Dynamic Calibration of Tyre-Road Contact Patch Stress Tri-Axial Transducer

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Abstract. The paper presents the dynamic behaviour verification for the sensing elements of the tyre-road contact stress measuring system developed at the Tyre Research Laboratory in University POLITEHNICA of Bucharest. The complex transducer for investigating distributions of tri-axial stress in the tyre-road contact patch consists of a transversal array of strain gauged pins covering the entire contact patch width. A verification of sensing elements behaviour in transient conditions was required, taking into consideration the highly variable character of tyre contact patch stress phenomena. The dynamic calibration of sensing elements has been performed by applying transient force successively on each measuring direction, using an impact hammer with piezoelectric force transducer. Tests have been performed in laboratory conditions, by measuring force simultaneously using the strain gauged sensing elements and the piezoelectric transducer of the impact hammer. Very good correlation has been obtained between shapes and magnitudes of forces measured on each direction using the impact hammer force transducer and the strain gauged sensing element. Thus, the dynamic calibration of sensing elements has been verified for tyre speed ranges corresponding to real rolling conditions.

Keywords: Dynamic calibration · Sensing element · Complex transducer

1 Introduction

In the tyre-road contact patch, distributions of stresses appear on three orthogonal directions as consequence of tyre deformations due to simultaneous actions of internal pressure, wheel load and road contact [1]. These tyre-road stresses represent the source of all forces in the contact patch which control the vehicle dynamics, consequently influencing safety, rolling tyre vibration and noise, tyre wear and road damage [2]. The main challenges concerning measurements of tyre contact stress pertain to the requirement of maintaining contact of the tyre with the road unaltered by insertion of sensors.

The distributions of tyre-road stresses are influenced by various factors, some related to tyre design and construction (radial or bias, tread design, tyre dimensions, etc.), and others to exploitation and rolling conditions (inflation pressure, vehicle speed, tyre vertical load, slip angle, etc.) and therefore cannot be precisely determined by using simple physical models. Finite element models allow obtaining distributions of contact

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patch stresses [3, 4], but also require measurements of tyre-road stress distributions, which are necessary for evaluation and verification of models.

An overview of the main equipment for measurement of tyre-road stress distributions developed worldwide has been presented in [5] and has ascertained that most of the existing test rigs are designed for indoor use, and many include sensing elements consisting of strain gauged pins for measuring tri-axial stresses [6–18].

For experimental investigation of the tyre-road contact stress distributions, outdoor (road-embedded) as well as indoor (laboratory-use) test rigs have been designed and produced in recent years at the Tyre Research Laboratory in University POLITEHNICA of Bucharest [5, 19, 20].

Results of experimental research performed in real rolling conditions using the road-embedded test rig have been presented in [20] and in [21], for truck tyres in free rolling and braking conditions. Alongside, the study of contact stress distributions continued using finite element models of truck tyres [22], and some comparisons between results obtained through finite element modelling and experimental data have also been shown in [21].

The calibration of sensing elements in static conditions has been presented in [5]. In addition to the calibration with forces applied statically, the dynamic calibration of sensing elements has also been considered necessary, taking into consideration that the stress distributions in the tyre contact patch represent dynamic phenomena. The current paper objective is to investigate the dynamic behaviour of sensing elements, representing an important phase in test rig calibration.

2 Overview of Tyre Contact Stress Measuring System

Details about technical specifications of the road-embedded test rig with complex transducer for measuring stresses distributions have been presented in [5, 20, 21]. The transducer includes a transversal array of 30 sensing elements with strain gauges, each sensing element having three half-bridges that correspond to the three orthogonal directions, resulting 90 data acquisition channels for measuring tri-axial stress distributions in the entire contact patch, mainly for truck tyres but also for other tyre types.

The transducer design provides minimum change in contact surface, as well as the option of performing either road or laboratory measurements; the measuring system can be used for free rolling/traction/braking tyres, and allows different rolling speed ranges.

The simplified shape of a sensing element is represented in Fig. 1, together with force components applied schematically on three orthogonal directions, and with the strain gauges constituting half bridges that correspond to each of the measuring directions [23]. Foil strain gauges for steel, each with one measuring grid, have been used.

The measuring system also includes signal conditioning modules and data acquisition system with embedded computer manufactured by National Instruments, and software applications developed in LabVIEW for measuring strain channels, converting and decoupling force components, computing and displaying stress distributions.

Longitudinal displacement of the tested tyre is also monitored and stored using a mobile data acquisition system with dedicated software applications developed in LabVIEW for correlation with the stress measuring system in view of spatial representation of tyre-road stress distributions over the contact area.

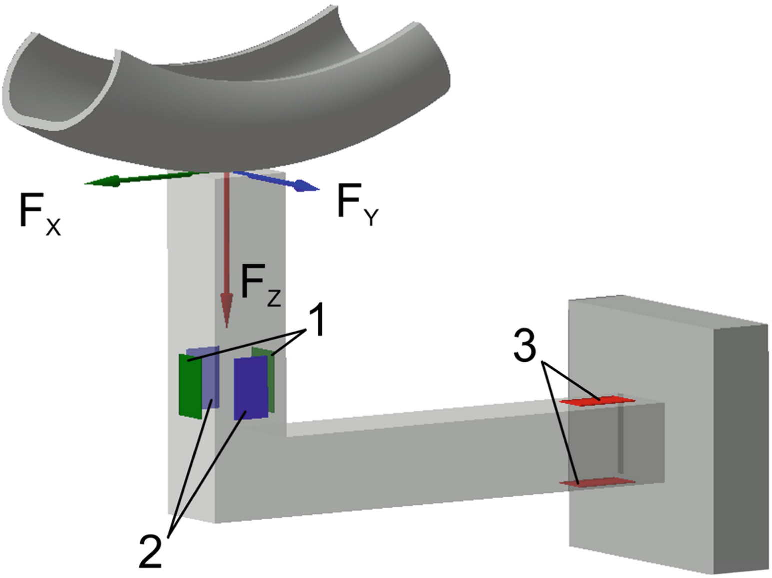

Fig. 1. Representation of a sensing element under the effect of three orthogonal forces: 1, 2, 3 strain gauges [23]

3 Dynamic Behaviour of Sensing Elements

Taking into account the dynamic character of tyre contact patch stress distributions measurement, dynamic calibration of sensing elements has also been needed. Impact duration was taken into account to be smaller than the duration of contact between tyre tread and sensing element of measuring system, in real rolling conditions. For verification of sensing elements dynamic behaviour, tests have been performed in laboratory conditions using an impact hammer with piezoelectric force transducer.

The layout for dynamic calibration is presented in Fig. 2 and an overall image of the equipment used is shown in Fig. 3 where the complex transducer, originally developed at the Tyre Research Laboratory in University POLITEHNICA of Bucharest, is displayed without the layer of coarse material on the sensing elements upper surface and on the top plates. The signal conditioning modules for strain gauges and the data acquisition system with embedded computer are manufactured by National Instruments Corporation; the impact hammer with piezoelectric force transducer and corresponding signal conditioning module are manufactured by PCB Piezotronics.

Dynamic force on each orthogonal direction has been applied successively on sensing elements; due to the configuration of complex transducer, an adapter has been used to facilitate impact application on longitudinal and lateral directions.

Software applications, such as the example shown in Fig. 4, have been specially developed by the authors in LabVIEW graphical programming environment [24] for

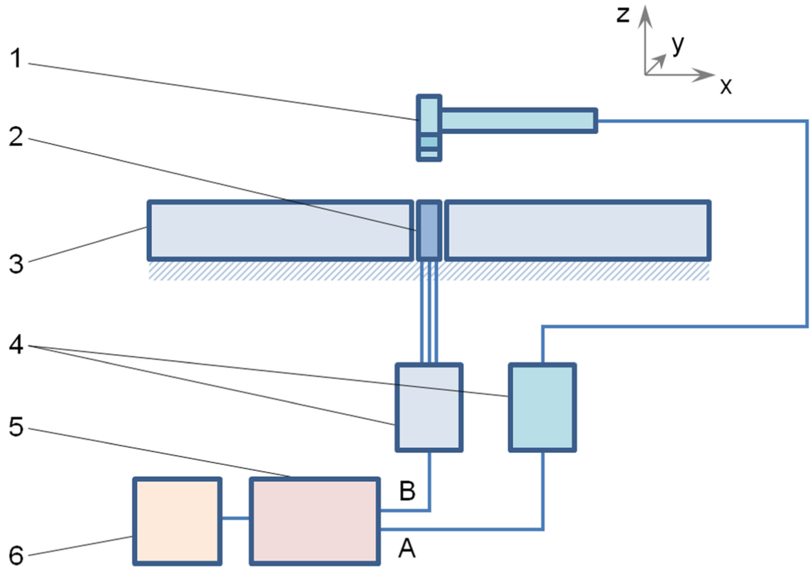

Fig. 2. Layout for the verification of sensing elements dynamic behaviour: 1. impact hammer with piezoelectric force transducer; 2. strain gauged pin; 3. complex transducer with array of strain gauged pins; 4. signal conditioning modules; 5. data acquisition system with embedded computer; 6. monitor; A. signal from force transducer of the impact hammer; B. signal from strain gauged pin

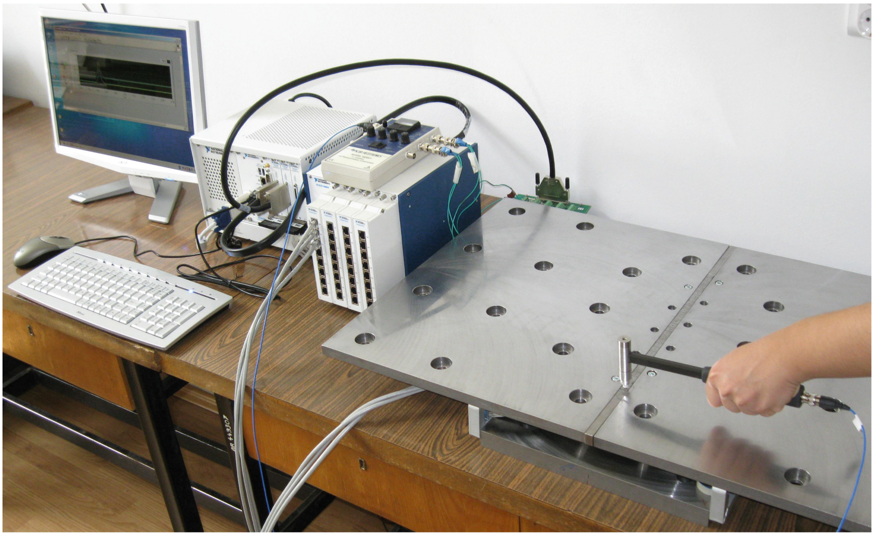

Fig. 3. Overall image of the equipment for verification of sensing elements dynamic behaviour

measuring force simultaneously using the strain gauged sensing elements and the piezoelectric transducer of the impact hammer. For the strain gauges signals, a lowpass Butterworth filter has been used. Details about software applications and connection of data acquisition channels to the measuring system have been presented in [5].

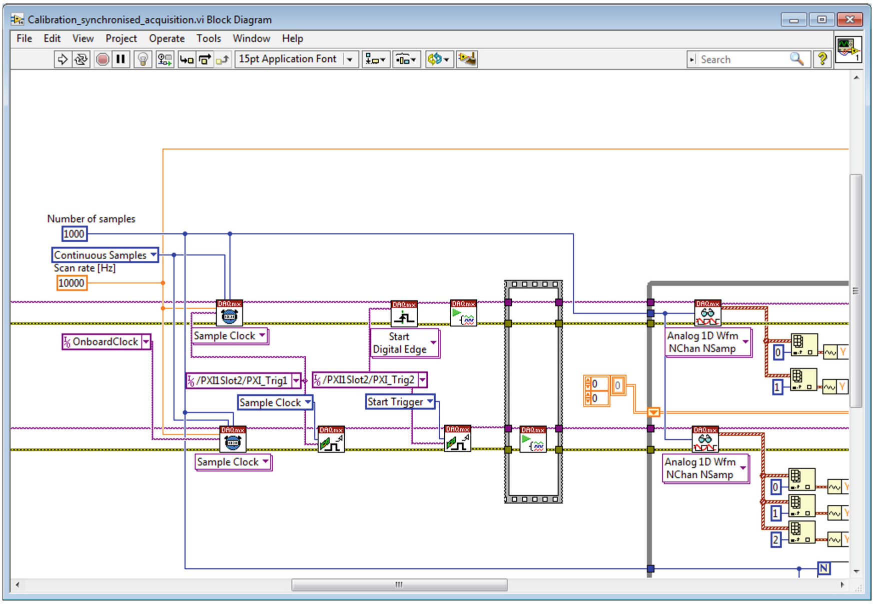

Fig. 4. Example of LabVIEW software application for simultaneously measuring force

Vertical force measured by one of the strain gauged sensing elements during an impact applied on vertical direction is shown in Fig. 5 in comparison to impact force measured simultaneously by the piezoelectric force transducer of impact hammer. Impact duration, shape and magnitude can be noticed, and good correlation between shapes and magnitudes of the two measured forces can be verified, with insignificant delay in the strain gauges results with respect to the piezoelectric force transducer of the impact hammer. Lateral force measured by one of the strain gauged sensing elements during an impact applied on lateral direction is shown in Fig. 6 in comparison with the impact force measured simultaneously by the piezoelectric force transducer of the impact hammer. The lateral impact has lower magnitude and slightly longer duration than the vertical impact. Also in this case, the good correlation between the shapes and magnitudes of the two measured forces can be remarked, with negligible delay in the strain gauges results with respect to the piezoelectric force transducer.

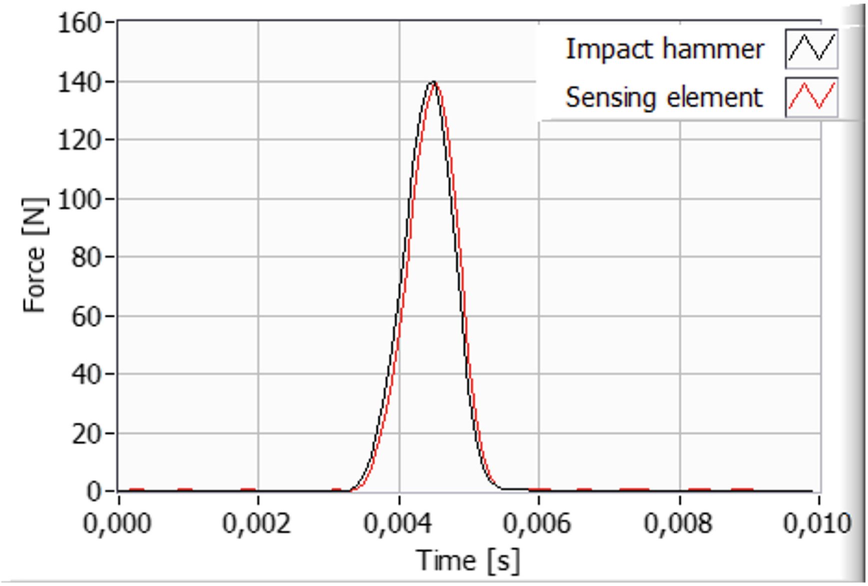

Fig. 5. Forces measured during an impact applied on vertical direction, using impact hammer force transducer and strain gauged sensing element

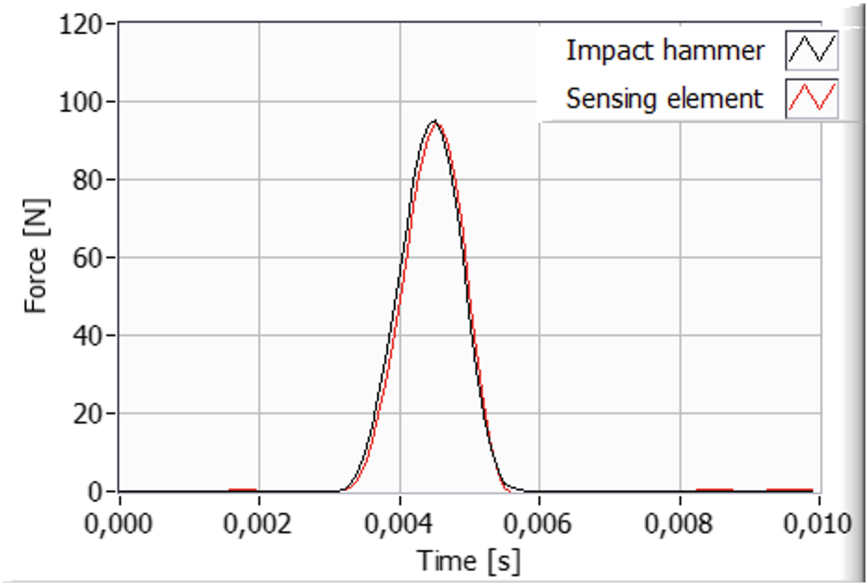

Fig. 6. Forces measured during an impact applied on lateral direction, using impact hammer force transducer and strain gauged sensing element

Longitudinal force measured by one of the strain gauged sensing elements during an impact applied on longitudinal direction is shown in Fig. 7 in comparison with the impact force measured simultaneously by the piezoelectric force transducer of the impact hammer. The longitudinal impact has lower magnitude and longer duration than the vertical and lateral impacts. However, the 50 N force applied on the sensing element with a contact area of 10 mm × 10 mm would be equivalent to a 500 kPa contact stress, therefore above the estimated range for the magnitude of longitudinal stress in the contact patch of a passenger car tyre.

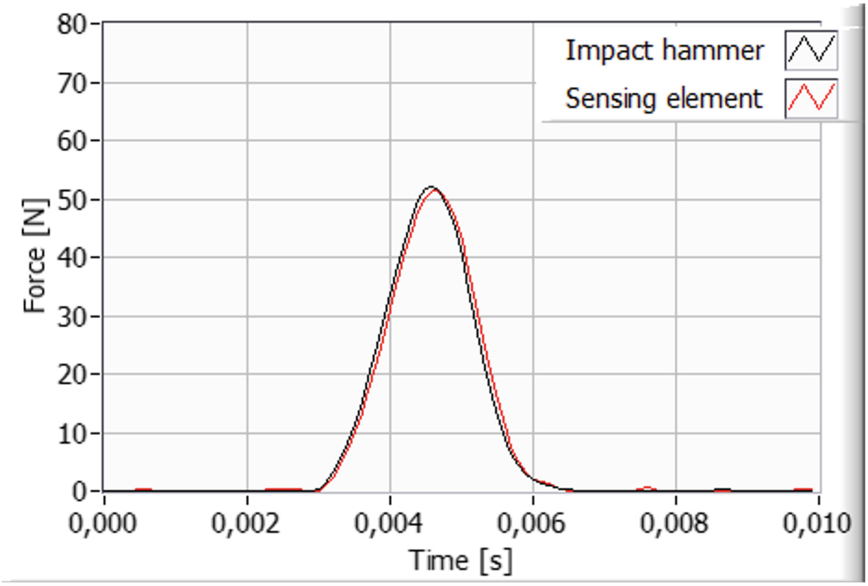

Fig. 7. Forces measured during an impact applied on longitudinal direction, using impact hammer force transducer and strain gauged sensing element

For the longitudinal impact also a good correlation between the shapes and magnitudes of the two measured forces can be noticed, with insignificant delay in the strain gauges results with respect to the piezoelectric force transducer. Additionally, in this case, some minor vibrations can be detected on the curve corresponding to the strain gauged sensing element immediately after the impact.

The abovementioned comparisons have proven very good correlation between the forces measured by strain gauged sensing elements during impacts applied on each orthogonal direction and the impact forces measured simultaneously by the piezoelectric force transducer of the impact hammer. Therefore, the calibration of sensing elements has been verified in dynamic conditions, thus allowing measurement of contact patch stress distributions for tyre speed ranges corresponding to real rolling conditions.

4 Conclusions

The experimental layout including an impact hammer with piezoelectric force transducer has allowed performing dynamic calibration on the tyre-road stress measuring system. Transient force has been applied successively on each orthogonal direction for verification of dynamic behaviour of sensing elements in laboratory conditions. Impact duration has proven to be smaller than the duration of contact between tyre tread and sensing elements in real rolling conditions.

Very good correlation exists between the impact forces measured by sensing elements and the impact forces measured simultaneously by the piezoelectric force transducer of the impact hammer. Thus, the dynamic calibration of sensing elements has also been verified for tyre speed ranges corresponding to real rolling conditions.

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