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Ride comfort Evaluation with Various Agricultural Tyres

Subjective Riding Impressions and Objective Measurements

The tyres, as the link between an agricultural tractor and the ground, have a strong impact on ride comfort. In a benchmark test the effects of different agricultural tyres on ride comfort and vehicle behaviour during test drives was subjectively evaluated. Simultaneously, the vibrational accelerations of several components in the testing vehicle were recorded. Objective and subjective data was analyzed and interrelationships between these sets of data were examined.

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Literature

Literature references can be called up under LT 07411 via internet http://www.landwirtschaftsverlag.com/landtech/local/literatur.htm.

Although driving speeds have been reaching 60 km/h, modern agricultural tractors are not equipped with suspended rear axles. This means that the tyres have to perform all suspension and damping work. Vibrations are transferred via the axles to the vehicle body which is usually designed as a block, frame or auxiliary frame. The vehicle body has a high portion of the vehicle's overall mass. Vibrations are transferred from the body via the cabin suspension to the seat, where they are induced to the operator. As seat positions are increasing in height, the pitching and rolling motion of the body cause relatively high displacements of the operator. The low damping of the tyres, together with different vibration excitations, have a strong influence on workplace convenience and ride comfort. As an objective measure for the assessment of vibration comfort the acceleration of the seat in vertical direction is widely used. Furthermore, it is common practice in the development of vehicles to subjectively evaluate comfort impairing vibrations by test persons. While vibration properties of agricultural tractors driving on different types of ground and the influence of the dynamic characteristics of the tyres have been repeatedly described [1, 2, 3], aspects of the subjective evaluation of the ride quality by the operator itself until now only rarely have been investigated. Within a comparative test ride comfort experiments were carried out with 10 different sets of agricultural tyres in order to investigate interrelations between subjective evaluations and objective measurements of comfort relevant parameters. For this purpose the properties of the tyres in operating conditions were subjectively evaluated by a group of test persons. In parallel objective measures, primary in form of acceleration signals, were recorded.

Subjective evaluation of ride quality

Investigations on the interrelations between subjective and objective evaluation of ride comfort have been conducted mainly in the automotive sector. Particular criteria for the examination of subjective ride quality like those described for example by Heißing et al. [5] can only be transferred to agricultural tractors in certain limits due to great differences between both vehicle systems. Normally, the subjective evaluation is carried out with special evaluation sheets which are used for the documentation of the subjectively perceived ride comfort [4]. For the evaluation of a single criterion, such as for example vibration or braking behaviour, a scale with 10 scores has proved to be functional. By using correlation analysis of subjective evaluations and objective data the most meaningful measures and parameters can be identified. The linkage of these two sets of data results in an objectification of the human perception of vehicle properties.

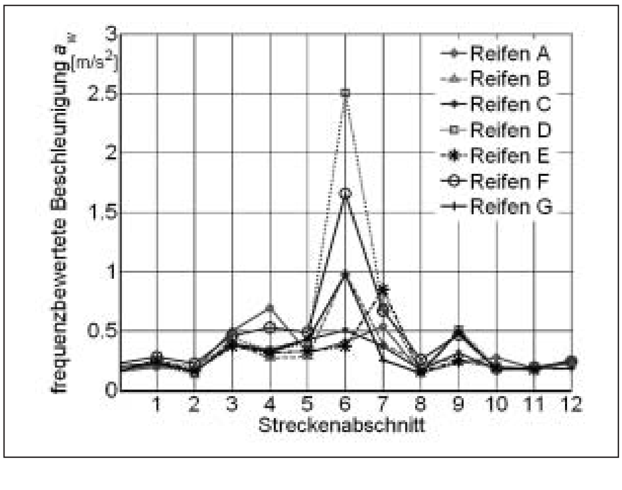

Fig. 1: Frequency-weighted vertical seat acceleration a_W

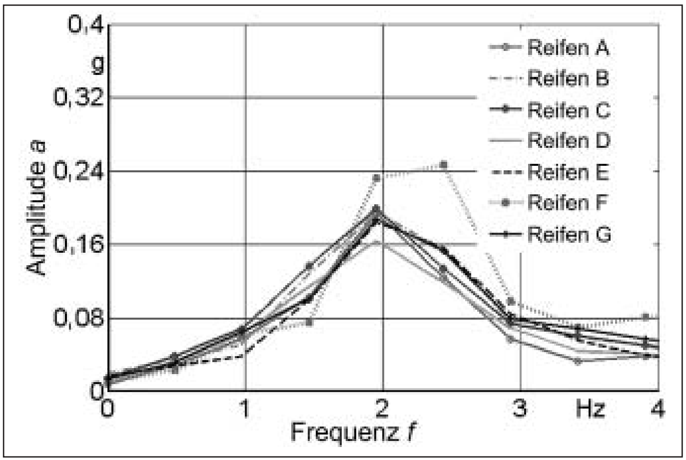

Fig. 2: Amplitude spectrum Peak-Hold, vertical acceleration cabin floor, section 1

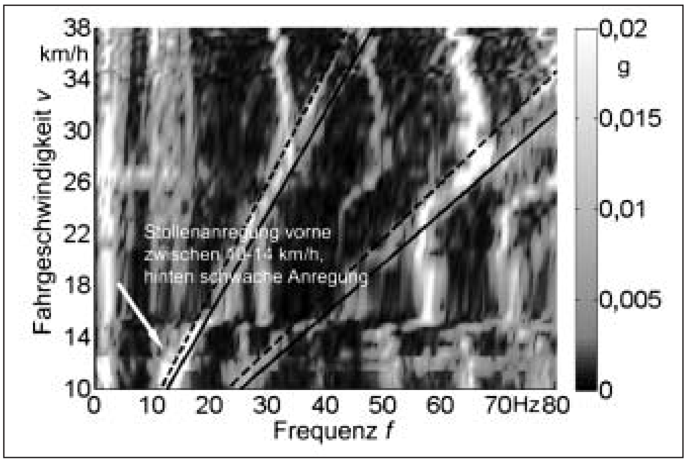

Fig. 3: Spectrogram vertical seat acceleration, tyre D, section 0

Thus, objective parameters reciprocally become describable by subjective evaluations. In the course of this test primarily the vibration characteristics of a test vehicle were subjectively evaluated.

Experimental setup

For the ride comfort tests a middle-class agricultural tractor Fendt 411 Vario with continuously variable transmission and a maximum driving speed of 50 km/h was used. This tractor has a tare weight of 5240 kg and a rated power of 87 kW. This vehicle is equipped with a lockable and level controlled front axle suspension, adaptive cabin semi-suspension and an adaptive seat suspension. In the front and rear three-point hitch, the tractor was ballasted each with 870 kg in order to simulate a realistic scenario. 10 different sets of tyres were tested. On the rear axle radial tyres of the dimension 460/85R38 were mounted, the front axle was equipped with radial tyres of the dimension 420/85R38. One set of bias tyres of the dimension 18.4 - 28 and 13.6 - 28 served as base reference. The inflation pressure for all test drives was set to 1.2 bar, which is a compromise between travel on the road and field work. The position of the vehicle and its driving speed were determined with D-GPS. On both sides of the rear axle, sensors for the vertical acceleration were applied. Three accelerometers with triaxial sensitivity were located on the cabin floor, two additional accelerometers for the measurement of horizontal and vertical accelerations were applied to the seat shell.

The recording of these signals was conducted with DASYlab together with an A/D converter at a sampling frequency of 1000 Hz. The continuous transmission proved to be practical as it helped to release the test persons from changing gears thus facilitating the persons to concentrate on the evaluation task. The driving tests were carried out on a defined course of 4.5 km length. This test course was divided into 12 sections of which 10 sections were used for the experimental analysis. These sections featured different ground characteristics (smooth and rough tarmac road, gravel track, normal and rough farm track). Except one, none of the sections showed significant inclination. Approximately at the geodetic centre of the test terrain the reference station for the D-GPS system was mounted. Five male test persons conducted the tests. Four of them were trained operators with regular practical experience; one test person holds rather occasional practical experience. 36 test drives were carried out overall with some 12 minutes per course. At the beginning of the test drives the operators were explained, what criteria to survey and under what conditions in particular sections had to be travelled (e.g. unlocked front axle suspension). Three comfort relevant criteria (vehicle bouncing, seat acceleration and lug excitation) were documented right after a test drive using evaluation sheets with 10 score scales. Additionally, the ride quality and the vibration properties could be described with free comments.

Test analysis and results

The signals of the accelerometers and of the GPS system were recorded in ASCII format. Data processing and analysis was performed with self-developed MATLAB code. According to the fragmentation of the test course the measurement data was divided and analysed for each section. Frequency spectra of selected acceleration signals were calculated with Fourier analysis and several diagrams (peak-hold, power spectrum density) as well as the spectrogram were built. In order to calculate the frequency-weighted acceleration aw and the root mean square values of the accelerations the signals were filtered with frequency-weighting functions according the directive VDI 2057 [6] in the frequency range between 1 and 80 Hertz. This was done in consideration of the fact that human perception of motion not only depends on amplitude and direction but also on the frequency of the acting vibration. For the analysis of the vertical seat vibration the frequency-weighted accelerations a_w were compared with the subjective evaluations. Tyre F was subjectively evaluated worst during travel on tarmac. In the relevant sections 0, 1, 2, 5, 8 this tyre holds the highest frequency-weighted acceleration a_w (*Fig. 1*), in the sections 4 and 9 it holds the second highest value. This tyre also was described with free comments as a very stiff tyre with bad damping characteristics. Tyre E, which was subjectively evaluated best, holds very low frequency-weighted accelerations aw in the sections 0, 2, 4, 5, 8 and 9 or holds the lowest value. Only in section 1, in which all tyres show similar values, this tyre is placed in the middle range. All other tyres are placed in a narrow range for the frequency-weighted acceleration a_w as well as for the subjective evaluation and show changing rankings. With the criterion vehicle bouncing during travel on tarmac correlations between subjective evaluation and objective measurement could not be identified in such a precise manner. It was found that tyre F, which holds the worst evaluation also with this criterion, showed the highest amplitude of the cabin vertical acceleration in a frequency range between 2 and 3 Hertz in section 1 (*Fig. 2*). The same is the case for the power spectrum density. For the analysis of the subjective evaluation of the lug excitation a section with smooth tarmac was considered (section 0). *Figure 3* for example shows the spectrogram of a test drive of an operator with tyre D. During that drive the operator noticed strong lug excitations of the front tyres in a driving speed range between 10 km/h to 14 km/h. In the spectrogram it is evident that the solid line which represents the lug excitation of the front tyres runs pretty exactly through the area of elevated amplitudes at this driving speed. In the same way the observation of light excitations of the rear tyres (represented by the dashed line) can be found. In contrast to travel on tarmac identification of interrelations between subjective evaluation and objective measurements during travel on farm tracks only was possible in very few cases. As a reason for this the strong prevalence of stochastic excitation of the test vehicle by the ground can be seen.