A CONTROLLER FOR A HANDICAPPED MEN VEHICLE SEAT WITH ER-FLUID-BASED DAMPER

Viorel Stoian

University of Craiova, Faculty of Automatic Control, Computers and Electronics, Mecatronics Department, Lapus Street No. 5, 1100, Craiova, Romania.
stoian@robotics.ucv.ro

Abstract: This paper proposes a controller with ER-fluid-based damper for a handicap ped men vehicle seat. The control performances of a semi-active suspension using electro-rheological fluids (ER) are discussed. Methods to control robotic joint vibrations are classified. After evaluating field-dependent damping characteristics of the ER seat damper, a sliding mode controller is formulated to control the seat vibration due to external excitations. A damper with mobile electrodes is used. The dynamic model of the system is obtained and the state space equations are presented. The properties of the active-controllable electro-rheological fluids which change their material characteristics in presence of an electrical field are pointed. By employing the ER damper in a handicapped men vehicle seat, undesirable vibrations can be rapidly compensated. Numerical simulations are achieved.

***Keywords**: electrorheological fluids, variable structure, ER damper, sliding mode controller.*

1. INTRODUCTION

The increased number of moving hours for handicapped men which are traveling on their seats with locomotion systems and the rough road conditions results in extended demand for an increased comfort. The perception of the road comfort is based upon road shock, impact and vibration transmitted through the seat. In this paper is considered an extra suspension system of the seat based on an ER-damper with mobile electrodes which are added to the classical suspensions and to the tires (Figure 1).

The control methods of the vibrations are classified [Seko 1992] as passive, semi active and active. The passive type device is called a dynamic absorber. In the passive method the control is obtained by combining masses, springs and dampers. The most important featuring of the passive seat suspension system are the simplicity and cost-effectiveness. The performance limitations are inevitable.

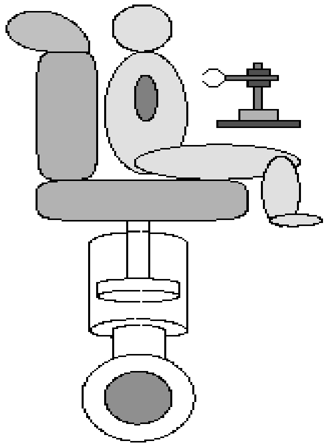

Figure 1. The seat suspension system.

Since it has no sensory feedback, however, a dynamic absorber cannot compensate for vibrations of the controlled system. While active control can reduce undesirable vibrations, it is expensive and requires a high power source for the actuators, sensors, servo-valves and sophisticated control logics. Active control is based on instrumenting a dynamic absorber with external sensors and actuators. This method provides high control performance in wide frequency range. The semi active approach is based on altering the characteristics of the spring or the damper of the passive dynamic absorber to achieve optimal operating conditions. This method retains the benefits of an active system without requiring additional power requirements and system complexity. The semi active systems offer a desirable performance generally enhanced in the active mode without requiring large power sources and expensive hardware. Recently, Brooks [Brooks 1987] proposed a diaphragm-controlled ER seat damper and showed its effectiveness of high damping forces. Control systems frequently employ this method. The concept is based on using an electrorheological fluid to implement the semi active control of the system.

2. ELECTORHEOLOGICAL FLUIDS

When a sufficiently large electric field is applied to certain fluids, they undergo marked changes in their rheological proprieties. These electrorheological (ER) fluids can, in a matter of milliseconds, make a transition from the liquid state to a “weak solid” state with solid-like properties. These fluids are suspensions of fine particles in liquids such as non-conducting oils [Duclos 1988]. An ER fluid is a suspension of hydrophilic (water-retain) particles suspended in a hydrophobic (water-repelling) dielectric fluid. This suspension is placed between electrodes for application of an electric field. In an electric field the particles polarize and interpartice forces then lead to the formation of chain which tends to orient perpendicular to the electrode gap. Because these chains resists shear along a direction vertical to the field the liquid reacts like a solid: with enough particles and a field of sufficient strength, the fibrils will bridge the gap and cause an appreciable increase in the viscosity of the suspension. When the field is removed, the material reverts back to a liquid state within milliseconds. Moreover, the degree of gelling is proportional to the strength of the electric field. By varying the voltage, any state between liquid and solid can be quickly selected. There are a great number of papers [Brooks 1982, 1987; Choi 1997, 1998; Duclos 1987, 1988; Hill 1991; Ivanescu and Stoian 1996; Stangroom 1983 Stevens 1987, 1988; Weiss, Coulter 1992, etc] which describe the two major methods of exploiting the ER effect in practical devices: “valve method” and “clutch method”.

3. TECHNOLOGICAL STRUCTURE OF THE ER BASED DUMPER

The general form of the technological structure of the ER based damper is shown in Figure 2 [Stevens 1985].
The ER damper has a mobile electrode (the piston) and a fix electrode (the inner cylinder). The damper volume is divided by the piston in two chambers: the upper chamber and the lower chamber.
The damping force F_d of the ER damper is [Choi 1998]:

$$F_d = k_e q_d + c_e V_p + F_{ER} \qquad (1)$$

where, k_e is the effective stiffness due to the gas pressure, q_d is the displacement, c_e is the effective damping due to the viscosity flow resistance, V_p is the piston velocity and F_{ER} is the field-dependent damping force which is a function of electric field.
The controllable damping force F_{ER} can be expressed by [Choi 1998]:

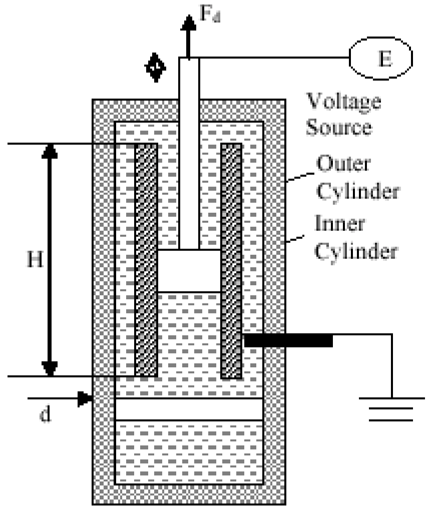

Figure 2. The ER based damper.

$$F_{ER} = 2(A_p - A_r)\frac{H}{d}\alpha E^{\chi}\,\mathrm{sgn}(V_p) \qquad (2)$$

where A_p and A_r are the piston and the piston rod areas, respectively, H is the electrode length, d is the outer-inner cylinder gap, E is the electric field, α and χ are the intrinsic values of ER fluid (experimentally determined) and sgn (*) is the signum function.

4. THE DYNAMICAL MODEL OF THE SYSTEM

In mechanical models, Hookean deformation is presented by a spring (i.e. an element in which the force is proportional to the extension) and the Newtonian flow by a dashpot (i.e. an element in which the force is proportional to the rate of extension). The behavior of more complicated materials is described by connecting the basic elements is series or in parallel. For example the Kelvin model results from a parallel combination of a spring and a dashpot (Figure 3). A requirement on the interpretation of this and all similar diagrams is that the horizontal connectors remain parallel at all times equal to the extension (strain) in the dashpot.
The relation for this model is:

$$\sigma = kq + c\dot{q} \qquad (3)$$

where k is the Hookean constant and c is the Newtonian constant. Hence, for the Kelvin model the total stress σ is equal to the sum of the stresses in each element: $\sigma = \sigma_E + \sigma_V$.

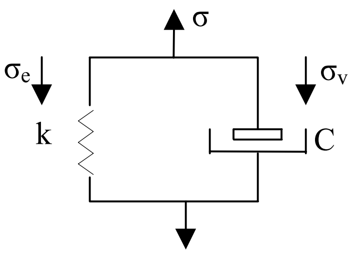

Figure 3. The Kelvin model.

Figure 4 presents the mechanical model of the system.

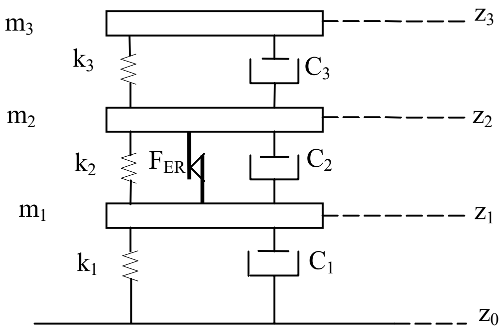

Figure 4. The mechanical model of the system

m_1, k_1, c_1 correspond to the wheel, k_2, c_2, F_{ER} correspond to the ER damper, m_2 is the mass of the seat frame, k_3, c_3 correspond to the cushion and m_3 is the mass of the men.
The equations of the motion are:

$$m_1 \ddot{z}_1 = -c_1(\dot{z}_1 - \dot{z}_0) + c_2(\dot{z}_2 - \dot{z}_1) - \\ - k_1(z_1 - z_0) + k_2(z_2 - z_1) + m_1 g + F_{ER}$$

$$m_2 \ddot{z}_2 = -c_2(\dot{z}_2 - \dot{z}_1) + c_3(\dot{z}_3 - \dot{z}_2) - \\ - k_2(z_2 - z_1) + k_3(z_3 - z_2) + m_2 g + F_{ER} \qquad (4)$$

$$m_3 \ddot{z}_3 = -c_3(\dot{z}_3 - \dot{z}_2) - k_3(z_3 - z_2) + m_3 g$$

If we will define the state vector as $x = [q_1 q_2 q_3\ \dot{q}_1\ \dot{q}_2\ \dot{q}_3]^T$ and $F_{ER} = u$, the state space equation is

$$\dot{x} = Ax + Bu + D \qquad (5)$$

where,

$$A = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ -\frac{k_1+k_2}{m_1} & \frac{k_2}{m_1} & 0 & \frac{c_1+c_2}{m_1} & \frac{c_2}{m_1} & 0 \\ \frac{k_2}{m_1} & -\frac{k_2+k_3}{m_3} & \frac{k_3}{m_2} & \frac{c_2}{m_2} & -\frac{c_2+c_3}{m_2} & \frac{c_3}{m_2} \\ 0 & \frac{k_3}{m_3} & -\frac{k_3}{m_3} & 0 & \frac{c_3}{m_3} & -\frac{c_3}{m_3} \end{bmatrix},$$

$$B = \begin{bmatrix} 0 & 0 & 0 & 1/m_1 & -1/m_1 & 0 \end{bmatrix}^T,$$

$$D = \begin{bmatrix} 0 & 0 & 0 & \frac{c_2}{m_1}\dot{z}_0 + \frac{k_1}{m_1} z_0 + g & g & g \end{bmatrix}^T \qquad (6)$$

5. CONTROL SYSTEM

In this paper we use a variable-structure control. A block diagram of the variable-structure controller used to the seat suspension system is prezented in Figure 6.

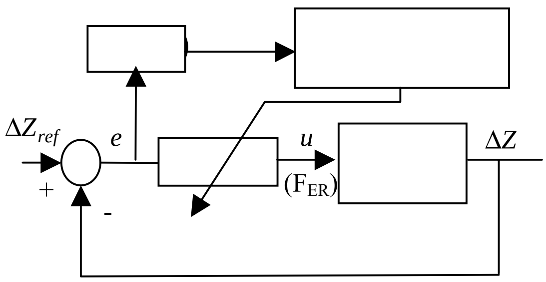

Figure 6. The variable-structure controller

Variable-structure controllers are robust in the sense that they are insensitive to errors in the estimates of the parameters as long as reliable bounds on the parameters are known. In the case of the seat suspension system, since the mass of the man m_3 is not fixed, we impase the mass uncertainty Δm which is unknown, but bounded.

$$m_3 \to m_3 + \Delta m = m_3^* \qquad (7)$$

In this case we have: $A \to A^*$

We assume that $\left| m_3^* - m_3 \right| \le \rho \qquad (8)$

where m_3^* is an estimation of the upper bound of the mass of the man.
Given a reference element Δz_{ref} , the objective is to find a variable-structure control law $u = f(e)$ such

that the solution of the closed-loop system satisfies $e(t) \to 0$ at $t \to \infty$.

For this tipe of control we define the switching line (Figure 7) [Ivanescu 1995; Schilling 1990]:

$$\sigma(e, \dot{e}) = me + \dot{e} = 0 \qquad (9)$$

The control law will drive the system to the switching surface in a finite time and then constrain the system to stay on the switching line.

There are two posibilities to drive the system on the switching line: the sliding mode and the direct mode.

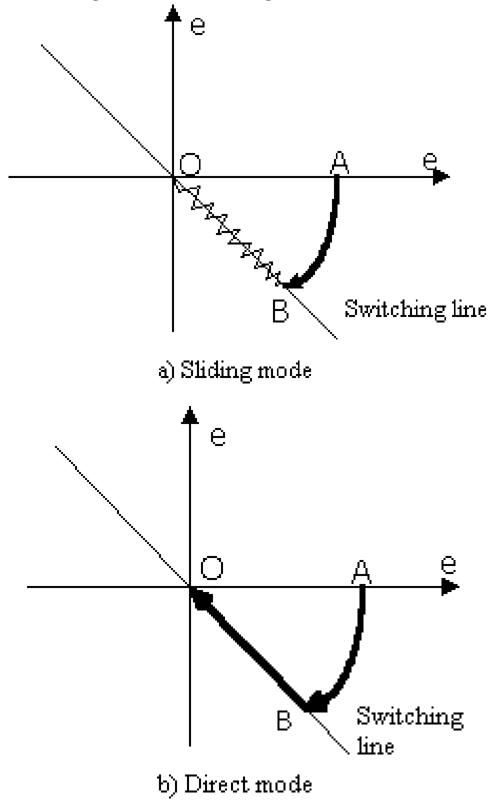

Figura 7. The variable-structure control

In the first case (Figura 7a), once the trajectory penetrates the switchingline, the control law $u = f(e)$ switches and the reby directs the system back towards the switching line, obtaining an oscillating mode with a high frequency.

The control law of this case is [Ivanescu, Stoian 1995; Schilling 1990]:

$$u = -\{k_1 \operatorname{sgn} e + k_2 \operatorname{sgn}[\sigma(e, \dot{e})\dot{e}]\dot{e} + k_3 \operatorname{sgn}[\sigma(e, \dot{e})e]e\} \qquad (10)$$

where k_1, k_2 and k_3 are positives controller gains that are determined such that the control law will drive the system to the switching line and then keep it there.

In the second case (figure 7b), the system starts from the initial point A towards the switching line and then it evolates directly (B), on the switching line, towards the origin. This evolution requires the variation of the damping ratio ξ of the system abruptly from small values $\xi < 1$ to high values, $\xi > 1$.

The evolution of the system will hit the switching line at time t_{switch}, where [Schilling 1990]:

$$t_{switch} \le \frac{\|\sigma(e(0))\|}{\gamma} \qquad (11)$$

where $\gamma > 0$ such that $\sigma^T(e)\sigma(e) \le \gamma \|\sigma(e)\|$ (12)

This control does not require a high performance of the driving system, it imposes a single switching of the viscosity η by the electric field at the time t_{switch} which is easily computed off-line.

The control law actuate in following mode:

$$\text{If } u \operatorname{sgn}(\Delta \dot{z}) > 0 \text{ then } u = u \text{ else } u = 0 \qquad (13)$$

The electric field to be applied to the ER seat damper system is obtined from relation (2):

where F_{ER} or u is presented in (Choi et al. 1998).

Figure 8 presents a simulation of the control ssystem. The curve a represents the trajectory of the system for a step input without a variable-structure control. The curve b contains two domains: the first domain is characterized by a damping ratio $\xi < 1$ and in the last part the damping ratio is switched at $\xi > 1$.

6. CONCLUZION

This paper proposes a controller with ER-fluid-based damper for a handicapped men vehicle seat. The control performances of a semi-active suspension using electro-rheological fluids (ER) are discussed. Methods to control robotic joint vibrations are classified. After evaluating field-dependent damping characteristics of the ER seat damper, a sliding mode controller is formulated to control the seat vibration due to external excitations. A damper with mobile electrodes is used. The dynamic model of the system is obtained and the state space equations are created (writer, presented). The properties of the active-controllable electro-rheological fluids which change their material characteristics in presence of an electrical field are pointed. By employing the ER damper in a handicapped men vehicle seat, undesirable vibrations can be rapidly compensated. Numerical simulations are achieved.

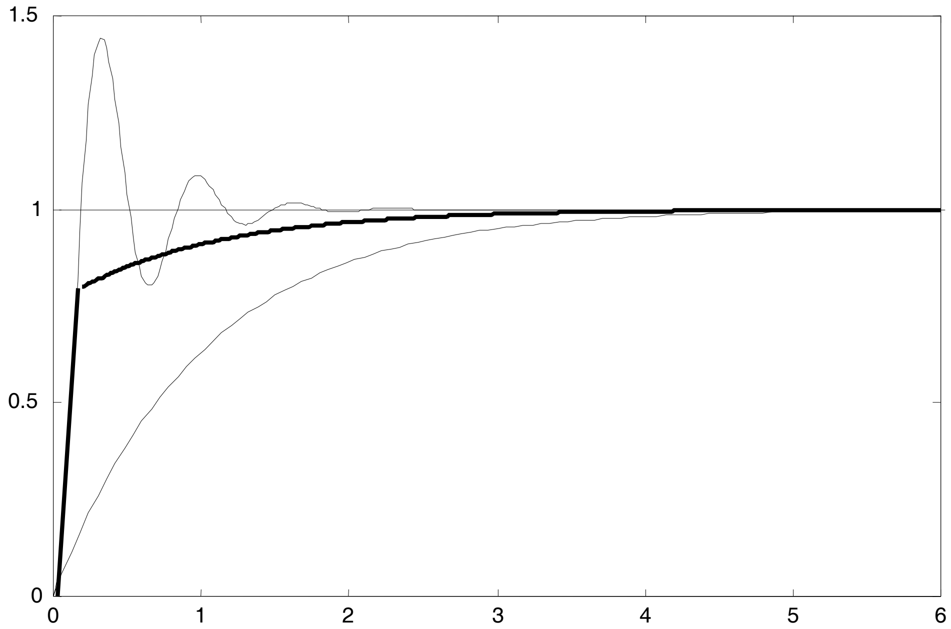

Figura 8.

REFERENCES

Begon, P., Pierrot, F., (1995), *"Fuzzy Sliding Mode Control of a Fast Parallel Robot"*, Proceedings of the 1995 IEEE International Conference on Robotics and Automation, Nagoya, Japan, vol. 1, pp. 1178-1183.

Brooks, D. A., (1982), *"Electro-Rheological Devices"*, CME September, pp. 91-93.

Brooks, D. A., (1997) "*MRS and Their Applications*", Proceedings of the IEEE International Conference on ERF, pp. 250-251

Bullough, W. A. (1995), "*Proceedings of the 5th Internat. Conference on Electrorheological Fluids, Magneto-rheological Suspensions and Associated Technology*", World Scientific, Sheffild, UK.

Choi, S.B., (1997), "*MRS and Their Applications*", Proceedings of the IEEE International Conference on ERF, pp. 53-54.

Choi, S.B., Choi, Y.T., Chang, E.G., Han S.J., Kim C.S., (1998), "Mecatronics", Prentice Hall, New York.

Dorf, R.C., "*Modern Control Systems*", Addison Wesley Publ. Co.

Duclos, Th. G., (1987), "*An Externally Tunable Hydraulic Mount which Uses Electro-Rheological Fluid*", SAE Technical Paper Series, 870963.

Duclos, Th. G., (1988), "*Design of Devices Using Electro-rheological Fluids"*, SAE Technical Paper Series, 881134.

Hill, J. C., Van Steenkirte, T. H., (1991), "*Response Times of Electro-Rheological Fluids",* Journal of Applied Physics. 70 [30], pp. 1207-1211.

Ivanescu, M., Stoian, V., (1995), "*A Variable Structure Controller for a Tentacle Manipulator*", Proceedings of the 1995 IEEE International Conference on Robotics and Automation, Nagoya, Japan, vol. 3, pp. 3155-3160.

Ivanescu, M., Stoian, V., (1996), "*A Sequential Distributed Variable Structure Controller for a Tentacle Arm*", Proceedings of the 1996 IEEE International Conference on Robotics and Automation, Minneapolis, Minnesota, vol.4, pp. 3701 - 3706.

Ivanescu, M., Stoian, V., (1998), *"Electro-rheological fluid controllers"*, 4th European Conference on Smart Structures and Materials and 2nd International Conference on Micromechanics, Intelligent Materials and Robotics, Harrogate SPA, Near York, UK.

Ivanescu, M., Stoian, V., (1998), *"Electro-Rheological fluid controllers"*, Journal of Intellligent Material Systems and Structures, Editor James S. Sirkis, vol. 9, no. 8, pp. 607-615, ISSN: 1045-389X.

Itkis, U., (1976), "*Control Systems on Variable Structure*", Willey: New York.

Li, J., Jin, D., Zhang, X., Zhang, J., Gruver, W.A., (1995), *"An Electrorheological Fluid Damper for Robots"*, Proceedings of the 1995 IEEE International Conference on Robotics and Automation, Nagoya, Japan, vol. 2, pp. 2631-2636.

Mishkin, E., Braun, L., (1981), *"Adaptive Control Systems"*, New-York, Mc Graw Hill.

Nigam, N.C., Narayanan, S., (1994), “Applications of Random Vibration”, Ed. Springer-Verlag, pp. 225-282.

Schilling, J.R., (1990), "*Fundamentals of Robotics, Analysis and Control"*, Prentice Hall, New York.

Seko, K., (1992), “*Trends on Active Vibration Control in Japan*”, First International Conference on Motion and Vibration Control, Yocohama, pp. 1-11.

Stangroom, J., (1983) *"Electrorheological Fluids"*, Phys.Technol.,Vol.14, pp. 290-296.

Stevens, N.G., (1988), *"An Experimental Study of Electrorheological Torque Transmission",* Transactions on the ASME, vol. 110, pp. 182-188.

Stevens, N.G., Sproston, J.L., Stanway, R,. (1987), "*On the Mechanical Properties of Electro-Rheological Fluids"*, Transactions of the ASME, Vol. 54, pp. 456-458.

Thurstm, G.B., (1991), *"Viscoelasticity of Electrorheological Fluids During Oscillatory Flow in a Rectangular Channel"*, Journal of Rheology, October, pp. 1327-1343.

Utkin, V.I., (1978), *"Sliding Modes and Their Applications in Variable Structure Systems”,* MIR Publishers.

Utkin, V.I., (1992), *"Sliding Mode Control"*, Ed. Springer-Verlag.

Weiss, K. D. , J. P. Coulter, J. D. Carlson, (1992), "*Electro-Rheological Materials and their Usage in Intelligent Material Systems and Structures", (Recent Advances in Sensory and Adaptive Materials and Their Applications),* Rogers, C.A. (editor), Technomic Publishing Company, Inc., Lancaster, P.A., pp. 1-17.

Whittle, M., Atkin, R.J., Bullough, W.A., (1996), *"Dynamics of an Electro-Rheological Valve"*, International Journal of Modern Physics B,Vol. 10, Nos. 23 & 24, Pp. 2933-2950.