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Optical 3D Measuring System for Investigating Tyre Deformations

After laser measuring devices for determining the inner contour of tyres [1] and for 3D surface mapping [2] were successfully developed and implemented in Hohenheim, dynamic deflection measurements on tyres with the optical 3D measuring system, "PONTOS" of GOM in Braunschweig, show promising results. Especially tests on tyre eigenfrequencies and the corresponding tyre belt mode shapes for the rolling wheel can be tested. In the following, the measuring system, its configuration and setup, as well as first results and further possible applications, are presented.

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Keywords

Tractor tyre, tyre deformation, optical measuring system

During the last years requirements on tractor tyres have been increasing enormously due to bigger, faster and more powerful vehicles. Growing comfort demands require as optimal vibration adaptation of all vehicle components as possible, where the tyre represents an important link. For this purpose it is necessary to know the vibration characteristics of the tyre also in the comfort relevant frequency range up to about 80 Hz, which includes especially information on tyre belt eigenfrequencies and their mode shapes. At the Institute of Agricultural Engineering of the University of Hohenheim extensive investigations on this subject are being conducted at different testing facilities [3; 4], which can be expanded via the PONTOS measuring system.

Design and operation

The measuring system PONTOS uses the concept of the calibrated stereo camera setup (*Fig. 1*) for the determination of 3D coordinates and consequently 3D displacement and 3D deformation. For this purpose optical markers are applied to the surface of the object which do not have any disturbing effect during the test because of their small weight (<0,05 g) and size. The number of markers is not limited and has no influence on the sampling rate. The PONTOS measuring head is positioned arbitrary on a tripod in front of the measuring object. The calculation of coordinates and displacement resp. object deformation is carried out via offline analysis. For the present application the PONTOS system was used with high-speed cameras and triggered LED light. Hereby typically recording rates up to 500 images/s at 1.3 Megapixel camera resolution can be achieved or higher rates at reduced camera resolution. Short exposure times at high-speed recordings usually require expensive lighting systems. This problem was solved via the integrated lighting and the optical reflecting markers. Complex and dynamic motions and deflections are recorded as a spate of pictures and can be played back also as video. Additionally, the output of diagrams into reports resp. the export in standard data format is available.

For the present application the optical measuring system PONTOS was used to investigate the dynamic deformation and vibration behaviour of a large-volume tractor tyre at different operating conditions. For this purpose the system was set up in front of the Hohenheim flat-belt tyre test stand and optical markers for the identification of the measuring points were applied to the tyre and the test stand rocker (*Fig. 2*). The tyre is mounted to the rocker and rolls on the steel belt. The driving velocity can be varied continuously from 0 to 60 km/h. On the top of the rocker centrally above the wheel there a shaker is mounted device, which can excite the wheel single-frequency in the vertical direction. Parallel to the optical measuring system PONTOS, all tests are also recorded with the conventional measuring system installed on the test rig, so that accelerations

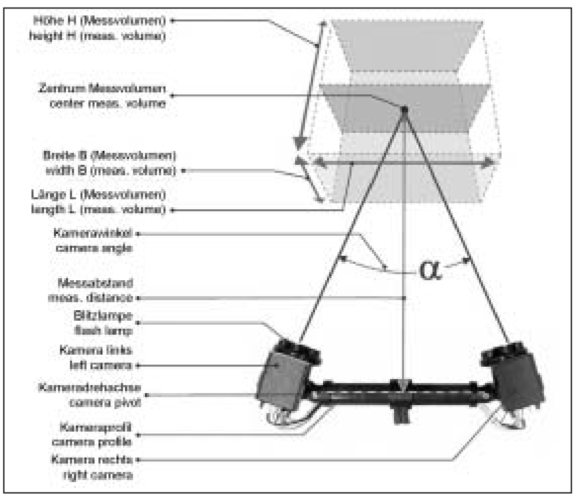

Fig. 1: Measuring principle of the optical 3D measuring system PONTOS

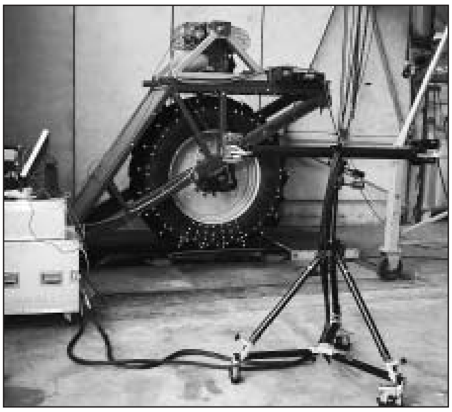

Fig. 2: Measuring setup at the Hohenheim flat-belt tyre test stand

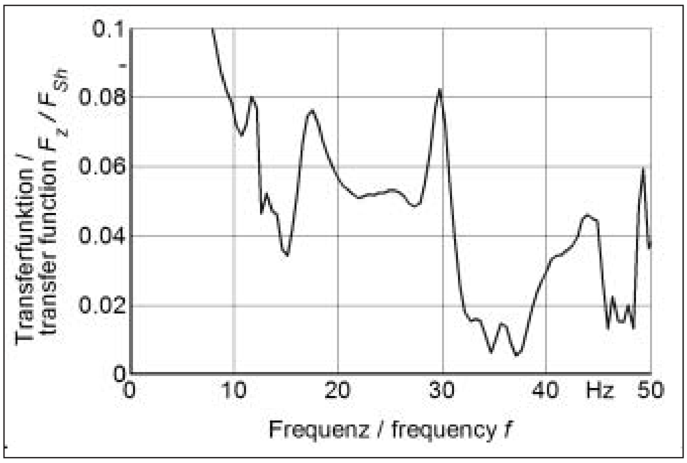

Fig. 3: Transfer function between vertical force F_z in the tread pattern and shaker excitation force F_{Sh} ($F_{z,stat}$ = 20 kN, p_i = 1,2 bar, v = 0 km/h, f_{Sh} = 3 – 50 Hz, A_{Sh} = 5,72 mm)

(3D), rotation speed (wheel and shaker), tyre deflection and forces (vertical and longitudinal) are also available for further analysis.

At first, tests at a static tyre load of 20 kN, an inflation pressure of 1,2 bar and with vertical excitation by the shaker for the non-rolling tyre and at a driving velocity of 5 km/h were carried out. Finally, it was measured at different driving velocities (10, 20, 30 and 40 km/h) without shaker excitation to determine the tyre deformation during usual operating conditions.

Results of preliminary tests

Limited to a maximum sampling time of 1,6 s of the PONTOS system at a sampling rate of 500 Hz and a resolution of 1280 • 1024 pixel it is not possible to record a complete frequency sine sweep (4 min). Therefore, the sine sweep at first was recorded with the conventional measuring system and analysed in a frequency range between 3 and 50 Hz at an eccentricity of the four shaker masses (6.18 kg) of 5.72 mm. *Figure 3* shows the transfer function calculated from the ratio of vertical force in the tread and excitation force of the shaker. Obviously to notice are peaks at about 12.0 / 17.5 / 30.0 / 42.5 and 49.0 Hz. These peaks represent tyre eigenfrequencies which each show a typical mode shape. In [4] the results of the experimental modal analysis of the same tyre are presented and the eigenfrequencies determined here are matching quite well.

With the measuring system PONTOS the belonging mode shapes should be acquired optically, depicted and compared with the mode shapes determined by the experimental modal analysis. For this purpose each of the eigenfrequencies shown in *Figure 3* are excited individually by the shaker. At constant shaker excitation frequency, a recording with the optical measuring system is conducted meanwhile. In spite of constant single-frequency excitation the tyre, however, not only vibrates with the excited mode shape, but also further mode shapes can be excited. For the rolling tyre the excitation by radial runout and by the lugs have to be considered. Therefore, for visualization of each mode shape, a band-pass filter has to be applied. Exemplary the first vertical mode shape at about 30 Hz is depicted in its top reversal point (*Fig. 4*). The arrows show direction and magnitude of the displacement of each measuring point. All points of the rim were chosen as global transformation points, meaning that direction and magnitude of the displacements are referenced on the measuring points of the rim. It can also be noticed, that also the rim shows small deformations. On the one hand this effect can be attributed to the measuring inaccuracy, on the other hand to the vibration and deformation behaviour of the rim. A comparison with the first vertical mode, determined by the modal analysis shows very good correlation. Also for the further eigenfrequencies up to 50 Hz shown in *Figure 3* the corresponding mode shapes determined by the modal analysis can be found.

Outlook

The presented analysis results of the conducted measurements with the optical measuring system PONTOS show a good correlation with the results of the experimental modal analysis for the standing tyre, which was carried out under comparable conditions. Thus, the general applicability of the measuring system for the investigation of tyre vibration and deformation was proven. In the following tests with a rolling wheel will be analysed in order to make a statement on the mode shapes of the tyre for the rolling condition. Furthermore, the vibration behaviour for real operating conditions with self excitation only will be examined.

From the conducted measurements further analysis will be carried out concerning the deformation behaviour of the free rolling tyre perambulating the tread pattern. By further tests on steered and driven wheels the presented investigations in [5, 6] on the displacement of contact and force application points will be expanded.

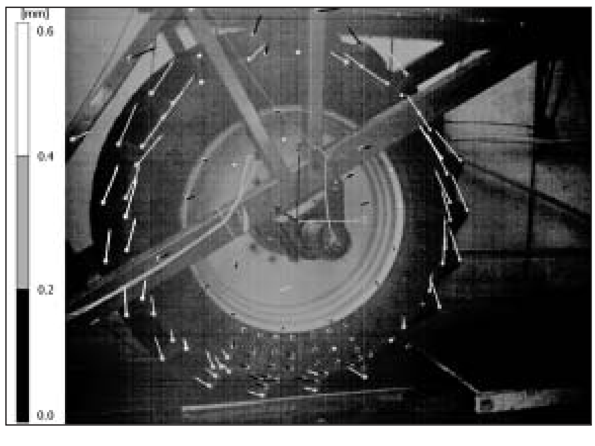

Fig. 4: 1st vertical mode shape in the top reversal point at ~ 30 Hz

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