Ullrich Hoppe, Berlin

Influence of tractor rear axle suspension on driving safety and comfort

Higher tractor travelling speeds reduce driving safety and comfort. Rear axle suspension can help. Investigations using multi-body simulation show this offers great improvements in dynamic properties during different load conditions. These determinations applied to driving in a straight line. Further investigations are required for information on the lateral dynamics of tractors with full suspension.

Dipl.-Ing. Ullrich Hoppe is a member of the scientific staff in the specialist department Agricultural Machinery and Oil Hydraulics (director: Prof. Dr.-Ing. D. Severin), TU-Berlin, LT1, Zoppoter Str. 35, 14199 Berlin; e-mail: *uh@fax-lt.kf.tu-berlin.de*

Keywords

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The structural change in farming with expanding distances between steading and field, increases in transport journeys and, not least, rising numbers of tractors in municipal work all encourage a change to faster tractors. „Fast" for tractors means crossing the 60 km/h threshold so that they can then travel on HGV routes and motorways. With this relatively high travelling speed for tractors the non-symmetry of their large volume tyres and the associated self-initiated changes in form as well as their low damping capacity bring a susceptibility to strong dynamic stresses. This in turn has a negative influence on driving safety because the vehicle oscillations can lead to short-term lifting of the wheels from the road surface. Fitting suspension to both axles offers a way of avoiding such problems. To investigation driving characteristics of tractors with full suspension a multi-body simulation model was developed at the Institute for Agricultural Machinery and Oil Hydraulics, TU Berlin within the remit of a DFG project. This demonstrated the improvement potential of two axles with suspension compared with front axle suspension alone.

The requirement

First aim was conception of possible rear axle suspension variants with regard to fitting requirements and then to optimise those regarding suspension and damping characteristics so that afterwards the driving properties of the tractors could be investigated under different load conditions and driving speeds. Wheel loading factor RLF and the proven driver seat acceleration RMS_{Sitz} were evaluation criteria. In the process of the investigations a conflict in aims emerged in that one optimum solution relating to driving safety brought with it only a limited reduction in the demands on the driver through vibration, and vice versa. A further target for the theoretical work must therefore be discovering a rear axle suspension solution offering the best possible answer to both demands.

Simulation model and method

Starting off with real „Trac 160s" from Doppstadt, a multi-body model was first of all prepared for the vehicle without rear axle suspension. For determining specifications and geometrical data of the individual construction modules, the vehicle was represented in detail in the CAD program Pro/Engineer. For some construction modules the moments of inertia were determined through weighing and free-swinging. Where not known, individual test stand trials were used to determine the performances of force-absorbing elements (rubber absorbers, axle suspension/dampers and tyres). On the basis of this data the multi-body simulation program DADS from LMS was used to develop a simulation model for the Trac160 and verify it through driving tests.

After it had been proven that the model conformed sufficiently to the real tractor the rigid rear axle in the model was replaced with a rear axle with suspension. From the possible variants two rigid axles with suspension as well as a construction with single wheel independent suspension were involved in further analyses. These axle conceptions were constructed in Pro/Engineer and then implemented in the MKS model.

Using the simulation model it was then possible with the assistance of evolution strategies to investigate the driving properties of the different tractor variants under the load situations „empty vehicle", „front", „rear" and „fully" ballasted, as well as under different driving speeds when travelling straight ahead.

Results

Used for evaluating driving characteristics were the acceleration of the driver seat RMS_{Sitz} calculated according to ISO 2631 and the wheel load factor RLF. The wheel load factor pertains to driving safety and is the quotient from static and dynamic wheel load. The influence of both criteria alters with driving speed. Whereas at high speeds the driving safety (smaller wheel load factor) is of decisive importance, a good standard of

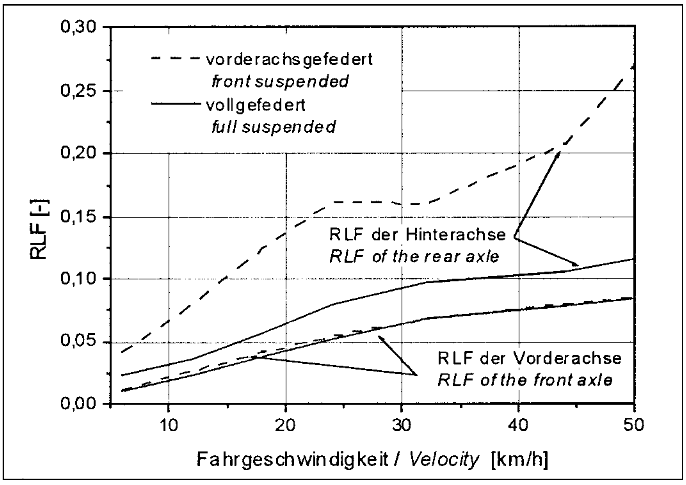

Fig. 1: Comparison of wheel load factors at front and rear axle of an unloaded vehicle according to driving speed

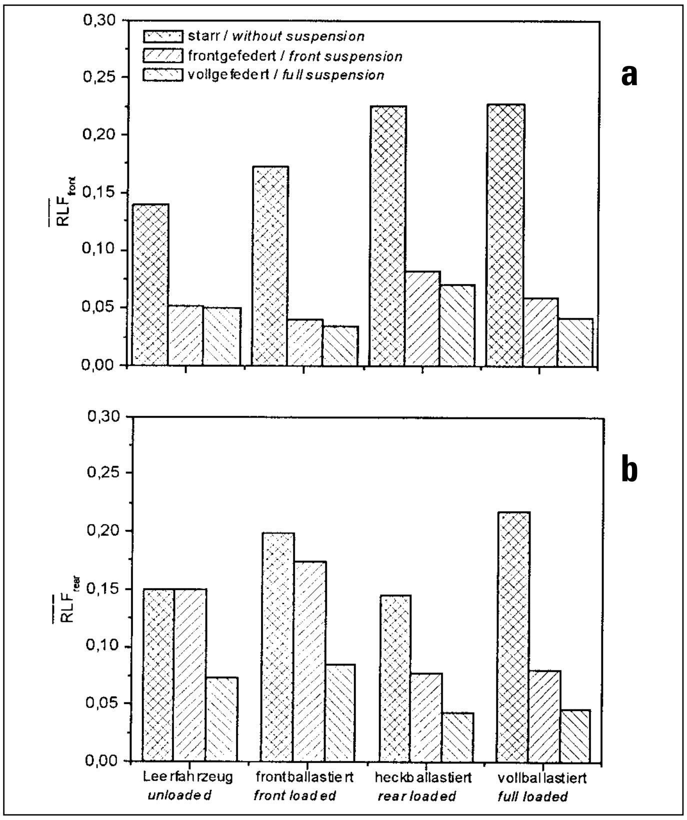

Fig. 2: Comparison of wheel load factors determined in association with driving speed at the a) front and b) rear axle

comfort is required in the range of lower driving speeds (smaller RMS value). For this, a criterion has been developed that concerns both driving security and driving comfort with different weighting applied to both parameters in relationship to the driving speed. The target function Z, to be minimised through optimising, is described through:

$$Z = f_s \cdot RLF_{norm} + f_K \cdot RMS_{norm} \qquad (1)$$

RLF_{norm} and RMS_{norm} are weighting criteria standardized according to the respective limiting value and f_S as well as f_K the speed-dependent weighting factors.

$$RLF_{norm} = RLF/RLF_{Grenz};$$
$$RMS_{norm} = RMS_{Sitz}/RMS_{Sitz,Grenz} \qquad (2)$$

Unacceptable values were selected as limitations for RLF and RMS_{Sitz}. For the wheel load factor this was $RLF_{Grenz} = 0.33$ and for the weighted seat acceleration $RMS_{Sitz,Grenz} = 1.7\ m/s^2$. Through this it was possible to simultaneously award a single weighting for two parameters with different dimensions.

With all vehicle variants the parameters for the front and rear axle suspensions were first of all optimised according to equation 1 with the help of the target function. The following simulation procedure then investigated the driving characteristics of the vehicles fitted with the different axle variants in association with driving speed and different loadings.

In *figure 1* the progression of the wheel load factors on both axles in association with driving speed is shown for a vehicle with front axle suspension as well as for an unballasted vehicle with rear axle suspension. As suspension activation was used an artificially generated driving surface profile representing a field way. The comparison of the wheel load factors for the rear axle with and without rear axle suspension emphasized the important role of rear axle suspension in increasing driving safety whereas, under the same loads, no significant difference was noted as far as the front axle was concerned. The safety gain with rear axle suspension was especially noticeable at high driving speeds.

When comparing the wheel load factors determined through the speed range for the different loadings (*fig. 2*) the advantages of suspension on both axles were clearly showed. In particular where load was lifted off one axle through ballasting, full suspension led to an increase in driving security in this axle. Also involved in the comparison were values from a tractor with both axles without suspension.

Figure 3 shows the evaluation of the simulations with regard to driving comfort. Although seat suspension was done without in the tractor variants with full suspension the resultant comfort lay clearly under that found in the variants with front axle suspension and seat suspension. This applied for the total speed range. Front axle suspension on its own in association with driver seat suspension improved driving comfort only to a limited extent, however.

Alongside the vertical dynamic properties, lateral dynamic forces have a substantial influence on driving security when tractors with full suspension are driven at higher speeds. So far, reliable evaluation method exists for the lateral dynamics of tractors and for the tyre performance values necessary for theoretical investigations in this respect. For this reason only limited investigations into the behaviour of tractors with full suspension in curves was attempted within this work. What was done showed that the horizontal axis stabilizer had a strong influence on the self-steering capability. Especially with one-side ballasting (front or rear ballast) handling was shown to alter dramatically according to the position of the stabiliser and further investigations on this theme are urgently required.

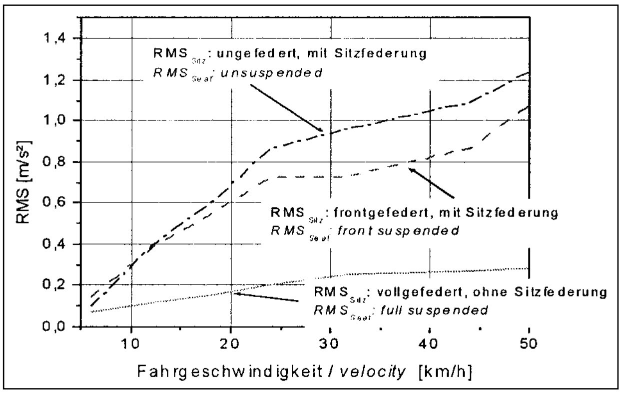

Fig. 3: Comparison of the weighted seat acceleration in association with driving speed in tractors with different suspension