Fiber Bragg Grating-based optical sensing for *Smart Monitoring In Train Systems*

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Abstract

The European Commission promotes initiatives enhancing rail grid competitiveness through a planned upgrade of train transportation network [1]. In such a context, the *Smart Monitoring In Train Systems* (SMITS) European project [2] is devoted to control contact forces between pantographs and Overhead Contact Lines (OCL), enabling infrastructure managers to control the rolling stock and to optimize the predictive maintenance. Optical Fibre Bragg Gratings (FBGs) sensors were integrated into current collectors, turning pantographs into 3-point bending-based sensors in contact with the OCL. A semi-empirical model was introduced into the software of an innovative self-calibrated dedicated measurement system, providing accurate data at 500 Hz over several FBG optical lines. On-track tests were performed on a "TGV Duplex" train at speeds up to 320 km/h. Contact forces, and temperatures inside the collectors were computed in real time, on 4 optical fibers. During these runs, the FBG measurement system has demonstrated its reliability and accuracy with temperature measurements, and coherence with contact force in comparison with reference records provided by the SNCF.

Introduction

Transport deregulation is currently in process in Europe, transforming the rolling and standing stock activities, traditionally hosted within the same train transportation companies until the recent years, in two shared businesses, introducing new monitoring and control needs. In this frame, the interface between the pantograph and its Overhead Contact Line (OCL) appears to be critical in many aspects: vertical force and temperature being the two main relevant parameters to be controlled in order to develop qualitative predictive maintenance parameters based on current collector's wear. SMITS FP5 European project, led by Siemens and involving several R&D actors [3] introduced a new monitoring approach, based on embedded FBGs controlling the pantograph's current collector bending when submitted to the OCL contact force.

1. Force and temperature measurements on smart pantographs

Current collection is performed by the pantograph, whilst the OCL line is powered in part of France at 25 kV (AC). Traditional contact force measurements are obtained through electrical strain gages-based force cells [4] and force and momentum equilibriums relationships. These electrical force cells are usually located inside the mechanical supports of the current collectors, and need both electrical insulation and compensation of inertial forces.
The European SMITS project approach solves partially these two drawbacks thanks to the silica optical fibers which allow measurements at 25 kV without additional specific electrical insulation. In the same time, the inertial forces dependence is partially eliminated with a location of the FBG-based sensors inside the pantohead, as close as possible to the contact point, turning it into a 3-point bending force and temperature sensor (Fig. 1 and 2) [5].

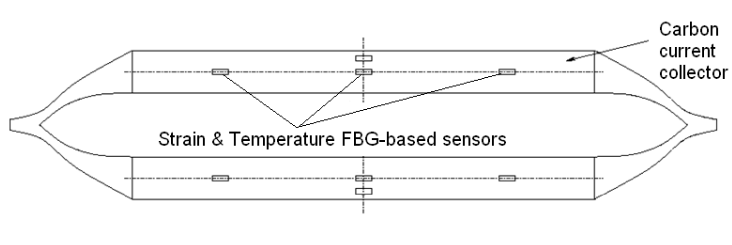

Fig.1 : Smart pantohead equipped with FBG sensors

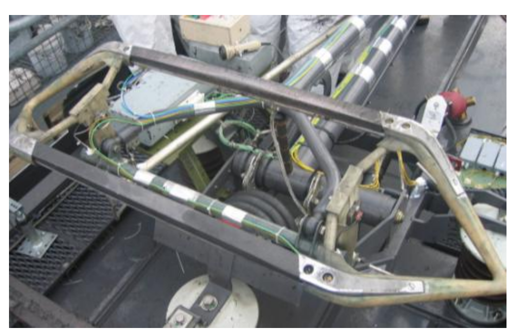

Fig. 2 Smart TGV pantograph

2. FBG-based sensors and associated monitoring/demultiplexing system

Rolling stock operators, like SNCF, have stringent specifications in terms of measurements frequency (500 Hz, equivalent to 0.2 m spatial resolution along the OCL at TGV commercial speed), and vertical force resolution (1 N) which turns to be equivalent to 0.6 pm in terms of FBG wavelength shift resolution. A semi-empirical model, validated by Finite Element Modelling as well as several static laboratory tests performed at high voltages, was introduced into the signal processing of a dedicated highly accurate and auto-calibrated FBG measurement system (accuracy & drift < 0.6 pm @ 1550 nm, and 0.5 kHz measuring rate), providing simultaneous measurements over several FBG optical fiber lines [6]. This optoelectronics measurement system has been developed and embedded into a 19" rack, and include a dedicated software able to deliver, in real time, the requested parameters (Fig. 3).

Such optoelectronic acts as a "Master Wavelength Server" (MWS) sending wavelengths data over an Ethernet link to a "supervision client" computing force, position and temperature parameters, and displaying them in real-time onto the screen (Fig. 4). Simultaneously, this "Supervision Client" provides 0-10 V analog outputs to the end-user reference system.

Fig. 3: Optoelectronic MWS

Fig. 4: Supervision Client screen with real time display of requested parameters.

3. High speed train (TGV) trials

On-line validation tests were performed on more than 6000 km during 5 full days on a very high speed train "TGV Duplex" between Paris and Vendôme (France) at speeds up to 320 km/h (Fig. 5). Contact forces between the pantograph and the OCL, as well as temperatures inside the current collectors were computed in real time at 500 Hz, on 4 optical lines in parallel. During these TGV tests, the innovative FBG measurement system developed by the CEA LIST has demonstrated its reliability and accuracy with pantohead temperature measurements (up to 160°C), and coherence with contact force measurements in comparison with SNCF reference records.

Fig. 5: 180° view of measurement systems during tests at 320 km/h

Conclusion

Both SMITS FBG-based sensors and related spectral measurement systems have demonstrated their ability to be used in harsh environments (high voltages, vibrations, shocks, temperature gradients, humidity…) for real-time measurements, as encountered in railway industry. Nowadays, industrial projects devoted to structure monitoring based on Optical Fiber Sensors, such as FBGs, require more and more high scanning rates, better resolutions, and simultaneous measurements on a higher number of sensors and optical lines. Based on its 15 years experience in this domain, the CEA LIST has been able to develop and build such a system compliant to the SMITS project specifications, and now continues these developments in a second European funded railway project, named CATIEMON, for enhanced performances and new parameters to monitor.

References

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