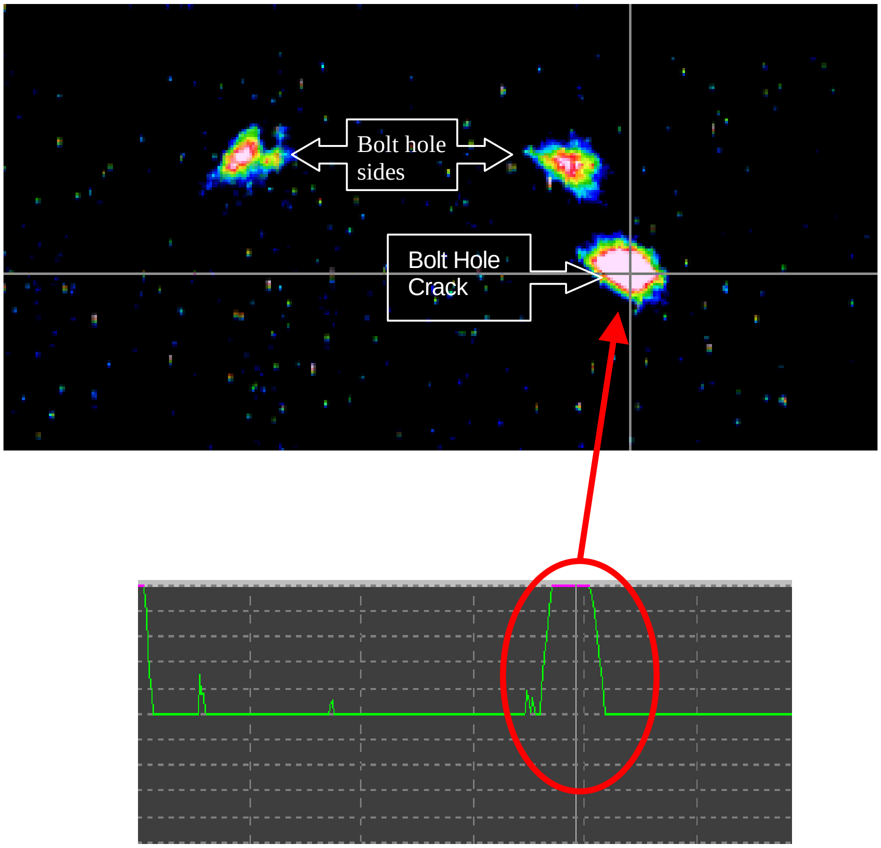


Figure 28 B-scan and corresponding A-scan of BHC #7

DEFECT #9: HEAD AND WEB SEPARATION DETECTED WITH TX 0°

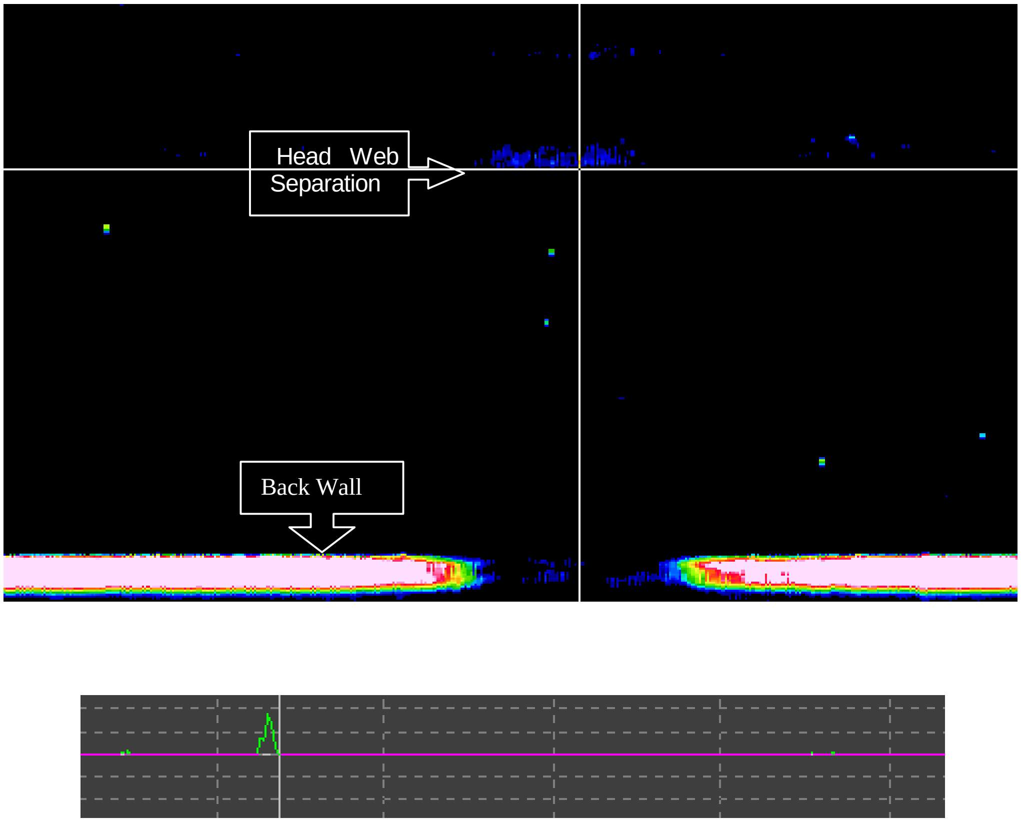


Figure 29 B-scan and corresponding A-scan of HW #9

DEFECT #11: BOLT HOLE CRACK DETECTED WITH TX 35°

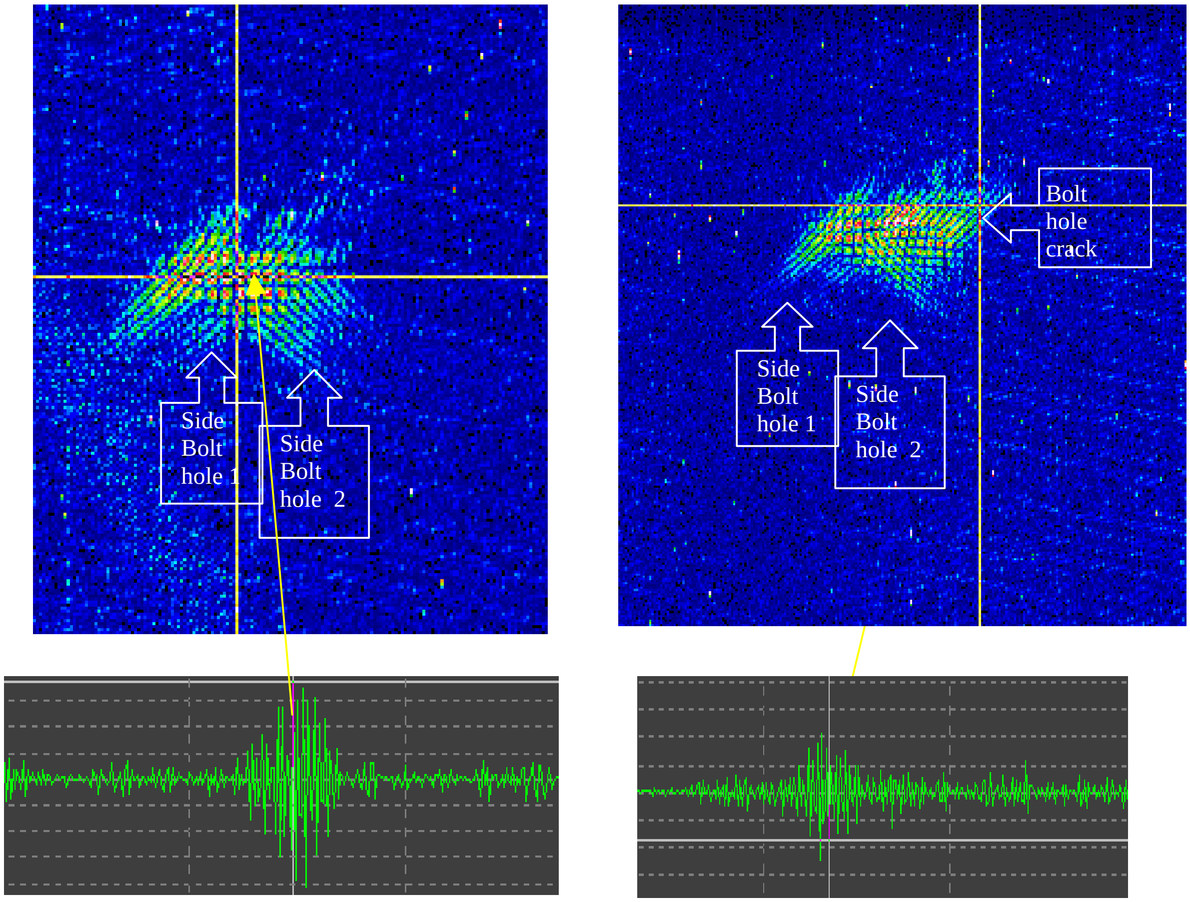


Figure 30 B-scan of BH sides of two bolt holes and BHC #11 with corresponding RF A-scans

All of the selected and tested defects were detected during the first testing round, which makes the testing reliability very high. For example, the reliability of detecting bolt hole cracks was of the order of 75%. Such superb detection performance is due to the high signal-to-noise-ratio of the collected signals. Tests were repeatable and accurate at a small range of different inspection speeds. Finally, it is important to mention that during these tests, only conventional and simple defect interpretation was used to make the calls for the defects. However, the system has advanced capabilities for defect characterization and visualization included in the software to assist the operator to distinguish between indications (defects) and anomalies (candidate defects).

3. Conclusions and Recommendations

This work has produced the development of an advanced inspection tool and procedures for real-time railroad testing based on ultrasonic stress waves and using EMAT probes. The project has created an operating high-rail system with enhanced defect detectability and efficient, reliable automated defect interpretation techniques. The project was also successful in addressing all the theoretical, mechanical and detectability problems we aimed to solve.

Encouraging test results were obtained with the RailPro vehicle over an evaluation track at Canadian National Taschereau Yard in Montreal. These results were interpreted as B-scan images and A-scan waveforms, which were observed in the inspection cabin of the vehicle on an LCD display. EMAT probes were used to perform all the field tests. They demonstrated efficiency in detecting several types of rail defects and showed capacity to generate different wave modes by changing the excitation frequency. When using these EMATs, no physical contact with the test specimen was necessary, making them attractive for high-speed field inspections. The tests proved that the RailPro system, together with inspection procedures, EMAT sensors and automated interpretation techniques, is an efficient and reliable inspection approach.