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Investigation and optimisation of the vibration characteristics of tractors with front-axle suspension and cab suspension

Untersuchung und Optimierung der schwingungstechnischen Eigenschaften von Traktoren mit gefederter Vorderachse und gefederter Fahrerkabine

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INTRODUCTION

The agricultural framework conditions of the EU and the WTO lead in all European countries to rationalisation measures and constrain the farmers to use more powerful agricultural equipment or to work encompassing. The resulting increase of working hours of tractors and increasing driving speeds lead to a higher physical strain of the drivers caused by vehicle vibrations which are unhealthy and impair the road safety (steer-ability, braking effect). So a lot of tractor manufacturers offer for tractors of the top performance class suspension systems for the front-axle instead of a rigid front axle. To improve the ride comfort some manufacturers combine this measure steps with a cab suspension as well.

Especially in the sixties and seventies the ride comfort of tractors was investigated in detail. The technical basis for the layout of front-axle suspension systems and for cab suspensions is documented sufficiently in literary. Indeed since 1970 the admissible top speed of tractors (from 25 to 50 km/h, Fastrac to 80 km/h) and the vehicle masses, including the mounted equipment, have more then doubled. Actual extensive investigations according ride comfort and road safety of modern tractors under different practical conditions and their comparison are not available. So in the years 1998 to 1999 BLT Wieselburg has investigated together with tractor manufacturers the effectiveness, the optimisation and tuning of the front-axle suspension system, cab suspension and of the driver seat and their influence on the ride comfort and road safety.

EXPERIMENTS AND METHODES

For the tests described in this contribution 3 tractors of the top performance class (110 kW/150 hp) of three different European manufacturers were available. Alternatively for all three vehicles the front-axle suspension and the cab suspension could be blocked for the trials. So in total four different suspension conditions were investigated. All three cab suspension systems worked with the principal of a suspended seesaw (single axe suspension) what means that the cabs were fixed elastically on both front mounting points while the both rear cab mountings were replaced by mechanical or hydrodynamic suspension damper elements.

In distinction to a full-suspended cab (e.g. Renault) and a full-suspended vehicle (JCB) this solution is not only in technical very simple and cheap but also tractors of series production can be fitted up relatively simple. Although already in 1988 R. Stayner (Silsoe Research Institute, UK) mentioned this in literary for the first time - it was developed for a British cab manufacturer – in 1993 Fendt was the first using this concept of a simple cab suspension for tractors of series production. Further manufacturers like Deutz, Same and Steyr as well as supplement manufacturers (Hegele) followed.

Under comparable conditions more then 2000 test rides were carried out on the existing test tracks of BLT (100 m and 35 m OECD test track according ISO 5008, 24 m testops track, BLT available asphalt- and concrete road) and under practical conditions as control of the relevance on praxis of the results of the test tracks. Test rides varied with different tyre pressures, ballast weights, driving speeds and driver seats.

The appearing vibrations in 3 directions were measured at selected points (e.g. seat area, seat mounting point, frame, front axle, rear axle) by a multi channel data measuring system (Hottinger) during the drive as well as the relative movements between front axle and frame and the forces in the upper link of the hydraulic linkage when mounted equipment was used. According ISO 2631 the measured vibrations were weighted in the laboratory. Vibrations not relevant for the ride comfort (e.g. engine vibrations) were separated by filters and evaluated according to different criterions. Together with the tractor manufacturers the 3 vibration systems (front-axle suspension, cab suspension, seat suspension) were optimised and tuned.

RESULTS

A respectable opinion on the vibration behaviour of tractors with front-axle suspension, cab suspension and suspended seat has to include different road conditions, different conditions of use and especially driving speeds. Because of the different behaviour of tractors on resonance comparisons at a single speed are not allowable and can lead to incorrect conclusions. To remove the influence of the highly different quality of tractor seats it makes sense to choose the seat mounting point as point of reference.

Figure 1a shows a typical course of the measured and evaluated acceleration on the seat mounting point (identical with the cab floor) in dependence on the driving speed for the 4 suspension conditions when riding on the 100 m OECD test track (rough track 100 m). Typical for the vehicle without suspension (OFF/OFF) are the resonance effects between 12 to 14 km/h and between 20 to 24 km/h. When the measure points (driving speeds) are chosen closer then the figure shows points of singularities. Aspects of costs and time showed that in general steps of 2 km/h in driving speeds are enough to make an evaluation.

In difference to older tractors modern tractors have a differently distribution of masses, higher driving speeds and a higher position of the driver. This effects that the importance of the vibration strain in z-direction decreases and the importance of the very unpleasant nod vibrations, especially when the tyres are not ideal round, increase strongly. This nod vibrations lead to higher horizontal vibrations in direction of travel (x-direction) as well on the driver seat and on the seat mounting point and can be measured quantitatively. By front side added weights and heavy equipment mounted on the rear side this effect is intensified.

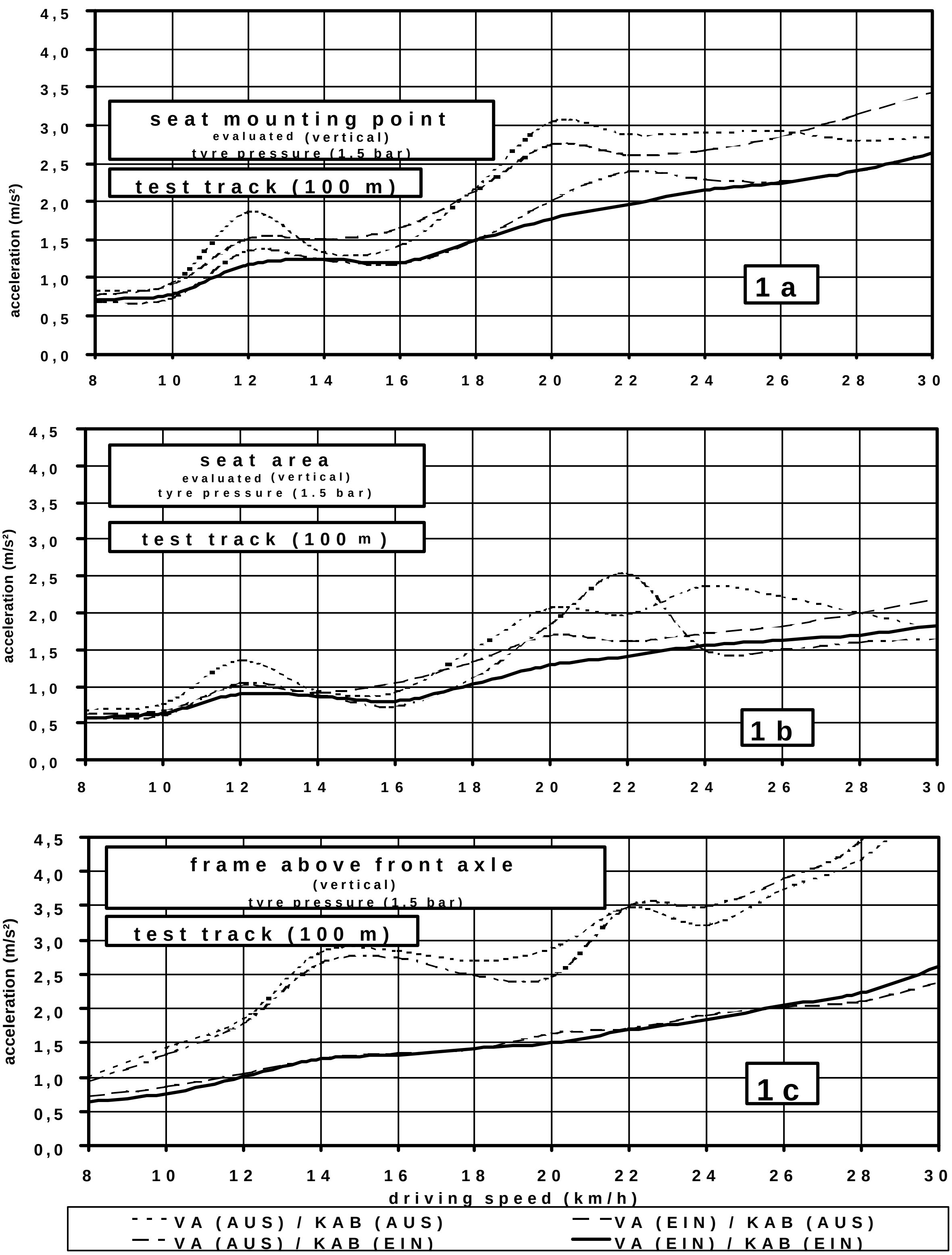

Fig. 1: Effect of speed on tractor weighted vertical vibrations on the 100 m OECD test track with fixed and/or activated front-axle suspension and cab suspension: a) at the seat mounting point (cab floor), b) at the driver seat, c) at the frame, directly above the front axle

Bild 1: Einfluss der Fahrgeschwindigkeit auf die bewerteten vertikalen Schwingungen auf der 100 m OECD Testbahn mit ein- und/oder ausgeschalteter Vorderachsfederung und Kabinenfederung: a) am Sitzmontagepunkt (Kabinenboden), b) am Fahrersitz, c) am Rahmen, direkt über der Vorderachse

Is the front-axle suspension activated (ON/OFF), then this leads to an essential calming down of the vehicle and to a smoothing of the acceleration peaks. While the vertical vibrations on the seat mounting point (because of its position approximately above the rear axle) can be reduced only a little bit, the nod accelerations can be reduced demonstrable and visible (look at figure 1c). Is the vehicle rigid and the cab suspension activated without front-axle suspension (OFF/ON) then the nod vibrations are preserved but the vertical vibrations are reduced strongly over the whole speed range. Is the vehicle full activated (ON/ON) and has a good tuned front-axle suspension and cab suspension then this two suspension systems complement and the result is the best ride comfort over the whole speed range. Is the suspended driver seat well selected then no resonance effects appear and an additional ride comfort can be achieved.

Figure 1b shows the weighted acceleration values in z-direction on the driver seat for the same test rides like in figure 1. A comparison of the two figures shows the influence of the driver seat for all 4-suspension conditions. At 22 km/h the unfavourable combination of cab suspension and the suspended seat is remarkable!

For the same test rides figure 1c shows the influence of the front-axle suspension and cab suspension on vertical vibrations at the frame directly above the front axle. While the cab suspension has in fact no influence the front-axle suspension reduces the vibrations at the frame very essential (OFF/OFF and OFF/ON in comparison to ON/OFF and ON/ON).

Figures 2a and 2b show as example the effect of the front-axle suspension on the acceleration values at different selected points of the tractor when riding with a 5-furrow reversible plough (2,050 kg) and 1,400 kg front ballast at the 100 m test track weight and at a bad asphalt-road. The test track shows the same trends like the bad asphalt road. By activating the front-axle suspension when the cab suspension is activated the vibrations at the frame above the front-axle (z-direction) and the horizontal accelerations in direction of driving at the seat (x-direction) are reduced essential. In difference to the rigid vehicle (figure 2a from 14 km/h on, figure 2b from 40 km/h on) the vehicle drives with front-axle suspension with this actually nod vibrations producing combination of equipment substantial calmer and up to higher driving speed ranges the vehicle steer-ability and brake-ability are given and the strength strain is lower.

Certainly the front-axle suspension has to be optimal (that means soft suspension, enough free space for suspension movement and lowest friction) to work perfect. Furthermore for tractors with a very effective brake system it has to be secured that the vehicle cannot build up by the front-axle suspension.

All tests showed that only an optimal tuned combination of the 3 suspension systems (front-axle suspension, cab suspension and suspended driver seat) bring best ride comfort and highest driving safety. For tractors of the top performance class with front-axle suspension and cab suspension under an economic sight of view an approximate value of reduction of acceleration values of 50 % (in the average) as against a stiff vehicle can be achieved. The driver can directly understand the reduction of vehicle vibrations when doubling the driving speed and having the same vibration stress. Figure 3 compares the vibration stress at the seat mounting point of the 3 different tractors with activated front-axle suspension and cab suspension and in relation to the full-suspended JCB Fastrac.

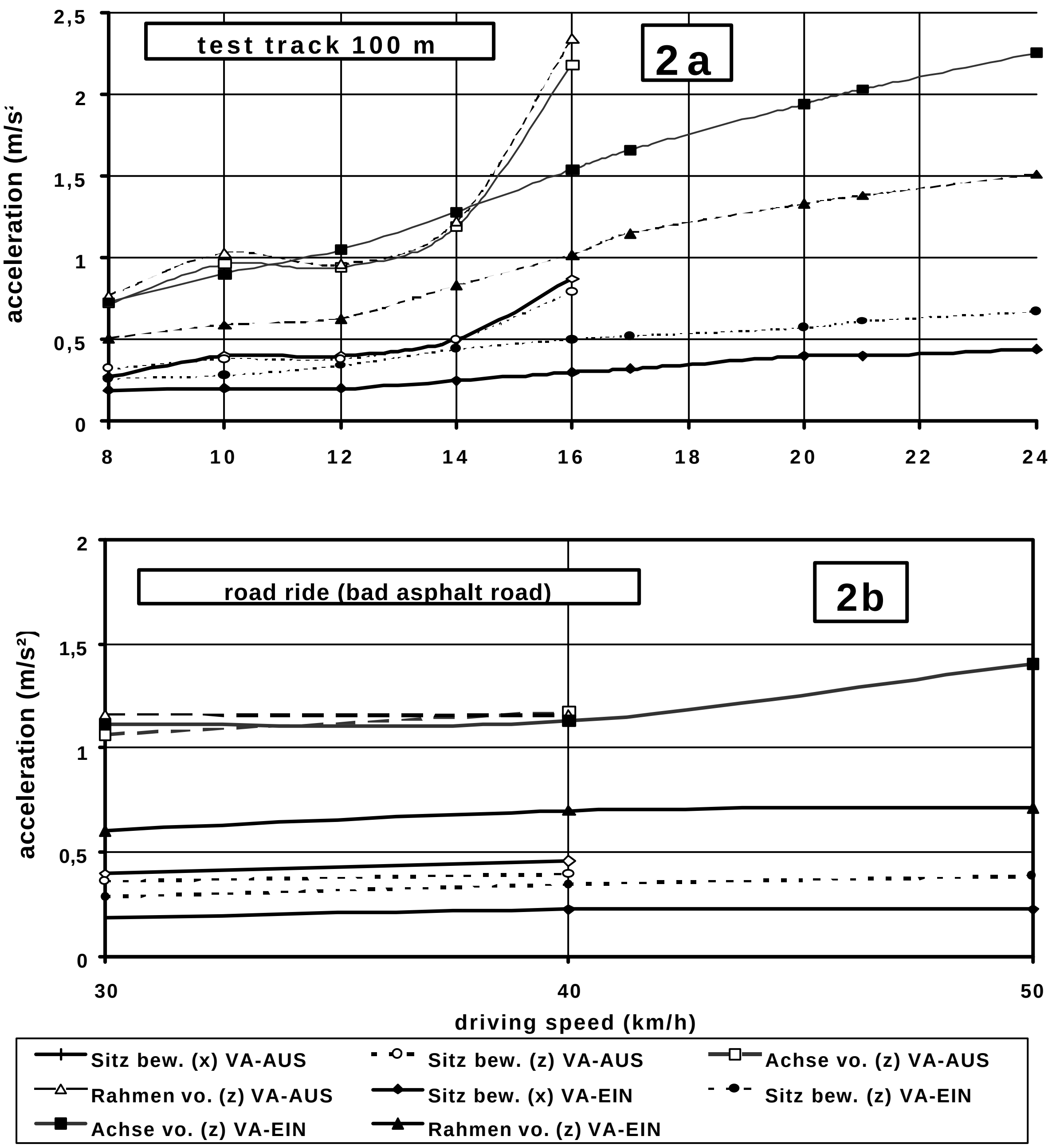

Fig. 2: Effect of the front-axle suspension and of the speed on the weighted vibrations at different points of the tractor with cab suspension (seat x, z-direction, front axle (z) and frame directly above the front axle (z))

a) at the 100 m OECD test track (8 – 24 km/h)

b) at a bad asphalt road (30 – 50 km/h)

Bild 2: Einfluss der Vorderachsfederung und der Fahrgeschwindigkeit auf die bewerteten Beschleunigungen an verschiedenen Punkten des Traktors mit Kabinenfederung (Sitz in x, z-Richtung, Vorderachse (z) u. Rahmen direkt über der Vorderachse (z))

a) auf der 100 m OECD Testbahn (8 – 24 km/h)

b) auf einer schlechten Asphaltstraße (30 – 50 km/h)

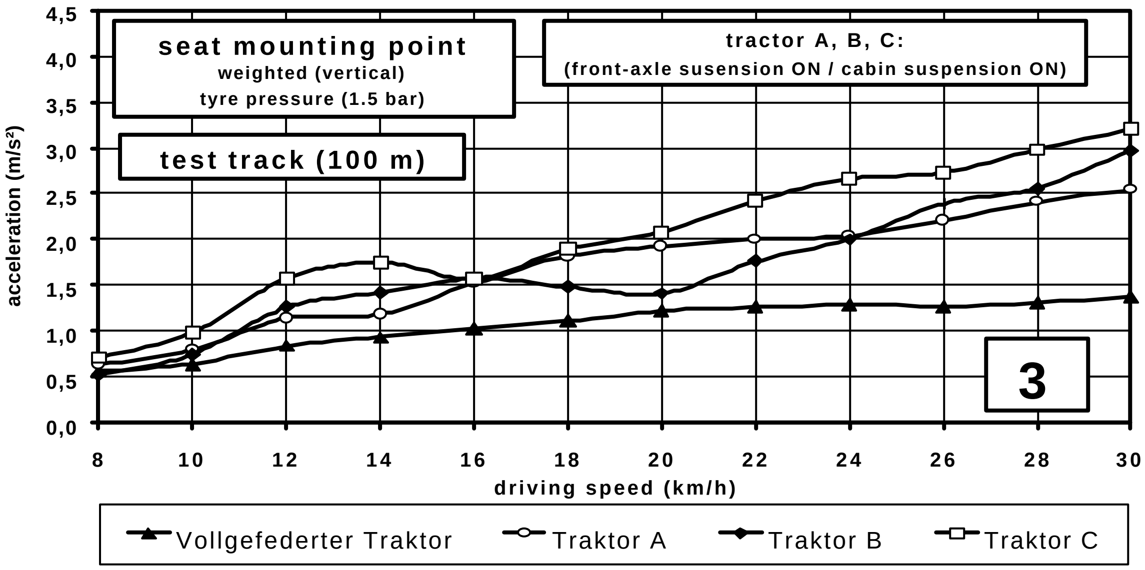

Fig. 3: Effect of speed on the weighted vertical vibrations on the seat mounting point of 3 different 110 kW/150 PS tractors (A, B, C) with front-axle suspension and cab suspension in relation to the full suspended vehicle (Fastrac)

Bild 3: Einfluss der Fahrgeschwindigkeit auf die bewerteten vertikalen Schwingungen am Sitzmontagepunkt von 3 verschiedenen 110 kW/150 PS Traktoren mit Vorderachsfederung und Kabinenfederung im Vergleich mit einem vollgefederten Fahrzeug (Fastrac)

Because all of the investigated vehicles have been adjusted subsequently the including of a front-axle and cab suspension and their optimisation should be taken into consideration for new concepts of tractors from which further improvements of ride comfort and cost reductions can be resulting. The present results of the investigation should be integrated in a mathematical simulation model to make the optimisation of the vibration properties of different tractor models possible in the planning stage.

SUMMARY

The ride comfort and safety of 3 tractors of the top performance class (110 kW/150 PS) with front-axle suspension, cab suspension and suspended driver seat from different producers were investigated on different test tracks at the BLT Wieselburg and on natural tracks. The vibration characteristics at different points of the tractors (i. e. seat, seat mounting point, frame), at different speeds, different tyre pressures and with different equipments are determinate with fixed and activated suspensions. The tuning of the three suspension systems (front-axle, cab, seat) were analysed and optimised.

Only an optimised combination of front-axle suspension, cab suspension and suspended seat reduces the unhealthy ride vibrations by 50 % and brings high ride comfort and better steering and braking conditions.

This contribution is available at the homepage of BLT Wieselburg, <u>http://www.blt.bmlf.gv.at</u> and can be downloaded without any costs.