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Onboard load sensor for use in freight railcar applications

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Introduction (300 words)

Accounting for weight and distance, rail is currently the most prominent method of intercity freight transportation, leading transportation by truck by 10.9% in 2010. This trend is expected to persist over the next thirty years as our highway systems are strained and experiencing increased congestion and costly delays. Freight by rail is described as arguably “the safest, most efficient, and cost effective” method in the world by the Federal Railroad Administration. Yet despite its advantage in efficiency, current methods utilized to weigh freight railcars are archaic, inefficient, and do not allow for continuous monitoring of the railcar load. Hence, there is great merit for an onboard load sensor that can accurately and effectively track the load of a railcar, minimizing overloading issues that can result in costly fines and damages to the rail infrastructure. The proposed onboard load sensor equipped with temperature sensing capability can also be used in bearing condition monitoring, as it will be able to identify unbalanced loading of the railcar. The work summarized here provides proof of concept validation for an onboard railcar load sensor, and presents analysis on the accuracy of two proposed correlations: one second-order model, and one multivariate model that incorporates the bearing operating temperature as read by the onboard sensor. Laboratory testing is used to extrapolate a hypothetical service scenario that serves to demonstrate the use of this sensor in field service. The incorporation of the temperature sensors to the proposed onboard load sensing system provides added condition monitoring capability, and allows for a much-improved load measurement with an accuracy of within 2% of the actual value. Hence, this load sensor-insert incorporates two bearing health-assessment measures, providing for a reliable, onboard freight railcar load and temperature condition monitoring system that can be readily implemented with minor modifications to the current bearing-adapter assembly.

Methods (300 words)

Experimental testing was performed utilizing the two dynamic bearing testers housed at the University Transportation Centre for Railway Safety (UTCRS) laboratories. The first experiment, plotted in Figure 1, was designed to devise a calibration for a fully-loaded railcar (153 kN per bearing) whilst maintaining accuracy during unloaded (empty railcar) conditions. The test was run at a laboratory temperature of 25□ on the single bearing tester. The experiment entailed three eighteen-hour loaded segments of dynamic testing separated by six-hour unloaded periods (26 kN per bearing). The latter was followed by static testing (axle not rotating) that consisted of several eight-hour constant load segments separated by one-hour unloaded periods. In dynamic testing, the test axle simulated a railcar traveling at a speed of 40 km/h. Therefore, each eighteen-hour loaded interval (83%, 99%, or 100% of full-load) resulted in approximately 720 km of rail track travelled, whereas, the 17% load (typical weight of an empty railcar) intervals equate to a distance of 201 km. Static testing conditions utilized load steps of 17%, 80%, and 100% of full-load.

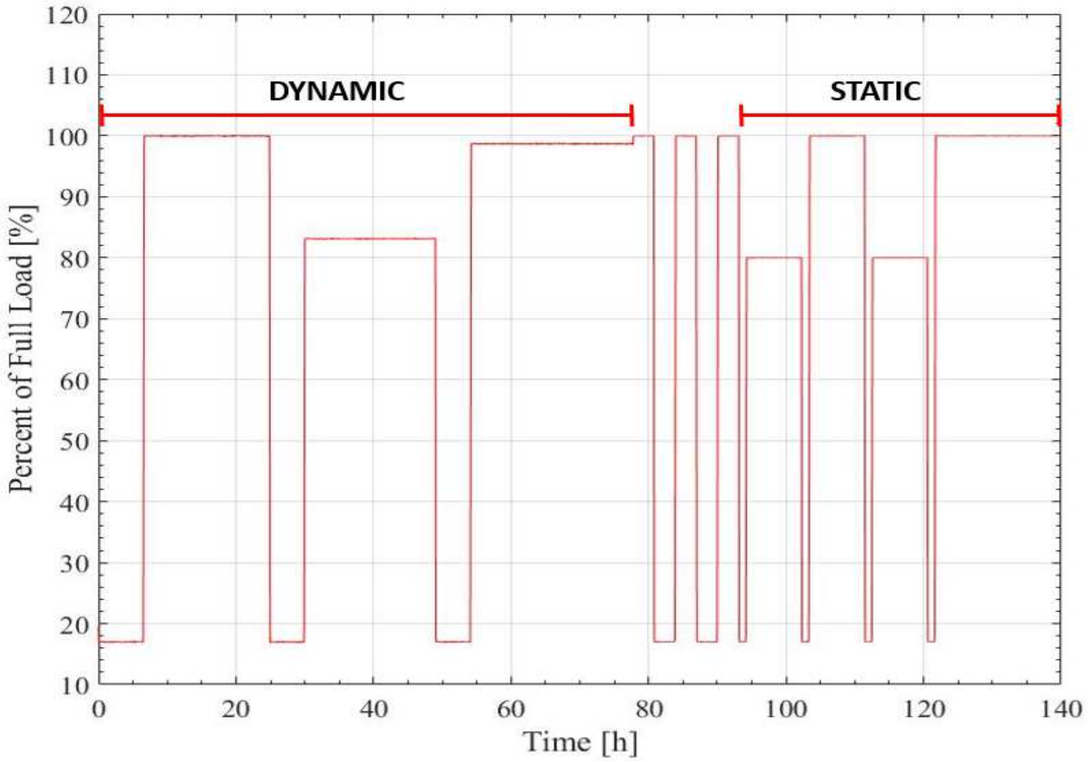

Figure 1: Typical test overview.

The second set of experiments were carried out utilizing the four-bearing tester, which is housed in an environmental chamber, and they incorporated temperature and ramping effects into an optimized calibration. The system started with a loading of 52 kN (empty railcar) and ramped up to 306 kN (fully-loaded wagon). Note that the load values are doubled since the hydraulic cylinder on the four-bearing tester applies load on the two middle bearings simultaneously. The experiments encompassed static ramping tests of 1.5, 2, 3, 5, and 7 minutes that were carried out at different ambient temperatures of -10, 0, 10, 20, 35, and 50˚C. Once full-load, as indicated by the load cell, was reached, the hydraulic system load controller maintained the load according to the sensor for approximately 120 seconds. Additionally, dynamic two-minute ramp experiments, at speeds of 53 and 106 km/h, were performed at the various temperature conditions stated earlier.

Results (300 words)

Experimental testing of the load sensor prototype revealed that the multivariate correlation produced load readings that are more accurate than those of the second-order correlation. Sample test results applying the multivariate correlation can be seen in Figure 2. The overall average error for the loaded portions of the dynamic test is 1.12%, which corresponds to a 1.71 kN (385 lb_f) error in the strain-gauge load measurement as compared to the load cell readings. Table 1 provides a summary of the results obtained from the various dynamic and static testing conducted utilizing the load sensor prototype.

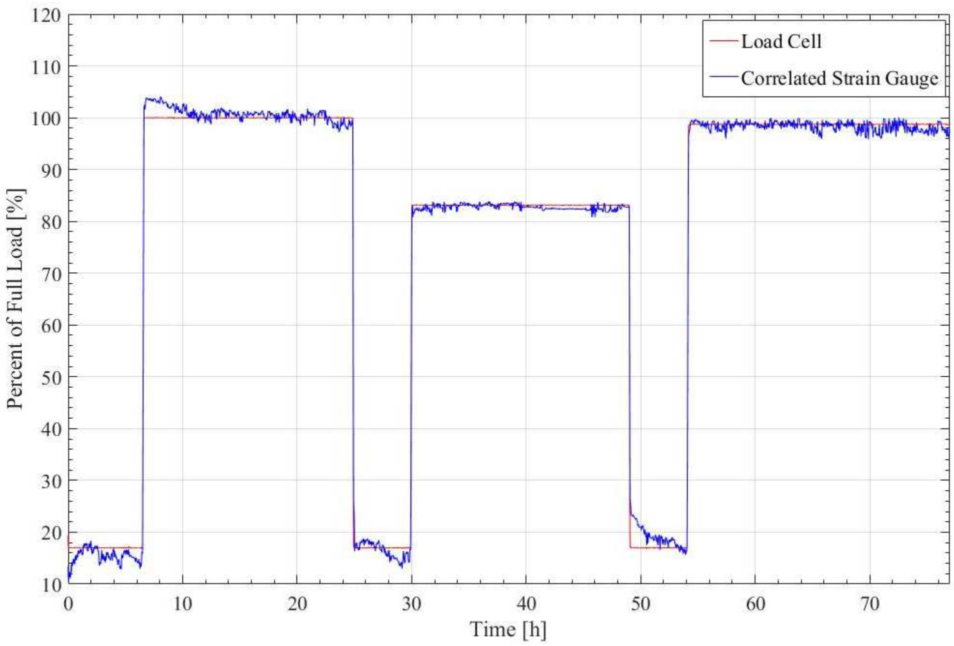

Figure 2: Dynamic test utilizing the multivariate correlation.

Calculated Average Errors for Various Test Segments			
Test Parameters	Second-Order Correlation [%]	Multivariate Correlation [%]	Estimated Load Difference [N] / [lb_f]
All Testing Combined	2.41	1.56	1300 / 292
Dynamic – Fully Loaded	1.65	1.12	810 / 182
Static – Fully Loaded	1.41	0.43	1500 / 337
Dynamic – Unloaded	1.82	1.49	507 / 114
Static – Unloaded	3.11	1.66	2220 / 499

Table 1: Load sensor measurement optimization test summary

Testing conducted to simulate loading of a wagon at various ambient conditions yielded similar results to those of the dynamic testing. For most static tests at various ambient temperatures, the load sensor produced a steady signal for the different ramping rates. These experiments demonstrated that incorporating temperature into the calibration correlation along with the addition of more coefficients markedly reduced the percent error in loading. Results presented in Table 2 show less than 1% error in the load measurements for almost every full-load ramp at the various ambient temperatures. A maximum error of 1.63% was detected for the two-minute ramping test at 0°C, which corresponds to approximately 2.49 kN (560 lb_f) on a full-load scale.

Ramp Rate	Ramp Time	Calculated Average Percent Error [%]					
[kN/min] / [kips/min]	[min]	-10˚C	0˚C	10˚C	20˚C	35˚C	50˚C
102.0 / 22.9	1.5	0.09	0.37	0.17	0.18	0.21	0.15

76.5 / 17.2	2.0	0.88	1.63	0.69	0.22	0.18	0.29
51.0 / 11.5	3.0	0.27	0.57	0.33	0.19	0.20	0.12
30.6 / 6.9	5.0	0.17	0.59	0.58	0.14	0.34	0.09
21.9 / 4.9	7.0	0.19	0.35	0.05	0.17	0.54	0.11

Table 2: Average percent error for various ambient temperatures at full-load [load ramping occurs from 0 to 306 kN (68.8 kips) on two bearings over the listed time]

Conclusions and Contributions (300 words)

Currently, the railroad industry utilizes weighbridges at special sections of track to measure the load of freight cars. These weighbridges are found in railyards and loading stations and are not commonly present along the 140,000 rail miles operated by the US railroad companies. Thus, once the railcar leaves the railyard, there is no way for the operator to track the load, which is especially important for wagons carrying hazardous material.

To this end, an onboard load sensor that can accurately and reliably track the load was developed and validated in the laboratory through carefully designed experiments that mimic field service conditions. The load sensor is strain-gage-based and is encapsulated within a steel insert that sits just below the polymer steering pad on a groove on top of the bearing steel adapter. Eight of these load sensor inserts are used on one freight car to determine the total weight of the railcar. Each load sensor insert is equipped with two temperature sensors that measure the bearing operating temperature at both outer ring raceways. Hence, other than accurately tracking the railcar weight, the load sensor insert is also capable of identifying any abnormal operating conditions caused by load shifting within the railcar or unusual bearing operating temperatures.

Detailed information on the load sensor design criteria and specifications is provided along with the laboratory testing performed to validate the design functionality. Two methods of calibration were examined: one second-order method and one multivariate regression method. Several testing scenarios were carried out which produced repeatable and optimized results. The incorporation of raceway temperatures into the calibration algorithm of the load sensor insert allows for improved accuracy in the estimation of the load applied on the bearing adapter. The average percent error in the load readings for a stationary or moving fully-loaded railcar was within 1%, which is remarkable considering the nonlinear creep behaviour of the polymer steering pads.

Keywords: onboard load sensor, freight railcar load measurement, real-time load sensing, railcar condition monitoring