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EFFECT OF STRESS ON IMPACT-BASED VIBRATION IN STEEL RAILS

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ABSTRACT

Here we investigate the use of impact-based vibration applied to steel rail structures to observe the effects of axial stress in the structure. Observations from field and laboratory tests using a contactless sensing configuration show that resonances generated by a single impact have different sensitivities to the same stress/temperature change. The study identifies resonances that may characterize absolute stress state of the rail that are minimally affected by complicated rail sub-structures.

Keywords: stress, vibration, impact, rail

1. INTRODUCTION

Continuously welded rails (CWRs) suffer risks of serious deformation due to stress accumulation. Constrained by ties and fastener, free thermal expansion or contraction of CWR is no longer possible. This constrained thermal deformation causes stress to develop and eventually excessive stress will be present in CWRs under extreme temperatures. Evaluating in-situ rail stress therefore becomes essential to rail safety management.

Previous efforts to estimate the stress state in rails or, alternatively, the rail neutral temperature (RNT) at which temperature the rail presumably undergoes zero axial stress, utilize various physical phenomena ranging across acoustoelasticity, rail up-lift force, forced vibration, nonlinear guided ultrasonic waves, and electro-mechanical responses [1-6]. Several of those studies developed techniques that are capable of predicting either stress state or RNT, but uncertainties caused by rail sub-structure (tie, fastener system, etc.) or passage of trains over the inspection area adversely affect the accuracy of measurements to a noticeable extent.

The proposed measurement technique here uses a single impact to excite a vibration event composed of a considerable number of individual resonances across a broad frequency response. Based on the idea that the sensitivity of resonances to a given stress/temperature change may differ, we propose to characterize absolute stress states through relative frequency changes among resonances, especially those that are less sensitive to variations from rail sub-structures. A discrepancy in the sensitivity to load/temperature is observed for both laboratory and field tests, demonstrating the potential of this approach for being a measure of stress states.

2. METHOD AND TESTS

2.1 Vibration test configuration

Vibration events are excited by mechanical impact from a 16 mm steel ball impactor, and the responses are collected by a PCB condenser microphone, which provides contactless sensing and easily changed measurement locations. The configuration for excitation and response collection comprises combinations of 5 locations across the rail cross-section, which make up 25 measurement sets for each test condition. For example, E-A denotes the test configuration where the excitation is applied at location E and collection of response at location A. Figure 1 illustrates this configuration.

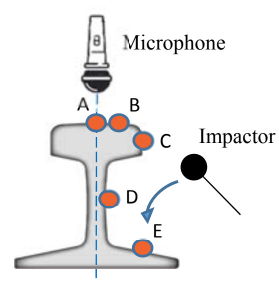

FIGURE 1: EXAMPLE OF TEST CONFIGURATION AT WHICH THE EXCITATION IS AT LOCATION E AND COLLECTION OF RESPONSE AT LOCATION A

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2.2 Field and laboratory tests

A piece of AREA 132 RE rail measuring 24 inches in axial length was used in laboratory tests to simulate a typical tie-to-tie span that is found in the field. The rail was tested under simple axial compression following a loading path in 9 steps to a maximum of 100 MPa, then unloading following the same path; this comprises 17 loading steps in total. Vibration measurements were conducted at each loading step while the load is held constant. The vibration responses were excited and collected at the cross-section at the mid-length, where the responses are expected similar to free rail vibration. Note that this laboratory test is to investigate the effect of stress by mechanical loading in a controlled fashion; however, the stress by thermal loading may not necessarily affect resonance frequencies in the same way or represent the stress occurred in rails in reality. In fact, we have observed the difference as comparing the results to the field test ones. Recognizing this difference prompts our interest to conduct tests with confined thermal loading in the future.

To study the effect of stress in a real-world context, field tests were performed on an in-service AREA 132RE rail section located near Champaign, Illinois. Two separate measurement locations on the same rail were chosen that were located two tie-to-tie spans apart. At each location, the rail was instrumented with one strain gauge aligning with the neutral axis using a quarter-bridge configuration on each side of rail (gauge and field sides). The rail temperatures on both locations were monitored throughout the day with an attached thermocouple. Tests were carried out on 2 separate days to examine the consistency of the response and the measurement approach. The test starts around 7 am before sunrise and ends around 3 pm as the measured rail temperature begins to decrease. The vibration measurements were taken half-hourly at one location, alternating between locations.

3. RESULTS AND DISCUSSION

3.1 Field test

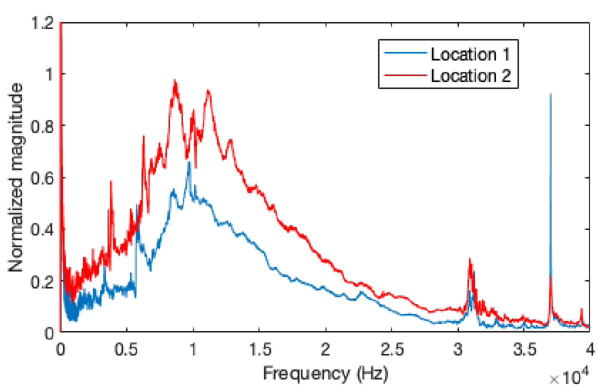

FIGURE 2: NORMALIZED SPECTRAL RESPONSES MEASURED AT DIFFERENT LOCATIONS IN THE FIELD TEST FOR ONE TEST

Figure 2 shows example average spectral responses (average spectra of multiple repeated tests) measured at two different locations at approximately the same time of day. The responses were collected with the same test configuration (A-A). The second location was measured 30 minutes after the measurement at the first location. This example demonstrates the consistency of the contactless measurement approach as well as its ability to collect high quality responses over a broad frequency range, up to 40 kHz. The broad range excitation is attributed to the natural excitation bandwidth of the impactor.

Close comparison of the data in Fig. 2 finds several resonances whose frequency is consistent at both locations, for examples those resonances indicated by peaks at approximately 32, 37 and 39 kHz. However the resonances at frequencies below 20 kHz, in spite of their strong excitation magnitudes, show little to no consistency between the two measurement locations. We presume that the behavior of lower frequency resonances are disrupted by the varying properties of the underlying rail sub-structure. In addition, the field test results measured throughout the day show that the frequency of most resonances decrease at both locations with recorded rising rail temperatures and compressive strains, which imply increasing internal stress.

3.2 Laboratory test

An example result of the laboratory test measured at a given configuration (E-E) over a full loading procedure stated previously is represented by a contour plot. The plot overlays vertically the measured spectral responses in the sequence following the loading procedure, where an image gradient procedure is applied to smooth the data points. The vertical axis indicates each applied loading step, where the load level reaches maximum at the 9th load step. The higher spectral magnitudes are indicated in warmer colors.

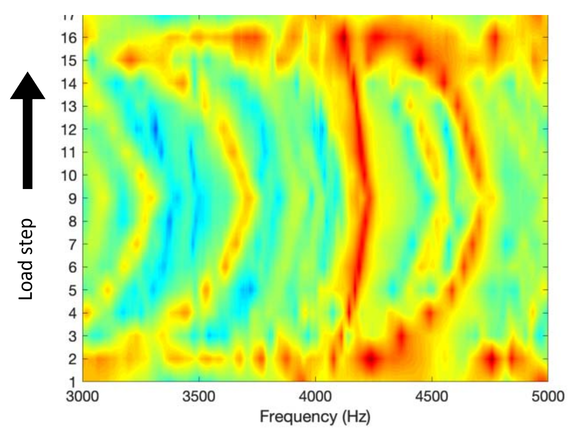

Figure 3: THE OVERLAID SPECTRAL RESPONSES OVER A FULL LOADING PROCEDURE IN THE LABORATORY TEST

As seen in Fig. 3, multiple resonances shift toward higher frequencies with increasing load levels and back to their initial frequency during the unloading process. Thus the applied axial stress at constant temperature is seen to increase the resonance frequencies. More study is needed to understand why this behavior is opposite our interpretation of that which we collected in the field. However, the traces of frequency shift appear to follow different curvatures, verifying that resonances have different sensitivities to a given stress change.

4. CONCLUSIONS

The following conclusions are drawn based on the presented material:

1) High quality vibration resonance data from rail structures can be measured well up to 40 kHz in a contactless fashion;

2) High frequency (above 20 kHz) vibration resonances in rail structures are not significantly affected by rail substructure conditions; and

3) Certain rail resonances are directly affected by axial stress level in the rail.

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