APPLICATION OF EMATs TO IN-PLACE INSPECTION OF RAILROAD RAILS*

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ABSTRACT

With the aging of the U.S. railroad system and the increased tonnage being moved, it is more important than ever to monitor the installed railroad track for defects whose growth could lead to track failure and derailments. Current ultrasonic inspection techniques utilize a liquid filled wheel to couple acoustic energy from several piezoelectric transducers into the rail at a variety of angles relative to the head of the rail. This approach limits the speed of inspection to approximately 10 mph, is very sensitive to the surface condition and orientation of the railhead and requires frequent maintenance stops. The feasibility of using EMATs to replace the water filled wheel transducers has been the purpose of this research effort at the Albuquerque Development Laboratory and was sponsored by the Department of Transportation with the cooperation of the Sperry Rail Service Division of Automation Industries, Inc.

INTRODUCTION

Railroad rails are subjected to very high, periodic loads so they usually fail by the growth of flaws under fatigue type conditions. Since the initiating flaws are too small to be reliably detected at the manufacturing facility, they must be found by routine inspections when the rail is in service and after the flaw has had a chance to grow to a detectable size. Thus, inspection cars have been developed that travel along the railroad tracks at 10 to 20 mph looking for cracks and large flaws in each rail. They use both magnetic flux leakage and ultrasonic inspection techniques. The latter method utilizes a rubber wheel filled with water to couple the ultrasonic waves from the piezoelectric transducers into the rail as shown in Fig. 1. By mounting the transducers inside the wheel at an angle relative to the rail head surface, ultrasonic waves can be sent into various parts of the rail. A wave propagating normal to the head detects cracks or separations at the foot of the rail or between the head and web. Waves at an angle of 30 degrees to the head normal are well suited to locating cracks at the bolt holes in the ends of each rail. For flaws in the head of the rail, an ultrasonic wave propagating at 70 degrees to the normal is used.

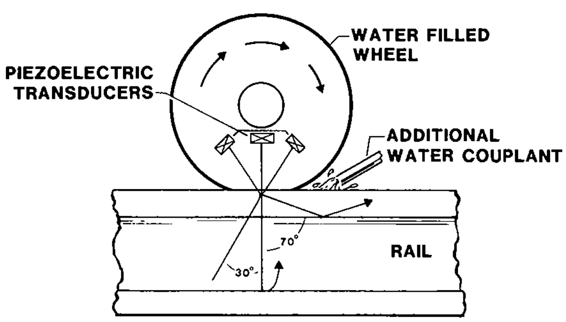

Figure 1. Conventional method of ultrasonic inspection of railroad rails.

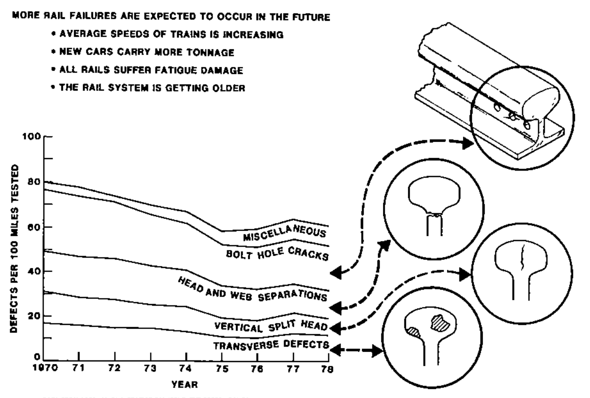

Figure 2. Types of rail flaws and their frequency of occurrence.

Figure 2 shows drawings of the most common rail flaws and displays a graph from which the relative frequency of occurence of each type can be deduced.

Ultrasonics has proven to be a very powerful technique for locating these flaws but the wheel type transducer has proven to be a major source of

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problems in that it has a restricted top speed, it looses coupling when dirt and oil are on the rail surface and small variations in the rail head geometry cause large changes in the direction of the refracted ultrasonic beam inside the rail. In order to overcome or mollify these difficulties, the Department of Transportation awarded the Rockwell Science Center a contract to demonstrate the feasibility of replacing the wheel type transducer with electromagnetic acoustic transducers (EMATs). These devices excite and detect ultrasonic waves in metals by an electromagnetic induction process across an air gap. Hence, they can operate reliably at high speed, over dirty or oily rail heads and are not subject to temperature effects. By using special coil designs, acoustic waves can be launched into the rail at an angle and the transducer can be made light enough to survive the mechanical shocks of moving along an operating railroad system. The program goals of this feasibility demonstration were: (1) to demonstrate operation from the top of the rail head only; (2) to determine how large an air gap could be tolerated between the transducer coil and the rail; (3) to show that angle beam inspection techniques were possible and (4) to establish the sensitivity of an EMAT inspection system to real flaws such as the transverse fracture, the horizontal split head, the vertical split head, the head-web separation, the bolt hole crack and surface shelling.

APPROACH

Figure 3 shows a schematic diagram of an EMAT rail inspection system in which a large electromagnet, suspended from the inspection car, supplies the magnetic field for an array of EMAT coils distributed about the head of the rail. Transducers B launch waves into the rail head propagating along the length of the rail. Transducers A launch waves across the head to locate longitudinal defects in the head. Transducers C launch

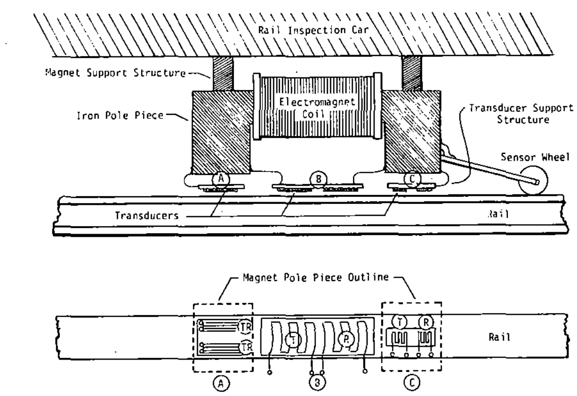

Figure 3. Schematic diagram of a possible EMAT rail inspection system.

waves through the head into the web to locate cracks at the bolt holes and head-web separations. Each of these transducers can be distinguished by its frequency of operation.

The feasibility experiments were also separated according to frequency as shown in Fig. 4. The advantage of the low frequency methods lies in the fact that they are less sensitive to lift off but they suffer from a lower EMAT efficiency. Hence, all three frequency ranges had to be investigated in order to develop trade-off data on lift off and sensitivity.

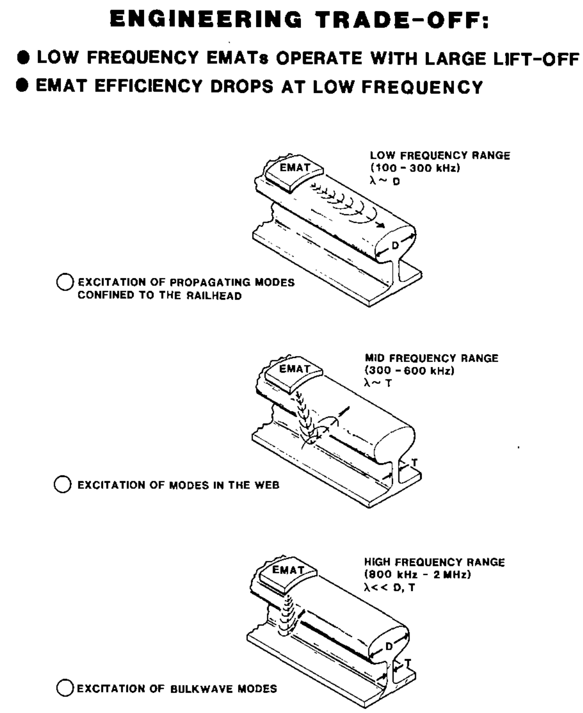

Figure 4. Configuration of EMATs tested in various frequency ranges.

Figure 5 shows a drawing of the oscilloscope trace observed when the low frequency EMAT arrangement was placed on a short length of rail containing transverse defects in the head.

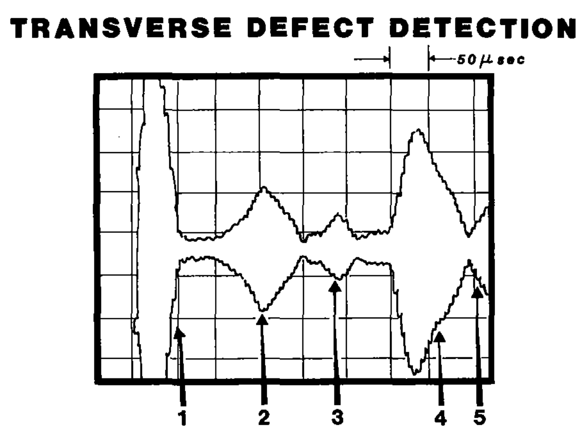

Figure 5. Oscilloscope presentation of echos observed with the low frequency waves on a short section of rail. Echos 1 and 4 are from the ends of the rail and echos 2 and 3 are from a transverse flaw in the rail head. (Frequency 220 KHz, λ=1.4 cm.)

EXPERIMENTAL CONFIGURATION

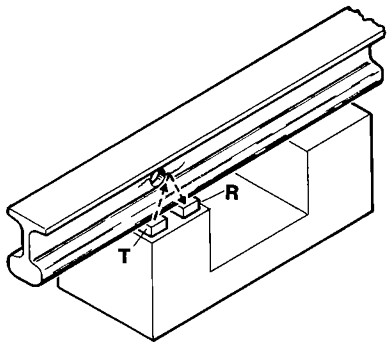

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Figure 6. Experimental configuration used to test EMAT detection of bolt hole cracks at mid-frequencies.

At mid-frequencies where a nominally 30 degree acoustic beam is needed to detect cracks at the bolt holes, the experimental configuration shown in Fig. 6 was used. In this case a meander coil type EMAT was used, operated at a frequency such that the ultrasonic energy entered the rail head at an

BOLT HOLE CRACK DETECTION

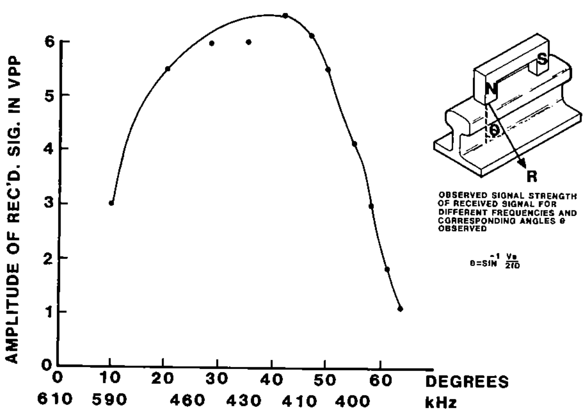

Figure 7. Dependance of EMAT efficiency on frequency and angle of propagation in a rail.

angle to the surface normal. Figure 7 shows how the amplitude of the ultrasonic signal depended upon the angle of propagation and the drive frequency. Figure 8 shows how the oscilloscope display appeared when flawless bolt holes and cracked bolt holes were examined. Because of the uniform circular shape of the flawless hole, there are striking oscillations in the amplitude of the signal reflected from it. A crack in the hole destroys the uniformity and with it the oscillations in the reflected signal strength.

The high frequency EMAT (~2 MHz) designed to launch bulk ultrasonic waves into the rail in a direction perpendicular to the rail head was configured as shown in Fig. 9 to detect defects in the web. In this case, the echo from the base of a flawless rail could be easily detected as shown in the top oscilloscope trace in Fig. 10. If a crack were present in the web such as for the case

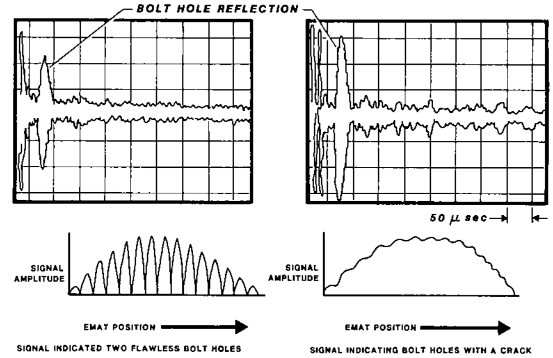

Figure 8. Characteristics of pulse-echo signals observed in the vicinity of flawless bolt holes and cracked bolt holes for EMATs with a spacing between wires of 0.5 cm and operated at 560 KHz.

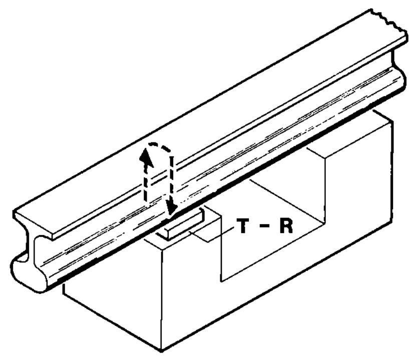

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Figure 9. Experimental configuration used to detect flaws in the web of the rail.

of a head-web separation, this base reflection would disappear because the acoustic energy would be dispersed or reflected away by the flaw. This condition is shown in the bottom oscilloscope trace shown in Fig. 10

Throughout the feasibility studies, it was important to measure how each of the EMATs responded to increases in the separation between the EMAT coil and the surface of the rail. Since the low and medium frequency cases utilized meander type EMAT coils their efficiencies decreased rapidly with lift off. The efficiency of a transmitter-receiver pair dropped by a factor of two with a 0.05 inch gap for the low frequency case and a 0.03 inch gap for the mid-frequency case. The high frequency case utilized a spiral coil which has much less inherent sensitivity to lift off than the meander coils. For this type of coil the efficiency fell by a factor of two when the gap reached 0.1 inches.

CONCLUSIONS

The results of the feasibility study showed that EMATs could be designed to inspect railroad rails with ultrasonic beams similar to those used by the wheel type transducers now in use. Studies on rail samples containing actual defects showed

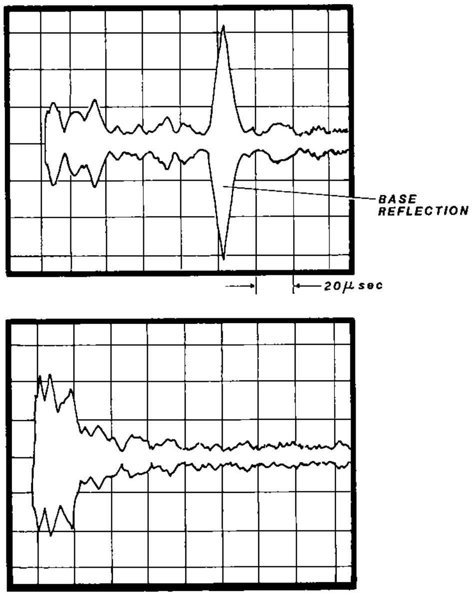

Figure 10. Oscilloscope presentation observed at high frequencies where the ultrasonic waves propagate into the web along the rail head normal direction.

that the EMATs were equal in sensitivity to the piezoelectric transducers because both were limited by the background noise in the metallurgical structure within the rail.