Ullrich Hoppe and Henning J. Meyer, Berlin

Vibration Isolation in Farm Machines

State of the Art

Since the beginning of tractor development, new suspension systems have always been conceived and designed. Simple seat suspensions were the starting point. Currently complete vehicle suspensions and implement suspension are state of the art. An end in the development cannot be foreseen. This paper discusses the benefits of the different systems and whether the costs exceed the real benefits achieved in many cases.

Dipl.-Ing. Ullrich Hoppe studied vehicle technology at the TU Berlin and has been working as a scientific employee since 2002 at the newly-created branch of machinery system design (Head: Prof. Dr.-Ing. Henning J. Meyer), Zoppoter St. 35, D-14199 Berlin; e-mail: *Ullrich.Hoppe@tu-berlin.de.; Henning.Meyer@tu-berlin.de*

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Literatur

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In order to get a basic idea of vibration reduction, we shall have a detailed look at the term of "vibration". In general, we distinguish between harmonic and stochastic vibrations, with actually any stochastic vibration being an addition of different harmonic vibration parts. Vibrations having a certain frequency domain (approx. 20 - 20.000 Hz) and being above a certain intensity are perceptible for man; these are called sounds. Here we distinguish between handling noise and air sound according to the way of the vibration spreading. Above a certain intensity, the entire human body - not only the sense of hearing - perceives the vibrations it is exposed to, even the audible ones.

The vibrations emerging from agricultural machinery and mobile working machines have various causes - on the one hand, these are events which are caused by the vehicle itself, e.g. vibrations

- by engine operation,
- the process (operation of the driven device) or
- as a result of in-stationary events between partial systems, e.g. transmission at the load alternation.

On the other hand, vibrations may get into the vehicle from outside or even arise from the vehicle's interacting with the environment. This applies both to wind noises and to the vibration stimulation caused by the vehicle going over road profiles. The way of vibration spreading is decisive for the vibration's further development after being introduced into the system. *Figure 1* shows the way of vibration spreading for those vibrations stimulated when going over way profiles: the coercive movement of the wheel is passed on over the elasticity of the tire into the rim and then into the axis. Thus, the axis together with the tire spring can be seen as a first vibration capable system. The vibrations of the axis are passed on via the axis, springing to the construction/frame, thus delivering a new vibration capable spring mass system. The vibrations of the frame finally reach the cabin or arrive directly into the seat springing, affecting the driver in the end. Depending on the question of whether the tractor is equipped with a cabin suspension or a driver's seat suspension only, there again will be vibration capable systems having dynamics, which may reduce or increase the amplitudes according to the vibrations' frequency.

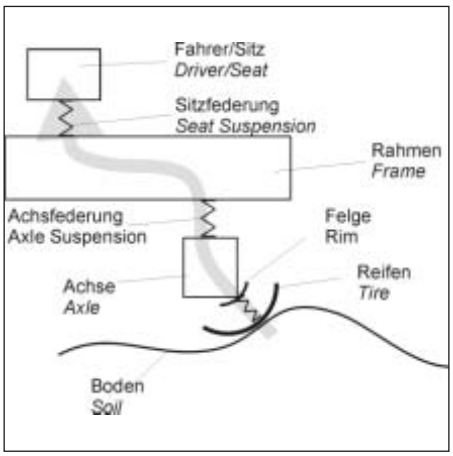

Fig. 1: Vibration expansion in tractors

Vibration Consequences

The consequences of the vibrations are dependent on the object considered. So vibra-

Table 1: Overview of useful vibration isolating activities in tractors

Activity	Isolation Range	Damping	Costs	Extension	Re-fitting
Tire	> 3-5 Hz	0	++	++	++
Front axle suspension	> 1-5 Hz	++	-	+	+
Rear axle suspension	> 1 Hz	++*	--	--	-
Cabin suspension	> 2 Hz	++*	0	+	+
Seat suspension	> 1-2 Hz	+*	0	++	++
Active Seat suspension	> 0,5 Hz	/*	-	-	+
Active EHR	0,5 - 5 Hz	/	+	+	++
Front hoisting		+	+	-	+
Engine hydro bearing	> 3 Hz	/*	0	0	+
Active suspension	-	/*	--	/	-
Spring-mounted hitch	> 3 Hz	0*	0	-	+

* Variable damping possible

tions affect
• the driver,
• the process,
• the machine and
• the environment
with different intensities (*table 2*).

The best known consequences, which are economically recorded are those syndromes described in the BK2110 [1] occupational disease. However, there is only little knowledge and economical consideration of the vibrations' influence on the driver's concentration, impeding his driving ability for complex machines and, thus, causing accidents.

Within the framework of the DFG project of "Lastkollektive am Traktorrumpf", the TU Munich has done intense studies on the vehicle's load, caused by vibrations [2]. Here the vibrations mainly cause material fatigue. Particularly electronic components can easily suffer from vibration influences, demanding an efficiently working vibration decoupling for modern electronically controlled systems.

The public is still more interested in the vehicle vibrations' influence on the environment. These are both the noise and increasingly the soil compaction, in particular with the continuous trend towards always heavier and faster machines.

It is finally the quality of the process itself, which is influenced by the vehicle vibrations. This is shown by the uneven distribution of spray with semi-mounted or pulled field sprayers or with semi-mounted fertiliser spreaders. With a rigid coupling, the dynamics of the device transfers to the material to be applicated, thus causing a heterogeneous distribution on the area.

Methods For Vibration Reduction

To avoid the vibration consequences or at least reduce them, engineers have developed measures for vibration decoupling. In principle, there are two different possibilities:
• specific vibration isolation of single assemblies –> selective vibration decoupling
• prevention of the vibration emergence at the complete system –> integrated vibration decoupling.

Both measures are used today and shall be explained using the following examples.

Vibration isolation

The vibration isolation means decoupling single parts or groups of parts with the help of spring muffler elements from the vibration stimulating rest system. This is based on the fact that muffled one mass swinger, which are e.g. the driver's seat or the cabin in this case, in their function as a transmitter do an isolating job above the system's natural frequency. The stimulation decreases. The system's natural frequency is dependent on the sprung mass and the spring stiffness of the system due to the equation

$$f = 1/2\pi\ (\sqrt{c/m})$$

The natural frequency decreases with increasing mass and sinking spring stiffness. If a system shall already isolate against vibrations of low frequencies, then the spring stiffness must be low, delivering huge excursions. To counteract this phenomenon, one makes use of variable spring characteristics, e.g. with the hydro-pneumatic cabin suspension. Here the spring stiffness is adapted depending on the mass of the cabin and on the springing way here.

Vibration prevention

Another attempt is to prevent the vibration emergence itself. Nowadays, engineers often make use of a so-called "Tilger" or vibration reduction system. This is an oppositely vibrating system, which therefore withdraws the energy from the vibration to be eliminated. This principle was used for vehicles and is realised for construction machines and tractors with the help of the front or back hitch cylinders. Since energy permanently must be supplied for vibration prevention by means of the hitch and the equipment appended, it is an active measure. The frequency domain of the vibration prevention is dependent on the dynamics of the hydraulic components and the vibration prevention mass. A considerable disadvantage of this system is the strong dynamic component load, acting on the interface between vibration prevention system and the swinging system.

If it is not possible to directly impede vibrations, e.g. when going over uneven profiles, it will at least be possible to reduce vibration transmission and vibration spreading near the source. With respect to any following system, this means impeding further vibration stimulation.

Table 1 shows vibration decoupling measures used today. Some of these possible measures already exist in almost any mobile working machine (pneumatic tire suspension), others are used rarely (full suspension) or even not at all (active undercarriage). There are various reasons for this, the main one is the financial effort compared to a (putatively) low use. The primary benefit of a front axle springing consists in an increase of the transport speed of 40 km/h to 50 km/h, on average 20 %. With a transport task share of 40% [3], this means productivity increases by 8%. A good seat suspension with a reduction of the rated vibration effective value by 60% facilitates an increase of the outline time, and so a prolongation of the working time by up to 60%. The working conditions will be decisive for having a quantitative increase of the productivity, but it might reach 60% in theory. The possible productivity advantages given by an active full suspension are nearly unknown, but it will be much more expensive to realise it.

Table 2 shows the consequences of the different springing measures. We can see that the different measures are designed to serve the same purpose. Measuring tests have shown that suspension of the front axis, the cabin and the seat of a standard tractor will deliver the same comfort standard as a full suspension tractor without cabin suspension [4]. On the other hand, the suspension of both axes is the only opportunity to increase not only the driving safety, but furthermore to improve the productivity and to counteract the soil compaction as well.

Table 2: Effects of suspension activities

Effect to	Driver	Vehicle		Process	Environment
		Strength	Drive safety		
Activity					
Tire	+	+	+	0	+(++)[1]
Front axle	0	0	++	0	0
Cabin	++	0	0	0	0
Seat	++	0	0 (-)[2]	0	0
Engine	0	++	0	0	++
Hitch	+	0	0 (++)[3]	++	0 (+)[4]
Front hoisting	0	+	+	++	+

[1] Tire pressure controlling; [2] with huge relative movement; [3] with vibration absorber; [4] selective application

Result

Although there are various methods for vibration reduction today, the possibilities offered by the available systems are not yet completely exploited. Sometimes less is more, i.e. a well-matched system might be preferred to a combination of several systems which are badly adapted. Too little attention is still paid to the effects of vibrations on the environment and on the process, but it will surely become a major research subject due to the demands for the farming's sustainability.

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