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Field Validation of Vertical Tie Reaction Force Measurement Using Rail Strain Gauges

SUMMARY

Strain gauges are often used to measure vertical wheel loads in a railroad track. This approach is based on the concept of Differential Shear Strain (DSS) measurement, which is *the difference in vertical shear force between two points along a beam equals the magnitude of the resultant applied vertical force in between*. This concept can be extended to measure vertical tie reaction forces and quantify tie support conditions by a slight modification to the strain gauge positions and installation of an additional set of strain gauges. This possible application was first proposed by Ahlbeck et al. (1980) and has been used by a limited number of studies in the past (Mishra et al. 2014).

Although the railroad community widely uses DSS methods to measure vertical wheel loads, the validity of this approach for tie reaction measurement has been relatively unexplored. Conceptually, the approach is identical to the vertical wheel load measurement system where strain gages are placed in the crib between the ties; the only difference is the placement of an additional set of strain gauges above the tie.

On October 2021 in Chambersburg, PA, the Federal Railroad Administration (FRA) tasked ENSCO Inc. and Oklahoma State University (OSU) to verify the concept and assess how different track and loading configurations can affect the accuracy of the measurements. This document provides a summary of the results for statically applied loads.

BACKGROUND

Measuring wheel loads over a section of track is standard practice. Several different methods are available, but strain gauge-based systems are the most common. These systems involve the installation of strain gauges on the rail web to quantify the difference in shear forces between two points. When a wheel load is positioned in between the two strain measurement points, the difference in the measured strains is directly related to the applied wheel load magnitude.

In practice, Ahlbeck et al. (1980), Rabbi et al. (2019), and Johnson et al. (2019) performed four individual shear strain measurements with two each on the field and gauge sides of the rail. The strain gauges are connected to individual arms of a Wheatstone Bridge (WB); the main advantage of a WB circuit is canceling out of the strains introduced due to out-of-plane bending of the rail. Figure 1(a)(b) shows schematics of the strain gauge installation circuits corresponding to the crib (crib-circuit) and above-tie (tie-circuit) locations, respectively. Equation 1 calculates the tie reaction force (R), where Pc is calculated from the crib-circuit using the same equation.

$$P_c - R(\mathrm{Crib}=0) = \frac{EIt}{2Q(1+v)}[(\gamma_a+\gamma_c)-(\gamma_b+\gamma_d)] \qquad \text{Equation 1}$$

Where: Pc = Wheel Load; R= Tie Reaction Force; γ_x = Maximum Shear Strain at Location x; E = Modulus of Elasticity of the Rail; I = Moment of Inertia of the Rail Section; t = Web Thickness; Q= Static Moment of Area of the Rail Section; v = Poisson's Ratio.

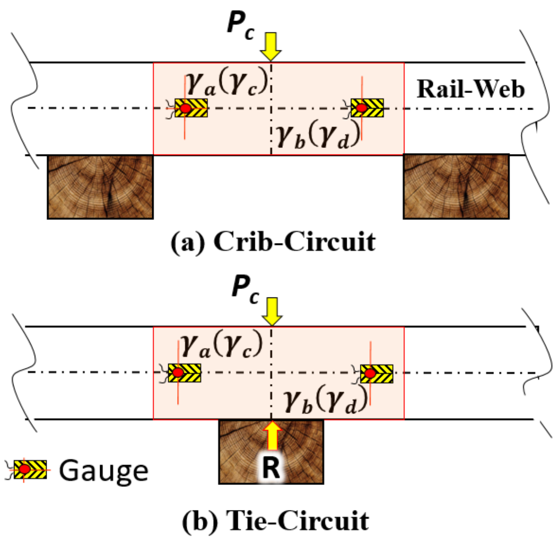

Figure 1: Schematics of Strain Gauge Installation Positions for (a) Crib-Circuit and (b) Tie-Circuit

RESEARCH QUESTIONS

Recently, several studies applied the DSS theory to quantify the support conditions underneath crossties (Mishra et al. 2014) (Mishra et al., 2017). However, no publication addresses the underlying theory of this approach and its validity to quantify the tie support condition. Therefore, the primary focus of this collaborative research effort was to validate the suitability of the DSS approach to quantify tie support conditions under different geometric and loading configurations. Moreover, researchers studied the effects of different calibration procedures on the strain gauge circuit accuracy. The two main research questions addressed by this effort were:

1. Are the strain gauge circuit measurements dependent on the calibration configuration?
2. Are the tie reaction forces calculated using Equation 1 similar in magnitude to those directly measured at the rail-tie interface?

FIELD INSTRUMENTATION

A tangent track section comprised of wooden crossties at the Letterkenny railroad yard in Chambersburg, PA, was selected for this field validation effort. The track section was instrumented using multiple strain gauges, and other sensors to directly measure the rail-tie interface force. Studying the effect of different calibration fixture geometries on the strain gauge required the crib-circuit and three different calibration configurations: (a) Short-Base A-Frame (Base: 34 inches and Height: 38 inches); (b) Long-Base A-Frame (Base: 66 inches and Height: 26 inches); and (c) Using a Hopper Car as a Reaction Frame. Figure 2 shows schematics of the crib-circuit calibration using the A-Frame (top) and pushing against a carbody (bottom).

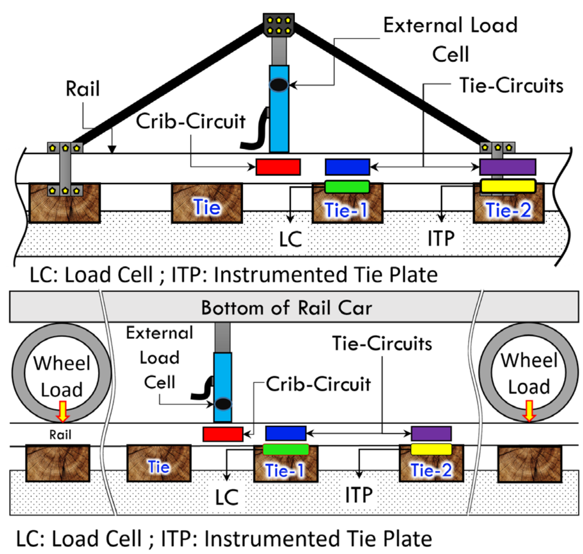

Figure 2: Schematic Showing (top) Crib-Circuit Calibration Using A-Frame; (bottom) Crib-Circuit Calibration Using Carbody

The research team installed two different types of load-measuring sensors to compare the strain gauge circuit results and actual forces being transmitted through the rail-tie interface. Tie-1 was equipped with a Load Cell (LC) at the rail-tie interface, whereas Tie-2 was equipped with an Instrumented Tie Plate (ITP). Strain gages were installed at the rail sections directly above Tie-1 and Tie-2 to compare the value of R (see Equation 1) with the load levels measured by the LC (Tie-1) and ITP (Tie-2). Static loading was applied to the rail directly on top of the ties by pushing against the empty hopper car. In both cases, researchers compared the reaction forces measured by the strain gauge circuits on top of Tie-1 and Tie-2 to the values directly measured by the LC and the ITP, respectively.

RESULTS

EFFECT OF CALIBRATION

Figure 3 shows the results from the short-base, long-base, and carbody calibration process of the crib-circuit. The output voltage from the crib strain gauge circuit is plotted against the applied load. The plots show that the Voltage vs. Load line slope remains almost identical irrespective of the calibration set-up configuration. Therefore, the team concluded that the performance of the crib-circuit is not dependent on the geometry of the calibration fixture.

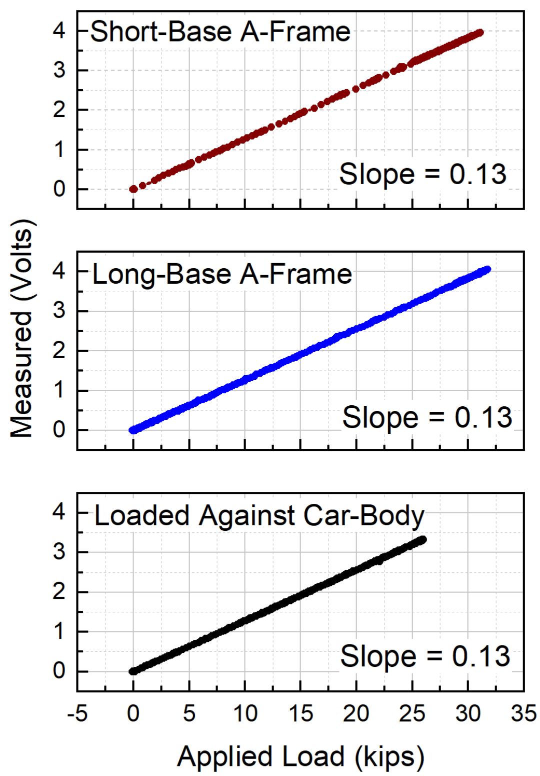

Figure 3: Load vs. Differential Shear Strain (Wheatstone Bridge output as Volts)

TIE REACTION MEASUREMENT

Figure 4 compares the tie reaction forces obtained by the strain gage approach to the values directly measured by the LC and the ITP at the rail-tie interface.

At Tie-1, the force transmitted through the rail-tie interface measured by LC was 37 percent of the applied load (i.e., measured using an external load cell in-line with the loading arm). The strain gage-based measurement using Tie-Circuit #1 was 41 percent of the applied load. At Tie-2, researchers observed an exact match between the measurements from strain gages using Tie-Circuit # 2 and the ITP. Both approaches measured the force at the rail-tie interface as 55 percent of the applied load. The difference between the proportion of the applied load transmitted through Tie-1 and Tie-2 can be attributed to differences between support conditions for these two ties. The ballast underneath the instrumented ties was hand-tamped after placement of the ties. This likely resulted in different support condition beneath the two ties. The results show that the tie-circuits can accurately measure the load transmitted through the rail-tie interface.

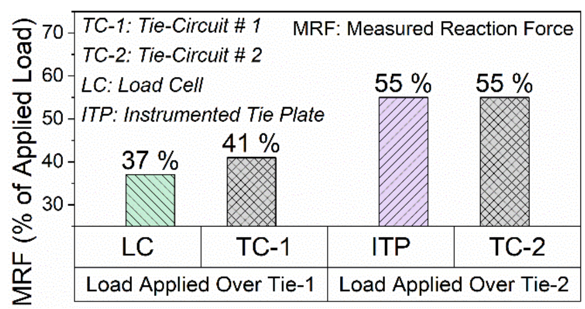

Figure 4: Measured Tie Reaction Forces by LC, ITP, and Tie-Circuits at Tie-1 and Tie-2

CONCLUSIONS

This research effort validated several aspects of strain gauge-based wheel load and tie reaction force measurement systems. The field test results showed that strain gage circuit performance is independent of the calibration set-up and geometry. The field data also showed that the rail-tie interface forces measured by the strain gauge circuits closely match those measured using traditional methods such as a LC or an instrumented tie plate placed directly at the rail-tie interface. These results indicate that the strain gauge-based tie reaction measurement system can be used in the field as a non-intrusive method to quantify tie support conditions.

FUTURE ACTION

The tests performed during Phase I of this study only considered vertical loading. The next phase will study the performance of the rail strain gage circuits under combined vertical and lateral loading.

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