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Combining ESPI with laser scanning for 3D characterization of racing tyres sections

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ABSTRACT

In this work is exploited the possibility to use two optical techniques and combining their measurements for the 3D characterization of different tyres with particular attention to the tyre's section. Electronic Speckle Pattern Interferometry (ESPI) and Laser Scanner (LS) based on principle of triangulation have been employed for investigating and studying the tyre's section and 3D shape respectively. As case studies two different racing tyres, Michelin S9H and Pirelli Diablo respectively, have been considered. The investigation has been focused at the aim to evaluate and measure the section's components in order to add to the 3D model obtained by Laser Scanning accurate information about the different layers along through the tyres sections. It is important to note that the assessment about the different layers along the section is a very difficult task to obtain by visual inspection or classical microscopy and even with the LS. Here we demonstrate that the different layers can be easily highlighted and identified by mean of the ESPI.

1. Introduction

Tyres characterization is of fundamental importance for vehicle dynamics modeling, since they are the main responsible of vehicles dynamical behavior. In fact, thanks to their ability to deform they allow to drive a vehicle, thus generating the appropriate interaction forces at the interface with the road. Their behavior is due to their very complex structure. They are composite materials made up of numerous different vulcanized rubbers compounds, metal and synthetic reinforcement wired fibers and cables. In general, along tyre thickness it is possible to identify three main layers with different structural characteristics, i.e. the tread, the carcass and the inner layer. The tread, the external layer, is made of diverse vulcanized rubber compounds; the carcass, the intermediate layer, is made of by fibers, cables and vulcanized rubber; the inner liner is again made of vulcanized rubber compounds and it is the most internal tyre layer in direct contact with the inflation air.

Such complex structure is necessary for supporting the interaction forces with the road. In literature there are different models able to describe tyre behavior both based on an physical approach [1–12] and based on an empirical one [13–16]. In order to parametrize physical based models [1–12], it is very significant the knowledge about the thickness of the different tyre layers. This aspect is particularly important as it concerns the physical models describing the tyre thermal behavior [8–10], the tyre grip behavior [1,2,6,7] and the tyre wear [11].

In this study two motorsport high performance tyres (Fig. 1), one for automotive (Michelin S9H used in GT2 race) and the other for motorcycle applications (Pirelli Diablo Superbike used in superbike race) have been considered as test case. Both tyres are slick, so that, they can ensure the maximum contact surface with the road, considering the high velocities in motorsport competitions and consequently the high values of interaction forces.

Here we show how by combining two different optical laser based measuring techniques, i.e. Electronic Speckle Pattern Interferometry (ESPI) and Laser Scanner (LS) respectively, it is possible to achieve a characterization of the tyres section highlighting the thickness of the layers.

Speckle interferometry is a customary contactless tool for precise measurements in engineering [17], displacement measurements [18,19], vibration analysis [20] and nondestructive testing [21–23].

Laser scanners based on the principle of triangulation are the most common non-contact Reverse Engineering (RE) systems used to acquire objects, even of complex shape, through principles codified in complete sets of procedures, specific to various applications [24,25]. The main

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Fig. 1. Racing tyres: Michelin S9H (on the left from www.michelinmotorsport.com) and Pirelli Diablo superbike (on the right from www.pirelli.com).

characteristics of a laser scanner is the high precision, the relative lower cost with respect to other systems, and the possibility it offers to acquire objects on site thus returning accurate 3D model by a fast procedure. However, as in the case of tyres section considered here, LS is not capable to give information on the layers positions through the tyre thickness thus precluding the possibility to retrieve a full 3D model of the test object for numerical studies and analysis.

The study reported in this paper is useful for all the physical models of tyres in which it is necessary to have a measure of the dimensions of the different layers present in the thickness and the overall dimensions. In particular, the measurement of the section's components made by means of an optical microscope is not an easy task. In fact, rubber is not rigid, consequently sharp cuts are not possible. The cut surface along the thickness is very irregular and not very flat. Moreover the rubbers layers have very low but similar reflectance and thus it is difficult to distinguish each-others.

We have performed measurements by means of ESPI that have been compared with the images obtained by a classical optical microscope. Interferometric images have been obtained by applying a slight thermal load to the tyre section. This gives the possibility to find out the dimensions of the thickness of layers having an homogenous behavior under the thermal point of view, finding out if these measurements are the same that coming out by the optical microscope. ESPI, thanks to its high sensitivity, is capable to estimate the different out of plane displacement of the different layers that respond in a different way (i.e. with a different deformation) to a thermal stimulus highlighting the layers themselves.

This information has an immediate application in the formulation of the tyre thermal models [8–10], which are necessary to predict tyre grip behavior, being grip strongly affected by temperature. This kind of approach is particularly important in all motorsport and racing applications and this is the reason why for the case studies have been chosen two motorsport high performance tyres.

2. Materials and methods

2.1. Tyres

Pneumatic tyres are composite materials made up of numerous different vulcanized (synthetic and natural) rubbers compounds, metal and synthetic reinforcement wired fibers and cables together with carbon black and other chemical compounds and fillers.

Their structure is mainly composed by tread, carcass (body plies), inner liner, sidewalls and beads. The tread is the external part in contact with the road, it is composed by different vulcanized rubber compounds and it is the main responsible of the interaction forces arising due to frictional phenomena.

The carcass is the intermediate layer, it is made up by fibers, cables and vulcanized rubber compounds and it is the "skeleton" of the tyre, having mainly a structural function, which is fundamental considering the high values of the forces the tyre has to support.

The inner liner is the most internal tyre layer, in direct contact with the inflation air, it is made up of vulcanized rubber compounds and its main function it is to guarantee air tight, together with the rim and the beads, so that the internal pressure can be kept constant at the opportune value.

Pneumatic tyres are used on many types of vehicles: cars, bicycles, motorcycles, buses, trucks, heavy equipment, and aircraft. As concerns physical tyre thermal behavior the tyre can be schematized by three layers [8–10] and so it essential to have the possibility to determine the physical thickness of each one of these layers. The investigation activity reported in this paper is aimed to give identification and high precision measurement of these layers thickness to be used to characterize firstly the physical tyre thermal model. In any case the results coming out from this research activity are usable in all physical tyre models based on a geometric characterization of the thickness composition.

2.2. ESPI

ESPI technique allows to measure the out of plane displacements of a stressed specimen and in such way enables to identify, strains, cracks on rough surfaces with high sensitivity in real time and full field modality without contact [26–28]. ESPI belongs to the family of coherent light interferometry techniques that include also holographic interferometry and shearography [29]. The detection of micro-deformations is possible illuminating the surface by a visible laser (i.e. wavelength 532 nm) and the measurement accuracy is related to the wavelength. A CCD/CMOS camera records the deformation under correlation fringes form, deformation due to a slight warming imposed to the material. A typical scheme of the system for recording speckle interferometry measurements is illustrated in Fig. 2.

The laser beam (Laser Quantum Torus 532 nm) is split into a reference beam and an object beam by means of a Beam Splitter (BS), which enables control of the intensity ratio between reference and object beams. The reference beam is coupled into a monomode optical fiber