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Project Title

The Feasibility of Promoting Local Rail Vibrations Using Electromechanical Impedance Method

University

University of Utah

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Research Needs

Safety is the principal concern of the railway industry, and track alignment irregularities can pose risks to the safe operation of trains. According to the FRA safety statistics for track-related train accidents, "track alignment irregularities (buckled/sun kink)" are the second leading cause of train accidents. $132 million damage was reported considering 241 derailments out of 244 accidents that occurred between 2007 and 2017. The high derailment rate and the potential destructive social and economic impact make track alignment irregularities a high-priority issue for the railroad industry. The mission of this project is to serve the rail industry by improving infrastructure safety and reliability with minimized risks of rail thermal buckling. The proposed work aims to advance the state-of-the-art of rail neutral temperature (RNT) measurement. The team will develop an electromechanical impedance (EMI) measurement system to promote local rail vibrations, which were recently found to be promising tools for RNT estimation [1, 2]. This mission will be accomplished by developing an innovative capability of consistent excitation and detection of local rail vibrations, which enables the use of stress-sensitive local vibration modes and thereby leads to more accurate RNT estimation.

Research Objectives

The objectives of this project are:

- Model the usage of electromechanical impedance method for local vibration modes promotion in rails
- Develop the data collection system for electromechanical impedance method
- Perform technology validation and evaluation on rail samples
- Present the results at national conferences and journal publications

Research Methods

The proposal team recently developed a Machine Learning for RNT (ML-RNT) predictive tool, which leverages field-collection vibration data, high-fidelity numerical models, and machine learning techniques. Its performance was evaluated with field data and can support RNT estimation with an accuracy of ±10ºC, as shown in Figure 1. This technology does not require baseline measurement. Furthermore, it concludes that the system performance can be significantly improved with a reliable method for local rail vibration promotion [1, 2] by enabling structural condition characterization with high stress-sensitivity modes. The local rail vibrations, in contrast to global ones [3], are immune from boundary condition variations [4].

The team hypothesizes that the electromechanical impedance technique can consistently excite and detect high-frequency local rail vibrations and thereby facilitate RNT estimation using the developed ML-RNT predictive tool. If successful, the proposed integrated system can potentially support RNT estimation with an accuracy of ±5ºC, which enables **non-destructive** RNT estimation **without track disruption**. Based on the team's experience and proof-of-concept results, we estimate that the Technology Readiness Level (TRL) of our work is currently at TRL 5: component validation in a relevant environment.

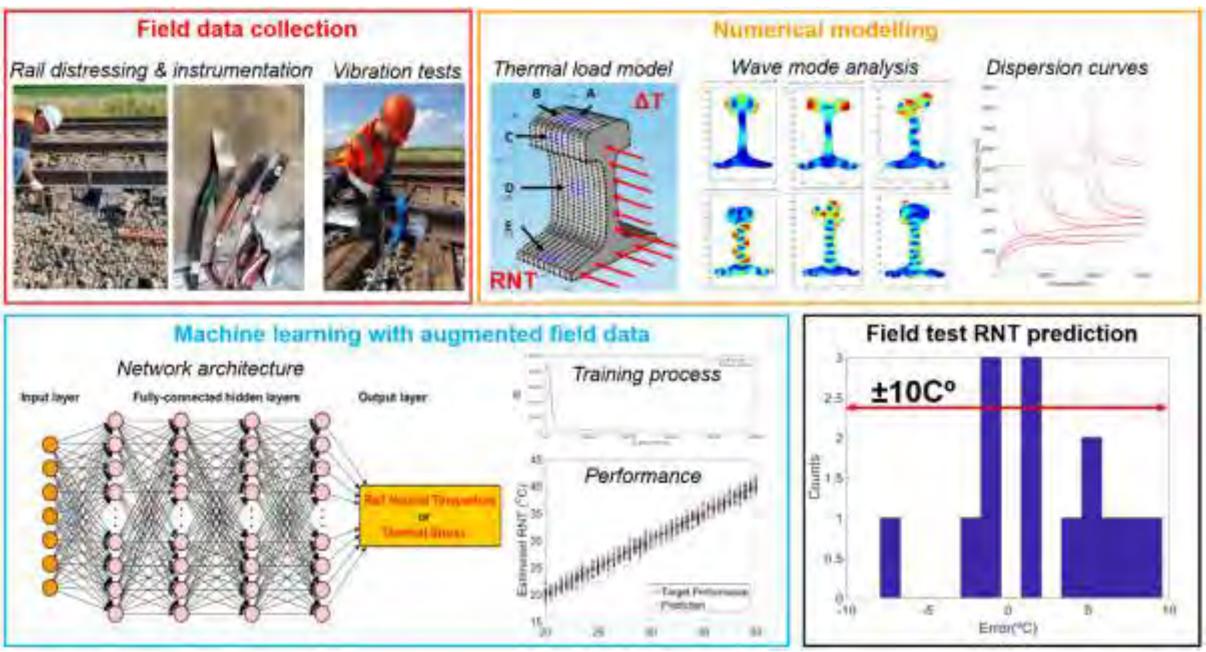

Figure 1. Summary of recent work on RNT measurement using ML-RNT predictive tool [1, 2]

Expected Outcomes

The proposed research will contribute to the development of a reliable approach for local rail vibration promotion. It will support an ongoing effort on nondestructive and non-disrupting RNT measurement without the need for baseline measurement. And the expected outcome is to improve rail safety by developing accurate RNT measurement technology. Especially, the proposed EMI data collection system and numerical models will contribute to stress-sensitive information extraction and a better understanding of wave propagation in rails. While boundary condition variations prevent existing vibration-based technologies to provide accurate RNT measurement [3], the proposed technology is highly likely to be not influenced by variations of tie conditions, clippers, and fasteners.

Relevance to Strategic Goals

The sensing technology to be developed in this proposal has a great potential for rail thermal stress measurement and internal defect detection. Based on FRA safety statistics, rail thermal buckling and internal defects are among the top rail accident causes for railroad networks in the U.S. The new sensing technology based on the electromechanical impedance method for local rail vibration promotion will enable rail internal condition characterization (thermal stress and internal defect detection) with high accuracy and immune from influences of boundary conditions. The analytical methods developed will be compared to experimental results. This research aligns with the USDOT strategic goals including 'State of Good Repair' and 'Safety'.

Educational Benefits

One Ph.D. student will be involved in the analytical and experimental work. The P.I. and the student will make presentations at national conferences including the SPIE Smart Structures+NDE conference and International Workshop of Structural Health Monitoring.

Technology Transfer

The main objective of this research is to develop a reliable approach for high-frequency local rail vibration excitation, which has potential applications of rail neutral temperature measurement. There is a need for developing such innovative technology and the proposal addresses that need. The resulting technology will lead to sensing systems that are capable of thermal stress measurement and management. The work will be presented at conferences, such as the SPIE Smart Structures+NDE conference and International Workshop of Structural Health Monitoring, and leading journals, such as the Journal of Structural Health Monitoring. In addition, technology transfer will occur through workshops, web pages, social media, and seminars.

Work Plan

Throughout this study, an EMI technique will be developed, validated, and evaluated for local rail vibration promotion. If successful, it allows the excitation and detection of high-frequency local rail vibration modes, namely the zero-group velocity (ZGV) modes, that feature higher sensitivity to longitudinal load, therefore support improved RNT estimation with the developed ML-RNT predictive tool. The proposed study will consist of the following tasks:

Task 1. Model electromechanical impedance method on local rail vibration promotion – 6 months

The existence of ZGV modes in rails was recently reported by the proposal team, which has great potential for RNT measurement and defect detection. ZGV modes are the non-propagating wave modes, whose group velocity is zero and energy is trapped within the cross-section of excitation. Thus, ZGV modes typically come with very a high signal-to-noise ratio and are immune from boundary condition variations [4]. The spectrum of impulse vibrational signal collected at a 132RE CWR is shown in Fig. 2(a), which demonstrates distinctive resonances at 31, 37, and 76 kHz. And these resonances correspond to the zero-group velocity points in the

132RE rail dispersion curves, as shown in Fig. 2 (b-d). It is notable that the vibration data was obtained from an impact-echo test with an upper limit of 80 kHz.

In this task, the team will develop a numerical model that can help to design and optimize the EMI test setup that can reliably promote high-frequency ZGV modes in rails, such that the stress-sensitive ZGV modes can be exploited by the developed ML-RNT predictive tool. EMI technique has been widely used for high-frequency structural vibrational tests but was rarely used for quantitative structural condition characterization. The team will establish numerical models on EMI for ZGV modes promotion. Specifically, we will study (i) the optimal EMI configuration for ZGV modes promotion, (ii) the influence of temperature on EMI-rail structure, and (iii) the influence of longitudinal load on EMI-rail structure. The envisioned test setup for the EMI technique deployed on rail structure is shown in Fig. 3(a), and a preliminary multiphysics simulation result is shown in Fig. 3(b) - the EMI technique can promote the three ZGV modes, which were identical to the ones observed in tests on 132RE rails. It is a reasonable inference that the EMI technique has the potential to promote high-frequency ZGV modes.

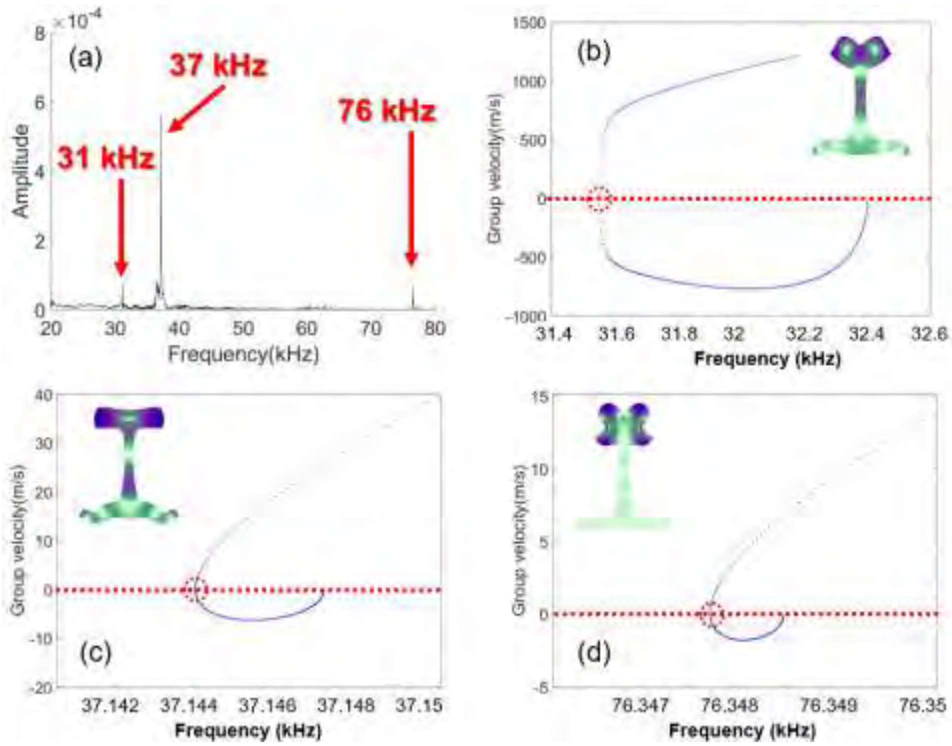

Figure 2. (a) Vibration signal spectrum of a 132RE CWR; group velocity dispersion curves of the 132RE rail at (b) 31 kHz; (C) 37 kHz; and (D) 76 kHz

Task 2. Develop Data acquisition system for electromechanical impedance signature – 3 months

The team will develop an electrical impedance measurement system for EMI data collection. The measurement system will be composed of an arbitrary waveform generator, potential divider, and oscilloscope. The data acquisition hardware and software will be configured based on a PicoScope platform, where a MATLAB program can control the excitation and acquisition parameters. Excitations including sine function and chirp signals will be considered for both steady-state and transit measurements. The performance of the measurement system will be evaluated by comparing measurement results against the ones obtained from a standard impedance analyzer or network analyzer. Testing samples include resistors, capacitors, free piezoelectric elements, and piezoelectric elements bounded to rail steel, where measurements on the resistor and capacitor shall provide measured results close to their nominal values.

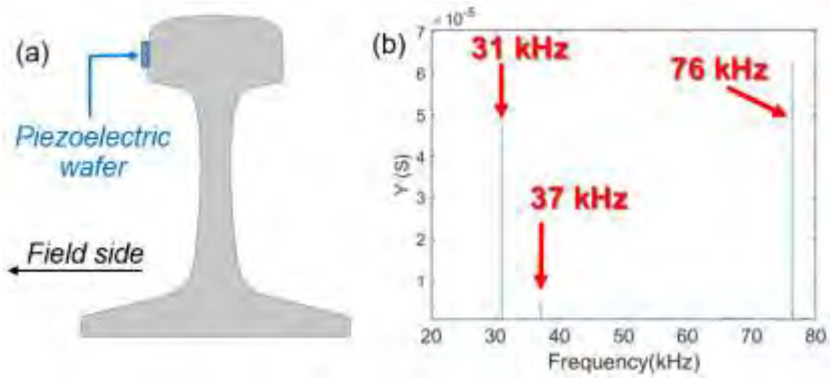

Figure 3. (a) Test setup for EMI measurement on rail; (b) simulated EMI spectrum from 20 to 80 kHz.

Task 3. Technology validation through laboratory and field test – 3 months

Upon the completion of Task 2, the team will test the effectiveness of the EMI technique for local rail vibration promotion. The test setup will be composed of the EMI data collection system (impedance measurement circuit with data acquisition system) and a piezoelectric wafer attached to a rail sample. A laboratory test will be conducted on a 5-ft 115RE rail sample to evaluate the effectiveness of this approach. Leveraging the long-term collaboration with Utah Transit Authority, the team will validate the model predictions in a field setup and investigate the performance of high-frequency ZGV modes in terms of RNT estimation accuracy, as shown in Fig. 4. This will be greatly reduced project costs on field data collection. Finally, we will evaluate the highest RNT estimation accuracy supported by the EMI-excited high-frequency ZGV modes.

Figure 4. Field site at UTA (a) 115RE rail testbed; (b) 132RE rail track testbed.

Project Cost

Total Project Costs:	$90,000
MPC Funds Requested:	$40,000
Matching Funds:	$50,000
Source of Matching Funds:	Utah Department of Transportation, financial support

References

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