Design and development of an auscultation system for the prevention of deformations in pavements and roundabouts

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1. Introduction

Pavement dimensioning is a fundamental process in road engineering that consists of determining the composition and thicknesses of the different layers of a pavement to achieve a specific service life and minimise costs. Areas where there are turns and curves, where the geometry of the terrain is more complicated, are more prone to pavement surface deterioration. This degradation is due to various parameters such as the type of axle, environmental conditions and the surface characteristics of the contact materials.

Pavement design studies, both theoretical and empirical, have mainly focused on the vertical loads exerted by vehicles on asphalt. Asphalt pavements have proven to be efficient in resisting longitudinal stresses, as they distribute the loads over the entire structure, thus absorbing traffic stresses. However, in the case of small radius curves and roundabouts, tangential stresses occur which affect the wearing course locally and can cause problems such as cracking and deformation [1].

The aim is to develop a remote monitoring system that combines sensor hardware with simulation software to continuously analyse in real time the response of pavements to the shear stresses of a particular bituminous mix in order to determine its ability to withstand significant stresses. This would allow detection of pavement deficiencies before permanent plastic deformations occur, thus facilitating preventive maintenance.

2. Methods

The monitoring system focuses on three lines of development: hardware, communication and software.

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2.1 Hardware

Conventional strain gauges are designed to measure strain in only one direction of the plane. This means that they can detect expansion or contraction of the material in a specific direction, either longitudinal or transverse. However, when it comes to measuring deformations in diagonals or at different angles, conventional gauges are not sufficient, as they can only provide information about the deformation in one particular direction.

To measure deformations in multiple directions and to detect angular deformation, rosette gauges are used [2]. A rosette gauge is an arrangement of three strain gauges that measure normal strain (x), normal strain (y) and shear strain in the same plane (xy).

$$\varepsilon_x = \varepsilon_a$$
$$\varepsilon_y = \varepsilon_c$$
$$\gamma_{xy} = 2\varepsilon_b - (\varepsilon_a + \varepsilon_c)$$

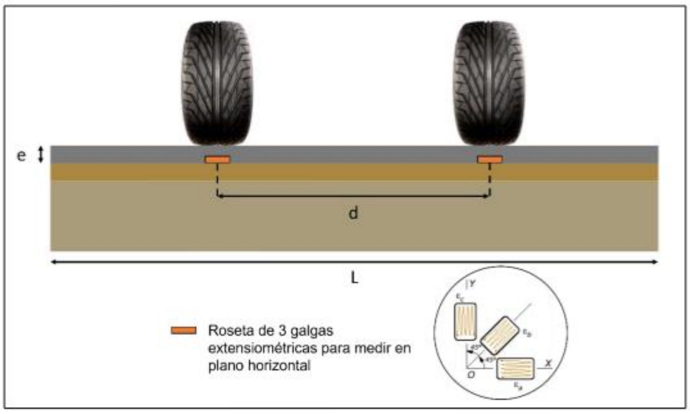

Figure 1. Instrumentation schematic of the prototype based on [3].

Therefore, the ideal arrangement of the strain gauges is embedded in the pavement at the bottom of the surface [4] wearing course and two rosettes of 3 strain gauges (at 0°, 45° and 90°) are arranged under the two centred longitudinal axes along which the traffic passes in the lane, where L is the lane width (3,5 metres as a reference value), d is the distance between the wheels of a vehicle (1,8 metres as a reference value) and is the thickness of the wearing course (between 5 and 10 cm as a reference value).

2.2 Communication

To guarantee the correct acquisition of the signals coming from the gauges, a printed circuit board is used which fulfils two important functions: the power supply and the conditioning of the signals.

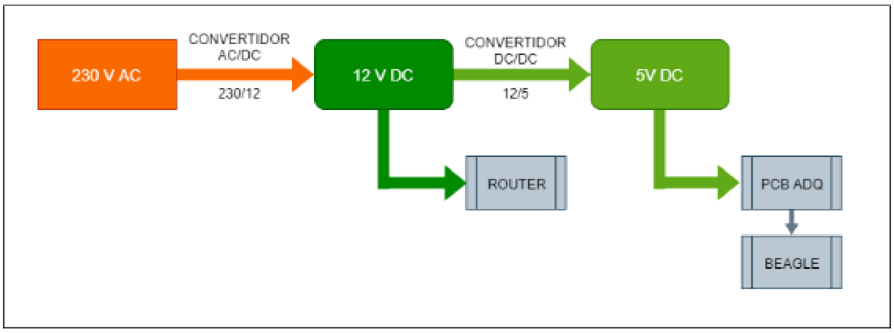

Figure 2. System power supply diagram

The second part of the system includes a printed circuit board that performs power supply and signal conditioning functions. This board has a voltage regulator to ensure adequate power supply, an instrumentation amplifier to improve signal quality, an analogue-to-digital converter to digitise the signals, and a processor with an embedded operating system, such as the BeagleBone, for data processing and transmission.

2.3 Software

Signal processing in the system is responsible for processing the data recorded by the strain gauges to obtain information on the strain and stress to which the material is subjected, specifically the tangential stresses.

Once the signals from the strain gauges have been recorded, the system processes the signal to obtain information on the strain and shear stresses. Once the signal is available in digital format, signal-processing techniques can be applied to analyse it and obtain information on strain and shear stresses.

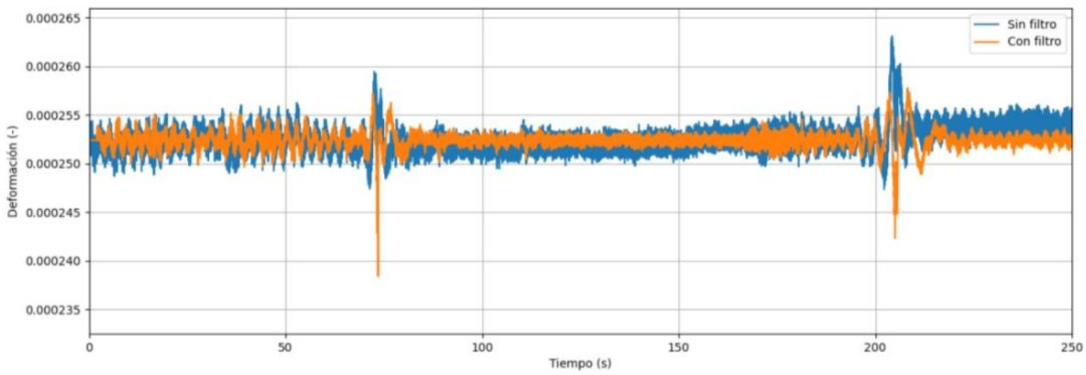

Figure 3. Strain gauge recording in terms of deformation.

3. Results

It is expected to demonstrate that the implementation of an improved asphalt capable of resisting higher tangential stresses will result in a significant reduction of asphalt deformation. This improvement will be monitored in real time, allowing tangential stresses and deformations to be visualised through a web-based platform.

The system will provide continuous data on the state of the asphalt, allowing remote access to crucial information for the maintenance of road structures. In addition, a predictive model will be developed that will analyse the collected data to anticipate when the asphalt is in poor condition. This predictive model will be able to estimate the lifetime of the asphalt and detect the optimal time for preventive maintenance, ensuring the durability and safety of the roads. This approach will culminate the work, offering a comprehensive solution for efficient asphalt monitoring and maintenance based on accurate data and advanced analytics.

4. Conclusions

In the context of the development of new construction solutions capable of resisting large tangential stresses in wearing courses, several areas related to this project have been explored. From the paper, the following conclusions can be drawn:

- The use of strain gauges is presented as a fundamental tool for measuring and analysing the tangential stresses in the wearing courses. These devices allow the deformation experienced by the material to be recorded and, by means of appropriate calculations and analysis, the associated shear stresses can be obtained. This provides essential information for assessing the strength and performance of road structures.
- The correct acquisition of strain gauge data is crucial to obtain reliable results.
- To calculate the shear stresses from strain gauge records, appropriate procedures must be applied. These include temperature correction if necessary, as well as the use of specific equations and mathematical relationships relating strain to shear stresses.
- It is important to note that the calculation of shear stresses is not straightforward from strain gauges, as these provide information on deformation. However, through analysis that is more advanced and the application of mathematical models or numerical methods, it is possible to obtain the shear stresses from the recorded strain data.
- The feedback between the experimental information and the finite element numerical model results in a twin model capable of faithfully representing the behaviour of the pavement.

References

[1] A. Coiret y P. O. Vandanjon, «Road safety assessment in curves based on a road embedded tire to road friction sensor,» de CETRA 2022, 7th International Conference on Road and Rail Infrastructure, 2022

[2] Wikipedia. (2011, 9 de junio). Roseta de deformación. En Wikipedia. Recuperado de https://es.wikipedia.org/wiki/Roseta_de_deformaci%C3%B3n

[3] eFunda Engineering Fundamentals, «Strain Rosette for Strain Measurement,» [En línea]. Available: https://www.efunda.com/formulae/solid_mechanics/mat_mechanics/strain_gage_rosette.cfm

[4] W. Zhang, Q. Wang y C. Suo, «A novel vehicle classification using embedded strain gauge sensors,» Molecular Diversity Preservation International (MDPI), vol. 8, nº 11, pp. 6952-6971, 2008.