Sensitivity to Axial Stress and Temperature of Local Resonances in Rails

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ABSTRACT

Measuring rail thermal stresses or rail neutral temperature (RNT) in continuous welded rails (CWRs) is a challenging task for the railroad industry, especially in a nondestructive and nondisruptive manner. This paper examines the potential of local resonances for thermal stress measurement in rails. Local resonances associated with zero-group velocity (ZGV) and cutoff frequency points usually demonstrate sharp resonances in amplitude spectra, which can be utilized for Nondestructive Evaluation (NDE) and Structural Health Monitoring (SHM), and we previously reported their existence in rails. In this study, we promote local resonances by bonded piezoelectric elements on a short rail sample. Two tests were performed: (i) the sample is subjected to stepwise increasing uniaxial compressive loads in a constant temperature environment, and (ii) the same sample is free to expand and subjected to rising temperatures in an oven. By measuring local resonant frequencies, we quantified the sensitivity of the resonant frequencies to axial stress and temperature. The results show that appreciable sensitivities of the local resonances are found under varying stress and temperature levels and can be utilized for in-situ rail thermal stress determination.

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INTRODUCTION

Ultrasonic guided waves are elastic waves that interact with geometric boundaries of waveguide structures, such as plates, rods, pipes, and rails, producing propagating and evanescent wave modes [1,2]. Among all guided wave modes, zero-group velocity (ZGV) modes are special points where the group velocity vanishes and the phase velocity remains finite. The dominant feature of ZGV mode and cutoff frequencies in the frequency domain spectrum is a sharp resonance peak and we can selectively promote desirable wave modes for applications such as damage detection, thickness measurement, surface condition characterization, and stress measurement [3-7]. The existence of local resonances in rails are proved and can be generated using piezoelectric lead-zirconate-titanate (PZT) sensors [8,9]. Due to the absence of expansion joints in continuous welded rail (CWR) structures, it will constrain CWRs from free thermal expansion and contraction in the axial direction, making them vulnerable to developing internal axial stresses caused by rail temperature changes. Therefore, it is essential to manage internal axial stress of CWR structures. This paper examines the potential of using local resonances to estimate rail thermal stresses.

MATERIALS AND METHODS

Experimental Configurations

In this work, experiments were conducted on a 610 mm standard 115-lb AREMA rail sample to relate local resonance signatures to applied axial and thermal loads. The dimensions of rail sample were 610 mm in length, 0.0072 m^2 in area. The axial load was applied by an INSTRON load frame, as shown in Figure 1(a). The rail sample was stressed from 0 MPa to 200 MPa in compression with a 12.5 MPa step increment. Electrical resistance strain gauges were also installed for an independent measurement of axial stresses. The applied stress levels were designed to meet the following criteria: (a) stress levels less than one third of the yield strength to stay in the linear elastic range; (b) strain levels less than 1000 microstrain to prevent mechanical depolarization of the PZT patches; (c) maximum compressive load less than half of the critical buckling loads to avoid global structural instability. The rail sample sat on rollers in a Despatch oven to allow free thermal expansion along the axial direction and introduce elevated temperatures, as shown in Figure 1(b). The temperature was increased from 20°C to 50°C with a 10°C-step increment. A thermocouple was also attached to the rail web for temperature indication. The rail sample was instrumented with a PZT patch (1372, APC International, Ltd., length: 11.70mm, width:10.50mm, thickness: 2.10mm) at the middle of the rail head. A chirp signal covering 20 to 120 kHz is selected as the excitation to cover the desired frequency range. We attached a Physical Acoustics Nano-30 sensor at the rail head on the center of rail sample to measure the out of plane wave motion in response to the excitation applied via PZT. At each load and temperature step, the vibrational signals were digitized by a PicoScope (PicoScope 4824), stored in the local hard drive, and processed using MATLAB signal processing toolbox. All measurements were averaged ten times to improve the signal-to-noise ratio.

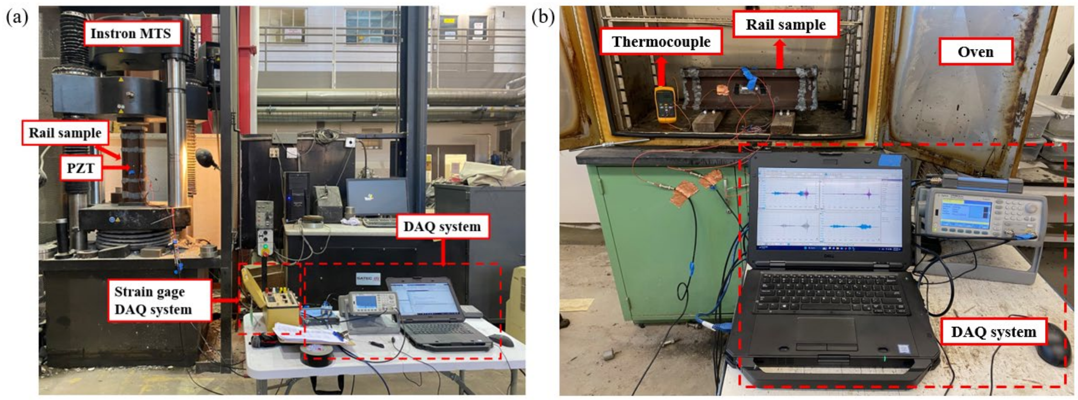

Figure 1. Experimental figures for (a) compressive loading test and (b) temperature test

RESULTS AND DISCUSSION

Axial Loading Results

Local resonances results from a head-head configuration (PZT excitation and signal receiver are both positioned at the rail head) are shown in Figure 2. Figure 2 gives the typical frequency spectrum of the rail vibrational response with a head-head configuration under axial loading test with PZT excitations. Several predominant resonances were identified such as modes close to 34 kHz, 63 kHz, 84 kHz, 99 kHz and 119 kHz. Those high amplitude are proved to be the local resonances associated with either cutoff frequencies or ZGV modes by performing a spatial sampling of wave propagation on standard 115-lb AREMA rail of all receivers along the wave propagation direction to calculate the dispersion relations experimentally via two-dimensional Fourier Transforms (2D-FFT) as shown in the team's previous work[8].

The frequency spectra obtained from the experiments for the 2 ft 115 rail at various axial stress levels are shown in Figure 3. From experimental results, it indicates that the resonance peak shifts towards lower frequencies as the applied stress varies from tension to compression, which is an expected result from structural dynamics of prestressed beams. The mode at 84 kHz shifts 24 Hz towards lower frequency with 150 MPa change in axial loads. And 50 Hz, 32 Hz shift towards lower frequency for mode close to 99 kHz and 119 kHz.

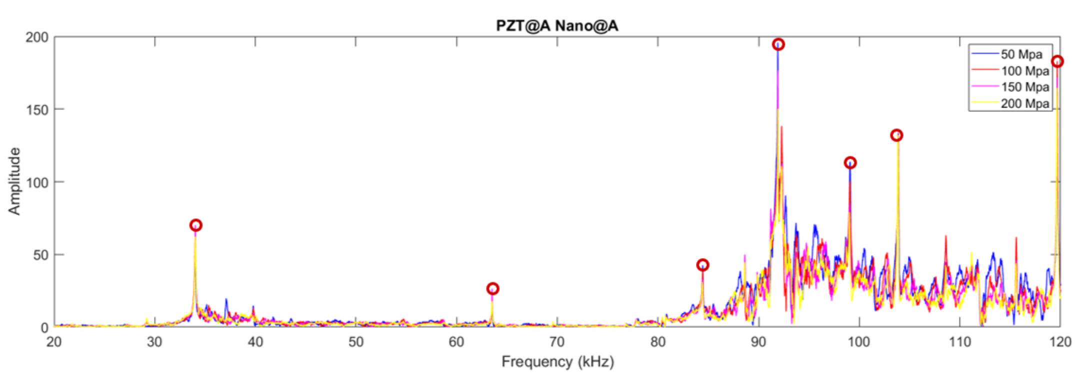

Figure 2. Frequency spectra of head-head configuration under axial loading test.

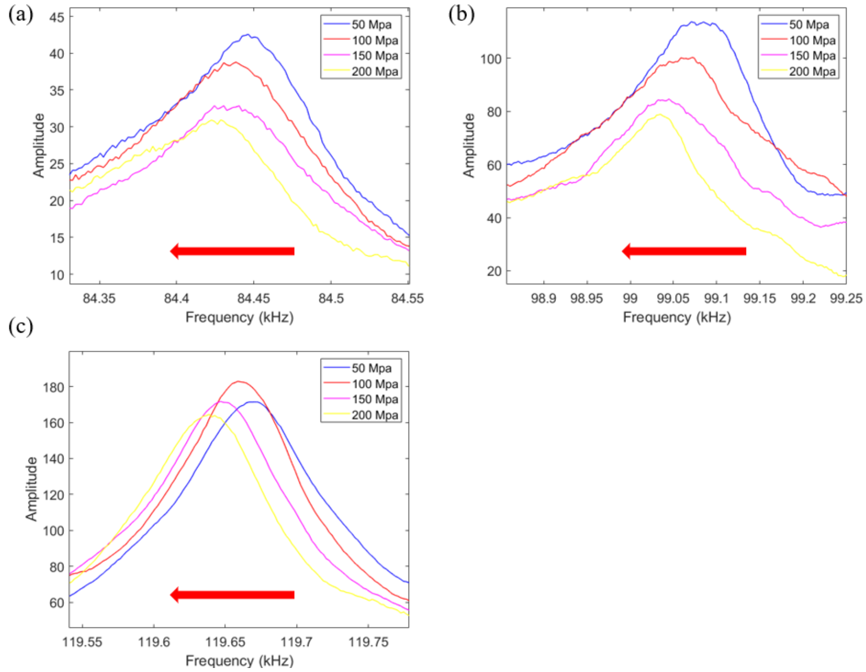

Figure 3. Shifts in resonance peak for varying axial stress levels (a)84 kHz, (b) 99 kHz and (c) 119 kHz.

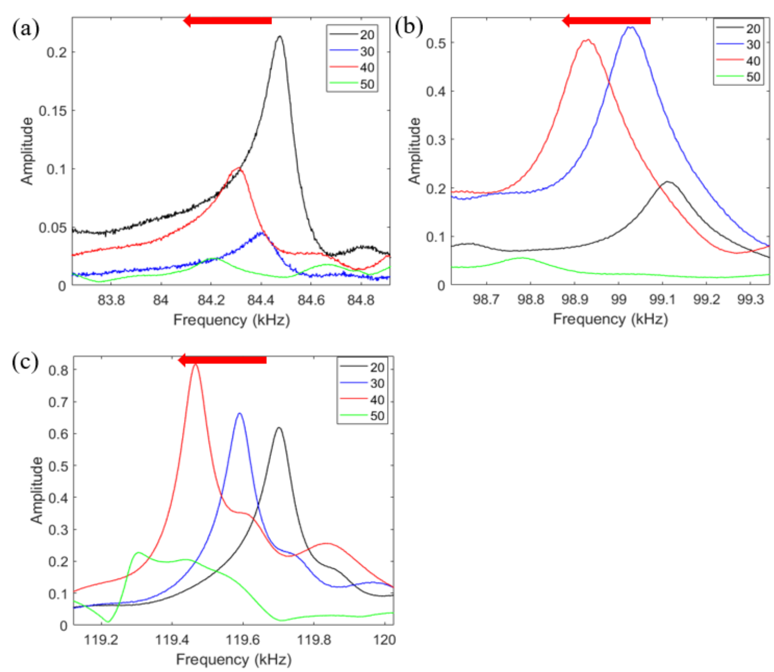

Figure 4. Shifts in resonance peak for varying temperature levels (a)84 kHz, (b) 99 kHz and (c) 119 kHz.

The frequency spectra obtained from the experiments for the 2 ft 115 rail at various temperature levels are shown in Figure 4. Same local resonances were identified. Based on experimental results, the local resonances shift towards lower frequencies as the applied temperature varies from 20°C to 50°C. The local resonances at 84, 99, and 119 kHz shift 262 Hz, 258 Hz, and 326 Hz towards lower frequency with a change of 30°C, respectively.

CONCLUSION

In this study, an investigation was conducted to explore the applicability of using local resonances related with ZGV modes and cutoff frequencies to estimate the uniaxial stresses and thermal stresses in a 610 mm rail sample. This study is one part of a broader research effort to develop techniques for estimating rail neutral temperature in continuous welded rails. Experiments were conducted on a 610 mm 115-lb rail sample instrumented with PZT elements and subjected to compression axial loads and temperature effects. For the frequency spectra, local resonance peaks mainly associated to ZGV modes and cutoff frequencies were found to shift towards lower frequencies when subjected to increasing compression loads and temperature.

ACKNOWLEDGEMENTS

This work was supported by the Federal Railroad Administration under Contract No. 693JJ621C000025 with additional financial support from the University of Utah. The support and resources from the Center for High Performance Computing at the University of Utah are gratefully acknowledged. The field data collection was coordinated and supported by the Utah Transit Authority.

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