A novel design of a compact S shaped balance with FBG sensors for the pantograph-catenary contact force measurement

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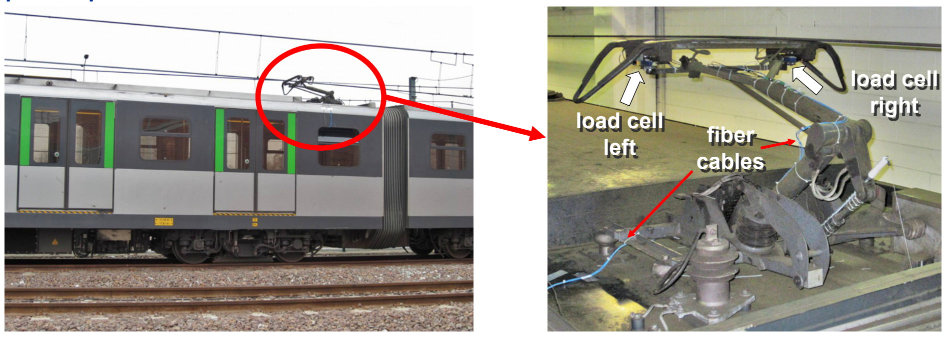
The need for an FBG load cell

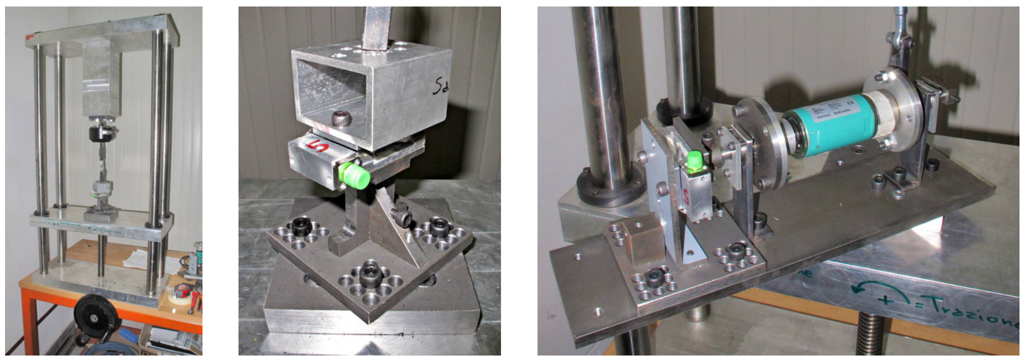
The measurement of the contact force between pantograph and catenary in railway engineering has been carried out in the past with conventional electrical load cells. This study evaluates the use of fiber Bragg gratings (FBG) sensors, so that electrical insulation of the load cells, placed on high voltage parts, is obtained by means of the fiber optic intrinsic insulation. While FGB sensors can be compared to traditional resistance strain gauges, their dimensional and strain profile characteristics required the development of a novel load cell design. A trade-off between two opposite requirements were made: an adequate sensitivity of the FBG output (high strains) and a high reliability (small strains). Moreover the application requested predefined dimensional constrains.



A real case of the need for FBG load cells: an instrumented pantograph on a train. The assembly of the setup was largely simplified respect to electrical load cells, because of the intrinsic insulation of optical sensors, and no need for power supply.

The designed load cell

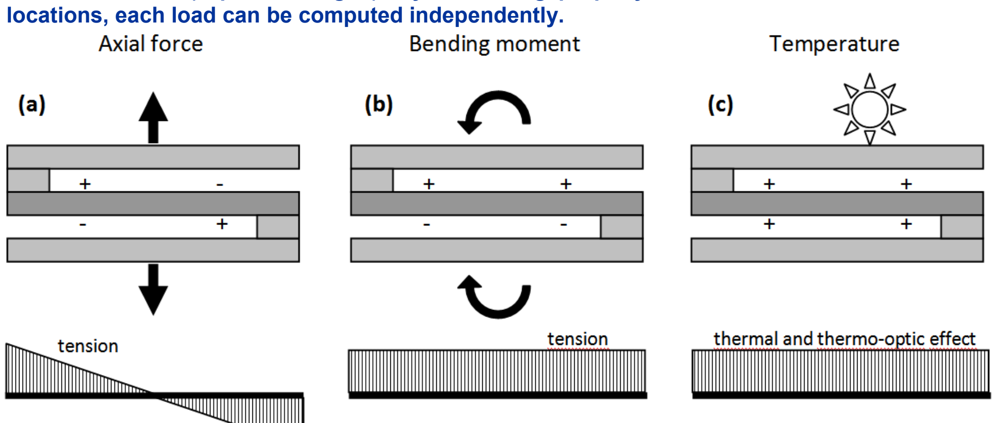
The selected design is basically an S-shaped load cell. Static and dynamic calibrations were performed also to asses the separation of the effects due to axial force, bending moment and temperature. Both test rig and in-service measurements has been performed, and the very first results show the good operation. The main metrological characteristics are: design full scale of ±500 N with a static safety factor of 5, equivalent spectral noise of 0.064 N/√Hz, first resonance frequency of mounted cell of about 200 Hz (so that a useful range of at least (0 to 50) Hz is obtained).



The calibration setup permit testing on 6 axes and uses certified load cells or torque meters. (Left) the testing machine, (middle) detail of axial force calibration and (right) detail of torque calibration in an axis where no sensitivity is expected, to evaluate the sensitivity to unwanted effects.

Working principle

An S-shaped load cell works with the strain of the central element (darker gray). When subject to an axial force (a) the central element is subject to a triangular strain profile (shown below), while the signs of the surface strain is shown in the upper scheme, and in particular two are positive and two negative. When the load cell is subject to a bending moment (b), the number of negative and positive signs is the same as before, but the position is different. When only a temperature change (c) is applied uniformly to the whole load cell, all the sensors will sense the same effect (4 positive signs). By combining properly the strain measured in those 4 locations, each load can be computed independently.

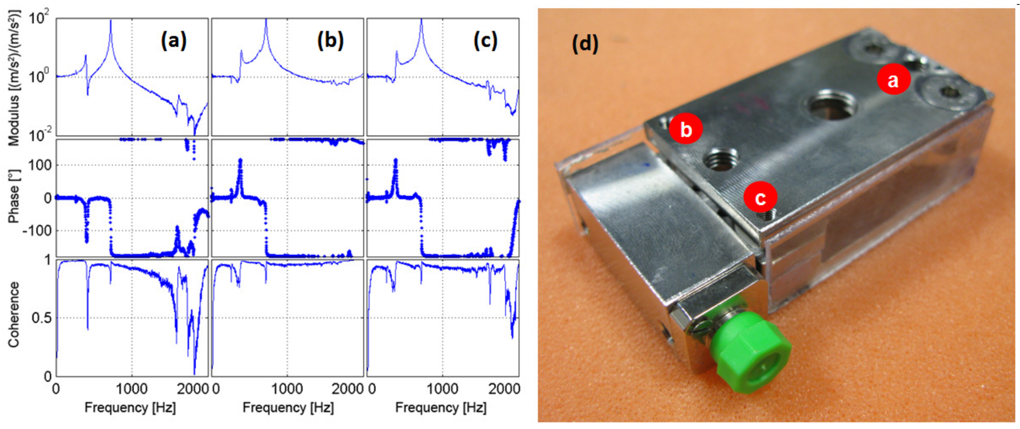


Strain of the upper surface of central element

Static and dynamic calibration

Like any measurement instrument, also this load cell must be calibrated to obtain a relationship between the measured readings and the quantity of interest. A calibration matrix was used to find static coefficients.

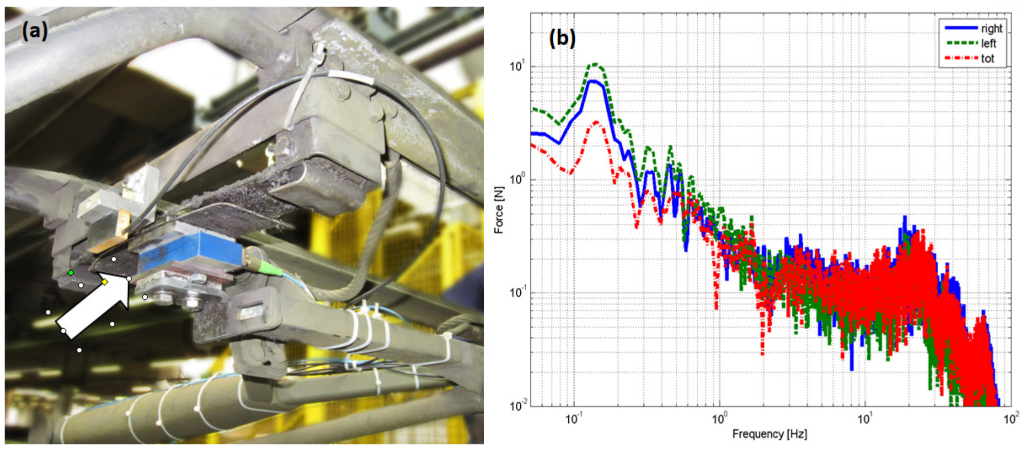
Having the need to measure also non-static signals, a dynamic calibration was performed, and the results are here below: lower frequencies are 400 Hz (pitch mode) and 700 Hz (axial mode).



Result of the dynamic testing of the optical load cell with random noise in the range (20 to 2000) Hz. The FRF is shown, with modulus (first row), phase (second row) and Coherence (third row), for accelerometers in the positions of the picture (d). The comparison of the phases from the three locations can reveal the axial and pitch modes.

In-line tests

To get a reliable proof that this load cell can operate successfully in the intended field of application, a series of tests were conducted, first on the pantograph test rig of our laboratories, comparing the data to traditional electrical load cells. Then in service tests on an underground train were performed: two load cells were mounted between the pantograph head and frame, as shown here below (a). A preliminary result is in (b).



(a) One of the developed load cells (blue, arrowed), mounted on a pantograph head, for in-service tests in an underground railway. In this test the positioning is between the frame and the collectors strip suspension. (b) A spectra obtained during the in service tests (right, left and total force): the peak at 0.15 Hz is due to the zig zag motion of the contact wire relative to the contact strip. Frequencies above about 10 Hz are attenuated due to the presence of the pantograph head suspension.

Conclusions

The described load cells proved to work well in a harsh environment such as on a railway pantograph. However they can be used in any other application where a reliable force signal, including the mean value, is needed, such as in example explosive, corrosive, or humid environments. Thanks to the passive nature of optical FBG sensors, they can work for an indefinite time, while on the contrary electrical sensors need power from batteries that must be replaced or recharged. The presented load cell can measure also the bending moment, allowing for the measurement of the friction coefficient between the contact wire and collector strip, an important advantage respect to other electrical or even optical solutions.

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