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High Frequent Excitation of Agricultural Tyres

At the Institute of Agricultural Engineering of the University of Hohenheim the existing flat-belt tyre test stand was extended with a new shaker device for harmonic excitation of the tyre. With this method a more detailed investigation of the dynamic behaviour of agricultural tyres at a broad frequency range of 2 to 80 Hz can be performed. In this paper concept and design of the shaker device are described and first results are explained.

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The tyres are the link between vehicle and ground and therefore of special interest for the driving behaviour of vehicles. For tractors and agricultural machinery being used for both transportation and field work there are various mutually contradictory demands. For increasing transportation speeds the tyres' spring and damping parameters of the vehicles mostly without suspension are of great importance. An evaluation of the spring and damping characteristics has to consider the driving safety as well as the driving comfort aimed to avoid health hazards for the driver.

Sources of Excitation

Vibrations are excited by different sources: the bumpiness of the driveway, the self-excitation due to the radial run-out of the tyre and the lug influence, engine and transmission vibrations as vehicle-sided stimulations. To determine the transfer behaviour of a tyre, several parameters have to be considered. In [1] Zhang describes a classification by the range of frequency:

- Handling performance and vehicle stability 0 to 5 Hz
- Ride comfort and vibrations 5 to 50 Hz
- Acoustic properties from 40 Hz

In the overlapping range of about 20 to 100 Hz phenomena are audible and tangible. Among the excitation by the surface the tyre natural frequency behaviour and the reaction of the chassis on the tyre have to be considered. With the new shaker device the broad frequency range for ride comfort issues can be investigated in Hohenheim.

As agricultural vehicles usually do not have both axles sprung and damped, the corresponding excitation can be called a free damped oscillation. This kind of oscillation can be generated as follows [2, 3]:

- Drop test or passing a single obstacle
- harmonic excitation
- stochastic excitation

Drop tests are performed in single attempts, whereas harmonic and stochastic excitation occurs during a dedicated period.

Harmonic oscillations consist of defined sine oscillations. The phase shift between excitation and response characterises the damping properties of the tyre. Stochastic excitation causes inordinate vibrations and display e.g. the passing of a bumpy farm track which is very close to reality.

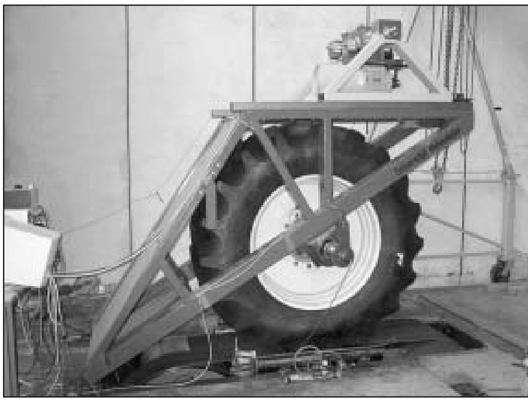

Fig. 1: Flatbelt tyre test stand with mounted shaker device

The Test Rig

The test rig developed at the University of Hohenheim is a flat-belt tyre test stand [1] and has been described in many publications [4, 5].

The tyre is guided in a rocker-arm and rolls on a 60 cm wide steel belt which is stuck with sandpaper with grain size 40 in order to simulate a road roughness. The driving speed is continuous variable from 0 to 62 km/h. On the top of the rocker-arm the shaker and/or weights to set the tyre load can be fixed.

The main function of the shaker is the introduction of defined oscillations into the rocker of the test rig. Therefore different concepts of excitation were created and after establishment and evaluation the following criteria compared:

1. Different possibilities of excitation (harmonic, stochastic, impact)
2. Handling
3. Application on different test rigs
4. Different directions of excitation
5. Installation
6. Control complexity
7. Complexity of manufacturing / purchase parts
8. Costs

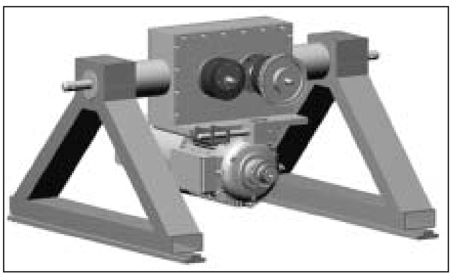

Fig. 2: CAD-model of the shaker device

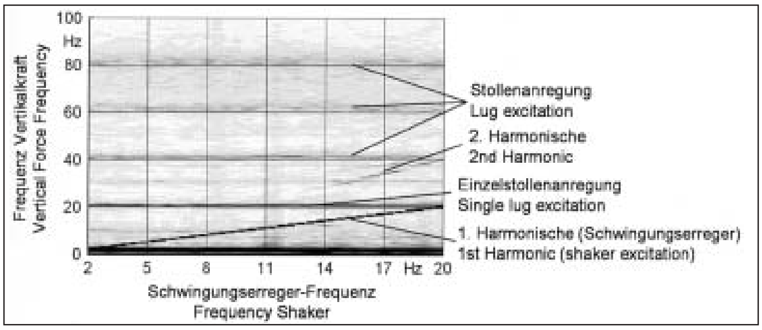

Fig. 4: Vertical force at 10 kph

Thus the inertial excitation was selected for design and construction of the shaker device. The main advantage is the availability for use in on-site testing, e.g. on mobile test rigs. The shaker consists of two shafts each with two eccentric masses mounted. By a spur gear unit the shafts counter-rotate with the same rotational speed. The centrifugal forces generate the resulting unidirectional sinusoidal force.

As the shaker should be able to run at different frequencies and amplitudes the eccentricity of the masses is continuously variable. An electric motor (5.5 kW) is flanged to the gear box and used to drive the device by a toothed drive belt. The design of the device suspension enables the adjustment of the inclination. The complete shaker device (*Fig. 4*) is guided on the rocker of the test rig in a rail system and can be fixed with a clamping mechanism (*Fig. 5*).

The electric motor has a maximum rotational speed of 3000 rpm. With a gear transmission ratio of 1:2, which also can be inverted, the maximum excitation frequency is theoretically either 25 Hz or 100 Hz. The minimum frequency of 2 Hz is limited by flutter of the electric drive at lower speeds.

Investigations of dynamic tyre parameters requires adequate measurement. At the test stand the physical values: vertical load, longitudinal force, vertical, longitudinal and lateral acceleration of the rocker, rotation angle of the wheel, deflection of the tyre, speed of the wheel and the belt are measured.

With a DaqBook (measurement data logging) all signals are transferred and saved on the PC. The measurement signals are acquired and stored with the software LabVIEW. For data processing MATLAB has been used.

Initiation and preliminary tests

For the first investigations a radial tyre of the size 580/70 R38 was used on the flat belt tyre test stand of the University of Hohenheim. All test runs were performed at a static tyre load of 15 kN and an inflation pressure of 0.8 bar. For the description of the tyre's spring and damping behaviour all parameters can be determined now by the harmonic excitation. After adjusting inflation pressure and static load the driving speed is selected. The speed of the shaker which represents the excitation frequency starts at 2 Hz and is increased in stages of 0.5-Hz-increments up to 20 Hz. For low frequencies the measurement period has to be long enough. Thus 20 sec. were selected at a sampling rate of 250 Hz.

Generally spring and damping behaviour and the mass distribution within a tyre can vary. Therefore the model of the damped single oscillator has to be improved, to be able to consider the vibration behaviour of a tyre more accurate. With the new shaker device arbitrary single-frequency excitation can be performed to investigate the vibration transfer characteristics of the tyre.

The results of the first tests are shown in the following figures. At first the not-rolling tyre is regarded. *Figure 3* shows the amplitudes of the vertical acceleration of the rocker. Very clearly the first 5 to 6 harmonics can be recognised. With higher excitation frequencies the amplitudes increase and are more sharp.

The contour plot (*Fig. 4*) covers the frequency spectra for all excitation frequencies. Among the first and second harmonic of the shaker excitation, the lug excitation with its harmonics appears quite clearly. The system eigenfrequency around 1.7 Hz varies a little more caused by outside influences at a speed of 10 kph.

Outlook

The results of an investigation of higher frequent dynamic behaviour of agricultural tyres with the flat-belt tyre test stand and the shaker device presented so far are very promising. The influence of an excitation frequency up to 20 Hz for the vertical force transmission can be seen clearly.

In future the excitation frequency will be extended up to 80 Hz; taking these results into consideration, the excitation frequency can be extended further up to frequencies in the range of the firing frequency of the engine or the lug excitation at higher driving speeds. This implies, that the investigation has to be extended to higher driving speeds. With the flat-belt test stand the driving speed can be increased up to 60 km/h, which is more than the limitation of most agricultural tyres. Furthermore, the influence of tyre parameters such as the inflation pressure and the tyre load have to be investigated. With this method a database for dynamic tyre behaviour at higher frequent excitation and the influences of the most important tyre parameters is created, which is essential for the development of a corresponding tyre model.

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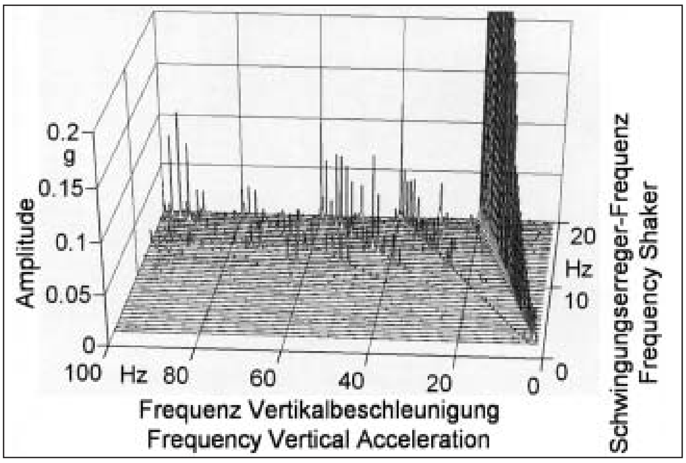

Fig. 3: Vertical acceleration at 0 kph