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Field Evaluation of a Rail Stress Measurement System

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Summary

Engineering faculty and students in the Association of American Railroads' (AAR) Affiliated Laboratory Program at Texas A&M evaluated its on-track prototype system for measurement of rail longitudinal stress. The system generates ultrasonic waves in the rails and uses the polarization of Rayleigh surface waves as the measure of longitudinal stress.

While the measurements system provided promising results in the laboratory, the measurements taken in the field revealed some challenges. Repeating the same measurement (without altering the experimental setup) results in a variability of the measured amplitude for the out-of-plane displacement and a variability of the displacement measured under a 45-degree angle. Calculating the polarization of the Rayleigh wave with the variability of both the out-of-plane and angled measurements produces an even greater variability.

Thus, the device cannot be used to reliably measure rail longitudinal stresses in its current configuration. The project team is working with the maker of the laser vibrometers used to measure the Rayleigh wave amplitudes to improve the accuracy and precision of the field measurements. This accuracy and precision issue may be attributed to the low intensity of the light reflecting from the rail surface in combination with the low signal amplitude of the Rayleigh wave (nanometer range). One solution is to increase the power of the laser vibrometer. Another solution is to increase the number of averages to improve the signal-to-noise ratio. Measurements taken with an increased number of averages revealed that averaging in the time-domain (as most data acquisition systems do) and/or complex frequency domain does not improve the signal-to-noise ratio significantly. This is due to some jitter of the instrumentation. However, averaging the magnitude in the frequency domain increases the signal-to-noise ratio with increasing number of averages.

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INTRODUCTION

Under sponsorship of the AAR Strategic Research Initiatives (SRI) Program, The Affiliated Laboratory at Texas A&M University developed and field tested a noncontact prototype apparatus designed to quickly measure longitudinal stress in rails. The measurement is performed by generating a Rayleigh wave along the surface of the web of the rail and analyzing the polarization of the Rayleigh wave some distance further down the rail.

Rayleigh Wave

A Rayleigh wave particle has an elliptical motion that is retrograde compared to the direction of the wave propagation. Thus, a wave travelling to the right will induce a counterclockwise motion in individual particles (Figure 1).

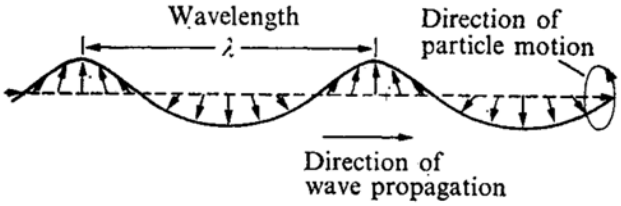

Figure 1. Rayleigh Wave Particle Motion[1]

The Rayleigh wave expends almost all of its energy propagating along the surface and thus is an ideal excitation mechanism to measure surface stress. It is slower than both the shear and longitudinal waves, and its wave speed is independent of wave number (and thereby wavelength), which makes it nondispersive.

The motion within a Rayleigh wave can be described by its polarization, which is defined as the ratio of maximum in-plane displacement to maximum out-of-plane displacement of a particle on the surface. For real media, Graff states that the out-of-plane displacement is always greater than the in-plane displacement, typically 1.5 times greater, and it yields a polarization value of around 0.67.[1] The polarization of the Rayleigh wave is an order of magnitude more sensitive than the Rayleigh wave speed. Thus, this research explores the method of measuring longitudinal rail stress using Rayleigh wave polarization (a technique which has proven effective in a controlled laboratory environment) and evaluates its practicality for in-field testing.

Results from laboratory testing of short pieces (i.e., 5 feet in length) of rail in tension and compression have been encouraging. The measurement method is equally successful for rail in tension or compression.[2]

Test Bed

In order to determine the practicality of this method for in-field testing, a test bed was constructed. It consists of a 40-foot long track panel with concrete ties and header beams. The header beams are connected with bars typically used in post-tensioning operations. The stressing is performed with a 100-ton jack and a hand pump. The rails can be stressed to a maximum force of 50 tons if the cylinder acts in the center of the header beams. Strain gages were installed at the neutral axis of the rail to measure the actual strain. The strain gage data serves as a benchmark to compare to the stress measurements. Figure 2 shows the in-field test bed.

Figure 2. Test Bed

Figure 3 shows the laser vibrometers affixed to the prototype measurement cart during static measurements at the field test bed. The one on the left (with the beam angled to the rail surface) is used to determine angled particle velocities, and the one on the right measures out-of-plane particle velocities.

Figure 3. Laser vibrometers attached to the prototype cart

Field Test Results

To test the repeatability of this measurement process, five measurements are taken at each stress level when the signals of the laser vibrometers are stable. The following compressive load levels are considered: 0 ton, 10 tons, 20 tons, 30 tons, and 40 tons. The stress is applied to the rails using the hydraulic jack.

Initial measurements are taken at 0 ton of compressive stress in the rail. Figures 4 and 5 show the out-of-plane and angled beam measurements for this stress level. Each plot shows five measurements taken in a short period of time, with no changes in rail stress.

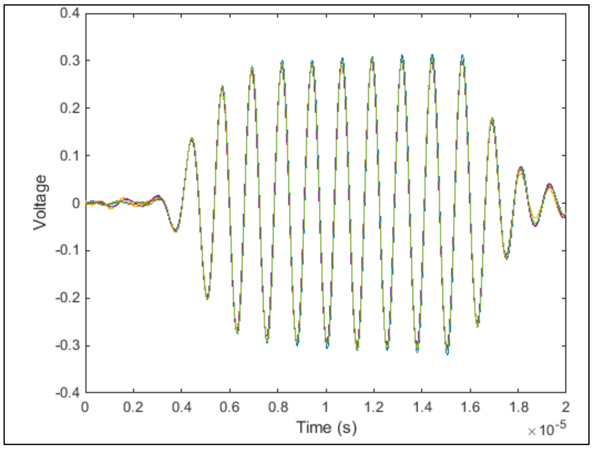

Figure 4. Out-of-plane, 0 ton

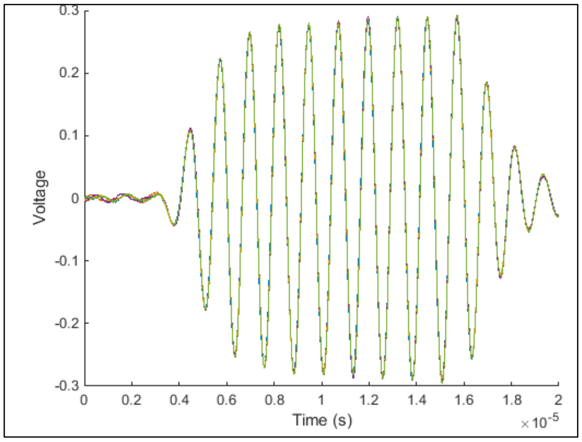

Figure 5. Angled beam, 0 ton

Initially, the measurements look consistent. However, a zoomed view of the highest peak reveals significant deviations between the repeated measurements. Figure 6 and 7 shows the zoomed in view of the highest peak for the out-of-plane and angled beam measurements. Again, each plot shows five measurements taken under the same load conditions.

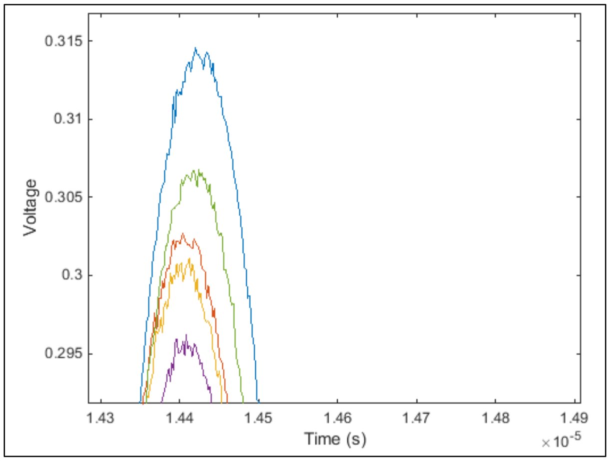

Figure 6. Out-of-plane zoomed, 0 ton

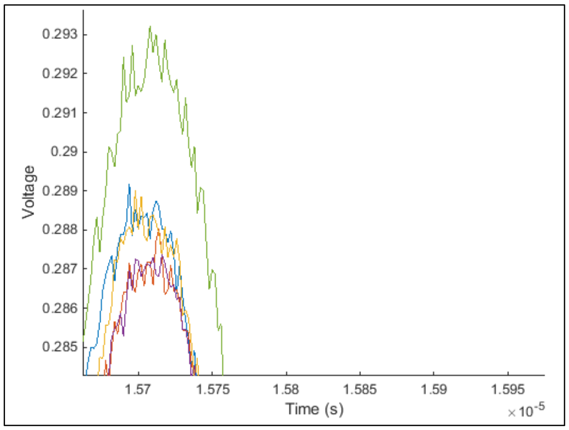

Figure 7. Angled beam zoomed, 0 ton

The errors in the amplitude for the out-of-plane and angled beam measurements are 6.2 percent and 2.0 percent respectively. The polarization values were computed for each of the five measurements. These values varied from 0.85 to 0.93 with a mean of 0.90 and a standard deviation of 0.028.

The same measurements were taken for each load level in the field test. An initial, no load applied, measurement was taken. The track panel was then loaded to 40 tons in compression and measured. Subsequent measurements were made at 30, 20, 10, and zero tons compression. From these measurements, Rayleigh wave polarization was calculated. The results are plotted in Figure 8. Shown are five measurements made at each applied load, plus the mean of the five measurements (shown as a line to indicate the sequence of tests).

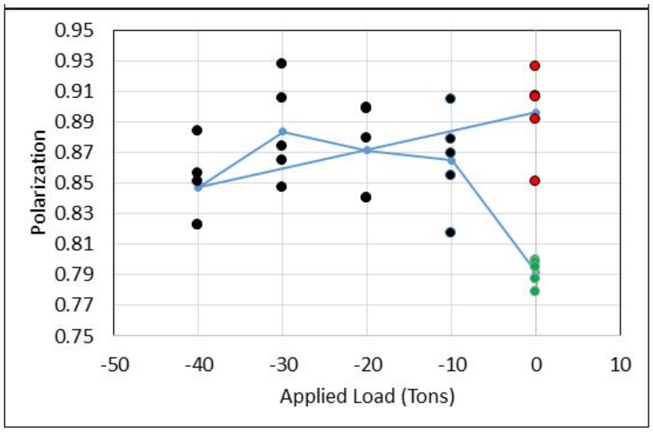

Figure 8. Rayleigh wave polarization for different loads

Clearly, the polarization values are inconsistent. Most discouraging are the values computed at 0 ton of load. The initial polarization values, computed before any stress is applied to the rail, are indicated by a red dot. These values are different from the final polarization values, computed after all stress is removed from the rail and indicated by a green dot.

Currently, the measurements taken by the laser vibrometers do not appear to be consistent enough for this method to be repeatable.

CONCLUSIONS

The prototype on-track longitudinal rail stress measurement device was evaluated under field conditions with rails in compression. While the measurement system provided promising results in the laboratory, the measurements taken in the field revealed some challenges. Repeating the same measurement (without altering the experimental setup) resulted in a variability of the measured amplitude for the out-of-plane displacement and a variability of the displacement measured under a 45-degree angle. Calculating the polarization of the Rayleigh wave with the variability of both the out-of-plane and angled measurements produced an even greater variability. These results indicate the device cannot be used to reliably measure rail longitudinal stresses in its current configuration. The project team is working with the maker of the laser vibrometers used to measure the Rayleigh wave amplitudes to improve the accuracy and precision of the field measurements.

FUTURE WORK

To increase the reliability and repeatability of the results, the following future work is recommended:

- Increase the power of the laser vibrometer
- Increase the excitation amplitude of the Rayleigh wave
- Capture each trace in the time domain, determine the amplitude, and then average the calculated amplitudes. One possibility of accurately determining the amplitude from the time domain signal is to curve fit a theoretical burst and then use an autocorrelation function to optimize a match with the measured data.
- Acquire the data in the frequency domain and use complex averaging. Ideally, the reference signal would be obtained from the signal that is fed directly to the piezo (not from the function generator). The time window (prior) to applying the Fast Fourier Transfer (FFT) should be exactly the width of the 10-cycle burst. The flat top window should be used for the FFT.
- Acquire the data in the frequency domain and use magnitude averaging. Same considerations as above except that no reference signal is necessary.
- Increase the number of cycles per burst. The more cycles the easier it will be to minimize amplitude fluctuations.
- Implement a vision system to make sure the two laser beams overlap all the time. A slight offset may work to avoid crosstalk; however, the beam separation must be the same all the time.

ACKNOWLEDGEMENTS

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REFERENCES

1. Graff, Karl F. 1991. *Wave Motion in Elastic Solids*. New York: Dover Publications Inc.
2. Hurley, Samuel and Stefan Hurlebaus. December 2014. “Development of a Rail Stress Measurement System,” Texas Transportation Institute, College Station, TX.