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Active Pneumatic Suspensions for the Tractor Seat

Microprocessor-Controlled Adjustment of Characteristic Curves for Driver Seats

Although the proportion of tractors with extensive suspension systems (front-axle suspension, cabin suspension, shock absorbers) is growing, it is still driver seat suspensions that play the most important role in reducing the vibrations vehicle operators are subjected to. This article presents an actively controlled suspension system that involves adjusting the characteristic curves. It discusses this system's operation principle and presents measurements.

Actively controlled driver seats have been tested and studied in university and industry laboratories since the 1970s. It did not take long to demonstrate that solutions of this kind are possible [1, 2]. The principal benefit of active-suspension seats is that they isolate the tractor operator much more effectively from vibrations that are induced by the vehicle's movements and transmitted via the cabin floor. However, design-related difficulties and cost constraints prevented actively controlled driver seats from achieving widespread adoption until a breakthrough occurred in 2002. That is when the "John Deere Active Seat" succeeded in reducing the amount of space required to install a driver seat with active suspension to the point that it became a feasible option for selected large tractors. The active seats used in these vehicles use an actuator driven by the tractor's hydraulic system.

The following discussion illuminates the technical foundations of the next stage in developing actively controlled driver seats take the form of "plug-and-play" solutions and can be used on tractors of all sizes. The prerequisite for this is a concept that not only minimizes the required space for installation, but also cuts down on the seat's energy consumption to eliminate dependence on the tractor's hydraulic system. To achieve this, the principle of characteristic curve adjustment was developed. This in turn is controlled by the seat's internal pneumatic system.

Suspension Types

A very precise distinction can be made among passive, semi-active and actively controlled suspensions by considering the corresponding simplified differential vibration equation for a base-excited single-mass oscillating system.

$$\underbrace{m\cdot\ddot{x}}_{mass} + \underbrace{b\cdot\dot{x}}_{damping} + \underbrace{c\cdot x}_{spring} = \underbrace{F_{floor}}_{ex.\,force\_floor} + F_{control}$$

b = Attenuation constant [(N•s)/m]
c = Suspension rate [N / m]
m = Mass [kg]

- If the attenuation constant and the suspension rate are not controllable and $F_{control} = 0$, then it is a passive suspension.
- If the attenuation constant and/or the suspension rate change as a function of the speed or acceleration, and if $F_{control} = 0$, then it is a semi-active suspension.
- It is an active suspension if the attenuation constant and/or the suspension rate can be controlled and $F_{control} \neq 0$.

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Keywords

Tractor seat, air suspension, active control, adjustment of characteristic curve

Literature

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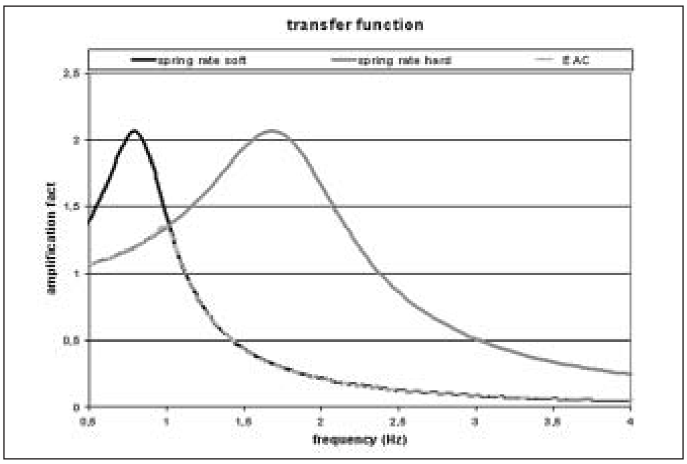

Fig. 1: Theoretical transmission as a function of a suspension's characteristic curve

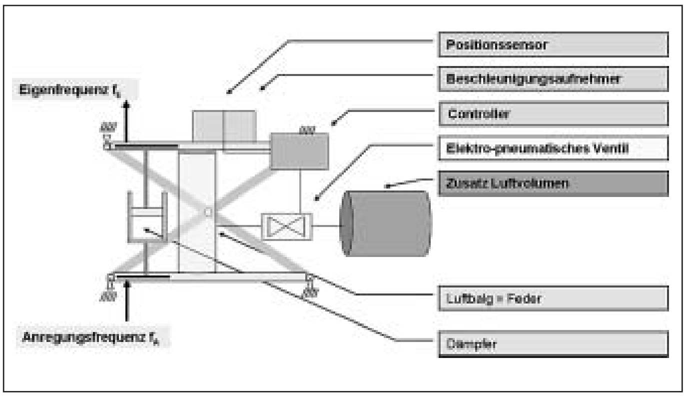

Fig. 2: Schematic diagram of Grammer EAC (electronic active controlled suspension)

How Characteristic Curve Adjustment Works

In order to understand the fundamental possibilities inherent in the functional principle of characteristic curve adjustment, it is expedient to consider the transmission function of a single-mass system that is capable of oscillating. The basic differential equation is modified by periodically applying the circular frequency ω_z to the force acting on the base.

The equation $x = A \cdot \cos(\omega_z \cdot t - \varphi_z)$ yields the following well-known transmission function:

$$\frac{A_z}{r_z} = \frac{1}{\sqrt{\left[1-\left(\frac{\omega_z}{\omega_0}\right)^2\right]^2 + 4\vartheta^2 \cdot \left(\frac{\omega_z}{\omega_0}\right)^2}}$$

$\omega_0 = \sqrt{\frac{c}{m}}$: Eigenfrequenz

$\vartheta = \frac{b}{2m\omega_0}$: Dämpfung

ω_z : Anregungsfrequenz

Figure 1 shows that a suspension with a variable suspension rate can always be controlled so that, with a periodically applied force, the vibrations are optimally isolated. The broken line in Figure 1 illustrates this case. The two continuous curves represent the transmission functions of suspensions with different characteristic curves having identical attenuation. Here it must be taken into account that the shape of the transmission function greatly depends on the attenuation of the suspension system. For example, a weakly attenuated system would exhibit a very low amplification factor in its isolated portion. Conversely, a pronounced increase in resonance would be observed in the resonance zone $\omega_z < \omega_0 \cdot \sqrt{2}$.

With characteristic curve adjustment, the most favourable suspension curve is chosen for each induced frequency. This principle is implemented by engaging or disengaging additional external volumes. At the same time, the compressed or expanded air stored in an additional volume while oscillation is taking place releases energy when re-engaged. This energy can be utilized to counteract the movement that is induced in the cabin floor. The energy stored in the additional volume in the form of compressed air is thus available for making the required corrections, virtually without any losses!

Control Algorithm

The above discussion of basic principles shows that a very simple control algorithm can be found for all periodic forces acting on the system.

However, the main forces acting on a driver seat are jolt-like stresses. The result of driving over uneven terrain and poor roads, these are characterized by large amplitudes of brief duration. Such non-periodic forces constantly yield frequency spectra that prevent the effective application of a simple frequency-dependent algorithm. This makes it essential and expedient to find an algorithm that depends on discrete time functions.

Results and Measurements

On test rigs in the laboratory and in field trials, it was shown that an actively controlled seat can significantly improve the isolation of vibrations compared to passive and semi-active low-frequency suspensions. *Figure 3* contrasts the transmission functions of an active suspension and a low-frequency suspension. It was established that active control markedly decreases the amplification factor across all frequency ranges! Also notable is the low increase in the resonance zone in combination with a flat curve in the isolated zone.

Comparative Measurements

The measurement setup for the comparative measurements discussed in the following was designed to ensure roughly identical measurement conditions for the seats being compared. To accomplish this, both seats were mounted on parallel beams acted on by a hydropulser. Measurements were made using identical acceleration sensors. Both seats were occupied by drivers of the same height and weight. The acceleration sensors were attached between the seat cushion and the driver in each case.

Figure 4 shows the acceleration values that typically occur when driving over high, pronounced obstacles such as furrows or ramps. The maximum acceleration values were considerably lower than the simultaneously measured semi-active low-frequency suspensions. "Severe jolts" resulting in maximum acceleration values above 30 m/s^2 can be completely prevented by an active suspension.

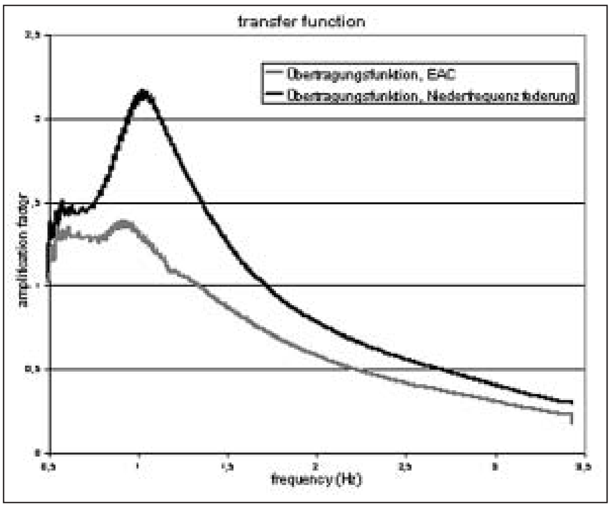

Fig. 3: Measured transmission of an actively controlled suspension compared to that of a seat with low frequency suspension

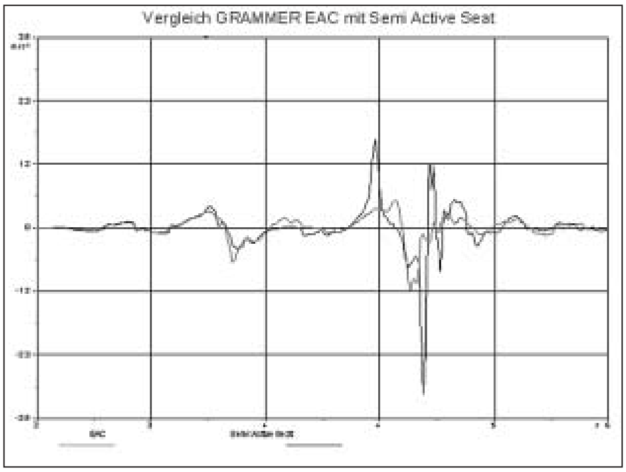

Fig. 4: Absolute acceleration values when driving over single obstacles (asmeasured between the driver and the seat)