NO FRA #

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	
IN-SERVICE WHEELFAX CONCEPT EVALUATION	5. Report Date January 1983
	6. Performing Organization Code
7. Author(s) W.T. Michael, D.K. Shaver, D. Levine, D.M. Dancer, D.E. Gray	8. Performing Organization Report No.
9. Performing Organization Name and Address Systems Technology Laboratory Transportation Systems Division 2045 North 15th Street Arlington, Virginia 22201	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DT FR53-80-C-00017
12. Sponsoring Agency Name and Address Federal Railroad Administration Office of Rail Safety Research 400 7th Street, S.W. Washington, D.C. 20590	13. Type of Report and Period Covered FINAL REPORT January 1983 14. Sponsoring Agency Code

15. Supplementary Notes

This report is in response to Section 1195 of the Explanatory Statement of the House and Senate Conferees with respect to subtitles E, F, and G of Title XI of the Omnibus Reconciliation Bill of 1981.

16. Abstract

Work performed on this task include the evaluation of the WheelFax concept; problems, difficulties and modifications made by purchasers of WheelFax systems; effectiveness of this detection concept with respect to the wheel inspection process defined in the Field Manual of the AAR Interchange Rules 1983; an analysis of total accidents attributed to wheel failures versus the number of these accidents where the WheelFax may have detected the faulty wheels; and finally recommendations on future research with respect to the WheelFax and other related wheel failure projects that are anticipated in the near future.

17. Key Words	18. Distribution Statement
WheelFax System, Wheels, Search Unit, Failure Detection, Cracks, Nondestructive Testing, Ultrasonics	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

03 - Rail Vehicles & Components

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

The purpose of this effort was to evaluate the WheelFax system concept as an in-service device for detecting wheel defects and recommend future work related to the WheelFax system and other wheel failure prevention systems.

This report is structured into the following sections: Section 1, Executive Summary, presents an overview of the report; Section 2, Introduction, presents the project objectives, background on railroad wheels and wheel defects and the theory of the WheelFax system; Section 3, History of the WheelFax System, provides background information on each WheelFax system; Section 4, WheelFax Operational Analysis, details the operating and maintenance requirements for the only currently operating system; Section 5, Accident/Cost Analysis, presents railroad accident and cost statistics for those accidents caused by wheel failures; Section 6, Conclusions and Recommendations; and Appendix A, WheelFax Theory of Operation.

Wheel imperfections that are condemnable by AAR Interchange Rules are called defects. Wheel imperfections that may or may not be condemnable are called flaws.

This report is an evaluation of an ultrasonic technique to detect defective wheels. The particular system evaluated, WheelFax, was designed to detect flaws in the tread and flange of railroad wheels. The frequency and angle of the ultrasonic crystals were optimized to produce an acoustic surface wave to detect small cracks on the tread and flange.

1. EXECUTIVE SUMMARY

Existing detection techniques for seriously defective wheels (primarily visual) are generally successful - out of over 15,000,000 wheels in revenue service, there are only about 400 railroad accidents per year attributed to railroad wheel failures. The consequences of wheel failures, however, can be catastrophic. For example, in Laurel, Mississippi and Waverly, Tennessee wheel failures caused the derailment of hazardous material tank cars with significant subsequent deaths, injuries, and property damage. There is a consensus in the railroad industry that wheel failures are one of the most serious safety problems.

Wheels are manufactured by forging and castings and come in a variety of sizes, shapes, and steel compositions. This makes an automated defect detection technique difficult to implement. Moreover, wheel failures can occur from many different causes. There is agreement, however that the most dangerous failure mechanism is thermal cracking which can lead to a catastrophic wheel failure.

Certain brake applications can adversely affect the safety of railroad wheels by creating too much heat in the wheels. Visual inspections are used to inspect wheels, and wheels showing signs of being overheated (e.g., oil or dirt on the wheel that appear to be burned, a blue metal color, or a reddish brown color that extends four inches from the rim onto the plate) are rejected. Wheels are also rejected if thermal cracks are evident.

The railroads, recognizing the severity of the wheel failure problem, are investigating non-destructive testing methods for wheels. These techniques include the Acoustic Cracked Plate Detector, the Hot Wheel Detector, the Barkhausen Noise Technique, X-ray Diffraction, Electromagnetic Acoustic Techniques, and the Kerr Magnetooptic Effect. Another potential promising concept is an ultrasonic technique (WheelFax).

The WheelFax system was designed to detect cracks on the tread, rim and flange of railroad wheels (See Figure 1).

There are several components in the WheelFax system, some are positioned in the rail of the track, some are at track side (See Figure 2) and others are located in a nearby equipment control center. There may also be a remote pen chart recorder that can provide a record of the test results for each wheel that passes through the WheelFax site. The wheel search units, the heart of the detection system, are mounted in a special rail on each track. These units are designed so that the maximum width of the wheel tread contacts the head of the search unit as the wheel is tested.

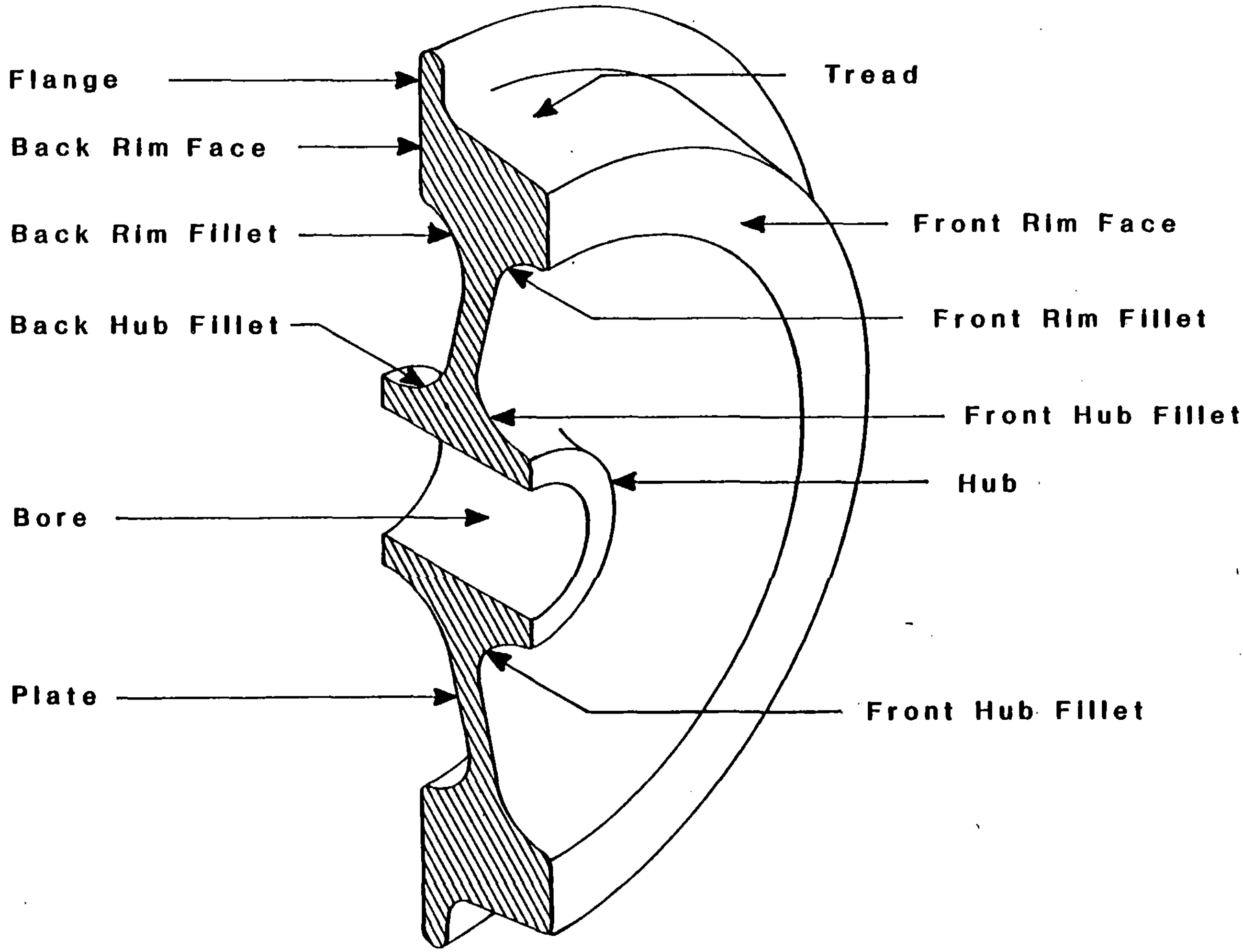
The liquid filled boot of the search unit contains the devices (crystals) which pulse the ultrasonic energy into the wheel. The boot extends 1/2" to 7/8" above the top of the rail (See Figure 3). Passing wheels push the surface of the boot downward so that it assumes the shape of the wheel tread surface.

A water spray system in the rail will wet the top of the search unit boot and the approaching wheel tread just before and as the wheel contacts the boot. This effectively eliminates a potential air gap and assures that the energy is conducted from the search unit to the wheel.

A wheel is in contact with the search unit for about six inches of travel. At 20 mph the contact time is approximately 1/60 of a second.

Wheels can approach from either direction. If the system registers an alarm a paint system will spray the wheel and the strip chart recorder will indicate this wheel.

The WheelFax system cannot detect 11 of the 21 wheel defects defined in the Field Manual of the AAR Interchange Rules. It cannot detect a thin flange, vertical flange, thin rim, grooved tread, cracked or broken plates, holes in plate, loose wheel, overheated wheel, wrong diameter wheel, out-of-gauge wheels,



TYPICAL RAILROAD FREIGHT CAR WHEEL

FIGURE 1.

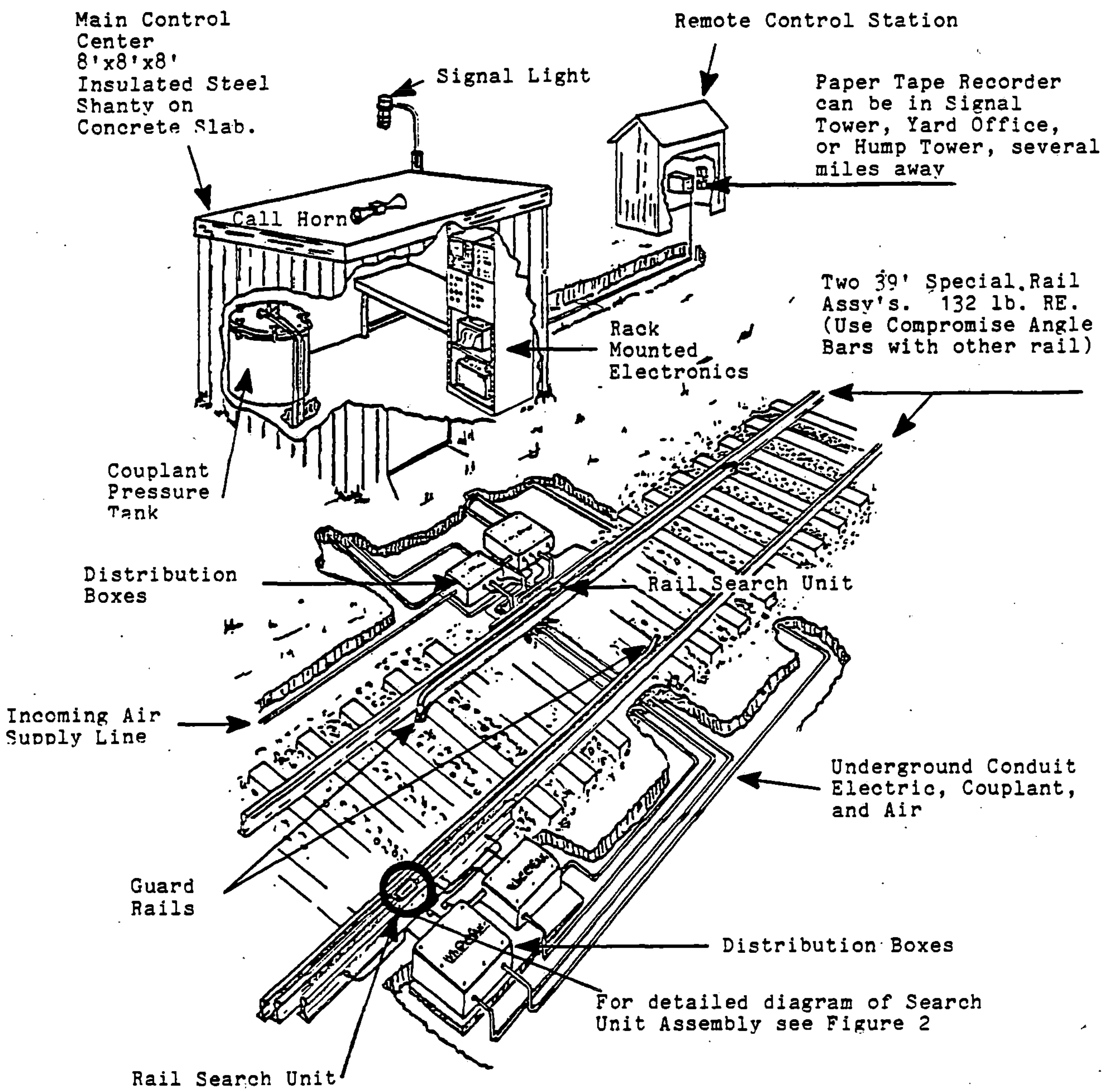


FIGURE 2. SITE PLAN FOR WHEELFAX SYSTEM

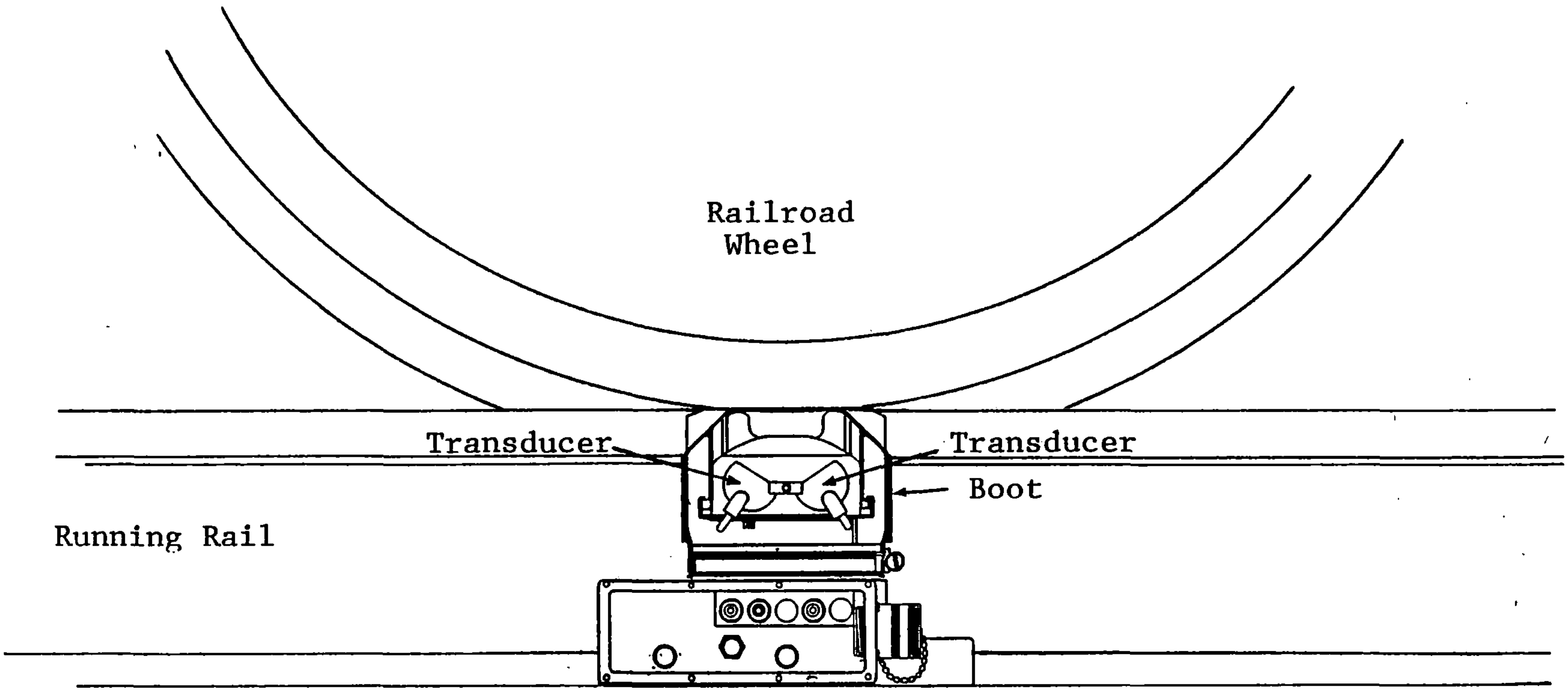


FIGURE 3. RAIL SEARCH UNIT ASSEMBLY

wheels to be removed on sight or wheels with a scrape, dent or gouge unless located on the tread or flange. It may detect but cannot quantify or distinguish between the remaining nine defined wheel defects: high flange, cracked or broken flange, cracked or broken rim, shattered rim, spread rim, shelled wheel, built up tread, thermal cracks and slid flats. Since the WheelFax cannot quantify or classify the different categories of defects located on the tread, rim and flange areas of a wheel, the system is prone to generating false alarms. A description of these defects and how the WheelFax responds to each is discussed in Section 2.

Another practical operating limitation is the restriction of vehicle speeds over the special track to 20 mph or less because at speeds greater than 20 mph there is insufficient time for each wheel to be completely tested. This relatively low operating speed limits the deployment of WheelFax units to entrance and exit tracks, to classification yards and other low speed tracks.

One prototype and three complete WheelFax systems were manufactured by Scanning Sytems, Inc. These units were manufactured and delivered in the mid-1970's. The prototype was delivered to the Atchison, Topeka and Santa Fe Railroad and installed in their Argentine yard. Complete systems were delivered to the Canadian Pacific Railroad (CP), the Federal Railroad Administration and the Florida East Coast Railroad (FEC). The FEC system is the only unit currently in service. The CP recently sold their unit to the Union Pacific Railroad. This unit is currently being restored to its original condition by its developer.

Review of railroad accident data for the years 1976-1980 has shown that of the 1,890 accidents caused by wheel failures, 463 (approximately 24 percent) of these may have been detectable by the WheelFax system, assuming the system had been in-place. However, the acquisition cost of the system, false alarm rates, operating and maintenance costs, difficulties of obtaining replacement hardware, and the low speed operating limitation could mean that additional information on mechanisms of wheel failures is needed before this type of device can be implemented on all railroads.

Much additional work is being done in this area to prevent wheel failures. These efforts may develop data that could improve the WheelFax system and help make it more operationally feasible for the railroad industry in the future.

A joint FRA/AAR program will determine stresses created in wheels by improper braking. This effort will be conducted at the Transportation Test Center in Pueblo, CO and will help provide an understanding of those conditions which lead to in-service fracture of wheels and determination of the margin of safety in railroad wheel operations. Further work will determine the validity of present wheel removal specifications.

NASA Langley and the FRA are also conducting research on non-destructive residual stress measurement which could possibly be applied to the determination of residual stress in railroad wheels. The technique being investigated is an advanced ultrasonics technique using pulsed phase locked loop spectroscopy.

The FRA is developing a wheel failure prevention system which utilizes an in-track inertial system to detect braking problems (e.g., stuck brakes, misapplied hand brakes, wheel/axle abnormalities, etc.). These conditions can cause a wheel to heat up, creating stresses and possibly thermal cracking and eventually lead to a wheel failure and a catastrophic train accident.

The results of all these programs will provide invaluable information which will enable the railroad industry to reduce wheel failures, and in the process save lives, property and accident damage costs.

2. INTRODUCTION

The purpose of this effort was to evaluate the WheelFax system concept as an in-service device for detecting wheel defects and recommend future work related to the WheelFax system and other wheel failure prevention systems.

As discussed in more detail in Section 5 of this report, wheel failures account for approximately four percent of the total rail accidents per year (about 400 accidents per year). However, these accidents can be catastrophic in terms of loss of life and property, equipment damage and third party liability. Therefore, detection of defects and prevention of wheel failures are a significant safety concern.

Wheels

Freight car wheels for cars of up to 70-ton capacity have been standardized at 33 inch diameter. Large wheels (36 inch for 100-ton and 38 inch for 125-ton cars) are used in high-capacity service and a special 28 inch wheel is used on some piggyback flatcars to lower the deck elevation.

A wheel not only supports the weight of a car and serves as the guiding element for the vehicle, but the tread also acts as the brake drum and dissipates heat generated during brake application.

The differences between Class A, B and C heat-treated wheels are compromises between wear and thermal-shock resistance. Class A wheels have lower carbon content, are softer and less wear resistant but have good resistance to thermal cracks which could be caused by frequent braking. Class C wheels with high carbon content are harder and more wear-resistant for heavy loads. However, the thermal-shock properties are not as good. Class B wheels are intermediate in these properties.

The tread and flange contours of a wheel are designed for wheel rail tracking stability and for resistance to wear (See

Figure 4). Wheel contour is one of the most closely monitored items in freight car inspection. The Field Manual of the AAR Interchange Rules details in Rule 41 the wear limits, gauging and causes for wheel renewal.

WheelFax Theory

A more technical discussion of the WheelFax system theory is included in Appendix A.

The WheelFax system tests railroad wheels by putting a pulse of ultrasonic energy into the tread and rim of the wheel. The energy of this pulse has a frequency of 400,000 hertz. The highest frequency that most people can hear is 20,000 hertz.

The WheelFax utilizes two crystals to generate the ultrasonic energy pulses. The design and development of these crystals are complex and the final product results from many trade-offs. In the case of the WheelFax, the energy must be injected into the wheel tread. This means there is a practical limitation on the physical size of crystals that can be used and the 400,000 hertz frequency was a good compromise.

In the WheelFax search units these crystals are used both as receivers and generators of ultrasonic energy. These interchangeable features are used in the WheelFax to permit the detection of flaws on the tread of a railroad wheel.

The WheelFax system can be divided into three sub-systems. First, there are two track mounted search units one installed in each rail of the track. As the wheel passes, the boot on the search unit will make physical contact with the wheel tread. At this point, ultrasonic energy can be passed to and from the wheel. Second, the wheel flaw detection electronics are enclosed in a wayside control center along with the paint and couplant holding tanks. The third sub-system is track side equipment, such as the paint system that marks defective wheels and the train direction sensors.

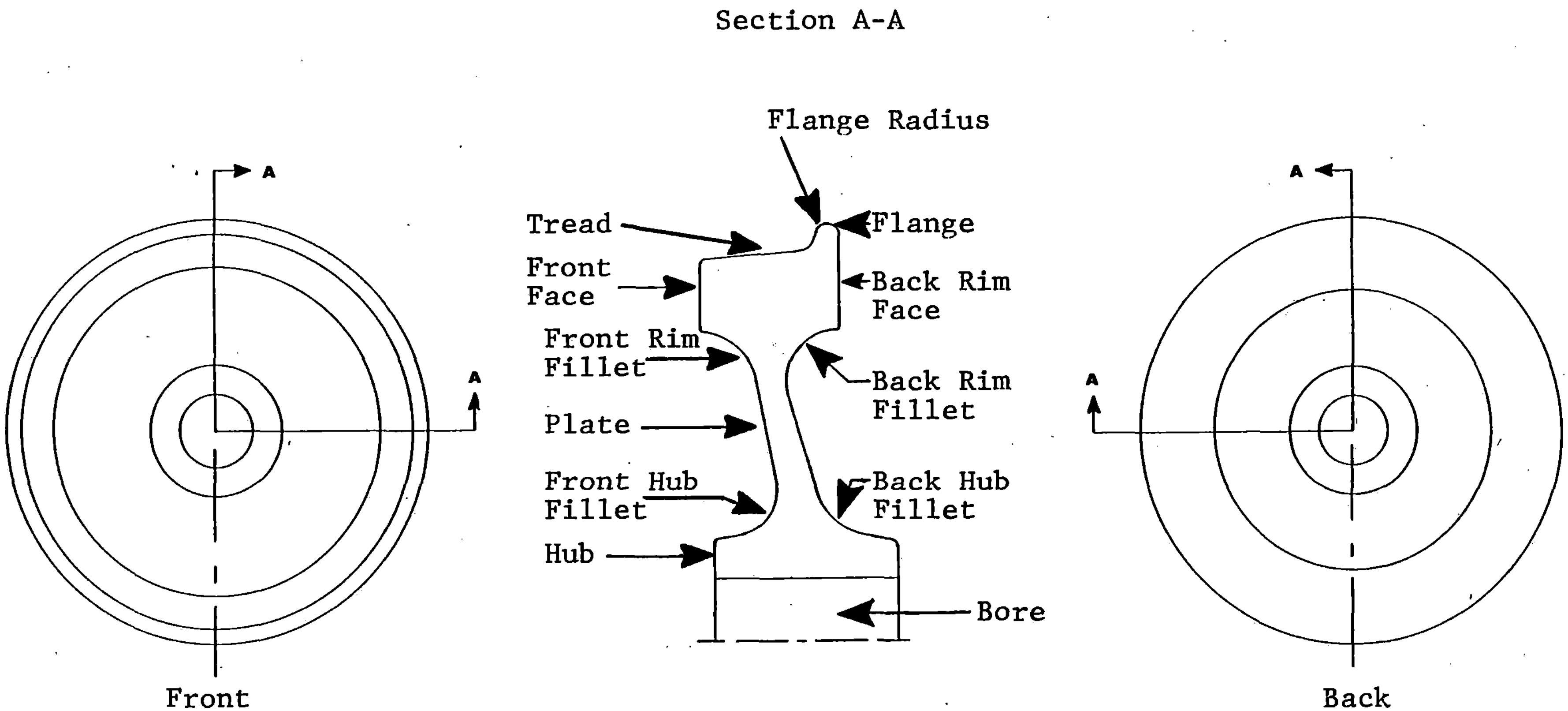


FIGURE 4. TYPICAL RAILROAD FREIGHT CAR WHEEL

As indicated earlier, there are two search units, one for each rail, and each of these units uses crystals as generators/receivers. Refering to Figure 5, these two crystals are labeled as CR1 and CR2. Both crystals are used as receivers, except during a short time period when one of them becomes a generator. The duration of the generated emergy pulse is a few micro-seconds.

The energy delivered into the wheel is directed so that it will penetrate the wheel surface and be guided by the wheel tread. Typically, the penetration beneath the wheel tread is approximately 3/8 inch.

As mentioned earlier, the two crystals alternate as generators. Referring to Figure 5, when CR1 is a generator, CR2 is a receiver. The two crystals can be thought of as being in the generate/receive mode. In a healthy wheel the energy generated by CR1 travels many times around the wheel before its amplitude falls below a set threshold. This means that the receiving crystal (CR2) will detect the sent signal as many times as it travels around the wheel and CR1 will not receive its own generated energy. In a badly flawed wheel the energy generated by CR1 will be returned to CR1 and will never be received by CR2. This indicates a calamity alarm.

In many cases the wheel flaw is not severe enough to prevent a portion of the energy generated by CR1 from being received by CR2. CR1 will also receive part of its own reflected energy (echo). Depending upon the strength of the echo the system will indicate an alarm.

The strength of the signal is also a function of many variables such as metallurgical composition of the wheel, type of service to which the wheel has been subjected, etc. During the time that the wheel is positioned on the search unit, the number of times which the crystals cycle between generating and receiving signals varies. If a train is traveling too fast and the wheel has certain characteristics, the crystals may not have enough time to function properly because the wheel was not on the

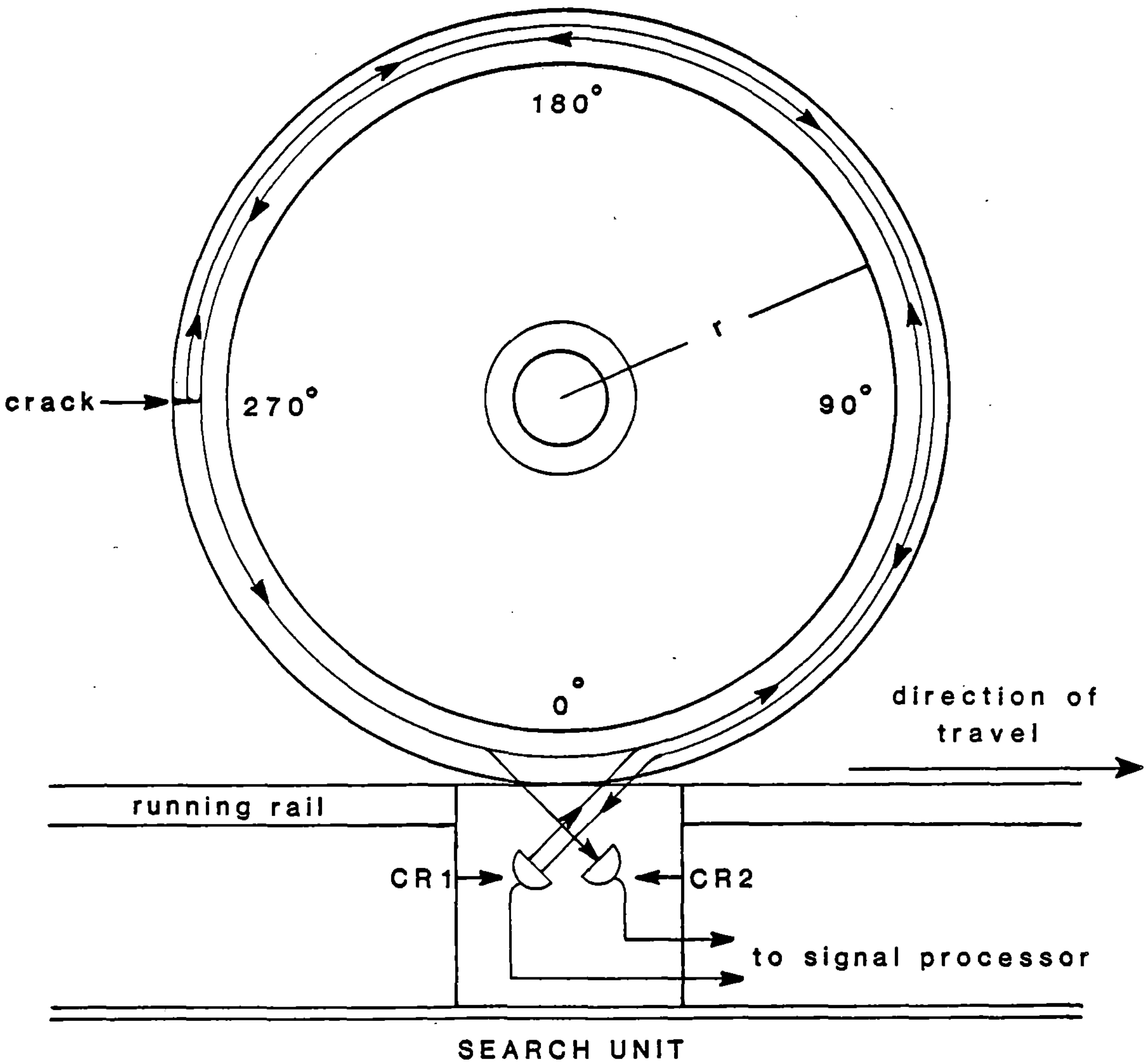


FIGURE 5. SIGNAL PATHS FOR ULTRASONIC SURFACE WAVES

search unit boot for a sufficient period of time. Hence the 20 mph speed limitation.

The recorder which makes a record of the train wheels tested may be located at a convenient remote location. The output of the control center for each of the two rail search units operates a pen which deflects in two directions. The resultant pattern enables rapid identification of a particular wheel.

Wheel Defects

Rule 41 Section A of the AAR field manual lists 21 different wheel defects that would require a wheel to be condemned. Out of these 21 defects, 11 are not detectable and 10 are detectable by the WheelFax system. Of the 10 detectable defects, four can exist on a serviceable wheel provided the severity of each are less than the limits defined in the AAR manual. In its present configuration, the WheelFax system cannot distinguish between defect types and cannot measure defect severity. Therefore, the WheelFax system would be expected to produce many false alarms on wheels that are serviceable.

The following provide brief explanations of each defect listed in the Field Manual of the AAR Interchange Rules and why the WheelFax may or may not detect each.

1. Thin Flange: 15/16 inch thick or less.

Due to crystal alignment, the ultrasonic energy injected into the wheel tread produces a surface wave that travels parallel to the wheel flange. Therefore, due to the geometry of the wheel, there is no wheel flange surface to reflect the energy to the receiver. Therefore, the WheelFax system will not detect a thin flange.

2. Vertical Flange: Flat vertical surface extending one inch or more from tread.

The WheelFax system will not detect this flaw for the same reasons as stated for thin flange.

3. <u>High Flange</u>: Height is 1 1/2 inches or more above the approximate centerline of tread.

The WheelFax system has an optional high flange detector. The FRA WheelFax unit was procured with this option. However, there are insufficient data to establish whether this option ever met its specifications. None of the other WheelFax units have used this concept and because of electrical problems it may be difficult to implement.

4. <u>Cracked or Broken Flange</u>: Any length. Chipped flange must exceed 1 1/2 inches in length by the width and not merely a flaking of the surface.

The WheelFax can detect both of these defects. The FRA has done considerable field testing in these areas; and it appears that when the system is adjusted to detect cracks in the flange area false alarm rates also increase. In addition, the WheelFax cannot measure defect severity and, therefore, can alarm on a non-condemnable chipped flange.

5. <u>Cracked or Broken Rim</u>:

The WheelFax system can detect both of these defects. With a cracked or broken rim, a portion of the ultrasonic energy that travels around the wheel should be reflected at the crack and will travel back towards the receiver. When the WheelFax detects a reflected ultrasonic pulse the system will generate an alarm.

6. <u>Shattered Rim</u>: (See Figure 6)

The WheelFax system can detect this defect as it does cracked or broken rims.

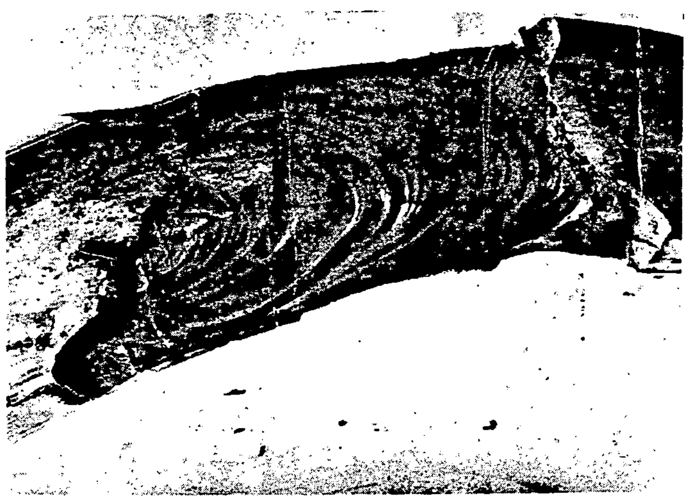


FIGURE 6. SHATTERED RIM

7. Spread Rim: (See Figure 7)

The WheelFax can detect a spread rim if the wheel has certain types of cracks in the tread surface.

8. Thin Rim: 3/4 inch or less for all wheels except 28, 36, 38 inch wheels which are 7/8 inch or less.

A thin rim will not be detected by the WheelFax because it cannot establish the inner radius of the rim.

9. Shelled Tread: (See Figure 8) When the shell or spall is 3/4 inch in length and in width or larger and are more or less continuous around the periphery of the wheel or one inch or more in length and width.

The WheelFax system can detect a shelled area on a tread. The system cannot determine the severity of the shelling; and, therefore, may alarm on serviceable wheels that have less than the condemnable amount of tread shelling.

10. Built-up Tread: Metal built-up 1/8 inch or more on tread (See Figure 9).

The WheelFax system can detect built-up tread. As in wheel shelling, it cannot measure the severity of this tread defect and therefore could alarm on serviceable wheels.

11. Grooved Tread: One or more grooves worn to a depth of 1/8 inch or more (See Figure 10).

The WheelFax system will not detect a grooved tread for the same reasons as for the thin flange.

12. Thermal Cracks: Certain types of cracks in tread, flange or plate of any length (See Figure 11).

The WheelFax system can detect cracks in the tread area but the length and depth of these cracks must be at least 1/40 inch. It can also detect cracks in the flange and the rim faces, both back and front. Total penetration of the surface wave is approximately 3/8 inch below the tread surface. System

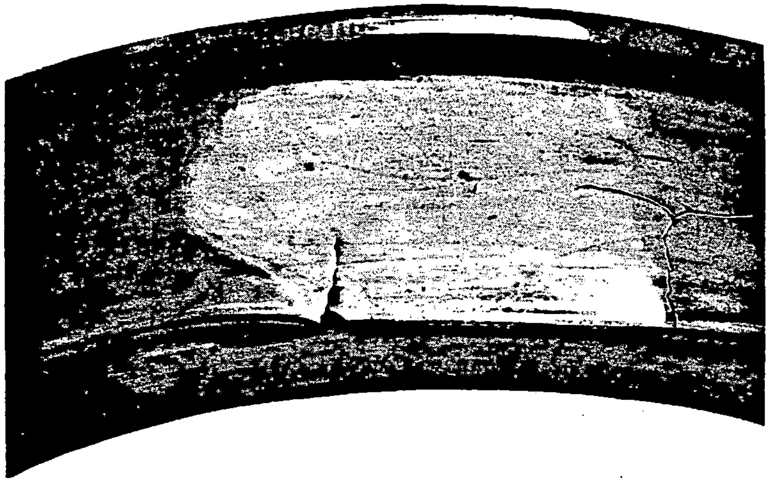


FIGURE 7. SPREAD RIM

FIGURE 8. SHELLED WHEEL

FIGURE 9. BUILT-UP TREAD

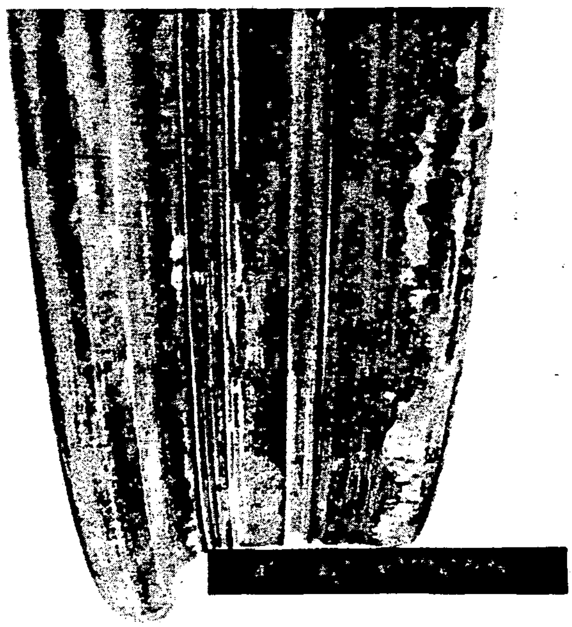


FIGURE 10. GROOVED TREAD

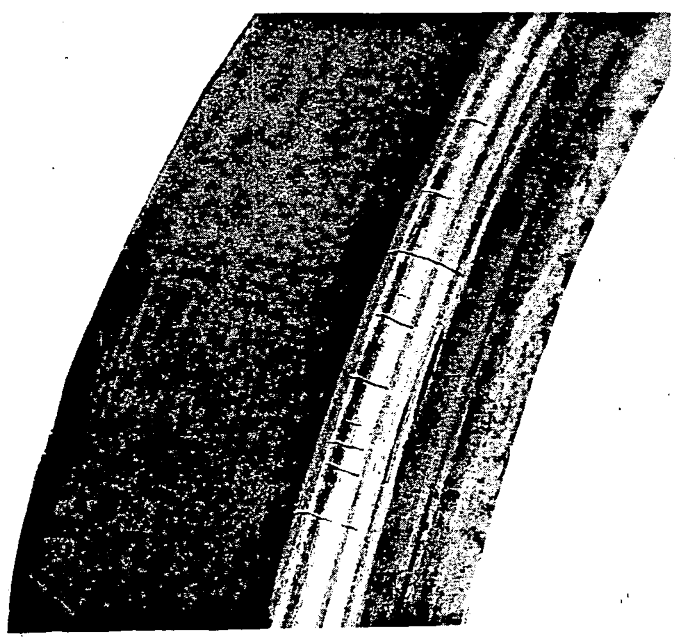


FIGURE 11. THERMAL CRACKS

sensitivities are typically increased to allow detection of thermal cracks other than ones found in the wheel tread surface. When this is done the false alarm rate increases.

13. <u>Cracked or Broken Plate</u>: (See Figure 12)

The WheelFax system will not detect a wheel with a cracked plate unless the crack originates from the plate and has propagated through the rim/tread surfaces.

14. <u>Holes in Plate</u>: (See Figure 13)

The WheelFax system will not detect any defects in the wheel plate area.

15. <u>Loose Wheel</u>: Wheel showing evidence of movement on the wheel seat or oil seepage on the back plate.

The WheelFax system will not detect a loose wheel.

16. <u>Overheated Wheel</u>: Due to stuck dragging brakes showing "reddish brown" or "blue" discoloration four inches from the front or back face of rim into the plate.

The WheelFax system will not detect a wheel that has been overheated.

17. <u>Wrong Diameter Wheel</u>: Wheel not standard to car.

The WheelFax system has optional equipment to measure wheel diameter. However, the optional equipment cannot determine whether the wheel under test is the right diameter.

18. <u>Out-of-Gauge Wheels</u>: (See Figure 14)

The WheelFax system will not detect out-of-gauge wheels.

19. <u>Remove On-Sight, Prohibited in Interchange</u>:

The WheelFax cannot detect these wheels unless the wheels have detectable flaws or defects located on their treads or flanges.

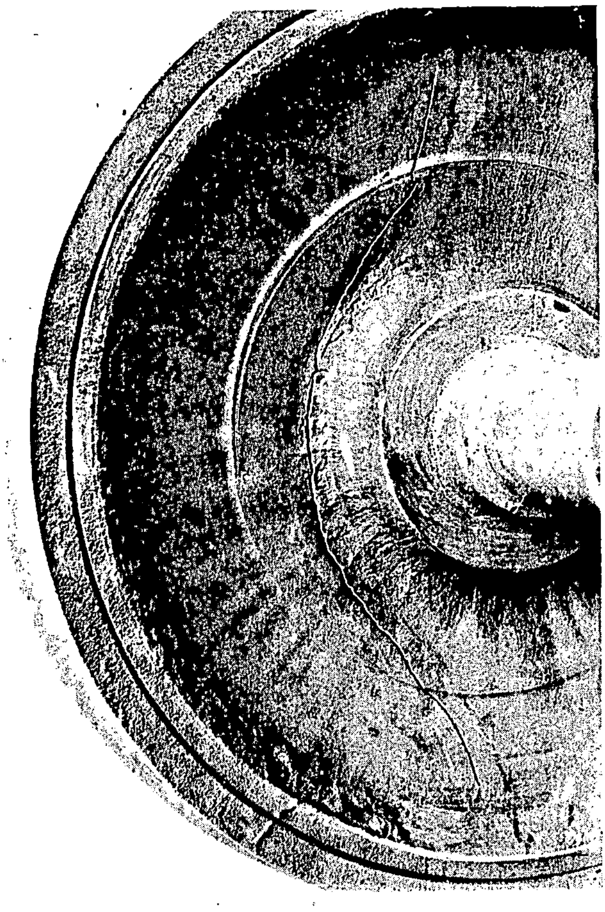


FIGURE 12. CRACKED OR BROKEN PLATE

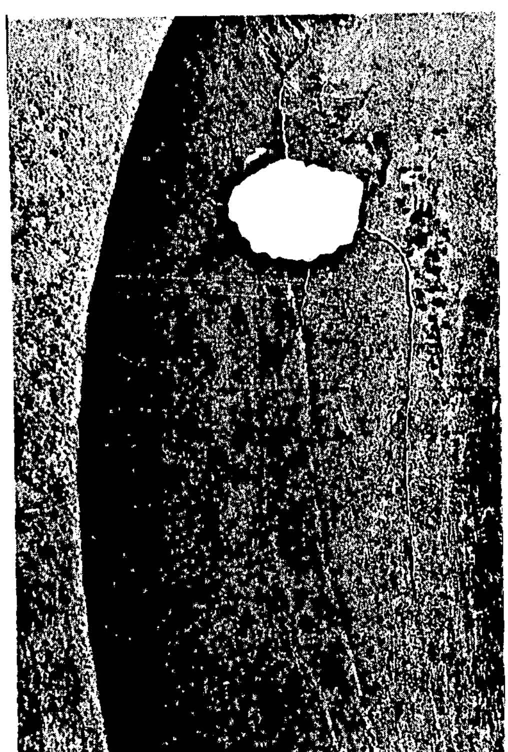
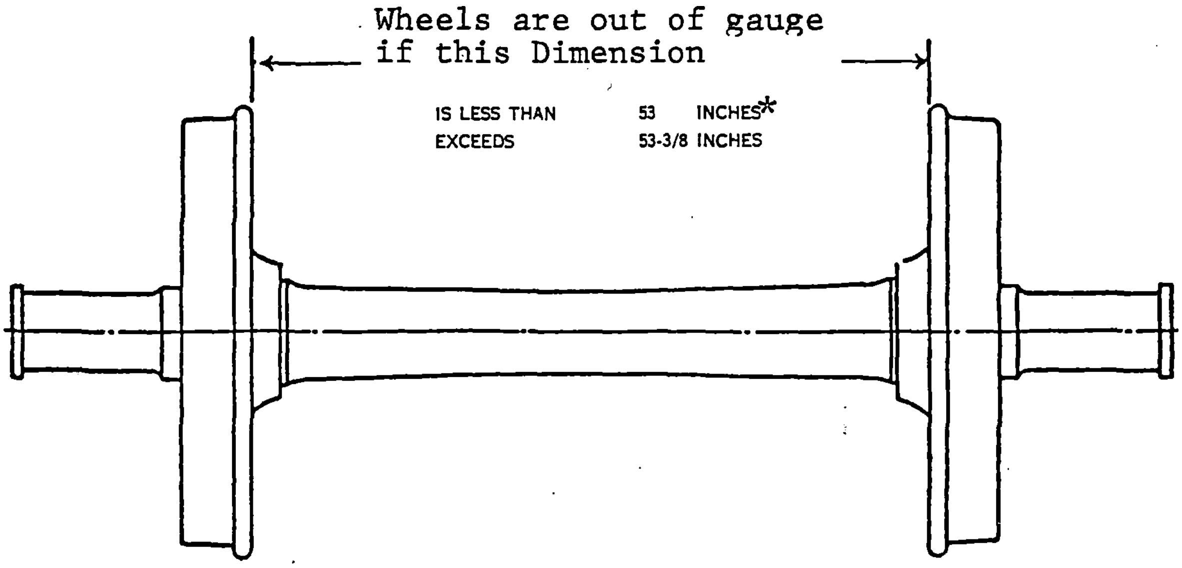


FIGURE 13. HOLE IN PLATE



*Wheels manufactured prior to 1965 will be out of gauge if the back-to-back dimension is less than 52-15/16 inches.

FIGURE 14. WHEEL GAUGE STANDARD

20. Scrape, Dent or Gouge: Wheels having a scrape, dent or gouge anywhere in the wheel surface more than one-eighth inch deep.

The WheelFax can detect a scrape, dent or gouge only when located in the tread or flange of a wheel.

21. Slid Flat: Flat two inches or more in length or two or more adjoining spots each 1 1/2" or over in length.

The WheelFax can detect a wheel flat. However, the WheelFax cannot determine the severity of wheel flats; and therefore may alarm on serviceable wheels.

3. HISTORY OF THE WHEELFAX SYSTEM

Background on WheelFax Systems

Scanning System, Inc. manufactured one prototype and three complete WheelFax systems in the mid-1970's. They delivered the prototype system to the Atchison, Topeka and Santa Fe Railroad (ATSF), and one complete system each to the Canadian Pacific Railroad (CP), the Florida East Coast Railroad (FEC) and the Federal Railroad Administration (FRA). Currently, the FEC system has the only operational system in service.

Atchison, Topeka and Santa Fe System

This prototype WheelFax system was installed in ATSF's Argentine yard in June 1973. The prototype system only tested wheels on one side of a passing train.

The prototype system was leased to the ATSF with an option to buy. The option was never exercised and the system was ultimately returned to the manufacturer. The system proved difficult to maintain during the evaluation phase; and had long periods of down time.

When the WheelFax system was operating it generated many false alarms because it was sensitive to tread flaws that were not condemnable defects. A false alarm is defined as the identification of a serviceable wheel as defective. Ultimately, the system was returned to the manufacturer.

Canadian Pacific System

The WheelFax purchased by the CP was the first complete system, for both left and right rails, delivered by Scanning Systems, Inc. The system was procured for a developmental wheel defect detection project and was installed in the St. Luc Yard near Montreal, Canada. The system was ready for field testing in the latter part of 1976. The test phase was approximately two years, during which time the system did show the capability of detecting wheel thermal crack defects in the tread and flange of wheels. However, the system was also prone to failures and required considerable maintenance to keep it operational.

In addition to maintenance difficulties, the CP WheelFax had an unacceptable number of false alarms. All wheels identified as defective by the WheelFax System require further inspection by railroad personnel. This takes manpower and equipment to cut cars for manual inspection. The WheelFax System can not distinguish between thermal tread cracks which are not acceptable and some tread flaws such as shelling, build-up or small slid flats which are acceptable depending on their magnitudes. Unfortunately, these acceptable flaws are often found on the running surfaces of a railroad wheel.

In the process of evaluating the WheelFax System, the CP made several modifications which include the following:

- Additional electronic circuitry was added to record the WheelFax logic decisions to aid in interpreting the data.
- Floating d.c. power supplies for various components (i.e., paint system, search unit heaters) to reduce noise.
- A train overspeed circuit to measure rail vehicle speeds over the search units. If the speed of the vehicle was greater than the maximum speed allowed, the WheelFax would not be activated.
- Modifications were made to calibration procedures due to the large number of alarms. The CP stopped using their rail test car that had wheels with machined flaws and started using a statistical approach to set the overall system sensitivity and reduce the number of wheel alarms.

The CP discontinued their evaluation program and in 1981 they sold their WheelFax system to the Union Pacific Railroad (UP). The UP is having the system refurbished by its inventor and developer.

Federal Railroad Administration System

Another complete WheelFax system was delivered to the Federal Railroad Administration in October 1976. This unit has been installed at three different locations at the Transportation Test Center in Pueblo, CO. The first site was in the active track at the Facility for Accelerated Service Testing (FAST). Eighty test runs at this site were carried out for acceptance of the system. The second site was on the FAST by-pass track. Testing at this location was done to collect data to be used to evaluate the system design of proposed additions (i.e., wheel size classification and high flange detection) to the system. The third installation site was the Wayside Research Test Facility where the WheelFax system with the wheel size and high flange detectors could be tested and evaluated along with the other detection systems such as the Acoustic Cracked Plate Detector, Loose Wheel and Broken Flange Detector, Hot Box and Hot Wheel Detector, etc.

The FRA unit has the following options:

- Wheel size detector;
- High flange detector;
- Data transmission to remote location;
- Bi-directional paint system;
- Track heaters; and
- Air conditioned track-side equipment building.

The FRA WheelFax system was evaluated while located at the Transportation Test Center (TTC). There were numerous tests using rail vehicles with machined flaws in their wheels. A significant portion of these evaluation tests were devoted to establishing system sensitivity thresholds. During these test sequences the sensitivity thresholds were varied. Determining these values are crucial because they directly affect the overall system accuracy. If the thresholds are set too high, there could be many faulty wheels that would go undetected; and if they are set too low, there may be an unacceptable number of false alarms.

A preliminary WheelFax report generated by the Transportation System Center (TSC) provides an evaluation of data taken at TTC. This report concludes that the WheelFax system had maintenance difficulties, but it did consistently detect the machined flaws in the wheels of rail vehicles that were operated over the in-track search units. Also, the WheelFax system was more repeatable in detecting man-made flaws located on the center of the tread of the wheel versus those found on the extremes of the tread, front and back face of the wheel rim and on the wheel flange.

Florida East Coast WheelFax System

In May 1974, the management of the Florida East Coast Railroad approved the purchase of a WheelFax system. The FEC provided labor and materials to support the manufacturer during installation and checkout of the system.

Since the FEC system is currently the only in-service WheelFax unit, a visit was made to their Jacksonville, FL installation during which a detailed analysis of their operation and maintenance procedures was performed. This analysis can be found in Section 4, WheelFax Operations on the Florida East Coast Railroad (FEC).

In general, the FEC experienced and solved difficulties in the following areas:

- Boots for the search unit required daily replacement. An adjustment in boot height above the rail from 1/2" to 7/16" solved this problem. Also, the boots were redesigned to improve their longevity.
- The container tank that holds the WheelFax coupling fluid was corroding and contaminating the fluid. The contaminated fluid would then clog the couplant spray nozzles. With the nozzles clogged, there is insufficient coupling fluid sprayed onto the wheel tread surface for the WheelFax to operate properly. With this condition, most wheels traveling over the WheelFax register as "no-test." The solution was to use a fiberglass rather than a metal storage tank.
- The WheelFax system uses eight strain gauge wheel detectors attached to the web of the rail. Due to

failures, four of these strain gauge bridges were replaced with magnetic wheel detectors.

- FEC developed necessary documentation.
- FEC had to procure additional hardware for the system.
- The internal temperature of the main control center is critical. This problem was solved by the installation of air conditioning.
- FEC had to develop their own calibration and maintenance schedules.

4. WHEELFAX OPERATIONS ON THE FLORIDA EAST COAST RAILROAD (FEC)

On the FEC the Communications and Signals (C&S) Department maintains the WheelFax electronics and they are responsible for its calibration. The Maintenance of Way Department under the direction of C&S personnel maintains the track structure, i.e., ties, joint bar tightening, etc.

A signal maintainer checks the unit every morning; this maintainer can do only limited maintenance such as replacing search unit boots or unclogging spray nozzles. Also, calibration is done once a week by an assistant signal supervisor. Due to the FEC operations, this calibration is split between the afternoon of one day and the morning of the next. If no system problems are encountered, the calibration can be completed easily in one afternoon (2 to 3 hours). That night or early the next morning, a yard engine crew picks up the calibration vehicle which is a gondola with defective wheels and operates this consist over the WheelFax search units. On the morning of the second day, the Assistant Signal Supervisor analyzes video data recorded from the previous night. The results of this analysis determines if the WheelFax system is operating properly. If it is not, the faulty unit(s) is repaired. After repairs have been made, the gondola test vehicle may or may not be used to verify system operations.

As a minimum, approximately 14.5 man-hours per week are used to maintain and calibrate the FEC WheelFax system. This assumes that a signal maintainer spends about one hour per day checking the unit, the Assistant Signal Supervisor spends approximately eight hours a week at the site and the crew on the locomotive is involved for at least 45 minutes (2 crewmen) once a week. If there are problems with the system, the required effort increases above this minimum.

With respect to the electronics the C&S Department maintains a complete set of spare printed circut (PC) boards. Their normal maintenance procedure is to replace defective boards and return these PC boards to their supplier for repair.

The FEC fabricated its own calibration wheel sets. Each wheel has a single saw cut made by a rail saw. The depth of these cuts vary from ones just through the flange to others that pass through the flange, the tread, the rim and into the plate of the wheel. The two wheels on a wheel axle set do not necessarily have matching defects. The saw cuts must be cleaned occasionally or they will eventually become clogged with brake shoe dust, rust or other debris found along the railroad right-of-way. These wheel sets are mounted on trucks that are placed under a gondola car. This gondola is used as a calibration vehicle which is operated over the in-track search units to verify that the system is calibrated and working properly. The FEC found that when the calibration vehicle is operated over the WheelFax search units and the saw cuts in the wheels are clogged, the response of the WheelFax system is degraded.

At the present sensitivity thresholds set by the FEC, the WheelFax typically does not detect the man-made saw cuts in the flange of the test wheels. The system reliably detects all of the other saw cuts.

Sensitivity thresholds currently used by FEC were derived empirically through field testing. During the initial test phase of the system, wheels that were rejected by the WheelFax were thoroughly tested using the WheelFax Junior (a portable, hand held version of the WheelFax) and also were machined to detect any hidden defects. Therefore, FEC derived their desired sensitivity threshold values by setting them such that the wheel rejection rate versus actual defects found was acceptable. A similar technique was used by the Canadian Pacific except they ultimately discontinued using the calibration test vehicle.

It appears that alarms from the in-track WheelFax unit account for only some of the total wheels replaced by the FEC. The majority of defective wheels are found during incoming or outgoing visual inspections. The wheels rejected are due mainly to flange defects, i.e., high or thin. The remaining wheels are rejected due to discoloration bands (heat) on the wheel plate, thin rims, shelling, thermal cracks, etc.

The strip chart recorder for the WheelFax is located in the Car Foreman's office remote from the in-track system. This recorder displays an identification mark for each wheel as it passes over the WheelFax search units. Also, at each identification mark there is one of four indications made by the WheelFax decision electronics.

- The wheel was tested.
- The wheel was not tested.
- Alarm.
- Calamity alarm.

As described in Section 2, Introduction, a track side paint system marks defective wheels.

Car inspectors must rely on seeing the painted wheel for identification. When the car inspector sees a wheel that has been painted the inspector examines the tread of the wheel. If there are non-condemnable flaws in the tread of the wheel that could possibly have caused the WheelFax to alarm, the wheel is left in service. If there are no visible flaws in the tread of the wheel, the wheel is inspected using the WheelFax Junior. If the WheelFax Junior detects an external defect or internal flaw the wheel is replaced; if not, the wheel is left in service.

5. ACCIDENT/COST ANALYSIS

For the years 1976 through 1980 there were an average of 378 accidents per year attributed to wheel failures (see Table 1). The average cost to the railroad industry due to these accidents was approximately $18.4 million/year. Additional costs (societal costs) as a result of these accidents other than damage to railroad rolling stock and fixed equipment and lading loss could be as much as 10 times greater adding as much as $184 million/year to the average accident costs.

The approximate annual cost of accidents to the railroad industry is estimated to be:

$$\$18.4M + \$184M = \$202.4M$$

During the period 1976-1980, there were 1,890 wheel failures that resulted in accidents. Given that the WheelFax system may detect 10 of the 21 wheel defects detailed in the Field Manual of the AAR Interchange Rules and the accident data shown in Table 1, in-place systems may have been able to detect 181 broken flange, 216 broken rim and 66 damaged flange or thread, thermal/flat for a total of 463 accidents due to wheel failures. Thus the WheelFax may have detected approximately 24 percent of the wheel defects which led to accidents during the 1976-1980 period.

The railroad industry could have potentially saved 24 percent of their estimated annual losses or $48.6M per year, assuming total efficiency of the WheelFax system, no false alarms, and the system being in-place at major classification yards across the country.

Although this would appear to be a significant annual cost savings to the industry, there are problems which might limit WheelFax's applicability at this time such as:

TABLE 1. SUMMARY OF WHEEL ACCIDENT/COST DATA, 1976-1980
FROM FRA ACCIDENT/INCIDENT BULLETINS

Accident Cause	1976	1977	1978	1979	1980	Total Accidents	Percent of Total
	YEARS						
*Broken Flange	31	47	39	28	36	181	9.6
*Broken Rim	46	48	57	34	31	216	11.4
Broken Plate	55	44	51	42	37	229	12.1
Broken Hub	17	10	16	8	8	59	3.1
Worn Flange or Tread	160	164	161	150	123	758	40.1
*Damaged Flange or Tread, Thermal/Flat	22	13	11	14	6	66	3.5
Loose Wheel	45	43	62	40	31	221	11.7
Cause Code Not Listed	37	39	39	22	23	160	8.5
TOTAL	413	408	436	338	295	1,890	100
Derailments	401	396	423	334	288	1,842	97.4
Collisions	3	9	6	2	6	26	1.4
Other	9	3	7	2	1	22	1.2
TOTAL RR ACCIDENTS	10,248	10,362	11,277	9,740	8,451	50,078	
Percent Due to Wheel Failures	4	3.9	3.8	3.5	3.9	3.8	
TOTAL DAMAGE	$15.5M	$17.8M	$19.4M	$22.5M	$16.6M	$91.8M	
Cost/Accident	$37,500	$43,600	$44,500	$66,600	$56,300	$48,600	

* Indicate defects which may be detected by the WheelFax system.

- The WheelFax system will not operate reliably at vehicle speeds greater than 20 mph.
- Systems would be required at rail yards throughout the U.S. to detect even 24 percent of the wheel defects which are potential failures and will cause accidents.
- Operational analysis of the system has shown that considerable time and manpower is required for system operation and maintenance.
- The system could create a virtual standstill of the railroad industry, especially if it were installed at the exit track, if there was a significant number of false alarms as yard personnel and equipment would be tied-up to cut out flagged vehicles and inspect the suspect wheels.

6. CONCLUSIONS AND RECOMMENDATIONS

The WheelFax System was developed in the mid-sixties by Scanning System, Inc. They built and delivered one prototype for the Atchison, Topeka and Santa Fe and three complete units, one each for the Canadian Pacific, the Federal Railroad Administration, and the Florida East Coast in the mid-1970's. The Canadian Pacific sold their system to the Union Pacific (UP). The UP plans to initiate an evaluation of the WheelFax. The Florida East Coast is continuing to use their WheelFax in service.

In general, there are several limitations of the WheelFax system. First, the system may only detect 10 of the 21 condemnable wheel discrepancies defined in the Field Manual of the AAR Interchange Rules, 1983, and it cannot classify or quantify these defects as acceptable or non-acceptable. Therefore, it may generate a number of false alarms which can create a virtual standstill of the industry as yard personnel and equipment would be tied up to cut out flagged vehicles and inspect the suspect wheels. Second, the WheelFax cannot reliably test wheels on trains traveling faster than 20 mph. This restricts the deployment of these units to exit and entrance tracks, to classification yards and other low speed track. Third, the system is complicated and requires highly trained technicians to operate, and there are no replacement spare parts readily available.

In order to enhance capabilities of devices such as WheelFax certain basic data on wheels and wheel failure mechanisms must be developed. Much additional work is being done in this area to prevent wheel failures. These efforts may develop data that could improve the railroad WheelFax system and help make it more operationally feasible for the industry in the future.

A joint FRA/AAR program will determine stresses created in wheels by improper braking. This effort, which will be conducted at the Transportation Test Center in Pueblo, Colorado, will help provide an understanding of those conditions which lead to in-service fracture of wheels. Further work will determine the validity of present wheel removal specifications.

NASA Langley and FRA are also conducting research on non-destructive residual stress measurements which could possibly be applied to the determination of residual stress in railroad wheels. The technique being investigated is an advanced ultrasonics technique using pulsed phase locked loop spectroscopy.

The FRA is developing a wheel failure prevention system which utilizes an in-track inertial system to detect braking problems (e.g., stuck brakes, misapplied hand brakes, wheel/axle abnormalities, etc.). These conditions can cause a wheel to heat up, creating stresses and possibly thermal cracking and eventually lead to a wheel failure and a catastrophic train accident.

The results of all these programs will provide invaluable information which will enable the railroad industry to prevent wheel failures, and in the process save lives, property and accident damage costs.

APPENDIX A

WHEELFAX THEORY OF OPERATION

WHEELFAX THEORY OPERATION

There are two in-track WheelFax search units, one for each rail. As indicated in Figure A-1, the WheelFax concept utilizes two piezo-electric crystals (CR1 and CR2) to transmit acoustic energy into and to receive acoustic energy from the tread of a railroad wheel. Each pair of crystals can be used as a transmitter or as a receiver. Both crystals are used as receivers simultaneously, except during the short "on" period when one crystal is operating as a transmitter. The following example assists in the understanding of the interchanging of the two crystal modes, transmitter and receiver. Refering to Figure 1, crystals CR1 and CR2 will be alternately placed in their transmitter and receiver modes. The CR1 crystal will be placed in the transmission mode and will be pulsed "on" for a short period of time (T). When the time T has expired the CR1 crystal will change from its transmitter to receiver mode. At this time, both crystals, CR1 and CR2, are in their receiver modes. Each of these crystals will detect signals that are traveling in different directions around the circumference of the wheel tread. Crystal CR1 detects signals (T_r) that are reflected back from anomolies in the tread or rim surfaces of the wheel, and CR2 will detect pulses traveling counterclockwise (T_x) around the circumference of the wheel tread.

A transmission pulse (T_x) is a pulse that has traveled at least one complete revolution around the wheel tread surface. Depending on the wheel's acoustic attenuation, a T_x pulse may travel many times around the wheel. T_x pulses that have sufficient amplitude will be detected as they pass the non-transmitter crystal. On low attenuation wheels the T_x pulse may travel more than a dozen revolutions around the wheel tread before its amplitude falls below a set threshold. Once the T_x pulse train has fallen below the set threshold, control logic

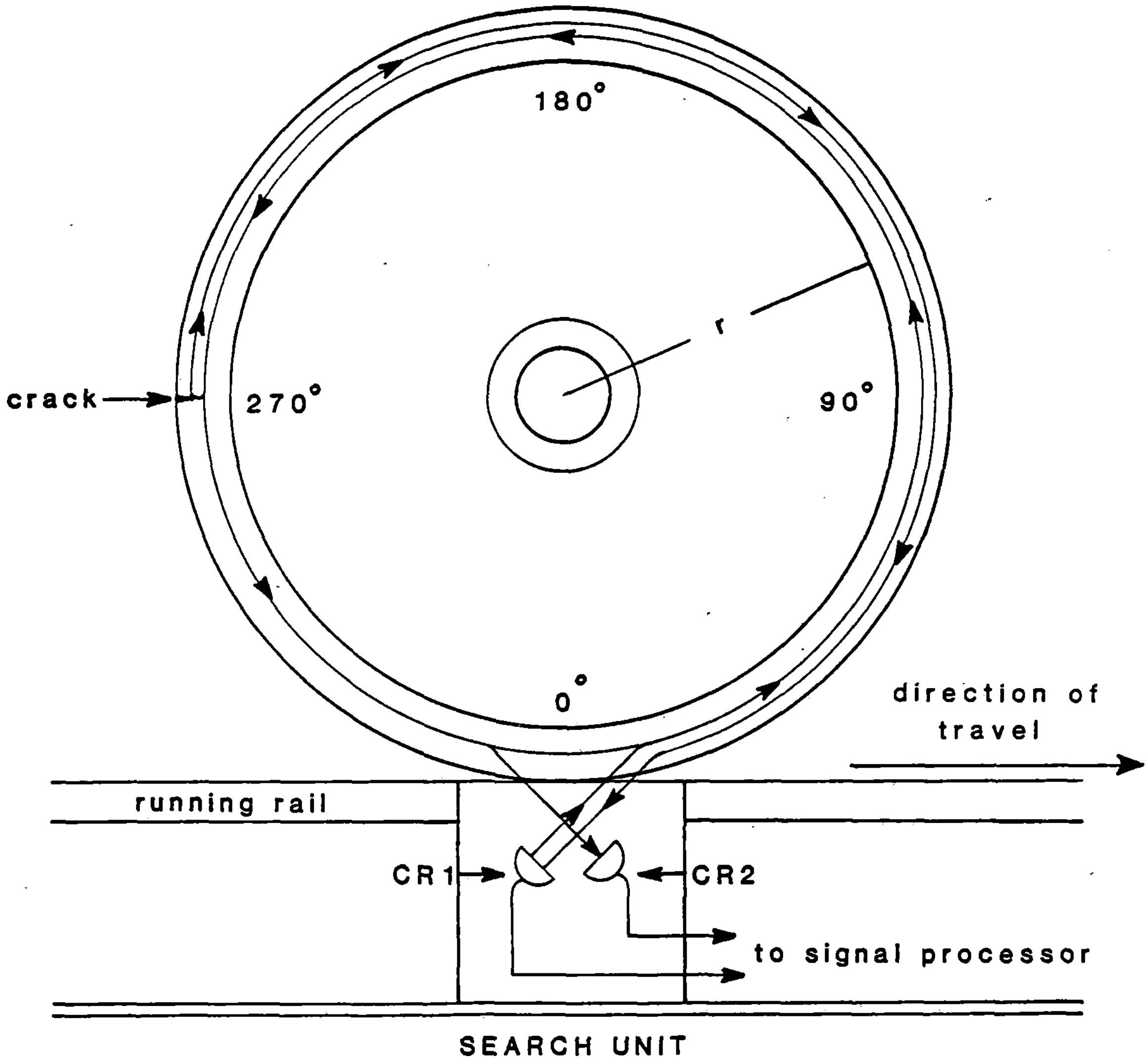


FIGURE A-1. SIGNAL PATHS FOR ULTRASONIC SURFACE WAVES will change states, exchanging the CR1 and CR2 crystal functions and will thus apply a short transmitter "on" pulse (T) to the CR2 crystal. The acoustic energy transmitted from the CR2 crystal travels in the opposite direction around the wheel tread than the acoustic wave created by the CR1 crystal. All crystal functions are now exchanged; i.e., the current transmitter crystal (CR2) now detects the T_r pulses where previously it had detected only T_x pulses. The CR1 crystal now detects T_x pulses where previously it detected only T_r pulses.

The reason for the transmitter crystal being alternated between CR1 and CR2 within each crystal pair is to minimize the positional effects created by the location of a flaw on a wheel with respect to its position on the WheelFax search unit. Example: referring to Figure A-1, visualize a wheel flaw at the 270° position of the wheel. The 0° point on the wheel is where the wheel contacts the search unit. The CR1 crystal then injects an acoustic energy pulse (T_x) into the wheel in a counterclockwise (CCW) direction. This T_x pulse must travel CCW from 0° to the location of the flaw, in this case, at the 270° location on the wheel tread. As the T_x pulse passes the flaw, a portion of its energy will be reflected clockwise (CW) towards CR1 (the T_r receiver) as a T_r pulse. For this example, the signal path (L) for a flaw located at 270° is

$$L = 2 \times \left(\frac{270}{360}\right) \times 2\ \pi r$$

where r is the mean distance between the wheel center and the wheel tread, and $\pi = 3.1416$. In this case, for a high attenuation wheel this reflected T_r pulse may have an insufficient signal level to be detected by the CR1 crystal.

When the transmitter/receiver crystals are exchanged the new transmitter CR2 generates a T_x pulse that travels from 0° to 270° CW around the wheel to the flaw and the flaw reflects a portion of the T_x pulse towards the CR2 crystal (T_r receiver) as a T_r pulse. The T_r pulse travels CCW from 270° to 0° where it is detected by the T_r receiver. In this case, the signal path length (L) is πr. Then due to the short signal path a relatively large amplitude pulse will be received by the T_r receiver.

This example, where the flaw is positioned at 270°, demonstrates that the amplitude of the reflected T_r pulse can have a relatively large dynamic range. This large dynamic range makes it difficult to optimize the sensitivity settings for the WheelFax system.