Measurement 44 (2011) 559–568

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Measuring system for investigation of tri-axial stress distribution across the tyre–road contact patch

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A R T I C L E I N F O

Article history:
Received 3 February 2010
Received in revised form 22 November 2010
Accepted 30 November 2010
Available online 6 December 2010

Keywords:
Tyre
Contact patch
Stress distribution
Sensing element
Measuring system
Truck

A B S T R A C T

A measuring system for investigation of stress distributions in the tyre–road contact patch was designed and developed. The transducer within this system comprises a transversal array of sensing elements, covering the entire contact patch width in a single run. The system simultaneously measures stress distributions on three directions for a truck tyre (or even airplane tyre). Each sensing element has 10 mm × 10 mm contact surface and optimized dimensions, allowing measurements in various wheel rolling conditions. The transducer induces minimum changes in tyre–road contact properties, as it has very small gaps around sensing elements. The system is road mounted, in real rolling conditions. The measuring system contains 90 strain measuring channels. Main aspects regarding system calibration and specially developed software are illustrated. Preliminary results of tyre–road contact stress distributions are presented.

1. Introduction

The automotive tyre is the only connection between vehicle and road. This connection is made through the contact patch. All loads involved in vehicle support and movement, except for the aerodynamic forces, are transmitted through the contact patch. Loads exerted between tyre and road are not applied in a single point in the contact patch, although in many cases in literature they are regarded so. In fact, in the contact patch area distributed stresses arise, which can be separated on the three orthogonal directions, resulting into longitudinal, lateral and vertical stress distributions. The three types of stresses are oriented according to the coordinate system established in [1]. By integrating the stresses on each direction, the global forces and torques in the centre of contact patch are computed.

Vertical stresses in the contact patch arise as an effect of vehicle weight acting on the road. These stresses materialized as reaction from the road are involved in vehicle support. If vertical stresses applied by the tyre are too high, they can cause road damage.

Shear stresses in the contact patch occur in all circumstances in which the tyre is in contact with the road. Vehicle longitudinal dynamics are determined by the distribution, magnitude and orientation of longitudinal stresses. These stresses have a very important contribution to the generation of traction forces and braking forces. Also, they have a decisive role concerning the fuel economy, by means of rolling resistance. Vehicle movement in lateral direction is determined by the distribution, magnitude and orientation of lateral stresses. Shear stresses in the contact patch contribute to tyre and road wear.

In addition, contact patch stresses are related to the appearance of other phenomena characteristic for tyre–road interaction, such as aquaplaning, rolling noise, tyre and road vibrations.

Experimental investigation of tri-dimensional contact patch stress distributions is a difficult task, because the insertion of a transducer in the contact area modifies the nature and properties of tyre–road contact.

By using simple physical models the contact patch stress distributions cannot be precisely determined. Finite

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0263-2241/$ - see front matter
doi:10.1016/j.measurement.2010.11.021

element models allow obtaining far more accurate distributions of contact patch stresses. These finite element models have become highly advanced in the last two decades as a consequence of computing resources development.

This paper presents a system for measuring tri-dimensional stress distributions in the truck tyre–road contact patch with minimum changes in the nature and properties of tyre–road contact.

2. Previous experimental achievements

The investigation of contact patch stresses began several decades ago by way of experiments. Most experimental research use sensitive elements mounted in the road or in tyre construction or sensitive layers placed between the road and the tyre. In all these cases, contact nature is modified to some extent.

Measuring equipment mounted in the road can have one or more sensing elements. A sensing element is an instrumented part, shaped as a pin or beam. If in one measuring equipment there are several sensing elements, they can be placed in a lateral or longitudinal array [1].

Seitz and Hussmann [2], as well as Lippmann and Oblizajek [3] used equipments with a single sensing element for experimental research of contact patch stresses.

Seitz and Hussmann measured stresses on three orthogonal directions in a very narrow area of the contact patch, using a rotating drum rig with the wheel rolling outside the drum. The rig was used for wheels fitted with passenger car tyres. Stresses were measured with a strain gauged element placed in the drum. Seitz and Hussmann stated that the rig allows measuring stresses for rolling speeds up to 150 km/h. However, stress distributions across the contact patch width can only be obtained by performing several runs consecutively, in which the wheel is moved in lateral direction.

Lippmann and Oblizajek measured vertical and shear stresses on a very narrow area of contact patch, using a fixed table rig. The wheel fitted with passenger car tyre is moved along the fixed table using a slider. Maximum rolling speed of the wheel is 5 km/h. The rig allows adjusting wheel steering angle and camber angle. The table surface contains two sensing elements. One of them measures global forces and torques on the entire contact patch. The second element, in miniaturized construction, is included in the structure of the first one, and measures vertical and shear stresses on three orthogonal directions, using resistive strain gauges.

For measurements of contact patch stresses most researchers used equipments with several sensing elements placed in a transversal array.

During the 90s, Pottinger patented and built a complex equipment for measuring stresses on three orthogonal directions and relative slip, consisting of a transversal array of 16 sensing elements [4,5]. Each strain gauged sensing element can measure tri-axial forces. The pins have cylindrical shape with 5 mm outer diameter. The distances between two consecutive pins are comparable to outer diameter of pins. Therefore, stress distributions across the entire contact patch width cannot be obtained in a single run. The sensing elements are mounted in a movable table rig. Stress distributions can be measured both for passenger car tyres and for truck tyres.

Another rig, mentioned by Douglas et al. [6], built at the University of Ulster, consists of sensing elements placed in a transversal array. Each sensing element has a 5 mm square head area. The square pin head is placed in a circular hole, which modifies locally the contact between tyre and road. Also, there are rather large distances between two consecutive pins.

Also during the 90s, De Beer built the rig Vehicle–Road Surface Pressure Transducer Array (VRSPTA), which contains a transversal array of sensing elements [7–9]. The rig consists of 1041 pins with coplanar top ends. Twenty of these pins are strain gauged. The array of twenty sensing elements for measuring tri-axial forces is placed across the contact patch width. The equipment containing the 1041 pins is placed in the road, so that the pins top ends are levelled with the road surface. The rig was gradually enhanced to allow simultaneous measurement of stresses on three orthogonal directions for all the four wheels of a truck axle. The rig allows measurements for truck wheels rolling freely at speeds between 1 km/h and 16 km/h. Because the supporting surface consists of pin top ends, the contact patch shape is modified with respect to normal rolling conditions. The existence of lateral gaps between pins diminishes the lateral resolution of stress measurements.

More recently, Koehne and co-workers [10,11] developed a rig with drum rotating in horizontal plane. The braking or driving torque, camber angle, slip angle, velocity, load, and inflation pressure can be adjusted for the wheel fitted with passenger car tyre rolling on the drum [10]. In the median plane of the drum there are several sensing elements with contact surface of 1 mm^2 area. The sensing elements are dispersed into an array on the circumference of the drum. Each sensing element can measure stresses simultaneously on the three orthogonal directions. The entire tread surface is scanned by moving the wheel in the direction of contact patch width, a process which takes between 12 and 16 h [11].

During the 70s, at the Automotive Engineering Department of the University POLITEHNICA of Bucharest a tyre–road interaction research centre was created and led by Negruş et al. [12]. During the 80s, in this centre a movable table rig was developed for measuring shear stress distributions of passenger car tyres [13]. The rig allows adjusting the vertical load. Only free rolling of the wheel is possible, at speed up to 1 km/h. The transducer included in the movable table surface comprises a transversal array of 11 sensing elements mounted on a base plate. The sensing elements are strain gauged beams, each having a 10 mm $\times$ 10 mm square contact area. After year 2000, the measuring system of the rig was modernized, and results were published in [14]. The resolution of this equipment is rather poor in the case of passenger car tyres. The distributions of shear stresses cannot be obtained from a single run, so the tests have to be repeated with the wheel moved in lateral direction.