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Research Results

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Ultrasonic Monitoring of Longitudinal Rail Stress

SUMMARY

Longitudinal stress in rail is an established problem in terms of both safety and maintenance. Daily and seasonal temperature cycles in continuous welded rail, can lead to high longitudinal rail stress (LRS). LRS that is excessive in tension can lead to failures in insulated joint bars and other rail fasteners. When LRS is excessive in compression, it may lead to track buckling. This problem has been an on-going safety-critical research area for the railroad industry for many years. The goal of this research is to address this problem by providing the rail industry with the ability to monitor LRS at desired locations, so that preventative maintenance may be performed in a rational and efficient manner. Ongoing research at the University of Nebraska-Lincoln (UNL), with the support of the Federal Railroad Administration (FRA), is focused on the use of ultrasound to monitor LRS*. The relationship between ultrasonic wave speed, and stress in a solid, referred to as the acoustoelastic effect, is the basis for this research. The primary development work takes place in UNL laboratories and in a 'field laboratory' consisting of a small rail bed. The measurement techniques developed are then used at railroad field sites on in-service rail. In the current study, the ultrasonic measurements are compared directly with measurements of LRS from stress modules attached to the rail.

* Such techniques are beneficial and novel as they would allow for LRS measurements from a moving platform.

(a) (b)

Figure 1. (a) Stress module test site on the UP south Morrill subdivision. (b) ultrasonic wave speed measurement device is attached to the rail by UNL students.

BACKGROUND

Since the 1950s continuously welded rails (CWR) have considerably increased railroad life and reduced the expenses of track maintenance. Today, one CWR can reach 10 km. CWR has also brought its own peculiar problems to the railroad industry due to the constant temperature changes that rails experience because they are exposed to the open air and radiant heat from the sun. These temperature changes in CWR can create longitudinal stresses in the rail due to the constraints along the rail in conjunction with the thermal expansion or contraction of the rail steel. During winter nights, the thermally induced tensile stress promotes the growth of fatigue cracking, welding separation and fretting corrosion in bolt-jointed parts. In the hot summer, the temperature rise can build up sufficient compressive stress, which together with dynamic loads and train velocities, can cause track buckling (lateral movement of the track) resulting in derailment accidents. Such buckling is often triggered by a passing train along curved track.

Longitudinal force assessment is a significant factor in railroad maintenance to ensure its safe service. Previous research has demonstrated that the main source of longitudinal force in CWR is the thermal expansion in the rail material. The value of the longitudinal force in CWR is proportional to the temperature change, thermal expansion coefficient, and Young's modulus of the rail steel. For a typical rail, a change of rail temperature of 1º C results in longitudinal stress change of about 2.5 MPa. The temperature at which the free rail is welded (i.e. stress free) is called the neutral temperature, T_n, and varies, depending on the specific climate of the location of concern. It is difficult to measure the longitudinal rail stress (LRS) in CWR based on ambient or rail temperature because many factors influence this force, including track bed resistance and uneven temperature distribution in the rail.

Various measurement techniques have been proposed to evaluate thermal stresses in CWR. Today, the methods most commonly used by industry do not allow the track to remain in service during the measurement. Thus, these techniques are less than desirable due to rail service disruption*. A LRS measurement technique that is not disruptive would be of great benefit to the industry provided that it has adequate stress resolution. Such a tool would provide important information for regular track maintenance associated with the state of stress in the rail.

OBJECTIVES

The primary objective of the current research is the development of measurement systems for longitudinal rail stress based on ultrasonic methods which would allow for LRS masurement from a moving platform.

METHODS AND FINDINGS

Several different ultrasonic techniques are currently being explored. The technique described here exploits subsurface longitudinal ultrasonic waves using a two-transducer pitch-catch experimental setup. The speed of propagation of this wave is proportional to LRS. The experiments are developed and tested in the laboratory, tested at a 'field laboratory site,' and then examined at active railroad field test sites. Each of these efforts is described here. The relationship between the propagation speed of ultrasonic waves and a stress applied to a solid is described as the 'acoustoelastic effect.' Each type of ultrasonic wave has a particular sensitivity to the stress applied to the solid. The wave type used here, the subsurface longitudinal wave (also called the critically refracted longitudinal wave), is the most sensitive to the type of stress that is dominant in LRS – primarily uniaxial tension and compression.

* For example: installation of rail force measurement units require cutting the rail in order to establish a zero-stress reference.

The experimental setup is shown schematically in Figure 2. A longitudinal source transducer excites a pulse of elastic energy that propagates through a coupling wedge into the solid (here, the outer surface of the rail head). The wedge angle is chosen optimally such that the subsurface longitudinal wave receives the maximum amount of energy. This wave propagates along the rail and is detected by the receiving transducer, oriented as well for maximum detection of the wave of interest. The signal received by the transducer is then digitized. Subsequently, signal processing algorithms are used to determine the travel time of the wave, so that the wave speed can be calculated. It is this basic measurement that is used for the applications described below.

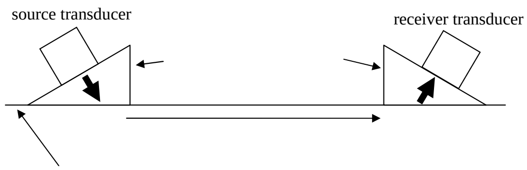

Figure 2. Schematic of the ultrasonic wave speed measurement.

Laboratory Testing

The primary development work for the ultrasonic testing device occurs in the Ultrasonics Research Laboratory on the UNL campus. In this lab, the several experimental parameters for these measurements are investigated. These parameters include the ultrasonic frequency, coupling wedge angle, coupling fluid, transducer separation distance, and rail measurement surface. Short pieces (approximately 1 m) of rail, instrumented with strain gauges and loaded using a hydraulic press, are used in the development phase of the project to optimize the measurement techniques.

Field Laboratory Testing

To assist in additional development aspects of this work, a 'field laboratory' was established at a test site located at the airpark in Lincoln, Nebraska (shown in Figure 3). This site has a small rail bed that includes rail with ties, clips, and ballast.

The field laboratory test site is used to test new experimental device designs in conditions that are as close as possible to real field conditions using a controllable applied load. The rail load is applied using a hydraulic ram that compresses a rail instrumented with six strain gauges. The strain measurements are used to determine the stress in the rail during the hold periods of the ram when the ultrasonic measurements are taken. Example results showing the linear relation between stress and wave speed from this test site are shown in Figure 4.

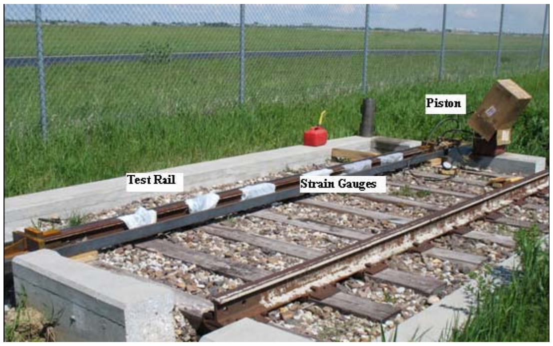

Figure 3. Photograph of the Lincoln, Nebraska airpark field laboratory. The piston applies a compressive load to the rail. The stress is monitored ultrasonically with the load measured independently using strain gauges.

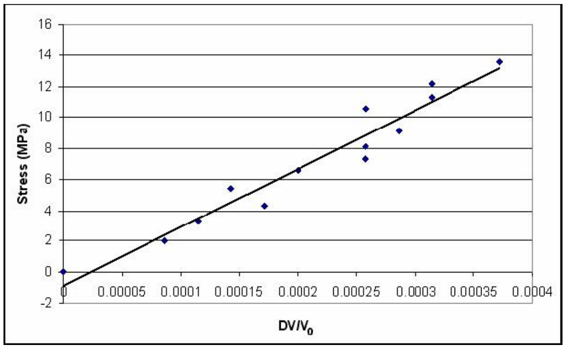

Figure 4. Sample data showing change in ultrasonic wave speed as a function of applied stress.

Active Track Field Testing

Testing of the ultrasonic LRS measurement system is ongoing at field test sites including the Union Pacific's heavy-haul line at MP 47, on the south Morrill subdivision in western Nebraska. This test site includes 1000 ft of track, instrumented with nine pairs of stress modules (one each on the north and south rails at nine locations spaced along the test track). Five pairs of modules are solar-powered and four pairs are battery-powered. UNL researchers have used this site to test the ultrasonic measurement device at the stress module locations, which serve as an independent measure of the rail load. One version of this device that attaches magnetically to the rail head is shown in Figure 5 at one of the stress module locations.

Measurements are made at the stress module sites at various times of year and with various rail temperatures. Figure 6 depicts, as an example, field test result from one of the stress module locations at the UP test site, showing the relationship between ultrasonic wave speed and rail stress. Testing at this site is ongoing.

Figure 5. Magnetically attached ultrasonic wave speed measurement device shown attached to the outer surface of the rail head at a stress module location.

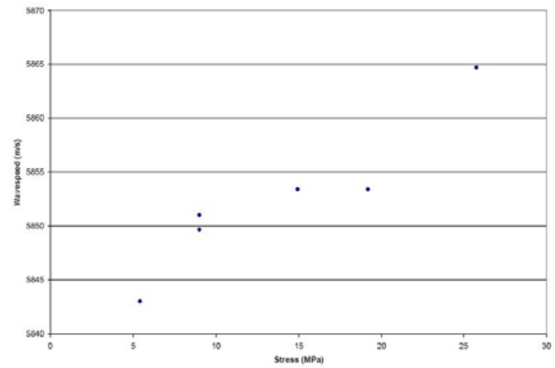

Figure 6. Example field test data from stress modules.

CONCLUSIONS/FUTURE WORK

The use of ultrasonic methods for monitoring longitudinal rail stress has been demonstrated in field conditions on in-service rail. The initial results are very promising. However, more data are needed to realize the full potential of this testing method.

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