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SEMI-ACTIVE VEHICLE CAB SUSPENSION USING MAGNETORHEOLOGICAL (MR) TECHNOLOGY

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ABSTRACT

Agricultural vehicle manufacturers are employing new semi-active cab suspensions using Magnetorheological (MR) technology. The use of MR technology in cab suspensions is a logical next step in improving operator safety and comfort. The speed and simplicity of MR technology enables the use of low-stiffness springs without the compromise between ride and stability, and can provide roll, isolation and pitch stability. MR fluids are materials that respond to a magnetic field with a dramatic change in rheological behavior. These fluids can reversibly change instantaneously from a free-flowing liquid to a semi-solid with controllable yield strength when exposed to a magnetic field. MR systems have been developed with a modular, integrated approach that can include a damper containing MR fluid, air spring, automatic electronic leveling, sensors, controller, and CANbus data communication.

KEY WORDS

WBV, whole body vibration, MR Fluid, Magnetorheological, Cabin suspension

INTRODUCTION

The impact of vibration on humans has been studied and reported since the 1930's with first reports on the relation of spinal trauma and truck and tractor driving published in the 50's. RM Stayner has compiled a report [1] with about 230 references on Whole-Body Vibration (WBV), Hand and Arm Vibration (HAV) and shock. WBV describes the vibrations generated by any machine, be it tools or vehicles, transmitted to the human body and which, if above a certain intensity and duration, causes detrimental physical effects (from motion sickness to spine and neck pain). The interest of this study goes to heavy duty vehicles used in agriculture, construction or transport, where WBV is caused by the wheels driving over uneven or rough surface or operating various attachments to excavate the ground or load materials.
Numerous measurements have been taken and compiled by various organizations like Landesamt für Arbeitsschutz (LAS) in Potsdam or in cooperative work under the EU mandated Advisory Committee on Safety

and Health at Work (by HSE, ISVR, HSL, BGIA, INRS) [2]. Vehicles that are often listed to contributing to WBV induced problems involve: forklift trucks, tractors and other agricultural machinery, heavy construction vehicles, like excavators, loaders, overhead (bridge) cranes, high speed boats, not to mention military numerous vehicles.

Vibration is defined by magnitude and frequency. For WBV it is most common to measure and report the vibration magnitude by its root-mean-square weighted acceleration (m/s²). As to the vibration frequencies their effect on health being variable, but the most relevant ones are between 0.5Hz and 80 Hz. To better modulate the effect of frequency, factors are applied (function of absolute frequency as well as for x, y or z directions) in order to obtain frequency weighted vibration values.
Figure 1 illustrates the levels of vibration magnitude in common equipment used in Europe [2].

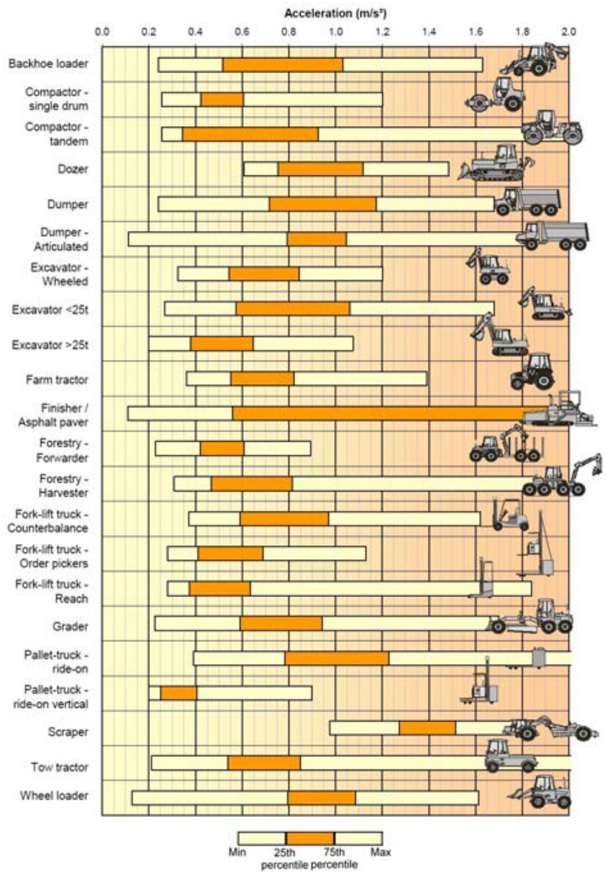

Figure 1: Examples of vibration magnitudes for common equipment on the EU market.

The physical agents Directive (Vibration) 2002/44/EC that came into force in July 2005 defines a WBV exposure action value, above which control measures must be implemented to limit the WBV risks, as well as exposure value limits above which workers must not be exposed to. The daily vibration exposure action value (A(8), the continuous equivalent acceleration, normalised to an 8 hour day) is 0.5 m/s² and the daily exposure limit value is 1.15 m/s².

TRACTOR MR SUSPENSION SYSTEM

Focusing on solutions to WBV in heavy duty vehicles, emphasis was put on agricultural vehicles as they move over all sorts of terrain, use attachments to perform tasks that increase vibrations and shocks, and eventually see their speed increased to the 60 km/h range. The size and weight of cabins continue to increase, and despite very good seat suspensions solutions, shocks, roll, pitch are increasingly difficult to mitigate. The impact on the health of tractor drivers caused by the transmitted vibrations is known and manufacturers have offered various levels of NVH solution to their customers. There are four types of tractor construction when it comes to suspensions:

1) Unsuspended tractor
2) Suspended cabin tractor
3) Suspended front axle & suspended cabin tractor
4) Fully suspended (front & rear axle) tractor

For tractors, the classic "one-piece" engine-transmission-rear axle construction makes integration of axle suspension difficult or expensive, such that many tractor manufacturers mitigate the vibration reduction challenge by installing seats with x,y,z suspensions (dampers and (air) springs). Those systems have been shown to reduce z-axis vibration acceleration by up to 65% [3]. The next step is the incorporation of various cabin suspension systems. In 1987 Renault, now Claas, developed and offered the "Hydrostable" cabin suspension system with four coil-over-damper suspensions at each cabin corner, struts and anti-roll bars. CNH offers a "Comfort Ride" system where the front of the cab is on rubber-metal mounts (or higher performance viscous versions) and the rear cab corners are suspended on coil-over-damper suspensions over the rear axle. This is a typical solution adopted by many manufacturers. Only JCB, towards the end of the 80's, launched the "Fastrac", a front and rear axle suspended chassis for speeds up to 65 km/h. Finally a commonly manufactured tractor suspension system is a front axle suspension system (CNH "Terraglide", John Deere "Triple Link Suspension"), which is combined with a two point cab suspension. Starting from those existing systems and based on the proven Lord magneto-rheological (MR) technology, an integrated adaptive cab suspension system was developed to further reduce WBV and improve ride comfort for tractors that have larger and heavier cabins and increased driving speeds.

DESCRIPTION OF ADAPTIVE MR SUSPNESION

The Lord Smart Fluids based on magneto-rheological (MR) formulations are widely used in automotive suspensions technology [4][5][6]. They are proven in GM, Honda, Audi, Ferrari car models and in development for adaptive engine mounts and bushings. MR dampers have wide control range that depends mostly on the applied current which generates a magnetic field which is in turn affecting the rheology of the fluid. As such, the applied magnetic field controls the energy dissipation of the fluid inside the damper. Figure 2 shows the forces obtained with a small MR damper.

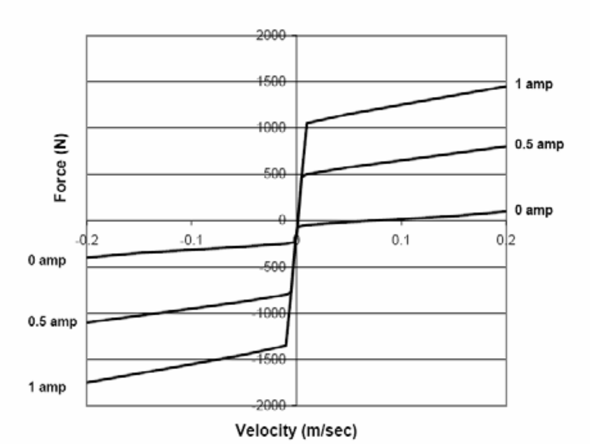

Figure 2 RD1005 MR Damper with 70 cm^3 fluid volume and max 240W dissipation @ 20 cm/s

The suspension unit is based on three components: first a MR damper with +/- 50 mm stroke, a maximum of 350N damping force in OFF (no current) state and up to 3500N in full ON state at 2A in extension or compression. Second, over the damper, an air spring is attached. Finally both parts are operated via a control module with integrated air levelling valves and microprocessor control board.

The control part of the damper locate above the air spring, contains an inlet and outlet for the compressed air used to regulate the air spring which is also used to level the cab.

The valves are controlled from the main electronic board that also contains the microprocessor and memories with the control algorithms and tractor specific tuning parameters. The damper position is determined by a magneto-strictive sensor located inside the damper rod, an xyz accelerometer on the electronics board delivers the data for movement control. The unit communicates with the other MR suspensions and the tractor ECU via CAN Bus.

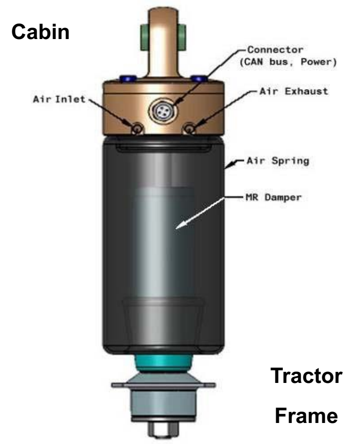

Figure 3: Integrated MR suspension prototype (integrated electronics) schematic view

In terms of mechanical integration on the tractor, the simplest design consists of two hard front rubber mounts which provide roll stability coupled with two MR units at the rear providing isolation and pitch stability. Next one can design a 2-point control with 2 MR suspensions at the rear providing isolation, pitch and roll stability, coupled with two soft front rubber mounts. This solution potentially eliminates the roll bar.

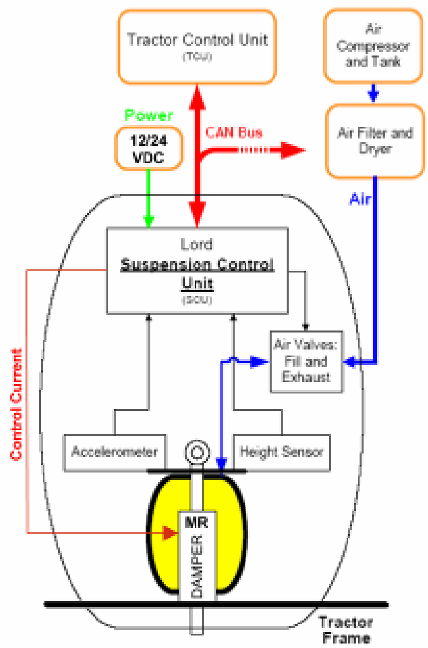

Figure 4: MR cab suspension system layout

Finally four MR suspensions at each corner represent an optimal semi-active control solution.

RIDE CONTROL STRATEGY AND PERFORMANCE

Following outputs are being addressed to optimize the ride comfort in view of minimizing WBV: 1) cab levelling control, 2) cab vertical control, 3) cab roll control, 4) cab pitch control, 5) end stop and snubber control. The inputs to the various control algorithms are numerous: right and left damper position and acceleration (lateral and vertical) come from the MR suspension and are used for pitch, roll and vertical skyhook control in order to minimize cab acceleration relative to the earth.

The CANbus also delivers information from the tractor to the suspension control unit. Acceleration (engine rpm), braking and direction (forward or reverse) and gear change are used for pitch control. Steering angle and speed are computed to counteract centrifugal force and control roll. The relative position of each unit and their relative velocity are also used to determine cab levelling and the air flow in or out of the air spring. This relative position is also used by the adaptive rate control algorithm to modulate the current to the MR damper allowing very precise, situation dependent damping control efficiently dealing with WBV.

The control algorithms have default setpoints which can be tuned to specific physical tractor cab configurations and driving situation (soft, medium, hard, field work or drive on public road). This Tractor specific tuning is done via specific software on a portable computer. The chosen gains and parameters are then sent via the CANbus to the MR suspension memory and the system operates independently thereafter.

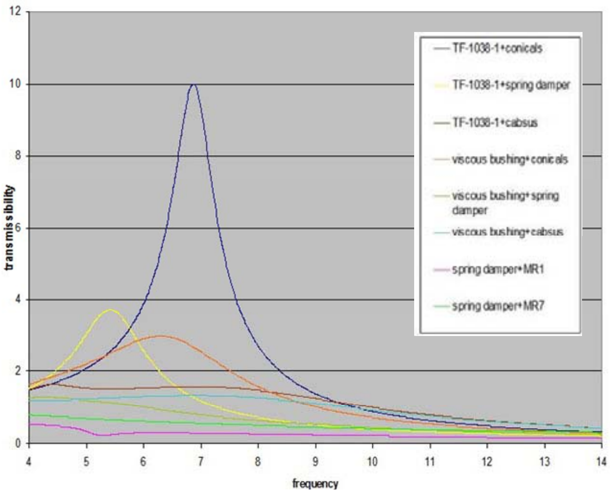

Figure 5: System performance results on test rig

Figure 5 compares the performance of various systems installed in a test rig. The MR based system insulates from vibrations in the entire low frequency range of interest. The two lower curves show the improvements of the MR adaptronic suspension vs. classical cab suspension systems. The implementation of the suspension system on heavy duty vehicles is underway and is detailed in different publications.

CONCLUSIONS

An adaptronic suspension system was developed to reduce or cancel acceleration in the detrimental WBV frequency below 20 Hz. This innovative integration of MR technology, air spring and dedicated control electronics is applicable to cabin suspension of large and heavy driver cabins in trucks, tractors or any heavy duty vehicles known to induce WBV. The MR based cab suspension offers a way to comply with the physical agents Directive (Vibration) 2002/44/EC, but mainly enables operators of heavy equipment to work under improved conditions of comfort, health and safety.

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