Volkmar Schlotter and Heinz Dieter Kutzbach, Hohenheim

Influence of dynamic wheel load changes on power transmission via tractor tyre

Wheel loadings have an obvious influence on transmittable longitudinal and lateral forces. This means an exact knowledge of the loading progression is indispensable. The moving belt testing stand at Hohenheim was applied for determining the influence of tyres on dynamic wheel load changes. The stochastic influences of actual driving surfaces were also assessed using single wheel recording equipment. Obstacles on the driving surface allowed the investigation of wheel load variation influences on generation of lateral forces. The creation of lateral forces was in this case determined through the sudden alteration of the contact surfaces.

Dipl.-Ing. Volkmar Schlotter is a member of the scientific staff at the Chair for Procedural Technology in Plant Production, Agricultural Engineering Basis, Institute for Agricultural Engineering (director: Prof. Dr-Ing. Dr. h.c. H. D. Kutzbach), University Hohenheim, Garbenstr. 9, 70599 Stuttgart; e-mail: *vschlott@uni-hohenheim.de*

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Literature

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Wheel load has a decisive influence on the transferable forces between wheel and road surface or soil [1, 2]. Therefore in many developments for the modelling and simulation of these forces on the wheel, a non-dimensional driving force or lateral force coefficient is defined [3]. Because in this case the wheel load serves as a starting parameter, it has to be constant for coefficient determination.

Equipment for measurement of forces on the wheel work either with ballasting [4] or with regulating apparatus [5] so that wheel load can be held constant during recordings. When measuring with weights, variations in the wheel loads caused by driving surface unevenness cannot be discounted. With regulated wheel loads the wheel load variations can be reduced to a minimum where the regulation is sufficiently rapid, but here too effects on force transmission are to be expected through changes in tyre contact area through tyre unevenness changes. However, it should be remembered, that wheel load changes always occur with vehicles.

Investigation methods

Used for the investigation the moving belt test stand [6] and the single wheel recording instrument [2] at Hohenheim were used. With the moving belt test stand the influence of the tyres on the wheel load variations could be recorded. The resulting dynamic of wheel load is determined alone through different tyre influence factors such as geometrical unevenness of form, mass impetus or tyre stiffness inconsistency over the circumference (non-uniformity).

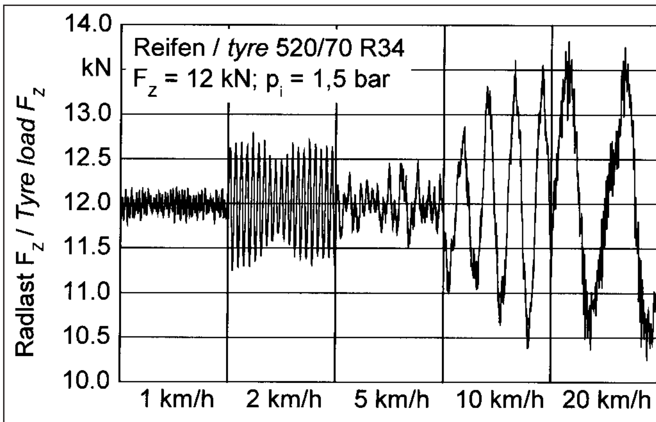

Fig 1: Dynamic wheel loads under differing driving speeds

Table 1: Wheel load shock factors for differing road surfaces: F_z static wheel load, P_i inflation pressure, v driving speed, S_e shock factor loading, S_b shock factor unloading

Road surface	F_z [kN]	p_i [bar]	v [km/h]	S_e [-]	S_b [-]
Steel band	12	1.5	5	0.96	1.05
Asphalt	14	1.6	5	0.93	1.07
			2	0.93	1.08
Asphalt	14	0.8	5	0.93	1.07
			10	0.92	1.07
			20	0.88	1.13
Field road	14	0.8	5	0.91	1.11
Grassland	14	0.8	5	0.88	1.13

For recording real driving surface influence the single wheel measurement apparatus was used. The regulating equipment for wheel load presented in [7] was removed. This meant that the wheel load was produced only from the measuring wheel's own-weight, its hub and the suspension. Apart from measurement on different driving surfaces such as asphalt road, field road or grassland, obstacles such as steps or bumps were created so that driving over them allowed recording of spring-type stimulation results.

Further investigations were carried out with activated regulating equipment for the precise stimulation of different forms of wheel load variations so that results could be compared with those achieved without regulating equipment.

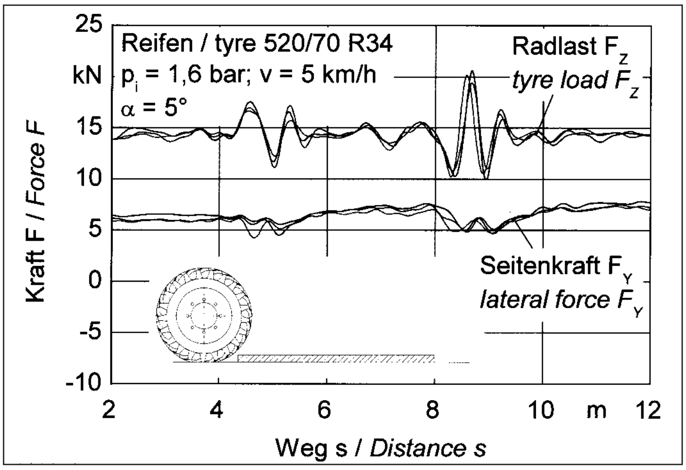

Fig. 2: Course of wheel load and lateral forces driving over a step with three repetitions

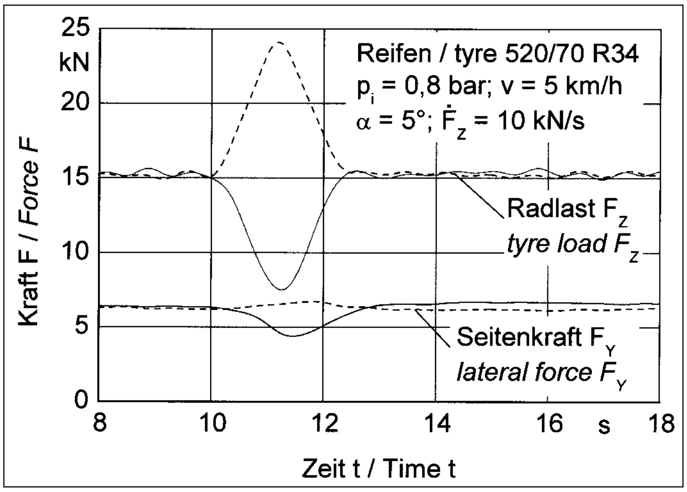

Fig. 3: The progression of wheel load and lateral force during ramp induced wheel load change

Wheel load changes on even road surface

The results from measuring vertical forces on the moving belt test stand for a wheel revolution in each case are presented in *figure 1*. The very different progression of the wheel load for different speeds is above all due to the own-frequencies in the area of tyre and also lug stimulation. For this reason these trials gave a very good reproducibility. With higher driving speeds, low frequency wheel load variations were more apparent, where v = 20 km/h represented a maximum through tyre own-oscillation behaviour [8]. Additional measurements gave further maxima as well as reduction of wheel load variants for higher vehicle speeds.

For better comparability of wheel load variations, a non-dimensional starting parameter, the wheel load impact factor S, could be established as quotient to the actual static wheel load:

$S = F_{tat} / F_{stat}$

In the case of the trials here presented, a range breadth of impact factor of ~ ± 25% was given for the tyres. When exact critical speed was reached impact factor values could be expected almost leading to tyres leaving the ground, e.g. nearly the value $S_E = 0$ [9].

Increasing wheel load led, on the other hand, to lesser impact factors. Because of this wheel load dependency, information was lost during non-dimensional recording through the impact factor. Taking account of the actual wheel load progression cannot therefore be avoided in description of wheel load dynamic.

Wheel load variations on different driving surfaces

In comparison to the results on the moving belt testing stand, wheel loading variation was increased slightly on asphalted field roads (*table 1*). Whereas the measurements on the moving belt test stand showed a very high reproducibility, stochastic wheel load variations were determined on the field road giving poor reproducibility. An increase on impact factors could be determined from measurements on gravel field roads and grasslands. Here, stochastic stimulations were increasingly apparent.

Additionally, special spring-causing stimulations were observed. This was because this form of wheel load variation brings not only driver stress and damage to driving surfaces but also can affect safety and lead to a reduction in the transmittable drive, braking or lateral forces [10].

Influences on the transmission of lateral forces

In figure 2 a 125 mm high and 3100 mm long step with constant surface slope was driven over. The spring-like stimulation caused by the step led, however, to no spring-like change on wheel loading. Compensation for the obstacle occurred through tyre shape change and there therefore occurred a progressive alteration in wheel load. The inertia and the damping effect of the tyre led to an absorption of the wheel load. The wheel load increased sharply while driving onto the step without the lateral force following this rise to the same extent. The reason for this can be found in the sudden reduction of the tyre/ground contact area whilst driving onto the step with contact area pressure rising steeply and the grip threshold being overstepped. The rubber element in the contact zone begins to slip, diminishing force-transmitting efficiency. The progression when leaving the step emphasises that the lateral force reacts more strongly to reduction of wheel load compared with its increase. Because of the cushioning effect of the tyres, the wheel load rises and this leads to a limited increase in lateral force. On average a substantial reduction in lateral force was also determined on leaving the step. In total therefore the lateral force was reduced through loss of tyre contact area in both cases.

In order to avoid this influence from contact area changes to a large extent, tests were carried out with the wheel load regulator and single wheel measuring instrument. With this it was possible to investigate the dynamic of the wheel load with precise stimulation (ramp stimulation) (*fig. 3*). While only a limited rise in lateral forces took place during wheel load increase, the reduction of lateral forces when reducing wheel load was clearer. With the additional loading of the tyres, the tyre carcase and walls were further deformed before an effect on lateral force transmission could take place. Where tyre load was reduced the changes took place very much more rapidly and a non-symmetrical behaviour could then be determined.

Summary

The transmittable forces with dynamic wheel load variations depend very strongly on the initial changes in tyres and their contact areas. In further investigations the reaction of the lateral forces should be quantified so that transmitting behaviour can be described. The trials so far have shown that in such a case regard of initial changes in wheel load gradients is indispensable.