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A novel method for producing low cost dynamometric wheels based on harmonic elimination techniques

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ABSTRACT

A method for producing low cost dynamometric wheels is presented in this paper. For carrying out this method, the metallic part of a commercial wheel is instrumented with strain gauges, which must be grouped in at least three circumferences and in equidistant radial lines. The strain signals of the same circumference are linearly combined to obtain at least two new signals that only depend on the tyre/road contact forces and moments. The influence of factors like the angle rotated by the wheel, the temperature or the centrifugal forces is eliminated in them by removing the continuous component and the largest possible number of harmonics, except the first or the second one, of the strain signals. The contact forces and moments are obtained from these new signals by solving two systems of linear equations with three unknowns each. This method is validated with some theoretical and experimental examples.

1. Introduction

All external forces acting on the vehicle, except for the gravitational and aerodynamic forces, are applied through the tyres. Consequently, in order to fully understand the dynamic behaviour of the vehicle, accurate experimental data of these contact forces and moments are needed. Several methods can be found in the literature for measuring the forces and torques generated at the tyre/road contact based on the instrumentation of the tyre [1–5] or of the wheel [6–8]. The methods based on the instrumentation of the tyre normally require the placement of measurement sensors (accelerometers, optical sensors…) embedded in the interior thereof. They are, therefore, invasive methods in the tyre itself that could lead to problems in the assembly of the wheel and produce a greater and irregular wear of the tyre. Due to these reasons, a method based on the instrumentation of the wheel is proposed in this paper.

A literature review of wheel force transducers can be found in [6,7]. In this case, the sensors are not directly placed in the original wheels of the vehicle, but the wheels are replaced by a standard wheel force transducer which is connected by adaptor parts to a rim and to the vehicle hub. These adaptor parts are usually known as "modified rim" and "hub adaptor". Once the wheel transducer and the adaptors are assembled, the assembly can be handled as a normal wheel. The wheel transducer is the element in which the sensors are placed, and therefore, it is the component that measures the forces and torques acting on the wheel. They can be classified according to the measuring principle they use into two basic types: transducers based on the piezoresistive effect, composed of piezoresistive sensors, (for instance, [9,10]) and transducers

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based on the piezoelectric effect, composed of piezoelectric sensors (for instance, [11]). Piezoresistive sensors can detect both dynamic and static loads, whereas piezoelectric sensors are better at detecting higher frequency signals and are not suited for true static measurements. On the other hand, piezoelectric sensors can detect strains in all directions, depending on the piezoelectric coefficients of the material. On the contrary, piezoresistive sensors can only detect strain effectively in the direction parallel to the strain sensor, requiring more than one sensor to measure all strain components.

However, the replacement of the original wheel and the placement of additional rotating masses in which the sensing elements, such as strain gauges, are placed are required. This can lead to technical difficulties in the assembly of the wheel, to a significant increase in its overall weight and to a change in its dynamic behaviour. Furthermore, they are characterised by having a very high cost, much higher than the price of the whole vehicle and are prohibitive for most potential customers such as universities and small research centres, especially if all the wheels of the vehicle have to be replaced by those measuring wheels.

The first instrumented wheel which allows measuring the tyre/road contact forces and moments that does not involve a significant increase in its weight or an alteration of its dynamic behaviour is presented in [8]. In this case, three strain gauges (least set) are placed on the inner side of the wheel rim at positions characterised by the highest signal-to-noise ratio to obtain the tyre/road contact forces and moments. The forces and moments are measured once per wheel turn, assuming that they are constant during one wheel revolution.

In this paper, a new method that allows the measurement of the tyre/road contact forces and torques in an economically feasible way is presented.[1] The forces and torques are obtained from signals measured by strain gauges bonded in the metallic part of the original wheels of the vehicle. Since the wheels of the vehicle are not replaced as in [6,7,9–11], its dynamic behaviour is not significantly altered. The method proposed in this paper allows obtaining the forces and moments at any angular position of the wheel. For this purpose, the method presented in this paper is based on some harmonic elimination techniques that have been successfully used for measuring the wheel/rail contact forces [12–14]. In these cases, the railroad wheels are instrumented with strain gauges whose signals, which are periodic with respect to the angle of rotation of the wheel, are linearly combined to obtain other signals that only depend on the forces to be measured but not on the rotated angle. The strain gauges must be placed at the angular positions that allow the largest number of harmonics, except the first one, to be cancelled when the signals coming from the sensors are added or subtracted. After the cancellation of these harmonics, the dependence on the rotated angle is also eliminated.

However, when instrumenting car or lorry wheels, the strain gauges can rarely be placed in the angular positions required by the techniques developed for measuring the wheel/rail contact forces. While train wheels are usually continuous flange wheels, spoke wheels are very frequent in the case of cars, or wheels perforated with certain patterns in the case of buses and trucks. There is a broad variety of car wheels, each one of which having a different number of spokes and arrangement thereof, and therefore, each one of which allowing the placement of strain gauges only in certain angular positions. For this reason, in this paper, a novel method for measuring the forces and moments in the tyre/road contact area that does not require the strain gauges to be placed in specific angular positions has been developed. Therefore, it is a flexible method that can be used in wheels with different geometries and number of spokes [15].

2. Strains at the measuring points of the wheel

In order to have a qualitative idea of the relationship between the strains generated in the wheel and the forces and moments acting in the tyre/road contact area, and to establish the most suitable points for placing the strain gauges, the strains generated in two types of wheels have been analysed by the FEM under different force and moment conditions. The analysed wheels are a lorry wheel (250/60 R22) and a five-spoke car wheel (195/65 R15). They are shown in Fig. 1.

2.1. Finite element models of the wheels

The finite element analyses of the chosen wheels have been carried out with the commercial software ANSYS®. Fig. 2 shows their finite element model.

Table 1 shows the type of element and the total number of nodes, elements and degrees of freedom of the lorry wheel FEM model. Table 2 contains the same information for the car wheel.

The properties used for the tyre model are those considered by Tönük et al. [16]. In the sequel, the considerations that have been taken into account for modelling the tyre are summarised as follows:

- A Mooney–Rivlin hyperelastic material model depending on two constants has been used for modelling the tyre. Table 3 shows the constants that have been used for the bead filler, the sidewall and the tread.

[1] Patent ES2363400.