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Vibration isolation analysis of new design OEM damper for malaysia vehicle suspension system featuring MR fluid

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Abstract. The applications of semi-active damper employing magnetorheological (MR) fluids keep increasing in fulfilling the demand to control undesired vibration effect. The aim of this study is to introduce the new design of damper for Malaysian vehicle model as well to evaluate its effectiveness in promoting comfort. The vibration isolation performance of the OEM damper featuring MR fluid was analysed physically under real road profile excitation experimentally. An experiment using quarter car rig suspension and LMS SCADAS Mobile was conducted to demonstrate the influence of current in controlling the characteristics of MR fluid in alter the damping behaviour under 5 cm bump impact. Subsequently, the displacement values were measured with respect to time. The new design OEM damper featuring MR fluid was validated by comparing the data with original equipment manufacturer (OEM) passive damper results under the same approach of testing. Comparison of numerical data of the new design OEM damper shown that it can reduce the excitation amplitude up to 40% compared to those obtained by OEM passive damper. Finally, the new design OEM damper featuring MR fluid has effectively isolated the disturbance from the road profile and control the output force.

1. Introduction

Since Karl Benz patent the creation of first car in the world in 1886, endeavour was completed so that the suspension system serves in a finest condition by enhancing the considerations of the suspension system. Rapid development and implementation of various vibration control system which are passive, active and semi-active have been introduced. Passive vibration control system provides design simplicity by typically consists of spring and conventional damper. This spring and damper have fixed characteristic and hence have no mechanism for feedback control. This is because the designed tuned frequency limits their performance and thus only yields nominal vibration control. Through applications of active forces, active vibration control systems have the ability to supply vibration isolation over large bandwidth disturbance. However, greater power sources is need to trigger the requisite active forces. If not accurately premeditated, it will disrupt the system. Contrariwise, by ensuring the consistency of passive yet sustaining the flexibility and compliance of fully active systems, semi-active control system had appeared between those two to utilize the superlative of both approaches [1]. Earliest findings point out that semi active control approaches hypothetically can succeed the majority of the performance of fully active systems because many active control systems work predominantly to adjust structural damping. Numerous approaches have been suggested to optimize semi active suspension. One of the approaches of semi-active suspensions uses controllable fluids. Magnetorheological (MR) fluids and Electrorheological (ER) fluids are viable challengers of controllable fluids [2]. ER fluid change its viscosity when an electric current is applied. Despite the development and research of ER fluid started early than MR fluid, there is very few practical applications using ER technology. This is due to ER fluid has limited shearing movement resistance. MR fluid on the other side able to produce ten times stronger shear strength than ER fluid [3].

MR fluid is the material upon an application of magnetic field. It exhibits quick, alterable and tuneable evolution from a continuous steady state to a highly viscous state. These fluids demonstrate dramatic changes in their rheological behaviours in reaction to a magnetic field [4]. Interest on the MR fluids keep increasing lately for their ability to deliver simple and immediate reaction interfaces between electronic control and mechanical devices and systems [5].

In order to attain high performance, one of the challenges of employing this knowledge is obtaining the accurate model to exploit the advantages of the excellent properties of MR fluids in real field [6]. Surprisingly, very few current published studies does focus on robustness of MR suspension control over real situation such as vehicle moving in uneven gravel road surface which is easily subjected to parameter of uncertainties and external disturbance in practice. The most recent study is done by Miao Yu and her co-worker using mix-mode monotube MR damper [7]. To the author's knowledge, there is no research done in Malaysia considering local technical standards and environment. For this purpose, a prototype of MR semi active damper will be prepared using standardized geometry dimension of original equipment manufacturer damper to evaluate the usefulness of MR technology in term of vibration isolation performance in Malaysian vehicle. Therefore, an experimental study will focus on vibration isolation of the quarter of the full vehicle suspension system on real field.

1.1. CAD Modelling of the Damper

Conceptual design (see figure 1) was developed using SolidWorks software. The objective is to establish full specification drawing before fabrication process. This approach is vital to prevent failure and argument of subsequent approaches. The design development with a precise and accurate dimension of OEM damper is important to be achieved initially before going to the next stage. Once the dimension is confirmed, a careful fabrication process is required before the experimental verification approach. The dimensions are summarized in table 1 and figure 1 shows the design of the damper.

Table 1. Geometry dimension of the OEM damper.

Part/ Assembly	Dimension (mm)
External housing outer diameter, $\emptyset_1$	39.00
External housing inner diameter, $\emptyset_2$	36.63
External housing height, h_1	342.29
Internal housing outer diameter, $\emptyset_3$	27.42
Internal housing inner diameter, $\emptyset_4$	24.82
Internal housing height, h_2	288.01
Piston head height, h_3	24.96
Stroke distance, h_4	299.52

The description of the conceptual design is serve to explain the principles of the present development. Figure 1 shows the view of the conceptual design in accordance with the principles of the present development. Referring to the figure, the design is a linearly-acting magnetorheological (MR) fluid damper, in particular a strut. In general, the strut is designed for operation as a load-bearing and shock-absorbing device within a vehicle suspension system. It is connected between the sprung body and unsprung masses (not shown).

The innovation consists of the followings:

- A magnetorheological fluid with serial number MR Fluid MRF-122 EG 0011369535.
- Electrical copper coil with standardized wire gauge system is 24 AWG
- Comprising two housing known as twin-tube. The internal housing holds the piston with respect of stationary exterior coil at the outside.
- Comprising a pair of rings to hold the electric coil.
- Comprising an external coil surrounding a portion of the internal housing, the external coil capable of generating a magnetic field across at least a portion of the flow gap.
- A piston assembly having disposed in the inner surface of internal housing with function to initiate a flow of the MR fluid between the external housing and internal housing.
- The bottom of the internal housing consists of foot valve as a flow gap permitting the flow of MR fluid.

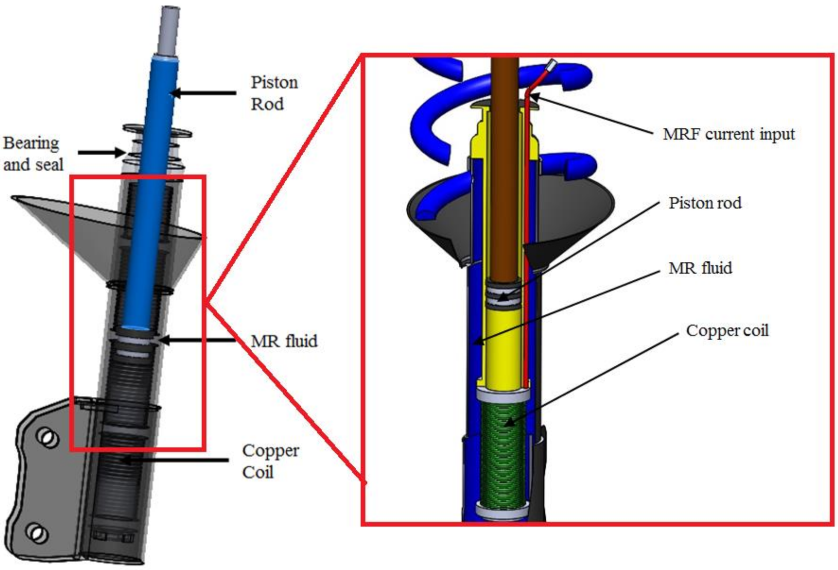

Figure 1. Conceptual design of OEM damper featuring MR fluid [8].

1.2. The Quarter Car Rig

The quarter car rig is designed (see figure 2) to provide specification of a real working system of a car. The characteristic of the quarter car rig are as followed [9]:

- Analogous dynamic behaviour as a car suspension. The dynamic behaviour which required being similar are nonlinearities, damping and resonance frequencies.
- Have the capability to sustain maximum excitation amplitudes within the frequency range of 25 Hz. For this experiment the excitation amplitudes is 5cm
- Have the ability to guide vertical movement of the chassis mass idyllically.

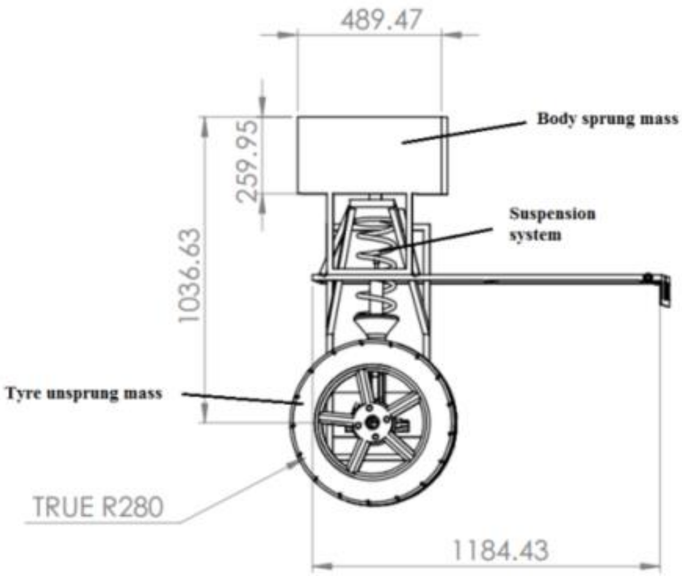

Figure 2. The Quarter Car Rig Drawing (Dimension in mm).

The mechanism of variable stiffness is the most vital embodiment in the quarter car design. The mechanism of various stiffness comprises the following:

- A linear spring encompassing damper with an upper end removable to a point of attachment on the sprung mass and having a lower arm that interlock to the tyre.
- Lower arm with ball joint as a receiving location attachable to an unsprung mass of tyre.

2. Experimental Set-Up

The experiment conducted on real road profile by pulling the complete quarter car rig behind a vehicle. The entire experiment set up is shown in figure 3. All the apparatus selected was connected to each other and kept ready to function respectively. Sprung mass frame was added to the quarter car rig frame to meet the requirement of quarter car mass which is around 250 kg. A bump was placed at appropriate distance (approximately 10m from the origin) to ensure the velocity of the quarter car rig was constant at 10 km/h when it hits the bump. The height of the bump is 5cm as shown in figure 4. All the wire connecting the accelerometer to LMS SCADAS Mobile and the electric coil to Agilent power supply were tie to their relevant position using tie rod to avoid loose of connection during experimentation. Other parameters of the experiment were stated in table 2. Initially the experimentation was done using OEM passive damper before being substituted with the fabricated new design OEM damper prototype.

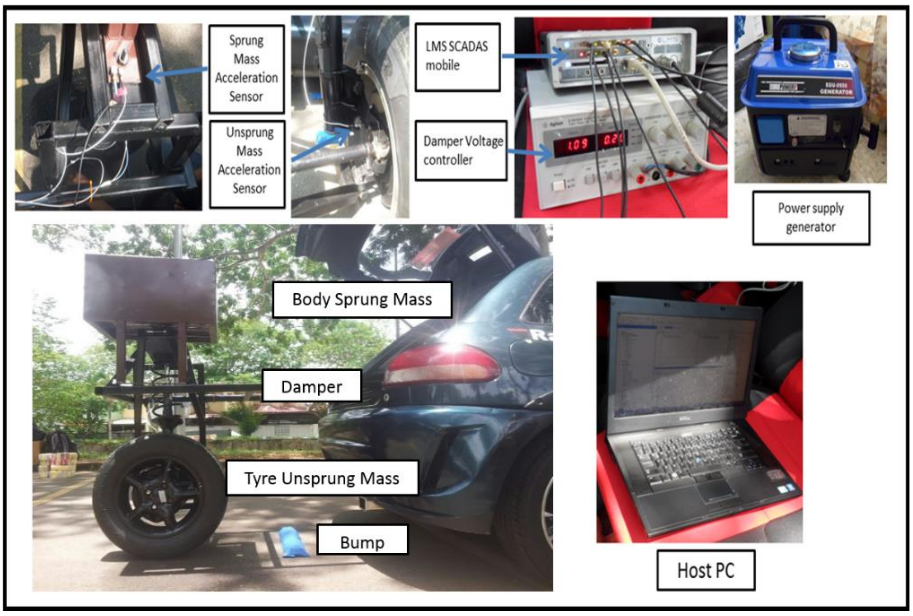

Figure 3. Experimental set-up.

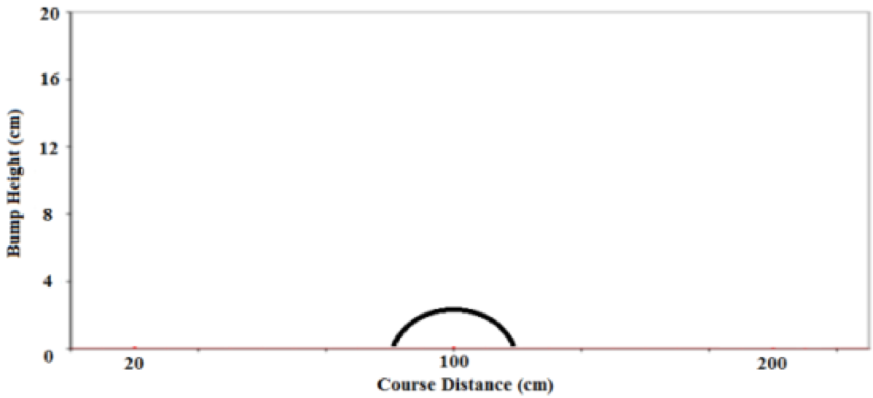

Figure 4. Equivalent suspension input graph showing suspension input versus course distance.

Table 2. Parameter of Malaysian quarter car.

Entry	Vehicle Parameter	Value	Description
1	m_s	250 kg	Mass of the body
2	m_u	25 kg	Mass of the tyre
3	k_s	17600 $N.m^{-1}$	Spring damping coefficient
4	k_t	15000 $N.m^{-1}$	Tyre damping coefficient
5	c	100 $N.s.m^{-1}$	Damping coefficient (only state for the OEM damper)

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3. Results and Discussion

The discussion of the result begin with explaining the first set of experimental result by referring to figure 5. As observed the OEM passive damper achieved almost 20 mm maximum displacement response of sprung mass after impact. The subsequent figure 6 shows the displacement response results of the new design OEM damper prototype at off-state condition where 0A current is supplied. As shown its maximum displacement response is found below 8 mm which is approximately 48% from the displacement recorded by the OEM passive damper. The finding provides evidence that the presence MR fluid alone without the influence of magnetic field is able to offer great vibration isolation. Figure 7 is illustrated graphically to show the vibration isolation performance gap between those two dampers as explained previously. Figure 8 represents one of the results showing the effects of magnetic field on the damping force as function of displacement response. There is a slight increase of amplitude of the displacement response compared to the off state condition. It is believe the viscosity of MR fluid is increase due to the formation of fibrous structure by magnetic field, usually referred as magnetoviscous effect. Yet, the new design OEM damper prototype still isolates more vibration energy transmitted from the bump than OEM passive damper.

Figures 9 is illustrated for comparison and better understanding of the result between the OEM passive damper and the new design OEM damper featuring MR fluid prototype at its almost fully stiff condition. Take in account that the displacement recorded by the new design OEM damper prototype still small compared to OEM passive damper. As current applied increase from 0.8A to 1.0A, it is observed that the difference of the maximum displacement recorded between these two is equal to 0.581mm. The plausible explanation for these findings is that the MR fluids in the prototype was experiencing the maximum saturation. Hence, the suspension system was at the highest stiffness condition. The new design OEM damper prototype was no longer absorbing the excitation energy from the bump, the prototype damper itself almost played the same role as the spring. However, the displacement recorded from the new design OEM damper is still far more inferior to the OEM passive damper for applied current of 0.8A and above.

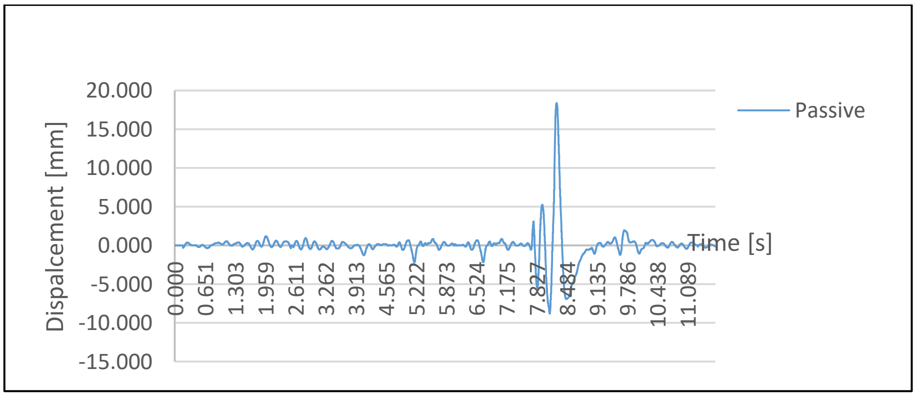

Figure 5. Displacement-time response of OEM passive damper for sprung mass.

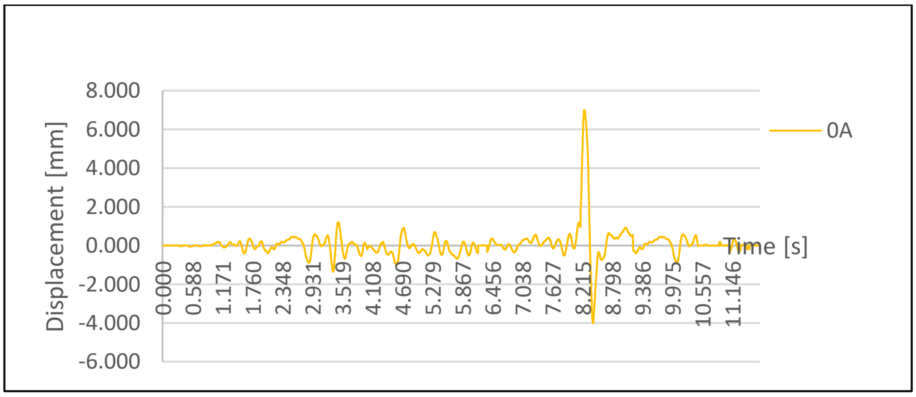

Figure 6. Displacement-time response of new design OEM damper featuring MR fluid at 0A.

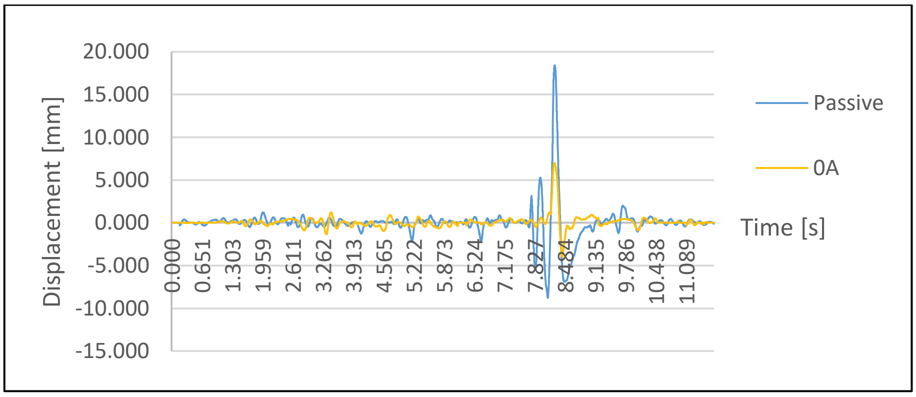

Figure 7. Displacement-time response of OEM passive damper and new design OEM damper featuring MR fluid at 0A .

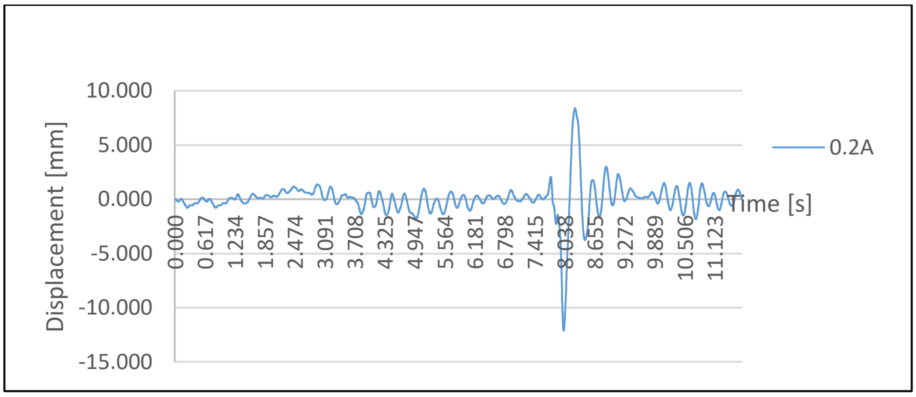

Figure 8. Displacement-time response of new design OEM damper featuring MR fluid at 0.2A.

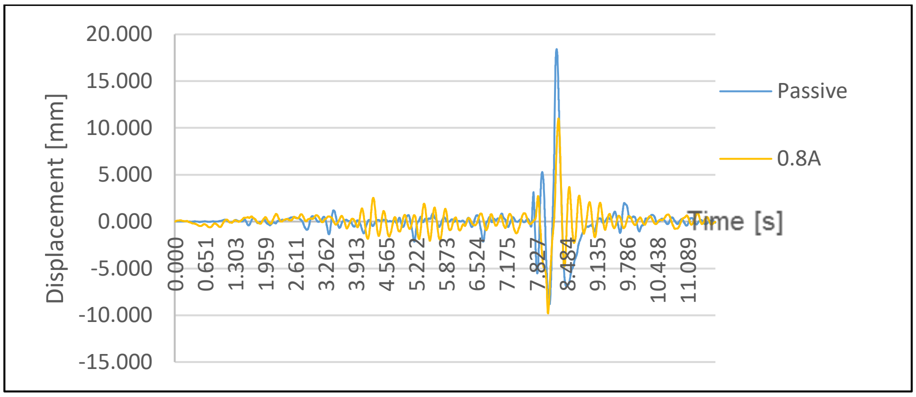

Figure 9. Displacement-time response of OEM passive damper and new design OEM damper featuring MR fluid at 0.8A.

Table 3 summarizes the results from all set of experiment. Notice that the new design OEM damper prototype has achieved a great level of performance. The results highlights that the new design OEM damper has reduced the excitation amplitude from the bump impact. In the condition of uneven road surface, the new design OEM damper prototype at lower supplied current is reliable such that it will caused the suspension system to become softer and has absorbed more vibration energy than the OEM passive damper. Low damping characteristic at low current supplied is needed to procure a good ride comfort. On the other hand, higher supplied current is needed to gain a good vehicle control on smooth road surface while speeding. This suggests that the new design OEM damper prototype can adapts damping characteristic to the profile of the road and the driver's gear shifting habits within just few milliseconds. The innovation had fully exploited the advantage of rheology properties of MR fluids.

Table 3. Displacement-time response result summarization.

	Max. Displacement (mm)	**Reduction (%)**
OEM Passive	18.423	-
0.0 A	7.008	61.96
0.2 A	8.399	54.41
0.4 A	9.400	48.98
0.6 A	10.282	44.19
0.8 A	11.014	40.22
1.0 A	11.595	37.06

The results from the experimental work indicates that the new design OEM damper prototype can control the input force and isolate the disturbance from the road profile and effectively control the output force to the sprung mass. MR fluid utilize in the development and the innovation in this work has micrometre-scale particles suspended in the main carrier fluid (oil) which align themselves and form a chains as soon magnetic field is applied. Our finding revealed that the act applying magnetic field in the foot valve of the prototype greatly increase the resistant for the fluid to flow from inner housing to outer housing and vice versa. This event will foster the damper to become stiff. Hence, it upsurge the handling control of the vehicle. The absence of magnetic field causes the damper became soft due to less viscosity of the MR fluid. A softer damper will offer mechanical grip as it will keep the tyres on the ground. Therefore, it will directly promote the increase to the satisfaction of riding comfort. The new design OEM damper prototype has directly proved its ability to solve problems in the constrained design of the OEM passive damper and can maintain its advantages over the active system. The prototype is able to alter the stiffness of the whole suspension system from soft to hard by utilizing the superior characteristics of MR fluid.

4. Conclusion

In this research, the development of passive original manufacturer (OEM) damper into semi-active based system is presented. The aim of the development is to use magnetorheological (MR) fluid to gain ultimate vibration isolation control. The new design OEM damper featuring MR fluid fabrication process was carried out and the prototype was tested physically in real environment rather than isolated environment. Vibration isolation performance is measured and the data is captured. The experimentation using the quarter car rig was successfully conducted. It is observed that there were significant reduction in displacement response recorded by the new design OEM damper prototype in compared with passive original equipment manufacturer results. At low supplied current, the prototype had greatly absorbed and isolated the vibration energy compared to OEM passive damper. The results demonstrates the new design OEM damper greatly isolate the excitation causes by the 5cm bump at applied current of 0.2A and 0.4A. The reduction computed were 54.41% and 48.98%. Optimum compromise between the level of driving comfort and vehicle control levels can be achieved by controlling the strength of magnetic field applied via the applied current to the prototype damper, tailored to the input or the state of the road travelled by the vehicle.

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References

[1] Guoliang H, Qianjie L, Ruqi D and Gang L 2017 *Journal of Advances in Mechanical Engineering* **9** 1-15
[2] Rashid M M, Rahim N A and Hussain M A 2011 *IEEE Transaction on Industry Applications* **47** 1051-1059
[3] Kulkarni A and Patil S 2013 *International Journal of Engineering Research and Application* **3** 1879-1882
[4] Premaltha S E, Chokkalingam R and Mahendran M 2012 *American Journal of Polymer Science* **2** 50-55
[5] Ashtiani M, Hashemabadi S H and Ghaffari A 2015 A*Journal of Magnetism and Magnetic Materials* **374** 716-730
[6] Miao Yu, Liao C R, Chen W M and Huang S L 2006 *Journal of Intelligent Material and Structures* **17** 801-806
[7] Jiang Z and RE Christenson 2012 *Journal of Smart Materials and Structure* **21** 65002-65013
[8] Ismail M A, Muhamad P, and Abu A 2014 *The International Conference on Kinematics* (Jakarta: Indonesia) **534** 111-116
[9] Lam A H F and Liao W H 2003 *International Journal of Vehicle Design* **33** 50–75