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Real-time monitoring of railway infrastructures using fibre Bragg grating sensors

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ABSTRACT

In this work we present the results of a field trial with a FBG sensor array system for the real time monitoring of railway traffic and for the structural health monitoring of both the railway track and train wheels. The test campaign is performed on the 2nd line of Milan metropolitan underground, employing more than 50 FBG sensors along 1.5 km of the rail track, where the trains are tested during daily passenger rail transport, with a roughly maximum speeds of 90 km/h. The measurements were continuatively performed for over 6 months, with a sampling frequency of about 400 Hz. The large amount of data/sensors allows a rather accurate statistical treatment of the measurement data and permits, with dedicated algorithms, the estimation of rail and wheel wear, key traffic parameters such as the number of axles, the train speed and load, and, in the next future, the detection of localized imperfections.

1. Introduction

The use of vibration measurements for structural health monitoring and control has attracted significant research attention during the last three decades [1–11]. However the majority of maintaining operations still relies on the direct inspection by experienced workers, such as in the railroad transportation industry. Considering that rail transport has become one of the most employed means of transportation, efficient monitoring devices are crucial to reduce maintenance costs and improve the safety of passengers and goods.

On this ground, strain gauge or piezoelectric sensors are generally adopted to monitor key parameters, such as axle load, train speed and wheel defects, or to vibration damping [12–14]. Even if the technology is well consolidated, it is not very efficient for railways, since it is affected by electromagnetic interference [15] and the sensors cannot be easily multiplexed in a single electric cable. More sophisticated techniques [16], based on ultrasonic [17] and acoustic [18] sensors, have also been developed. However the accuracy of these methods is deeply affected by electromagnetic interference from the railroad environment, suffered from the employed hardware. In the last years, the use of Fibre Bragg Grating technology has become more and more frequent [19,20], because it overcomes the mentioned problems, assuring immunity to electromagnetic fields and simple multiplexing, fitting a larger number of sensors accompanied by high performance acquisition units. Nevertheless, the complete dynamic characterization of a railway infrastructure is still far from being on the shelf [21,22].

In this work, we propose in service real-time monitoring of the working conditions of both the rail track and the wheels of the trains, using FBG sensors. The experimental setup is installed along the line 2 of the subway of Milan, near a heavily

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used suburban railway line with trains running under 90 km/h speed. The sensors measure the rail strain response under wheel–rail interaction. Given the high number of installed sensors, with a permanent acquisition system, a dedicated statistical algorithm permits to isolate the single contributions of the rail and the wheels from the acquired vibration signal, and to identify their health status.

2. Experimental setup

A FBG sensor is a distributed Bragg reflector, i.e. a periodical variation of refractive index, inside the core of optical fibre, able to reflect a particular wavelength of light and transmit all the others. The reflected Bragg wavelength λ_B is related to the refractive index of the fibre n and to the period of the refractive index modulation Λ by the formula: $\lambda_B=2n\Lambda$. Mechanical and thermal perturbations modify the index modulation Λ and the refractive index n then λ_B. These perturbations can be determined by monitoring the wavelength change of the FBG sensor. Characteristic wavelength variations of FBG sensors, with a central wavelength of 1550 nm, due to mechanical strain and temperature change are roughly 1 pm/$\mu\varepsilon$ and 10 pm/°C. FBG sensors allow distributed sensing over significant areas by multiplexing a large number of sensors on a single fibre; they are immune to electromagnetic interference and have compact size. For these reasons they have been widely applied in many applications for structural health monitoring [22].

In this work we analyse the data acquired by an experimental set-up consisting of 4 lines of FBG sensors, installed along a track of the line 2 of the subway of Milan, close to a train station. Each line is made of 15 FBG sensors, most of them are placed near the sleeper and work in pure flexion to detect the strain deformation of the rail. Two or three sensors per line are placed near the neutral axis of the rail, as in Fig. 1, and detect the environmental temperature; the spacing between two consecutive sensors is within the range 10–20 m, and the whole optical fibres apparatus covers about 1.2 km of a line track.

The FBG sensors were installed during the usual maintenance period, from 1:00 to 4:00, when the regular transportation service is stopped, pasting them directly on the rail track with epoxy resin. Unfortunately, the sensors were not placed by the authors, which had only the chance of analysing the acquired data. As a further improvement, the track will be equipped with an additional optical line with several pair of sensors with a 45° angle of inclination with respect to the rail neutral line and allowing an easy identification of the axle weight [23,24]. We selected 21 strain sensors among all of them, which present the highest signal to noise ratio, to analyse the recorded data.

The traffic conditions allow recording approximately 80 train passages per day, whose speeds are ranging between 50 and 80 km/h. The train type is a MNG M1 "Meneghino" shown in Fig. 2 whose data sheet is given in Table 1. The rail used is the S 50 UNI type, *Vignole*, the distance between sleepers axis being 0.6 m.

A schematic description of the measurement chain is shown in Fig. 3:

- a light beam signal, in the range of far infrared wavelengths, is generated by an optical led source; the light beam travels along an optical fibre equipped with FBG sensors attached to the rail;
- when the rail is deformed, the frequency bandwidth of the reflected light changes and such variation is detected by a spectrum analyser;
- the spectrum analyser samples the analogical signal before sending it to the computer and the signal can be suitably processed;

Fig. 1. FBG sensor installed on the rail neutral line to detect the temperature change.

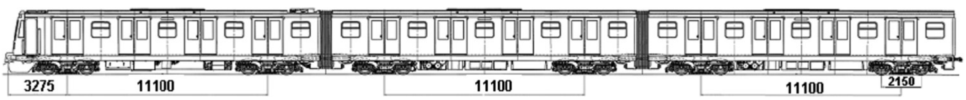

Fig. 2. Train type MNG M1 "Meneghino".