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RESEARCH RESULTS
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Rail-Mounted Strain Gauges for Tie Reaction Measurement Under Dynamic Loading

SUMMARY

Strain gauges are commonly used to measure vertical wheel loads in a railroad track. This approach uses the Differential Shear Strain (DSS) concept: the difference in vertical shear force between two points along a beam equals the resultant applied vertical force between the two points. Ahlbeck et al. (1980) proposed that this concept can measure the vertical rail-tie interface forces to assess tie support conditions. Previously, researchers numerically proved the applicability and accuracy of this concept (Rabbi et al., 2019) (Johnson et al., 2019). Some other studies have directly used this concept in the field to measure the tie interface forces (Mishra et al. 2014) (Touqan et al., 2021) (Bruzek et al., 2022).

Several research and field applications have backed the crib circuit (CC) (i.e., installed between two ties) for vertical wheel load measurement. However, no studies have explored whether the tie circuit (i.e., installed on top of a tie) is valid for rail-tie interface force measurement. Thus, questions remain about its accuracy. On October 2021, the Federal Railroad Administration (FRA) tasked ENSCO Inc., and Oklahoma State University (OSU) to field-validate this approach under actual train loading. This work took place in Chambersburg, PA. An earlier FRA report validated the accuracies of the crib and tie circuits (TC) under static loading (Thompson et al., 2022). This document describes the performance under dynamic loading.

BACKGROUND

Among several different available methods of wheel load measurements, a strain gauge-based measurement system is the most common. When a wheel load is between the two strain measurement points of the CC, the principal strains measured at the rail neutral axis allow the user to calculate the shear strains. The difference between calculated shear strains is related to the resultant applied force. In practice, the DSS is measured using four individual dual-element shear strain gauges, two each on the field and gauge sides of the rail. Connecting these gauges to four arms of a Wheatstone Bridge circuit removes the effects of out-of-plane rail bending (Ahlbeck et al., 1980).

RESEARCH QUESTIONS

The focus of the research effort was to show how accurate CC and TC were for measuring vertical wheel load and tie reaction, respectively, for static and dynamic loading. Thompson et al. (2022) reported the findings from the static loading scenarios. This document focuses on the strain gauge circuit performance under dynamic loading. The following research questions were addressed:

1. Does the combined application of crib and TC represent a valid approach for tie support condition assessment under dynamic loading?
2. Is the performance of this measurement approach affected by changes in vertical track support, such as missing or hanging ties?

FIELD INSTRUMENTATION

Researchers instrumented a tangent section of track at the Letterkenny railroad yard in Chambersburg, PA, with one CC and two TC (Figure 1). The team also installed two types of conventional sensors (i.e., load cells [LCs] and strain gauge-mounted tie plates or instrumented tie plates [ITPs]) at the rail-tie interfaces of two adjacent ties. These conventional sensors provide a way to validate the forces measured by the strain gauge circuits. The track construction was American Railway Engineering and Maintenance-of-Way Association (AREMA) 115RE rail and timber crossties.

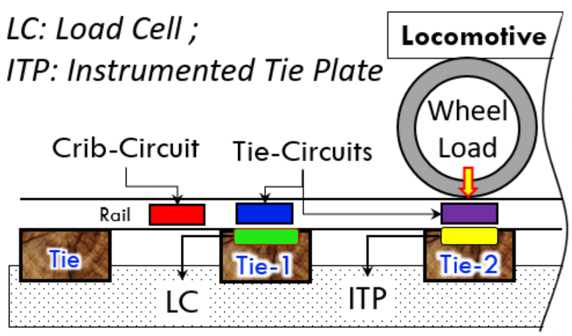

Figure 1: Instrumentation Layout

RESULTS AND DISCUSSION

The results from CC calibration and static loading, presented by Thompson et al. (2022), showed that the tie reaction forces measured by the strain gauge circuits closely matched those measured by the conventional sensors. Once the research team confirmed the circuits' performance under static loading, the next step was to study their performance under dynamic loading. The data from all sensors, collected under a passing locomotive, were analyzed to compare the tie reaction forces measured using the different methods. A simulation of three track support conditions occurred by removing selected ties from the test section (see Figure 2).

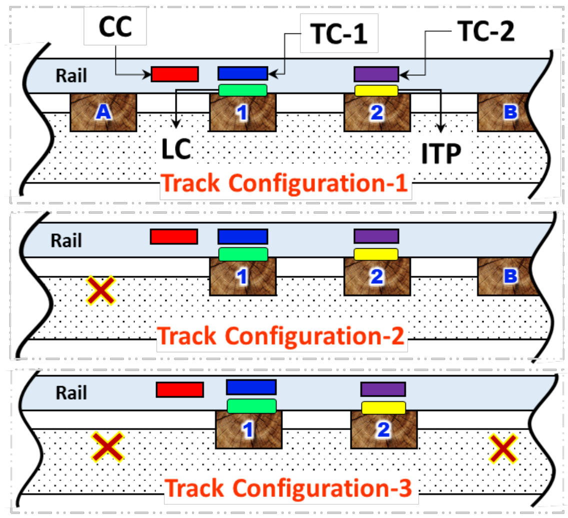

Figure 2: Track Configurations (TC) for Dynamic Testing

TC-1 was the base case with all the ties in place. Removing Tie A (i.e., next to Tie 1) was TC-2, while removing both Tie A and Tie B (i.e., next to Tie 2) was TC-3. The CC measured the vertical wheel loads (P). The TC measured the value of (P-R), with R representing the upward tie reaction force. Subtracting the value of (P-R) from P gives the value of R. The R values were also directly measured using the LC and ITP. Each TC was tested 12 times: 2 directions of movement (i.e., forward and backward) and 3 speeds (1, 5, and 10 mph) x 2 replicates.

Figure 3 shows the time histories of the data collected from multiple sensors during a single passage of the locomotive. The top plot shows data from the CC, Tie circuit # 1 (P-R @ Tie-1), and the LC installed at the rail-tie interface at Tie # 1. The bottom plot shows data for CC, P-R@Tie-2, and the ITP. There were two observations made. First, the wheel load forces were not equal for the four axles (see the CC trace), which resulted from an unequal distribution of weight within the locomotive. Second, the peaks for CC and LC are slightly offset along the time scale due to the physical distance between the two circuits. Note that subtracting the (P-R) trace from the CC trace results in the tie reaction force, which can be compared to the measurements from the LC or the ITP. Figure 4 presents the comparisons.

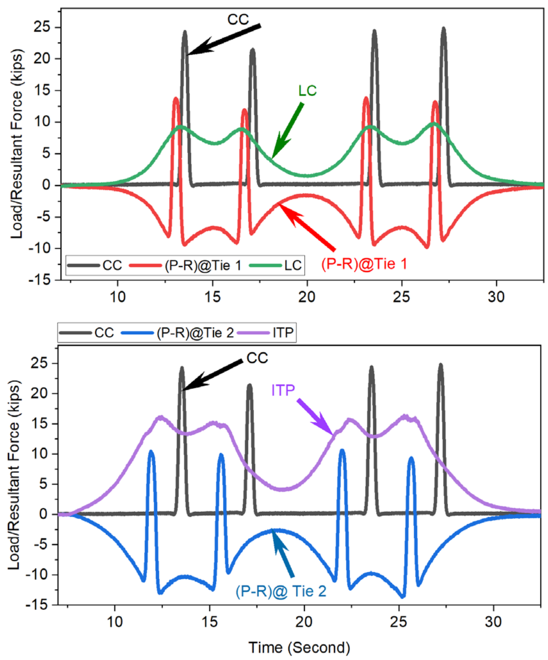

Figure 3: Time Histories from Strain Gauge, LC, and ITP Circuits

Figure 4(a) compares the tie reaction forces measured by TC-1 against those measured by the LC. Each box plot represents 48 data points (i.e., 12 passes x 4 wheels on the locomotive). The measurements from the tie circuit and the LCs are consistently within 5 percent of each other when comparing the median values represented by the horizontal lines inside the box. Interestingly, the LC measurements showed greater scatter in the data compared to the strain gauge circuit data for TCs 2 and 3. Figure 4(b) presents the same results for Tie-2. Figure 4(a) and (b) show the results from the strain gauge circuits were between 2–8 percent of those measured by the LC or ITP. This proves the strain gauge circuit as a reliable, non-invasive alternative to measure tie reaction forces. Figure 4(a)(b) also shows the measured reaction forces at the Tie # 2 rail-tie interface were higher than those for Tie # 1. This can be attributed to different support conditions underneath the tie from the hand-tamping operation.

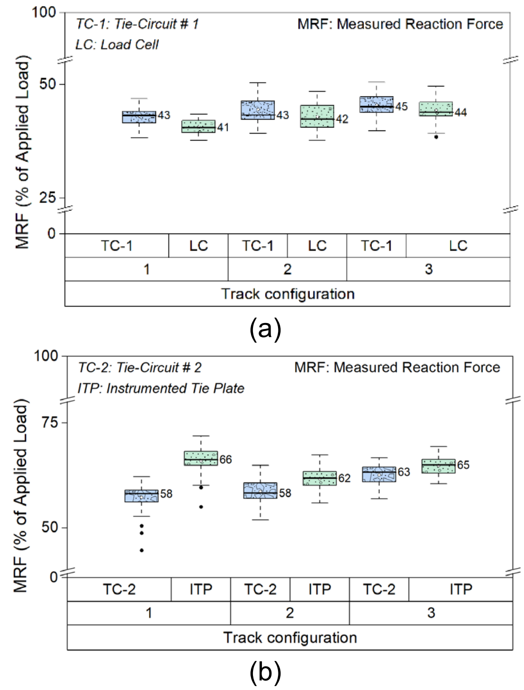

Figure 4: Comparison of TC Results with (a) LCs and (b) ITP

CONCLUSIONS

This research effort confirmed multiple aspects of strain gauge-based rail-tie interface force measurement systems. The field data showed that when under moving wheel loads, the rail-tie interface forces measured by the strain gauge circuits closely match with those from LC and ITP. Therefore, the strain gauge-based circuit produces an accurate measurement of the tie reaction forces. Future research will study how these systems perform under the simultaneous application of vertical and lateral loads.

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