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Development of smart pads for track and traffic monitoring in railway lines

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Abstract

This article contributes with the trend and potential for the use of smart components in railway monitoring, in this study focusing on rail pads and bituminous sub-ballast as components to include the sensors. For this, it was carried out a detailed analysis into different types of sensors to select the most appropriate ones for this application, while later assessing the influence of different variables aiming for optimal design of the smart materials. Also, the paper states the ability of these solutions to detect changes in traffic conditions and/or track performance, carrying out innovative full-scale tests instead of reduced models as commonly used in the testing of these solutions. Results showed that simple and economic piezoelectrics (commonly available) offered accurate, linear and reliable outputs under varying stress levels to be detected to monitor different traffic conditions and track states. Also, results reflected that the optimal position of these sensors could be at the bottom surface of pads (for example, in the interface pad-sleeper when applied as rail pads), providing durability and capacity to record signal variations after fatigue process. From full-scale box tests reproducing track section, it was proved the ability of the smart components to monitor the traffic loads and section performance, being more accurate when the sensors applied in rail pads controlling rail-wheel contact.

Keywords: monitoring, piezoelectric, rail pads, bituminous sub-ballast, laboratory, full-scale tests

1 Introduction

Monitoring the response of a track section under different levels of train traffic results essential for railway managers in order to establish more proper and adaptive load limits while allowing for preventive maintenance programs from detecting track response and deterioration under train loads [1-4]. Additionally, because of the "open market" trend where different rail companies can circulate on the same line, information regarding the loads applied by each train (e.g., due to freight and/ or possible faulty wheels) could be essential for track managers. For this purpose, monitoring the wheel-track contact has been seen to provide essential information to monitor traffic characteristics and infrastructure state [4-9], where the use of embedded sensors in track could present a great potential for real-time continuous monitoring.

Similarly, this could allow for managing railway freight lines, which require weight limits for passing trains in order to avoid the acceleration of track degradation, making it interesting to control the train axle loads to ensure their compliance to such limits. However, the weighing process commonly results in traffic jams, since it is carried out in a static or pseudo-static mode, reducing therefore the effectiveness of railway traffic. Therefore, an innovative solution for dynamic train weighing is necessary, where embedded sensors for track monitoring could play an essential role.

In this sense, this research aims to respond to these challenges by developing sensored track components with the capacity for both dynamic, real-time train weighing and assessing the response of a track through the application of these smart devices in control sections. In particular, this work focused on developing elastic pads equipped with different sensors (selected from literature review) to be used as both rail pads and encapsulated sensors to be included into bituminous sub-ballast, assessing their ability to detect changes in traffic loads and structure performance.

2 Methods

With the aim of developing a real-time dynamic monitoring system through the inclusion of sensors in common track components, three main stages were carried out (Table 1): (i) analysis of different types of sensors and selection of the most appropriate ones for this application; (ii) development and manufacture of the smart components with the sensors; (iii) study of the applicability and reliability of the solutions through full-scale tests.

For this study, the track components selected were rail pads and bituminous sub-ballast because of their feasibility for embedding sensors, while also providing a comparison between the effectiveness of "smartening" the super-structure and the sub-structure. The sensors used in this research were different types of accelerometers, of piezoresistive panels, and piezoelectric devices, which were selected according to a previous literature review by the authors. The selection of the most appropriate sensor for the development of the pads was carried out from diverse laboratory tests simulating train loads and track movements to be detected by the sensors under various expected conditions. Also, the ability of sensored components to control traffic characteristics and traffic state was evaluated through full-scale laboratory tests on ballast box reproducing track section.

Study stage	**Variable studied**	**Track component**	**Tests**
1. Sensor analysis and selection	Type of sensor under different train loads	Stiff pad Soft pad	Simulation of train loads over smart component
	Type of sensor for its use in different track supports		
2. Design and manufacture of smart components	Sensor position in the component	Rail pad	Simulation of different train loads
	Assessment of sensor durability	Bituminous sub-ballast	Fatigue tests under repeated loads
3.Applicability and reliability of smart components	Ability to detect changes in traffic loads	Rail pad	Different train sequences with various freight levels
	Ability to control superstructure performance	Bituminous sub-ballast	Load sequences over tracks with different characteristics

Table 1: Testing plan.

3 Results

From the testing plan, results shown that the piezoelectrics embedded into pads presented potential for their application in track monitoring. As example, Figure 1 displays the results of signal recorded when subjected to different levels of stress during their application in two types of pads over various types of simulated track support. Results states the ability of the sensored pads to monitor variations in stress level, but varying the signal depending on the type of pad (higher values when used in stiff pads due to stress concentration) and simulated support (also higher signal at stiff support).

Assessing the durability of the sensored pads and the influence of the sensor position into the pad, Figure 2 shows the results of signal recorded before and after the fatigue process when using different types of pads and various sensor position. It can be seen that the inclusion of the sensor at the bottom surface of the pad (such in contact with the sleeper) allows for conserving the capacity of the sensor to detect variations in the level of force (this fact being more accentuated when using soft pad, with lower degradation), in contrast to the use of sensors at the upper surface (in contact with rail).

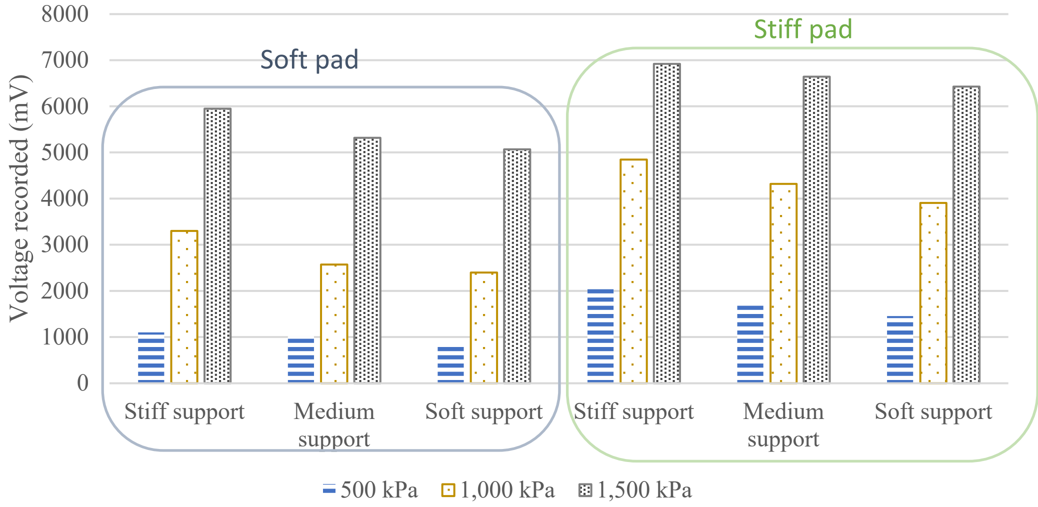

Figure 1. Signals from piezoelectrics on different pads under various track support.

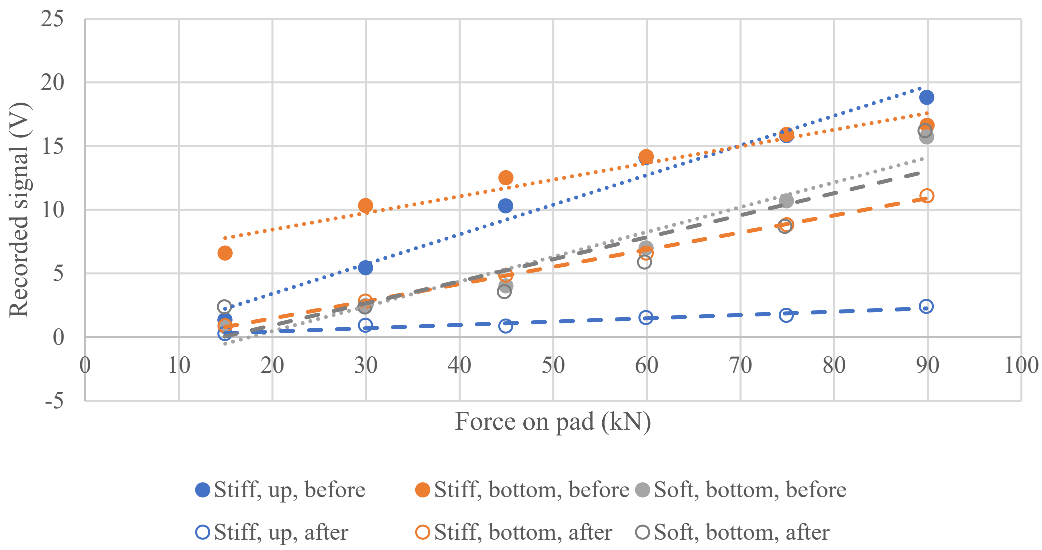

Figure 2. Results assessing the influence of sensor position (up or bottom pad surface) on durability before and after fatigue process

Figure 3 displays the ability of the sensored pads, when applied as rail pads and as encapsulated sensors into bituminous sub-ballast), to detect variations in force transmitted by traffic simulated in full-scale testing box in laboratory. Results show that both solutions obtained a proper correlation to detect variations in contact wheel-rail, but the case of rail pads presenting higher values.

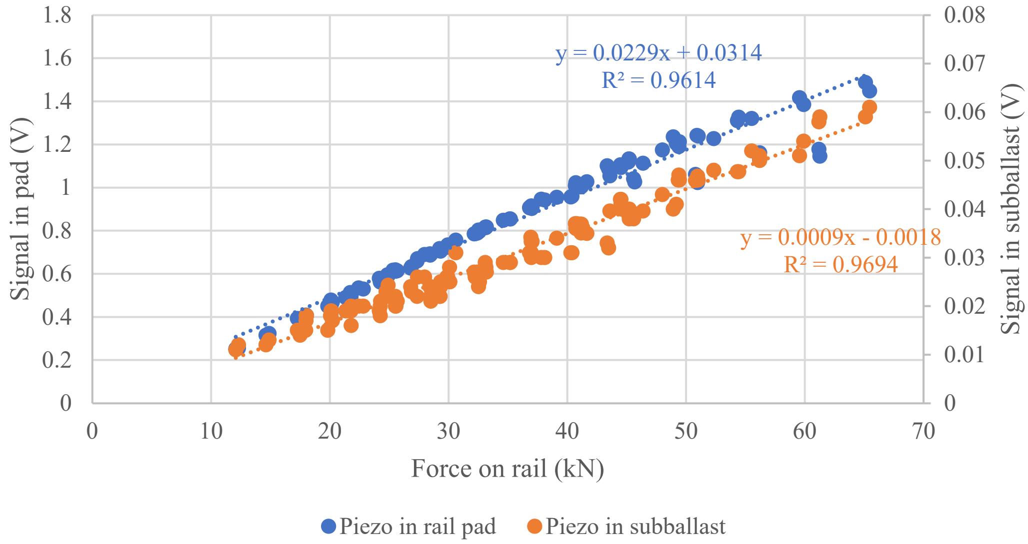

Figure 3. Correlation between signals and applied force.

4 Conclusions and Contributions

Based on the results obtained in this research, the following conclusions can be drawn:

1. From the different sensors analysed, piezoelectric devices showed the best potential for track components. These sensors showed a linear relationship between signal variation and the level of stress on the railway component, while providing the clearest signal outputs when measuring both track performance and oscillations in traffic loads. In addition, piezoelectric devices showed adequate durability after fatigue and climate testing.

2. The optimal position of the piezoelectrics in the rail pads was shown to be in a hole at the bottom of the pad (between sleeper and rail pads), covered by a polymeric resin. This provided the clearest output signals, while also protecting the sensor from external agents. In the case of the sub-ballast, results stated that the higher the depth of a piezoelectric sensor, the lower the signal measured, but the lower the susceptibility of poorer signal outputs from rail loads propagated horizontally to the side of the sensor.

3. Both smart components, with standard piezoelectrics embedded, were shown to provide an appropriate solution to measure traffic conditions. Nonetheless, smart pads presented a higher accuracy for monitoring passing traffic and freight weight. In addition, the smart rail pads showed a good potential for being used to monitor track performance by recording changes in load distribution through the superstructure.

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