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Ride Comfort with Agricultural Tractors

Interrelationships between Objective Measurements and Subjective Evaluations

Whole body vibrations greatly influence the perceptions of ride comfort that agricultural tractor drivers have. While measurements of acceleration levels deliver an objective representation of vibration intensities expressed in numerical values, ride comfort may be described also through the subjective perception of the operator himself, e.g. through questionnaires (see [1]). Four different types of tests on an agricultural tractor operated by a group of seven test persons were carried out to examine the interrelationships between objective measurements and subjective evaluations of ride comfort.

Beside the rise of engine power and vehicle speed the development of modern agricultural tractors is characterized by the application of increasingly sophisticated subassemblies aiming to improve the operator's ride comfort. Amongst all subgroups of the highly complex entity ride comfort vibrations surely are one of the most significant influencing not only the well-being of operators but have also a heavy impact on working performance and health. Principal sources of vibration excitation are the unevenness of the ground, the drive train and the tyres. Excitation by the tyres can be distinguished between high frequency vibration of the lugs hitting the surface and rather low frequency vibration caused by tyre imperfections such as radial run out. Vibrations are transmitted to the operator's body via multiple contact locations such as seat, armrest, cabin floor, steering wheel, pedals and levers. Human perception of vibration then is depending on its frequency, magnitude, waveform and direction. The perception itself is done by tactition and the vestibular sense. The intensity of an objectively measurable process or state is defined as stimulus whereas the transfer behaviour of the sense influencing the perception is referred to as sensibility [2]. For the generation of objective measurable parameters to describe ride comfort it is widely usual to record the accelerations at the seat cushion and build root mean square values of frequency weighted signals. The standard ISO 2631 [3] and the guideline VDI 2057 [4] deliver valuable tools to assess effects of vibration on the operator, taking into account innumerable studies of the perception of vibrations by human beings and its physiological impacts. Yet these standards lack an approach of a consideration, which is closely related to the individual perception of vibration comfort. In fact, there can be large differences between the responses of individuals and also large differences in the responses of an individual on different occasions [5]. Preliminary investigations of objective measurements and subjective evaluations showed promising results but also revealed the necessity of strictly defined test procedures [1].

Ride comfort investigations

The described experiments aim to detect interrelations between objective measurements, given as vibration amplitudes and subjective evaluation of their perception. These evaluations were documented by means of numerically scaled questionnaires

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Keywords

Ride comfort, subjective evaluation, vibration

Literature

Literature references can be called up under LT 07517 via internet http://www.landwirtschaftsverlag.com/landtech/local/literatur.htm.

Fig. 1: Research tractor with with mounted shaker device

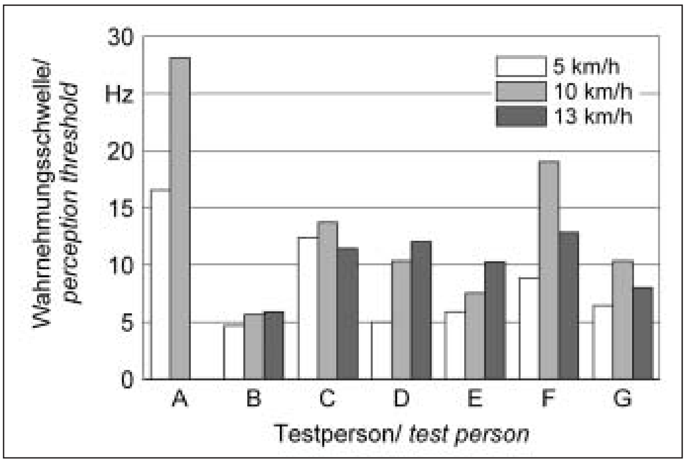

Fig. 2: Perception threshold with different driving velocities

with semantic variables (reaching from „very comfortable" (1) to „unbearable" (10). Additionally, two experiments aiming at the investigation of the perception threshold of the individual test persons were carried out in order to find possible relations between the perception threshold and test person features or subjective evaluations. As a test vehicle a standard tractor Fendt 509 (*Fig. 1*) with a hydropneumatic front axle suspension was used. Triaxial accelerometers are mounted to the front axle close to the right wheel, to the rear axle close to the right wheel. One accelerometer for the vertical direction is mounted to the cabin floor near the seat base. Furthermore, a triaxial accelerometer is placed in a seating pad between seat cushion and operator. A shaker device with four rotating unbalanced masses is mounted to the body of the tractor. The run out of the masses and the rotation frequency can be continuously adjusted allowing a theoretical excitation of the tractor in a frequency range from 3 - 50 Hz with forces up to 9000 N. Within all experiments the inflation pressure of the tyres was set to 1.6 bar. A detailed description of this vehicle and of its measurement system can be found in [6]. A group consisting of two women and five men with ages in a range between 30 and 52 years with different physiological features and experience levels in operating agricultural tractors took part in the experiments. All experiments were carried out on an apparently even, smooth and straight tarmac road surface. With all experiments measures to reduce interferences between sensations were made, e.g. wearing of ear protection. Two experiments under use of the shaker device aimed at the investigation of the perception threshold. With the experiment denoted as perception threshold the frequency of the shaker device on the standing still vehicle was continuously increased until the test person on the tractor signalled the unambiguous perception of the sinusoidal vibration. The experiment denoted as shaker perception threshold was carried out in a similar way with the difference that the vehicle was moving with constant driving velocities of each 5 km/h, 10 km/h and 13 km/h. Thus the sinusoidal vibration of the shaker device was additionally superposed with vibration components caused by the drive train and wheel-subsoil interaction. In both cases the perception threshold is defined as the frequency of the shaker device at which the test person just distinctively notes the sinusoidal shaker excitation. Two other experiments aimed at the interrelations between subjectively perceived vibration comfort and objective measurements within defined test runs. Within the experiment denoted fixed velocity the vehicle was run by the test persons at up to eight constant driving velocity levels between 6 km/h to 33 km/h for at least four seconds. The subjective perception of the vibration comfort at one velocity level was documented by the co-driver via questionnaires. Within the experiment denoted as roll out the vehicle first was accelerated upon a driving velocity of more than 35 km/h. Then the clutch was actuated and the vehicle was decelerated only by wind and rolling resistance. The vibration comfort was evaluated in unequally spaced time intervals in the same way as with the fixed velocity experiment until close to the standstill of the vehicle

Data analysis and results

For the analysis of the experiments, which aimed at the detection of the perception threshold, no sensor data was used. With the experiments fixed velocity and roll out the signals of the accelerometers were frequency weighted according the guideline VDI 2057 [4]. The block size of the FFT algorithm was set to approximately four seconds with an overlap of 50% including the application of a hanning window function. In order to identify interrelations between objective measurements of the sensor signals and subjective evaluation the block wise data sets of the frequency analysis and the data of the documentation were matched via correlation analysis. The correlation coefficient was calculated between each value of the subjective evaluation of one driving velocity level and the root mean square value of the frequency-weighted acceleration signals of each sensor in the corresponding time range. In order to take into consideration the time period needed by the test person to build the subjective evaluation, it was not only selected one identified block of the objective data (correlation single range) but also two respectively four of its neighbouring blocks (correlation 3 ranges, correlation 5 ranges). The results of the perception threshold experiments show irregular values of the perception threshold of the single test persons with very good repeatability. The perception threshold values range between 4 Hz and 12 Hz with a variance of a maximum of 0.56 Hz^2 per person. The perception threshold values of the shaker perception threshold experiments even differ

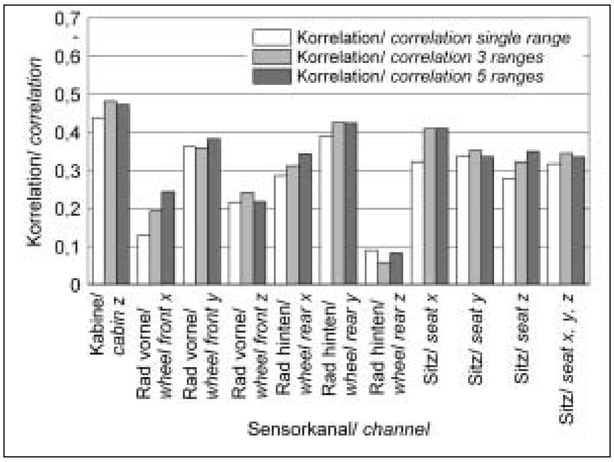

Fig. 3: Correlation per channel of all roll out experiment runs

in a larger scale (*Fig. 2*). The variance for all test persons is 9.7 Hz^2 for a driving velocity of 5 km/h, 35 Hz^2 with 10 km/h and 4.2 Hz^2 with 13 km/h. With a driving velocity of 5 km/h all test persons were able to clearly identify the harmonic shaker excitation. It is assumed that with 10 km/h the test persons had difficulties in distinguishing the harmonic shaker excitation from a rather dominant fraction of stochastic vibration. With driving velocities of 13 km/h the lowest perception threshold values could be found. Preliminary tests had shown that the vehicle in this velocity range shows a bouncing frequency of approximately 3 Hz so that this bouncing movement was noted instead of the shaker excitation. Relations between the results of the correlation analysis and the perception threshold values as well as the test person features could not be clearly identified. Figure 3 shows the results of the roll out experiment. Relatively high correlations between subjective and objective data could be found with the components of the tractor which are in direct contact to the operator (seat, cabin). Very noticeable are the high correlations of the sensor data of the rear wheel (wheel rear y) in lateral direction and the low correlations at the same place (wheel rear z) in vertical direction. It can be said that the transfer path of the vibrations between rear wheel and operator has a great attenuation and is well optimized whereas the perception of comfort at least without influence of the drive train is influenced by lateral vibrations in a rather dominant manner. The results of the fixed velocity experiments in average show slightly higher correlations and similar tendencies. Here the test person with the lowest perception threshold in the perception threshold experiment ranges within the highest correlation values. The correlation values of the different vibration directions feature lower discrepancies among each other so that in these experiments a greater fraction of vertical vibrations is influencing the perception of comfort. Further investigations with different tyre inflation pressures and excitation sources (e.g. cleat tests) are being planned in order to find more detailed conclusions about the perception of comfort also with shock excitation.

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