Sastry et al. 2018. *Int. J. Vehicle Structures & Systems*, 10(4), 268-272
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.10.4.08


**International Journal of**
**Vehicle Structures & Systems**
Available online at www.maftree.org/eja

# Evaluation of Human Exposure to Vibrations using Quarter Car Model with Semi-Active Suspension

**D.V.A. Rama Sastry[a,c], K.V. Ramana[a], N. Mohan Rao[b], M. Phani Kumar[a] and V.S.S. Rama Chandra. Reddy[a]**

[a]*Dept. of Mech. Engg., Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India*
[b]*Dept. of Mech. Engg., University College of Engg., JNTUK University, Kakinada, Andhra Pradesh, India*
[c]*Corresponding Author, Email: dvarsastry@kluniversity.in*

**ABSTRACT:**

*Exposure of human body to vehicular vibrations in transit may lead to the human discomfort. Ride comfort is one of the major issues in design of automobiles. Magneto rheological (MR) dampers are emerging as most feasible solution for various applications in controlling vibrations. An MR damper is a semi-active device, which will offer the advantages of both active and passive suspension. In this study, the MR damper based semi-active suspension system for a car is analysed for ride comfort of 7 degrees of freedom model human body lumped mass, considering head, upper torso, lower torso and pelvis, seated over a seat of a quarter car model and is compared with that of similar system using passive damper. A MR damper is fabricated and is filled with MR fluid made of Carbonyl iron powder and Silicone oil added with additive. Modified Bouc-Wen Model developed by Spencer is used to model the behaviour of MR damper. All the parameters of this model are identified using data acquired from experiments conducted to characterise MR damper. Further, using the Spencer model of MR damper, the human body seated over quarter car is simulated by implementing a semi-active suspension system for analysing the resulting displacement and acceleration of the human body. The ride comfort performance of vehicle model with passive suspension system is compared with corresponding semi-active suspension system. The simulation and analysis are carried out using MATLAB/SIMULINK.*

**KEYWORDS:**

*Magneto rheological dampers; Quarter car model; Suspension systems; Spencer model; Human body vibrations*

**CITATION:**

D.V.A.R. Sastry, K.V. Ramana, N.M. Rao, M.P. Kumar and V.S.S.R.C. Reddy. 2018. Evaluation of Human Exposure to Vibrations using Quarter Car Model with Semi-Active Suspension, *Int. J. Vehicle Structures & Systems*, 10(4), 268-272. doi:10.4273/ijvss.10.4.08.

## 1. Introduction

Many parameters influence the performance of Automobiles. Ride comfort of the passengers is considered to be one of the prominent among them. The suspension system consisting of springs, and the damper along with tires are responsible for this. Achieving better ride comfort is a serious issue to the automobile industries[1-2]. With the application of semi-active suspension system using Magneto rheological (MR) damper ride comfort can be attained without compromising on other factors [3]. Using MR damper, the stiffness and damping of the system can be varied continuously to achieve optimum ride comfort and vehicle handling. MR fluids, the major constituent in MR damper, consists of iron particles of micron size in a carrier fluid such as Silicone oil or glycol[4]. MR fluids when subjected to magnetic field, the yield strength changes drastically changing the fluid from liquid state to semisolid state, which is used to induce the damping[5]. Moreover, it also has several other advantages. Even if the semi-active suspension fails, it still works as a passive suspension system which is not possible in case of fully active suspension.

Several models have been proposed to study the performance of MR damper and their behaviour, but the most promising one is the Bouc-wen model which is further modified by Spencer [6]. In this paper, Spencer model of MR damper is considered. The human body is considered as lumped mass consisting of upper torso, lower torso, pelvis and head. The human body along with seat on quarter car modelled as 7 Degrees of Freedom (DoF) system is considered for the study of ride comfort levels on human body. Further, this study uses 7 DoF system to compare the effect of passive active suspension system with the semi-active suspension system on human body. The vertical acceleration is considered as representing factor to measure quality of ride [7].

## 2. Experimental setup and procedure

In order to conduct studies on human comfort using semi-active damper, a MR damper with dimensions similar to existing car damper dimensions is developed. MR damper consists of piston and cylinder arrangement with piston head assembly housing an electric coil. In this study, a coil consists of double wired parallel winding of a copper wire of 25 gauge for 200 turns, with a resistance of 3.5 ohms is used. To test the performance of the damper in terms of force with varying displacement and velocity, a setup is developed using VIB-LAB apparatus with speed regulator, NI-COMPACT DAQ with NI-lab view software installed in laptop, VARIAC (variable voltmeter), load cell and LVDT, as shown in Fig. 1. The developed experimental setup is used for testing of MR damper, at 0.4 amps current on VIB-Lab. Using data acquisition system (NI Compact DAQ) connected to the system, the damping force data in variation to displacement caused by roadway irregularities is acquired. The dimensions of MR damper are as given in Table 1.

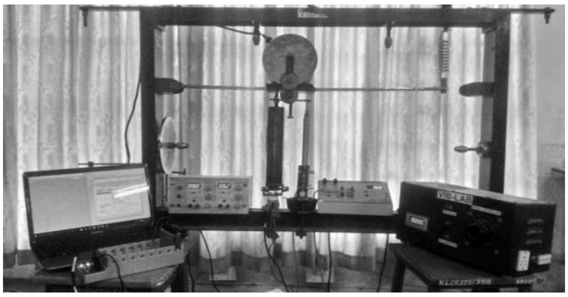

**Fig. 1: Experimental setup for testing MR damper**

**Table 1: Geometry of MR damper**

| Damper Parameter | Dimension (mm) |
|---|---|
| Extended height | 380 |
| Compressed height | 360 |
| Stroke length | 20 |
| Damper tube length | 300 |
| Damper tube outer & inner diameter | 60 & 50 |
| Piston head & rod diameter | 48 & 12 |

## 3. Modelling of MR damper using Spencer model

The modified Bouc-Wen model developed by Spencer for MR damper is shown in Fig. 2. According to this, the damping force generated by the MR damper is given by,

$$f_{MR} = \alpha z + c_0(\dot{x} - \dot{y}) + k_0(x - y) + k_1(x - x_0) = c_1(\dot{y}) + k_1(x - x_0) \quad (1)$$

Where

$$\dot{z} = -\gamma|\dot{x} - \dot{y}|z|z|^{n-1} - \beta(\dot{x} - \dot{y})|z|^n + A(\dot{x} - \dot{y})\dot{y} = \frac{1}{c_0 + c_1}\{\alpha z + c_0\dot{x} + k_0(x - y)\} \quad (2)$$

The values of various parameters mentioned in the above equations at 0.4 amps of current supply [8] are given in Table 2. These equations are modelled in MATLAB/SIMULINK and shown in Fig. 3. The comparison of Spencer model analysed in MATLAB/SIMULINK with experimental values is shown in Figs. 4 to 6. It can be observed that the results obtained from Spencer model are comparable with experimental values.

**Table 2: Spencer damper model parameters [8]**

| System parameter | Values at 0.4 amp |
|---|---|
| α | 866.65 N/cm |
| β, γ | 119842cm$^{-1}$, 5226cm$^{-1}$ |
| N, A | 2, 29.37 |
| $K_1$, $K_0$ | 6.7530 N/cm, 2807.8 N/cm |
| $C_1$, $C_0$ | 20626.5 Ns/cm, 1965.10 Ns/cm |

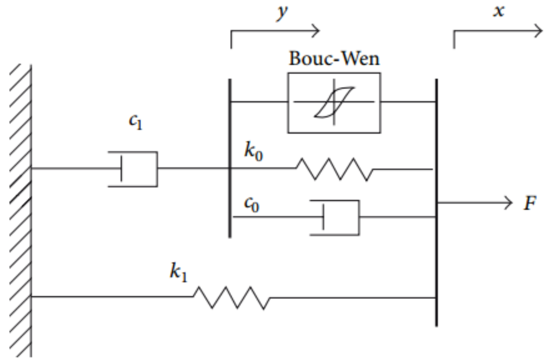


**Fig. 2: Spencer model of MR damper**

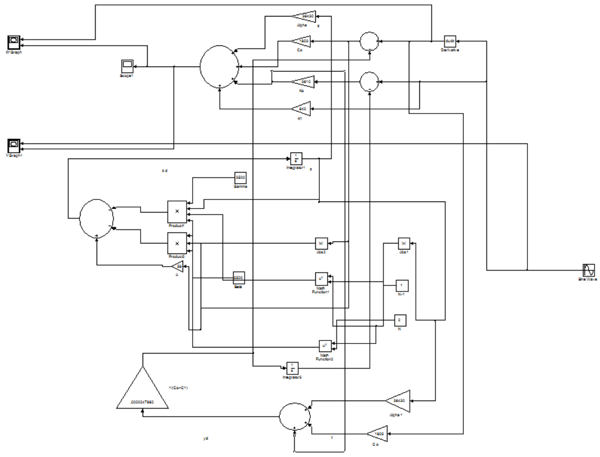

**Fig. 3: Simulink modelling of phenomenological Spencer model of MR damper**

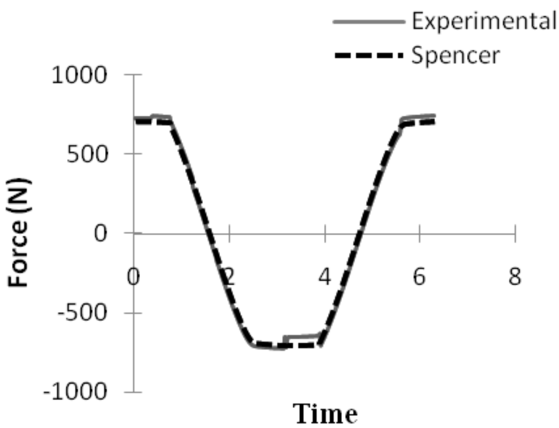


**Fig.4: Comparison of force vs. Time of Spencer model for MATLAB/SIMULINK and experimental analysis**

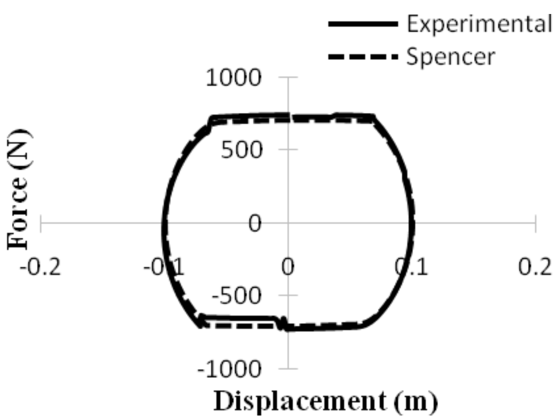


**Fig. 5: Comparison of force vs. Displacement of Spencer model for MATLAB/SIMULINK and experimental analysis**

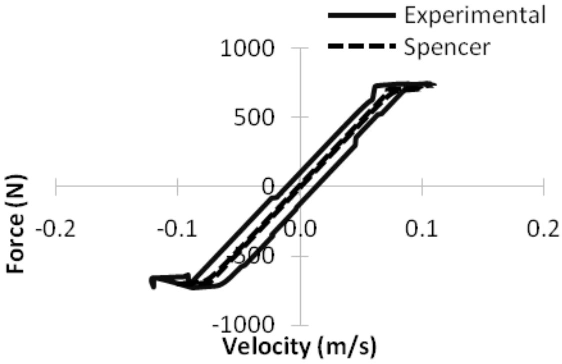


**Fig. 6: Comparison of force vs. Velocity of Spencer model for MATLAB/SIMULINK and experimental analysis**

## 4. Modelling and analysis of human body seated on quarter car

The Spencer model is adopted to represent behaviour of MR damper for analysing human body lumped mass on quarter car model in SIMULINK. Fig. 7(a) represents the bio dynamic human lumped mass model being seated on passive quarter car suspension system of ground vehicle. Considering only vibration in vertical direction, the equations of motion for the 7 DoF model can be written using the following,

$$m_1\ddot{x}_1 = -[k_1(x_1 - x_2) + c_1(\dot{x}_1 - \dot{x}_2)] \quad (3)$$

$$m_2\ddot{x}_2 = -[k_2(x_2 - x_3) + c_2(\dot{x}_2 - \dot{x}_3)] + [k_1(x_1 - x_2) + c_1(\dot{x}_1 - \dot{x}_2)] \quad (4)$$

$$m_3\ddot{x}_3 = -[k_3(x_3 - x_4) + c_3(\dot{x}_3 - \dot{x}_4)] + [k_2(x_2 - x_3) + c_2(\dot{x}_2 - \dot{x}_3)] + [k_2(x_2 - x_3) + c_2(\dot{x}_2 - \dot{x}_3)] + [k_2(x_2 - x_3) + c_2(\dot{x}_2 - \dot{x}_3)] \quad (5)$$

$$m_5\ddot{x}_5 = -[k_5(x_5 - x_s) + c_5(\dot{x}_5 - \dot{x}_s)] + [k_4(x_4 - x_5) + c_4(\dot{x}_4 - \dot{x}_5)] \quad (6)$$

$$m_s\ddot{x}_s = -[k_s(x_s - x_u) + c_s(\dot{x}_s - \dot{x}_u)] \quad (7)$$

$$\mathrm{m_u}\ddot{\mathrm{x}}_\mathrm{u} = -\{-[\mathrm{k_s}(\mathrm{x_s} - \mathrm{x_u}) + \mathrm{c_s}(\dot{\mathrm{x}}_\mathrm{s} - \dot{\mathrm{x}}_\mathrm{u})] + [\mathrm{k_s}(\mathrm{x_u} - \mathrm{q}) + \mathrm{c_t}(\dot{\mathrm{x}}_\mathrm{u} - \dot{\mathrm{q}})]\} \quad (8)$$

For the present study, the vehicle considered is Hyundai i20 with curb weight of 1180kg and gross total weight of 1580kg, of which 180kg is the weight of total unsprung mass leading to 45kg at each wheel. Therefore 1500kg is considered as the total sprung mass, of which 60% acts on the rear side leading to 450kg on each rear wheel. The value of parameters related bio dynamic human lumped mass model with seat and passive quarter car are considered as given in Table 3. Using these parameters, the suspension system of quarter car with human body lumped mass model (see Fig. 7) is analysed to identify the displacement and acceleration of the sprung mass. Modelling is carried out in MATLAB/ SIMULINK and shown in Figs. 8 and 9. The equations related to vehicle unsprung and sprung masses for semi-active suspension system, in comparison with passive system equations, will change as follows,

$$\mathrm{m_S}\ddot{\mathrm{x}}_\mathrm{s} = -[\mathrm{k_s}(\mathrm{x_s} - \mathrm{x_u}) + \mathrm{f_{MR}})] \quad (9)$$

$$\mathrm{m_u}\ddot{\mathrm{x}}_\mathrm{u} = -\big[[\mathrm{k_s}(\mathrm{x_s} - \mathrm{x_u}) + \mathrm{f_{MR}}] + [\mathrm{k_t}(\mathrm{x_u} - \mathrm{q}) + \mathrm{C_t}(\dot{\mathrm{x}}_\mathrm{u} - \dot{\mathrm{q}})]\big] \quad (10)$$

**Table 3: Parameters of bio dynamic human lumped mass model**

| System parameter | value |
|---|---|
| Head and neck mass($m_1$) | 5.31kg |
| Chest &upper torso mass($m_2$) | 28.49kg |
| Lower torso mass($m_3$) | 8.62kg |
| Pelvis and thighs mass($m_4$) | 12.78kg |
| Seat mass($m_5$) | 15kg |
| Sprung mass($m_s$) | 450kg |
| Unsprung mass($m_u$) | 45kg |
| Head and neck stiffness($k_1$) | 10000N/m |
| Head and neck damping coefficient($c_1$) | 400Ns/m |
| Chest and upper torso stiffness($k_2$) | 18300N/m |
| Chest and upper torso damping coefficient($c_2$) | 4750Ns/m |
| Lower torso stiffness($k_3$) | 162800N/m |
| Lower torso damping coefficient($c_3$) | 4585Ns/m |
| pelvis and thighs stiffness($k_4$) | 90000N/m |
| pelvis and thighs damping coefficient($c_4$) | 2064Ns/m |
| Seat stiffness($k_5$) | 66666.7N/m |
| Seat damping coefficient($c_5$) | 10000Ns/m |
| Suspension stiffness($k_s$) | 30000N/m |
| Suspension damping coefficient($c_s$) | 750Ns/m |
| Tire stiffness($k_t$) | 200000N/m |
| Tire damping coefficient($c_t$) | 125Ns/m |

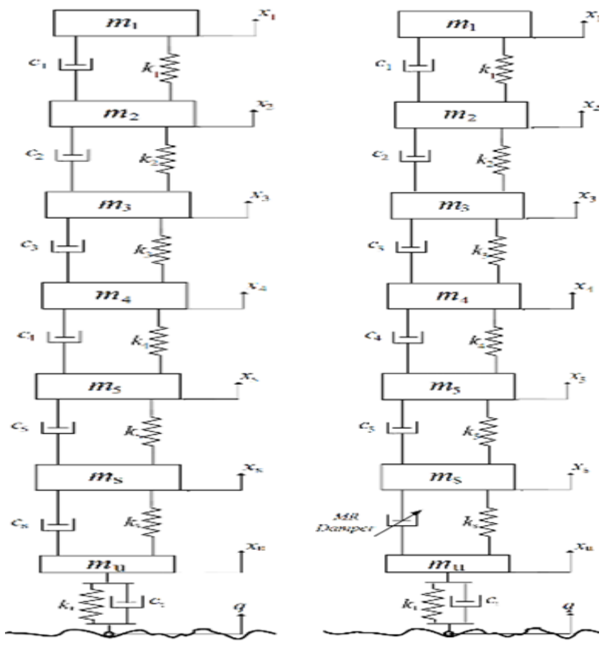


**Fig. 7: Quarter car Suspension with human body lumped mass model (a) passive (b) semi-active with MR damper**

The comparisons of acceleration variation for head, upper torso, lower torso and pelvis with quarter car for passive and semi-active suspension systems in are shown in Figs. 10 to 13 respectively. The actual disturbance applied is a bump road profile as shown in Fig. 14. Comparison of different parameters analysed for passive and semi-active systems are shown in Table 4. The peak acceleration of head for passive system is 8.82m/s$^2$ and semi-active one is 4.5m/s$^2$, which is reduced by 49%. The peak acceleration of upper torso for passive system is 8.82m/s$^2$ and semi-active one is 4.5m/s$^2$, which is reduced by 49%. The peak acceleration of lower torso for passive system is $8.225 m/s^2$ and semi-active one is $5.6668 m/s^2$, which is reduced by 31%. The peak acceleration of lower torso for passive system is $8 m/s^2$ & semi-active one is $7.2 m/s^2$, which is reduced by 10%.

**Fig. 8: MATLAB/Simulink Model for 7 DoF Bio Dynamic Human Lumped Mass Model using Passive suspension system**

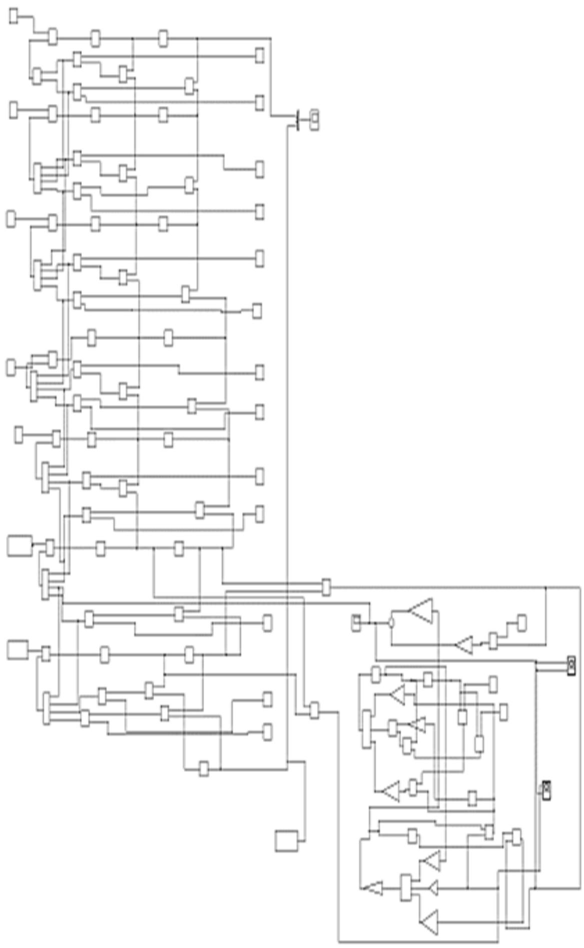

**Fig. 9: MATLAB/Simulink model for 7 DoF bio dynamic human lumped mass model using semi-active suspension system**

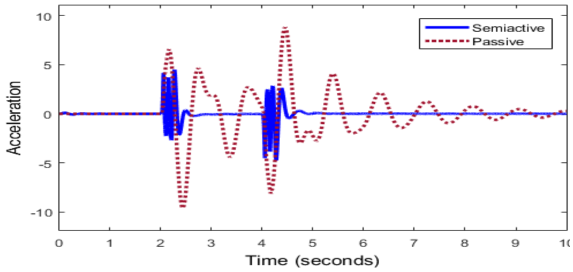


**Fig. 10: Comparison of acceleration of head for passive and semi-active suspension model**

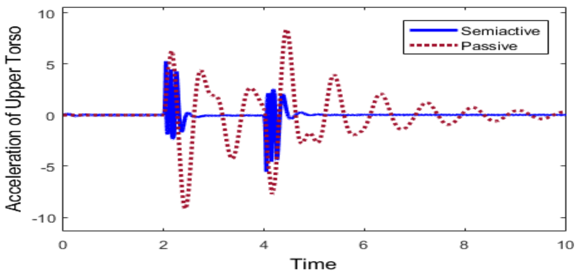


**Fig. 11: Comparison of acceleration of upper torso for passive and semi-active suspension model**

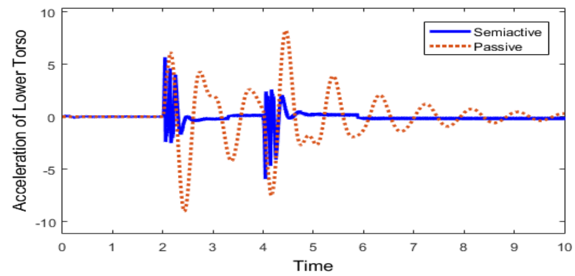


**Fig. 12: Comparison of acceleration of lower torso for passive and semi-active suspension model**

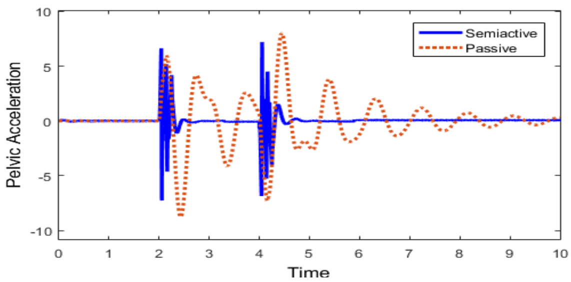


**Fig. 13: Comparison of Acceleration of pelvis for passive and semi-active Suspension model**

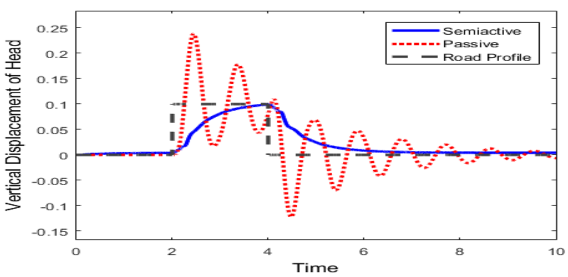


**Fig. 14: Comparison of vertical displacement of head for passive and semi-active suspension model**

**Table 4: Results summary: Passive vs. Semi-active system**

| Acceleration ($m/s^2$) | Passive | Semi-active | % of reduction |
|---|---|---|---|
| Head | 8.82 | 4.5 | 48.97 |
| Upper torso | 8.82 | 4.5 | 48.97 |
| Lower torso | 8.225 | 5.6668 | 31.10 |
| Pelvic | 8.008 | 7.195 | 10.15 |

## 5. Conclusion

In this paper, the comparison of passive system and semi-active suspension system with MR damper for human body was analysed. Acceleration of vertical motion was considered as the basic criteria for this investigation. Based on the results obtained from simulations, it can be concluded that better ride comfort can be achieved using semi-active suspension system compared to passive suspension system.

**ACKNOWLEDGEMENTS:**

The authors would like to thank the Department of Science and Technology, India and Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India for their financial support to this work through TSDP Scheme No. DST/TSG/NTS/2015/68 on MR damper.

**REFERENCES:**

[1] D. Ryba. 1974. Improvements in dynamic characteristics of automobile suspension systems: Part 1 - Two-mass systems, *Vehicle System Dynamics*, 3(1), 17-46. https://doi.org/10.1080/00423117408968445.

[2] R. Rajalakshmi, S.R. Kumar, J. Thiyagarajan and A. Vinothkumar. 2017. Evaluation of human exposure to vibration subjected to active suspension actuators, *Int. J. Vehicle Structures & Systems*, 9(2), 68-71. https://doi.org/10.4273/ijvss.9.2.01.

[3] J. Wang and G. Meng. 2001. Magneto rheological fluid devices: principles, characteristics and applications in mechanical engineering, *Proc. IMechE J. Materials: Design & Applications*, 215(3), 165-174.

[4] R. Turczyn and M. Kciuk. 2008. Preparation and study of model Magneto rheological fluids, *J. Achievements in Materials and Manuf. Engg.*, 27(2), 131-134.

[5] M. Jolly, J.W. Bender and J.D. Carlson. 1998. Properties and applications of commercial magneto rheological fluids, *Proc. SPIE 5th Annual Int. Symposium Smart Structures and Materials*, San Diego.

[6] B.F. Spencer, S. Dyke, M. Sain, and J. Carlson. 1997. Phenomenological model for magneto rheological dampers, *ASCE J. Engg. Mech.*, 1-23.

[7] V.K. Grag and R.V. Dukkipati. 1984. *Dynamics of Railway Vehicle Systems*, Academic Press Inc.

[8] B. Sapiński and J. Filus. 2003. Analysis of parametric models of MR linear damper, *J. Theoretical and Applied Mechanics*, 41(2), 215-240.