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ROLLING RESISTANCE AND ROLLING NOISE ASSESSMENT OF BITUMINOUS MIXTURES

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ABSTRACT

The following article presents the design and construction of a specialized trailer for measuring rolling resistance (RR) on different surfaces. This parameter is receiving increasing attention due to its environmental implications as it is often the most important parameter affecting energy consumption during the environmental life cycle assessment of pavements. It is one of the main opposing forces affecting on-road vehicles. The trailer is equipped with the necessary electronics to record forces generated during tyre/pavement interaction, allowing data to be collected under real driving conditions. This article details the materials and methods used in the construction of the trailer, as well as the tests carried out to validate its effectiveness. The results confirm that the device provides reliable and consistent measurements, making it a useful tool for research into technologies aimed at reducing the RR produced by tyre/pavement interaction. In conclusion, the development of this trailer represents an efficient and cost effective tool to assess RR directly in the field, offering a reliable method to analyse the impact of pavement materials and designs on vehicle energy consumption

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1. INTRODUCTION

Climate change is one of the biggest global environmental challenges, largely driven by greenhouse gas (GHG) emissions. The transport sector is one of the main sources of these emissions, contributing significantly to global warming due to the use of fossil fuels and emission of harmful compounds. In this context, a transformation of this sector will play a key role in this process, from improving fuel efficiency to the incorporation of vehicles powered by electric or alternative technologies.

One of the most important parameters characterising tyre-pavement interaction is rolling resistance (RR), which is the force that opposes the movement of a vehicle when its tyres roll over a surface. In a conventional car, energy is supplied by fuel, so RR has a direct relationship with fuel consumption: the higher the resistance, the greater the amount of energy required to keep the vehicle moving, which translates into an increase in fuel consumption and therefore a higher emission of carbon dioxide (CO_2), one of the main greenhouse gases, as well as other toxic compounds. Under certain driving conditions (moderate and constant speed), RR can be responsible for up to 25-30% of the energy consumed by the vehicle [1]. The energy dissipated due to RR not only increases fuel consumption, but also significantly harms the environment, as more than 90% of the environmental impact of tyres is attributed to the energy lost during

rolling [2]. Most of the energy dissipation in an operating tyre is due to hysteretic losses [3], which depend on tyre deformation and thus on load and inflation pressure. RR is also a determining parameter, as it is influenced by the micro- and macro-texture of the pavement, as well as the mechanical and structural properties of the tyre system, including its stiffness, deformability and dynamic behaviour [4].
Environmental noise is another form of road traffic pollution that affects health, especially when it exceeds certain limits. Road traffic is one of its main sources due to its widespread presence and volume of travel. The noise generated by a moving vehicle comes mainly from three sources: aerodynamics, engine and tyre-pavement contact [5]. The latter, known as rolling noise, predominates in passenger cars travelling at more than 40 km/h [6], which covers most urban and interurban displacements. The study of other parameters, such as the mean profile depth (MPD), are also fundamental for assessing the relationship between rolling noise and pavement surface. A rougher or deteriorated pavement can increase noise levels and pollutant emissions, affecting the quality of life of people and the environment.
The study of these pavement characteristics not only enhances environmental sustainability, but also represents an opportunity to optimise operating costs and improve vehicle performance. In this sense, the development and implementation of advanced technologies in the design and composition of tyres and pavements play a key role in the transition towards a more efficient and environmentally friendly transport system.
The following article presents, the design and construction process of a specialised trailer for the measurement of various parameters on different surfaces. The criteria used for its development, the materials used, and the test methodologies implemented are presented. This new equipment has been designed with the purpose of obtaining accurate and reliable data to assess the impact of pavement texture on rolling resistance (RR) and fuel consumption, as well as the relationship between RR and rolling noise emissions, thus contributing to the optimization of tire performance and road transport efficiency.

2. DESCRIPTION OF THE TRAILER. DESIGN AND STRUCTURE.

The trailer is a specialised equipment that allows the indirect measurement of the rolling resistance generated between a surface and a moving wheel at constant speed. Its construction is based on a robust and stable structure that ensures accurate measurements under various test conditions.
This work presents an experimental method for measuring RR, using a system consisting of a wheel coupled to an articulated structure, a mass spring system and a high-precision laser. These devices and electronic parts are mounted on a trailer. A schematic draw of the equipment is shown in Fig. 1. An axle is responsible for connecting the wheel to the main structure of the trailer. The equipment is also designed to allow a certain degree of displacement, which enables the wheel to adapt to the pavement to be measured. Also, to maintain continuous contact of the reference wheel with the pavement and to achieve higher rolling resistance values, additional mass has been incorporated into the system, ensuring controlled conditions during the measurement. In addition, its construction allows for different adjustments of the applied load and the possibility of adapting different types of wheels, facilitating studies in different conditions.

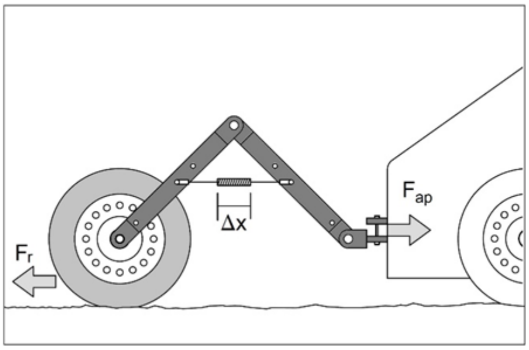

Figure 1. Schematic draw of the rolling resistance measurement trailer and forces diagram.

During the test, the wheel is moved over the pavement. The high-precision laser measures, with respect to a reference plate, the variation in the length of the mass-spring system.

The variation is directly related to the rolling resistance according to Eqn. (1).

$$Fr = k\,\Delta x \qquad (1)$$

where Fr is the rolling resistance [N], k is the spring constant [N/m] and Δx is the spring deformation [m].

This system, shown in Fig. 2, allows accurate data to be obtained, providing key information for rolling resistance analysis

Figure 2. Detail of the laser sensor employed for the rolling resistance tests.

Besides, the measurement of the vertical displacement of the road surface profile as a function of distance travelled provides parameters that characterise the pavement surface, such as the mean profile depth (MPD). The road profile influences not only the ride quality, but also other aspects related to the interaction between the tyre and the pavement. In this study, simultaneous measurements of the road profile were carried out in order to analyse the relationship between surface texture and RR. For this purpose, the LaserDynamicPG LA^{2}IC, a commercial high-speed laser profilometer designed for road surface quality control, was used. In addition, GPS coordinates were simultaneously recorded along the test section (Fig. 3).

Figure 3. Laser profilometer (LaserDynamicPG LA^{2}IC) in the front part of the vehicle.

Finally, two accelerometers were installed in a stable position inside the trailer to minimise vibrations and obtain accurate measurements: one was placed on the laser measuring the spring deformation while the other was placed on the reference plate. The main objective is to measure accelerations of the system during tests. The accelerometers also measure the orientation of the device in order to allow RR corrections due to the road slope variations (Fig. 4).

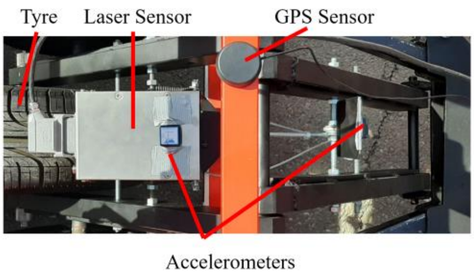

Figure 4. Measurement Equipment

3. INITIAL TESTING AND VALIDATION OF THE METHOD.

The study of noise and environmental pollution generated by road traffic requires the analysis of various factors that influence the emission of noise and vibrations on roads. This work presents the results obtained by means of a measurement carried out with the instrumented trailer on Avenida de Juan Sebastián el Cano, located in Ciudad Real (Fig. 5), with the aim of evaluating the quality of the pavement: texture profile, rolling resistance and rolling noise.

Figure 5. Avenida de Juan Sebastián el Cano,

The data collected includes GPS coordinates (Fig. 6) and mean profile depth (MPD) values (Fig. 7), a key parameter to determine the performance of the road surface and its impact on noise generation. Through graphical analysis of these results, it is possible to identify patterns and critical areas requiring intervention, thus contributing to the planning of more sustainable and quieter infrastructures.

Figure 6. GPS coordinates of the test section.

In the case of the mean profile depth (MPD), the records obtained using the LaserDynamicPG LA^2IC, (Fig. 7), show significant variations along the study section. As can be seen in the graph, the MPD fluctuates along the entire test section, with values generally between 0.5 mm and 2.0 mm, although with some peaks exceeding 2 mm. This behaviour reflects the heterogeneity of the surface texture of the pavement, suggesting the presence of sections with greater macrotexture. The accuracy of the system used allows these changes to be detected in detail, providing key information for the evaluation and maintenance of road infrastructures.

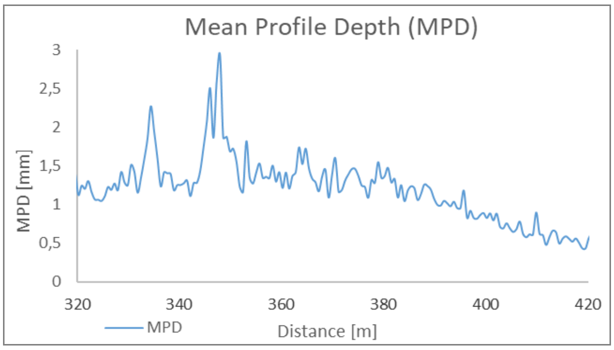

Figure 7. MPD as a function of the distance.

The following graph (Fig. 8) shows the variation of the longitudinal acceleration as a function of the distance travelled. The acceleration data, measured in the vehicle displacement direction, reflect a dynamic response of the system to surface irregularities. Variability is observed in both accelerometers over the entire distance travelled, with fluctuations reflecting the influence of the pavement conditions and the dynamics of the measurement system.

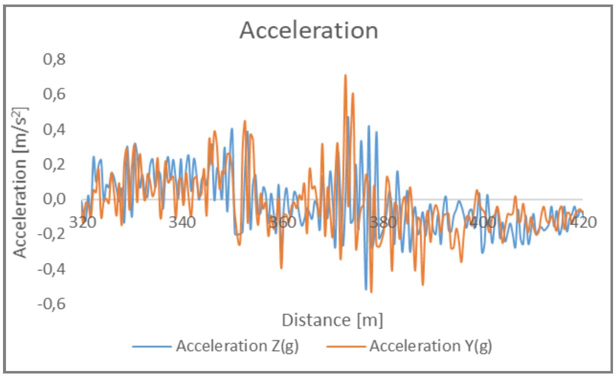

Figure 8. Acceleration as a function of the distance travelled on the test section.

The analysis of the road profile and its influence is essential for assessing driving comfort and safety. In this study, the relationship between pavement irregularities and rolling resistance (from spring system deformation: Δx) along the test section was examined. These data allow us to understand how variations in the road surface affect the vehicle dynamics. We can observe that variations in the road profile influence on rolling resistance, with Δx values between -60 mm and 80 mm (Fig 9).

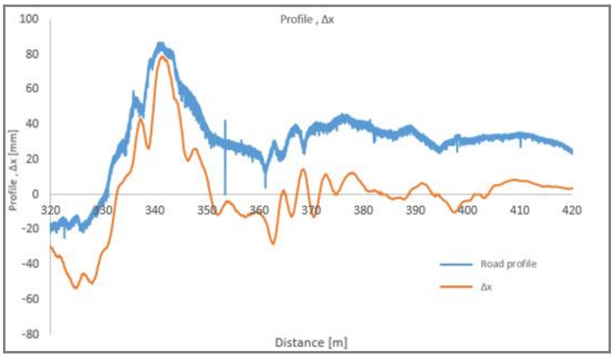

Figure 9. Road profile and deformation (Δx).

Finally, the following graph shows the variation of rolling noise as a function of distance (Fig. 10). The vertical axis shows the noise level ($L_{cPtr,\ 50\ km/h}$) in dB(A), while the horizontal axis shows the distance (m). Fluctuations in noise levels can be observed along the analysed stretch, which could be influenced by factors such as rolling resistance, pavement texture, surface type or tyre vibrations.

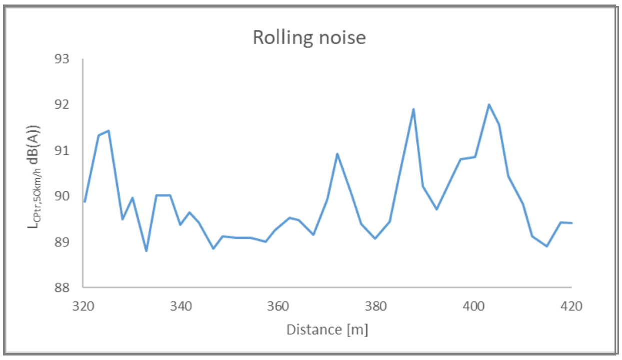

Figure 10. Rolling noise as a function of distance.

4. CONCLUSION

In this study, the design, development and evaluation of an instrumented trailer for the measurement of rolling resistance caused by tyre/pavement contact, as well as other related parameters, such as mean profile depth (MPD) and rolling noise, has been presented. The new measurement equipment is based on a mass-spring system, in which the registration of the displacement of the system allows the RR assessment.

Additionally, two accelerometers were incorporated into the trailer structure in order to obtain complementary information about the dynamics of the system and its interaction with the pavement surface. Preliminary results indicate that the proposed system can provide consistent and reproducible measurements; however, further studies are required to optimise its calibration and validate its performance under various rolling conditions and on different pavement types.

The implementation of this measurement system represents a significant advance in the characterisation of rolling resistance, with potential applications in the improvement of transport energy efficiency and in the design of more sustainable and efficient road infrastructures.

5. ACKNOWLEDGMENTS

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