Comparison of Passive Seat Suspension with Different Configuration of Seat Pads and Active Seat Suspension

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ABSTRACT

Exposure to vibration induced in and around underground mine's exploration is a major concern to vehicles operators. Most of these drivers over time develop serious spinal musculoskeletal and discs problems causing low back injuries. The first purpose of this paper is to analyze the performance and dynamic response of driver/operator when subjected to different levels of vibration due to rough road conditions depicted in a mine field. The second purpose of the paper is to quantify the energy transmission in the presence of seat padding with special characteristics and active suspension. Using experimental testing data collected at NIOSH/PRL (National Institute for Occupational Safety and Health/ Pittsburgh Research Laboratory) along with model simulation algorithms developed at the University of Illinois at Chicago we investigated how acceleration transfer functions as well as absorbed power affects the different parts of the body. To this end, we used a previously validated human model which includes the head, torso segments and legs. The connective forces between body segments were modeled through modal analysis techniques from previous experimental data at the UIC Vehicle Technology Laboratory. The absorbed power and energy transmitted to the body are used as an index measure to assess the viability of the different seat padding's and active seat suspension control strategies.

INTRODUCTION

Whole body vibration can affect not only comfort, working efficiency and performance, but also health and safety. Operators of mine vehicles are in particular subject to high levels of vibrations under very constraining conditions. The vehicle operator often is more confined to a less space than in normal cars or vehicles and the seats are not equipped with a suspension system. Injury statistics from the Mine Safety and Health Administration (MSHA) showed incidences of exposure to whole-body vibration (WBV). Sources of vehicle vibrations are generally divided into two classes:

Road roughness
On-board sources

In the case of heavy vehicles, an effective vehicle handling requires a significant torque on the front axle which creates vibrations in the driver's seat. Improving the ergonomics of the seat can lessen the adverse effects of vehicle vibration. Adding a secondary suspension mechanism to the driver's seat of heavy vehicles is another solution that was found to reduce the vibration induced by the seat [Tong et al].

The initial step in optimizing the seat suspension is to identify the spring and damping coefficients that provide the best performance. This technique usually is limited to the input profile used. The optimization helps identify the stiffness of the spring. Through identification of natural frequencies yet the damping leads to values where insufficient damping provides poor resonance control and good isolation at high frequencies. On the other hand, excess damping results in a good resonance control and poor high frequency isolation.

In a skyhook suspension configuration, the seat is attached to a fixed point in the sky through a damper. The response of this virtual configuration shows an almost complete elimination of the trade-off between resonance control and high frequency isolation as observed in a passive suspension system. The Semi-active suspension designs with a variable damping rate can emulate the principle of a skyhook suspension configuration. These control ideas are explored further in this paper.

METHOD

Using Simulink/Matlab a simulation was created to reproduce the behavior of the suspension design. The experimental results collected were used to validate the simulation. It is important to note that the simulation is a based on the real control algorithm used in controlling the actual suspension.

Meanwhile, the Pittsburgh Research Laboratory (PRL)/NIOSH were experimenting with a new padding for mine vehicles operator's seat. In order to validate the new design, field testing was conducted using passive suspension. The acceleration of the vehicle chassis and the seat were collected.

The acceleration for the NIOSH seat was then fed into a lump-mass model of the human body where the RMS (Root Mean Square) accelerations and absorbed power of the body were computed and used to evaluate the new ergonomic padding design.

Furthermore, the acceleration of the chassis was fed into the UIC seat with semi-active suspension simulation. The acceleration of the seat obtained was then used as an input for the human body model. Thus, providing the HBV needed for comparing the performance of the new ergonomic seat padding with the active suspension design.

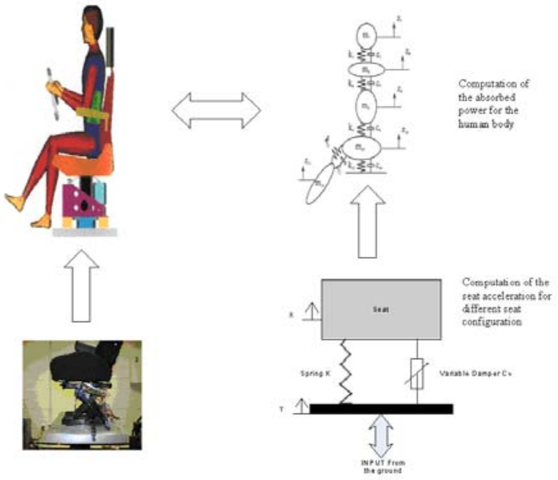


Figure 1: Scheme of the method used

SEAT VIBRATION

Let's consider the equation of motion for an ideal skyhook suspension:

$$m\ddot{x} \quad C(\dot{x} \quad \dot{y}) \quad C_{SK}\dot{x} \quad K(x \quad y) \quad 0$$

The equation is composed of three different terms:

Inertia force: $m\ddot{x}$

Spring force: $K(x \quad y)$

Damper force: $C(\dot{x} \quad \dot{y}) \quad C_{SK}\dot{x}$

If we consider a configuration with only one damper connecting the two bodies, the equation of motion would be similar to a passive suspension system case:

$$m\ddot{x} \quad C_V(\dot{x} \quad \dot{y}) \quad K(x \quad y) \quad 0$$

And the three terms become:

Inertia force: $m\ddot{x}$

Spring force: $K(x \quad y)$

Damper force: $C_V(\dot{x} \quad \dot{y})$

The damping coefficient C_V is adjusted in order to reach a damping force that matches the one given by the skyhook model this is achieved when:

$$C_{SK}\dot{x} \quad C(\dot{x} \quad \dot{y}) \quad C_V(\dot{x} \quad \dot{y})$$

$$so$$

$$C_V \quad \frac{C_{SK}\dot{x}}{\dot{x} \quad \dot{y}} \quad C$$

DESCRIPTION OF THE PROPOSED SUSPENSION DESIGN

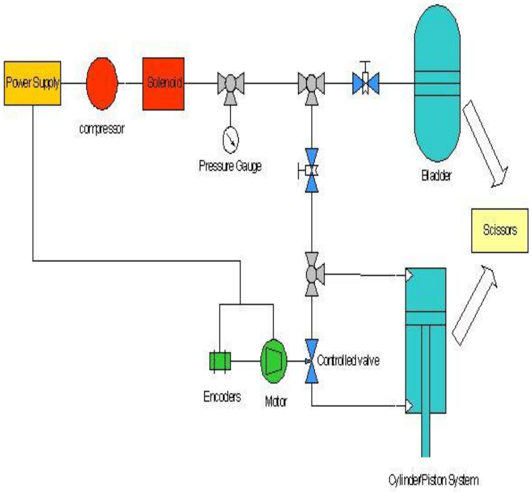


Figure 2: scheme of the proposed suspension design

The seat suspension is a scissors-type suspension forming an 'X' that opens and closes when the seat moves up and down. The seat is bolted to a platform that is driven by the system actuator. The platform corresponds to the chassis in real vehicle and depicts the input vibration to the seat. A bladder is mounted onto the crossing members as a safety precaution to prevent the bottom and top platforms of the support from colliding.

The actuator consists of a piston inside of a cylinder. Both sides of the piston are connected through a valve controlled by a motor. The proposed design is a pneumatic suspension which requires air pressure to be adjusted to achieve the required actuation vibration force.

The signals of two accelerometers placed on top of the suspension and onto the chassis are used as input by a control algorithm that returns a position for the valve in order to determine the right damping coefficient to minimize the vibration at the seat interface. The digital valve can be positioned at infinite number of positions between the fully close and fully open cases. In the current algorithm we have selected three scenarios where we can have the valve open either at 2, 3, or 4 positions, depending on the control strategy adapted.

EXPERIMENTAL TESTING

The seat suspension was tested using a single-axis MTS® shaker at the PRL NIOSH Vibration Testing Laboratory, Pittsburgh PA. The test protocol consisted of a sinusoidal vibration sweep of amplitude ±10mm and a frequency range of 1 to 4 Hz at 0.1 Hz intervals. A test weight of 40 kg was used to simulate seated vehicle operators.

Different control strategies were tested under the same input:

The pressure inside the suspension piston was set to 45, 60, and 85 PSI. The control strategies have been evaluated for each pressure, leading to a total of 12 different configurations of the suspension design that were tested.

The acceleration of the shaker and the seat pan was measured and used to calculate the ratio of the seat pan RMS acceleration to the shaker table RMS acceleration (i.e., *transmissibility ratio*). This ratio is commonly used to measure of how effective the seat suspension is and how much vibration we were able to cancel during the process.

The results show a reduction of the peak at the resonance for all the control strategies when the pressure inside the actuator increases. We also saw a direct correlation between the ability of having higher options in damping selection via the different positions of the valves and the resonance peak. The results clearly indicate how dual valves are not reliable.

SIMULATION OF THE PROPOSED SUSPENSION DESIGN

A model of the proposed suspension design was developed using MATLAB® and Simulink®. The simulation is based on the control code developed for the experimental set up. The control is performed in exactly the same fashion. Input of the accelerometer placed on the chassis is given. Displacement, velocity, and acceleration of the seat are computed according to the control strategy and mechanical characteristics of the system. The acceleration of the seat is then fed back in the simulation as an input from the accelerometer placed on the seat.

The parameters for the simulation are:

control strategy
pressure inside the system

Figure 3 shows the results obtained from both the experiment as well as the simulation under the same conditions. The correlations between the two are extremely close. Our main thrust is to be able to account for every component in the active suspension system including motor control and shaft that drives the valve as well as the encoder and feedback mechanism to set the right pressure in the piston/actuator. While the transmissibility can be approved further the lower pressure provided better results.

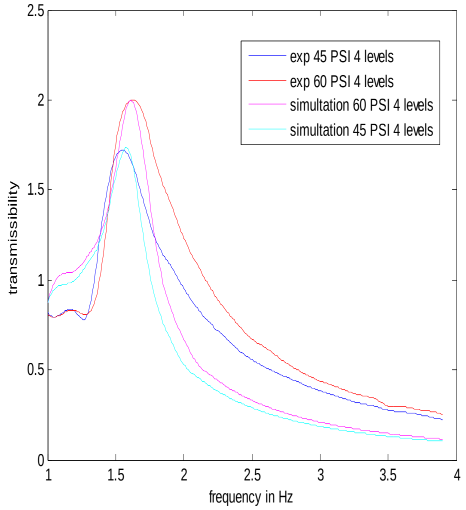


Figure 3: Transmissibility of the suspension obtained though experimental and simulated data

HUMAN BODY VIBRATION

The displacement of the seat is applied to the extremities of the spring and the dashpot connecting the lower torso to the seat. Our multibody model computes the acceleration of each body segment and its corresponding RMS (Root Mean Square) acceleration. The body segments dynamics is estimated at each step in time and the connective forces are evaluated. Furthermore, the work associated with each body segment is evaluated. Integrating further the work against time, we obtain the absorbed power for each body segments.

EXPERIMENTAL DATA

A team from PRL/NIOSH Vibration Testing Laboratory conducted a study regarding a new cabin design for a mine vehicle entitled: “Design Improvements in Operator Cab Seat and Vibration Considerations for Low-Coal Shuttle Car Haulage in Underground Mines” ASME 2005. Different loads for the vehicle were considered and various seat models were studied. The accelerations of both chassis and seat were monitored for different operators/drivers.

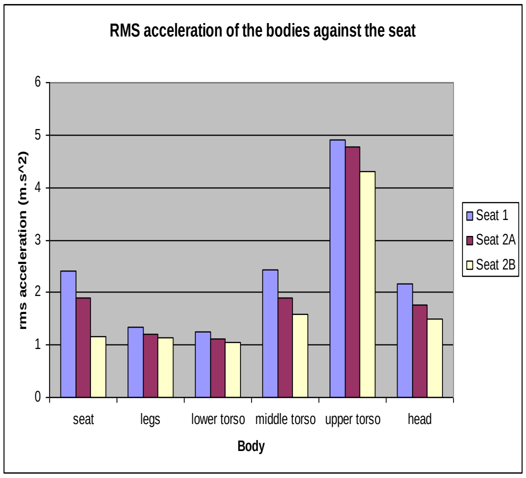
Experimental data from the above study was used as input to the current human model/driver. We used data obtained for a single operator driving a low coal shuttle with three different seat designs for the purpose of illustrating the effects of padding on the operator. The seat with the padding characteristics which provided best performance was selected.

To take advantage of the active suspension developed we used the experimental displacements for the chassis and provided that as an input to the simulation developed to emulate the new seat-suspension design. The same control strategies of the suspension were investigated against experimental results obtained using new seat pads.

RESULTS

Using the results from the human body model, we plotted the RMS acceleration, absorbed power for the legs, lower torso, mid-torso, upper torso, and head for all 3 different seat designs: a current commercialized seat (Seat 1 in the graph) and two seat designs proposed by NIOSH (Seat 2A and Seat 2B in the graph).

From the results shown in Figure 4 we see that the RMS acceleration for the new padding designs compared to the seat design from the market, seat 2B provided the best response. Yet, considering the absorbed power, the new designs reduction was seen only at the upper torso only.



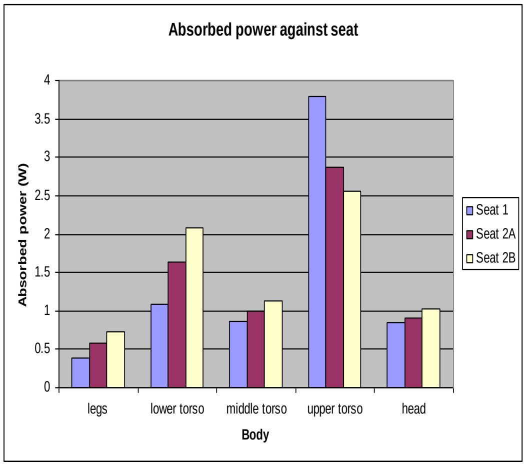
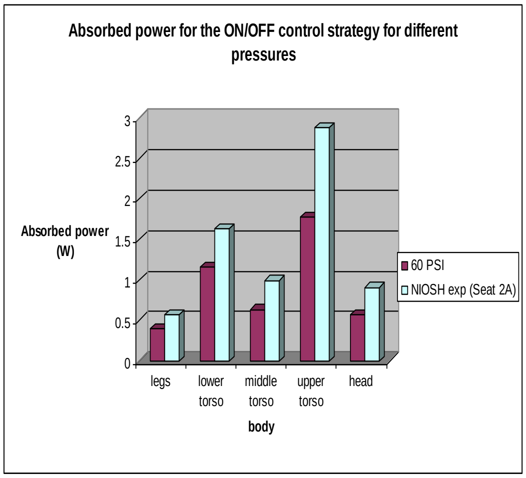


Figure 4: rms acceleration and absorbed power for a passive suspension with different seat pads

The second series of graph (Figure 5) show the human body response when the semi active suspension was employed. We plotted the RMS acceleration and the absorbed power for different control strategies and configurations of the seat suspension.

In all the configurations and for all the strategies the addition of the active suspension translates into a significant reduction of the RMS acceleration and absorbed power for each body component.



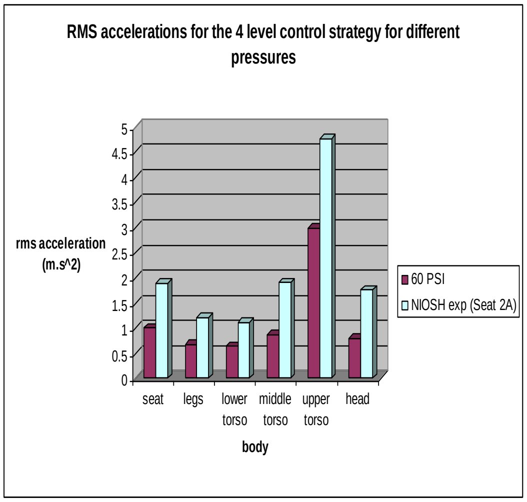


Figure 5: rms acceleration and absorbed power for an active suspension with different seat pads

There are two conclusions that can be drawn from this study. One is that padding can indeed help diminish the energy being transmitted to the body this is supported by examining both the RMS values as well as the power absorption at different body levels from padding simulation. Second, we have demonstrated that active suspension can lead to even better results and hence it should be considered as the ultimate mean to achieve low energy transmission. The cost associated with padding is a lot cheaper than the active suspension and if the difference is kept below 50% it may not justify the cost of an active suspension. This work needs further investigation and additional padding materials need to be investigated to address the advantages and disadvantages of both systems.

REFERENCES

1. F.Amirouche, *Computational Methods in Multibody Dynamics*. Practice Hall, 1993
2. F. Amirouche, *Advanced Topics in Seat Suspension Design and Human Body Vibration Control*. SAE Seminars, 1998
3. F. Amirouche, L. Palkovics and J. Woodrooffe, *Optimal driver seat suspension design for heavy trucks*, International Journal of Vehicle Design, 1992.
4. A. Mayton, F.M.L. Amirouche, Design Improvements in Operator Cab Seat and Vibration Considerations for Low-Coal Shuttle Car Haulage in Underground Mines **,** ASME 2005
5. A. Mayton, F.M.L. Amirouche, Design Improvements in Operator Cab Seat and Vibration Considerations for Low-Coal Shuttle Car Haulage in Underground Mines **,** ASME 2005

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