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MODELLING AND DESIGN SMART CONTROLLER OF MAGNETO RHEOLOGICAL USING BOUC-WEN AND SIM MODEL FOR MOTORCYCLE SUSPENSION SYSTEM

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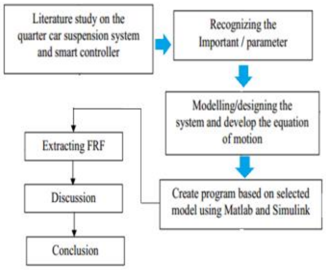
Graphical abstract



Abstract

Suspension system is a type of structural equipment attached to the wheels of a vehicle for the purpose of reducing the effects of irregularities on road surfaces. This paper investigates the Magneto rheological (MR) suspension system in motorcycle and compares its advantages with the passive suspension system. Passive suspension element can only store and dissipate energy associated with local relative motion. Moreover its energy cannot be controlled as the suspension properties remain fixed at all time, unlike MR suspension which has the ability to overcome these drawbacks. The characteristic of the latter is related to micron-sized particles, typically iron, that forms particle chains, when appropriate electric field is applied. Two modelling approaches which are the Bouc-Wen model and Sim models, were used in this research. By comparing these two MR models and passive suspension system, it can be concluded that the Bouc-Wen model gives the best result. It is also shown that MR suspension systems reduce the displacement amplitude around 30% whereas the time settling is reduced from 10 to 3 seconds, compared to the passive suspension system.

Keywords: Magneto rheological; motorcycle suspension; vibration control

1.0 INTRODUCTION

The first motorcycle was invented and manufactured by Daimler-Benz in 1885 and had no suspension [1]. This motorcycle was called *bone crusher* as it shakes and vibrates badly which caused an uncomfortable ride. Magneto-rheological (MR) fluids was first developed in the 1940s by Jacob Rainbow [2]. Its behavior is related to the micron-sized particles (typically iron) that will cause the formation of particle chains when appropriate field is applied (magnetic or electric). The strength of these chains provides an increased resistance to flow the form of controllable yield stress. This yield stress phenomenon is to be utilized to build highly-controllable semi-active devise in dampers [3]. In the early 19th century, a Swedish firm started to utilize the Magneto-rheological (MR) suspension at the race track with Wayne Rainey in the 500 class. The principal of magneto rheological damper system is similar to standard shock. The only difference is that it has a piston at the end of the shaft inside an outer that is filled with MR fluid [4]. MR fluid dampers exhibit highly nonlinear behavior, which makes it difficult to control. MR fluid can rapidly modify their flow characteristic in response to the magnetic field. Furthermore, the MR damper gained popularity and has been widely applied in the engineering field.

2.0 NUMERICAL MODEL FOR THE MOTORCYCLE SUSPENSION SYSTEM

In the present study, Honda CBR 600 is a parameter from [5] which is selected to validate the current MR suspension system. Table 1 shows the simulation parameters used to produce the response data for MR and passive suspension systems. The front suspension is the main focused as it contributed much to the influence of the handling, comfort and safety to both rider and passenger.

The simulation model for motorcycle suspension system is the two degree of freedom (2DOF) model as shown in Figure 1 which was also discussed in [5]. It consists of sprung and unsprung mass and an excitation base. The sprung mass represents the inertia supported by the suspension, including the driver and passenger. The unsprung mass is representative of the wheel and proportion of suspension linkage.The advantages of the 2-DOF model are that although it is relatively simple to analyse, it allows a good approximation of the motion of both the chassis and the wheel of a vehicle, and hence possesses great potential in future development of vehicle analysis.

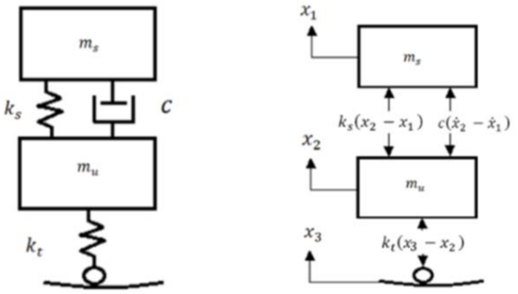


Figure 1 The 2DOF motorcycle system under base excitation Diagram [6]

Using Newton's second law of motion, the equation of motion for this system becomes:

$$m_u\ddot{x}_2 = k_t(x_3 - x_2) - k_s(x_2 - x_1) - c(\dot{x}_2 - \dot{x}_1) \quad (1)$$

$$m_s\ddot{x}_1 = -k_s(x_2 - x_1) - c(\dot{x}_2 - \dot{x}_1) \quad (2)$$

In this research, the primary system parameters for OEM and MR suspension systems are taken from HONDA CBR 600 motorcycle [6]. The parameters are given in Table 1. The vehicle parameters will be considered constant unless otherwise specified; these are the values that will be referred to as the "default motorcycle". The damping value, c for the OEM system will be replaced with Bouc-Wen and Sim et al MR models. All of the Simulink diagrams (passive, Bouc-Wen and Sim *et al*) are used to apply the sinusoidal excitation with different frequencies to get the Frequency Response Functions (FRFs) of the system. This can be done by averaging the steady state responses where systematic and clear solutions can be obtained [7]. FRFs are studied here because it is a direct interpretation that represents the response behavior of a given structure. Besides, FRF immediately makes available the position (in frequency) of resonances and the extent to which the resonances are damped. The FRF is of such importance that the standard instrumentation is available for its measurement in the laboratory. The FRF is calculated based on displacement transmissibility using the amplitude ratio of the relative displacement from the mass and the base of the steady state motion caused by a sinusoidal input displacement of the base amplitude.

Table 1 Parameters of Honda CBR 600 as taken from [5]
+

Entry	Vehicle Parameter	Value	Description
1	m_s	150 kg	Mass of the body
2	m_u	20 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

3.0 SIM et.al MODEL FOR MR MOTORCYCLE SUSPENSION

A two degree-of-freedom system from Figure 1 is now replaced with the system shown in Figure 2. MR model from [1] is adapted to the passive motorcycle suspension system and it is labeled as F_{MR}. According to [12], the force in this system is now becomes

$$F = k(x_2 - x_1) + k_{acc}\, x_2 \quad (3)$$

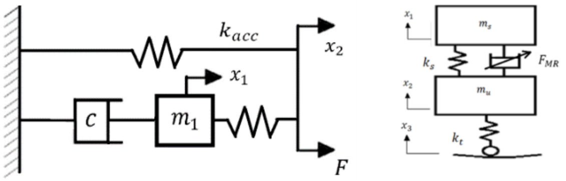


Figure 2 MR Sim *et.al* Model from [11] is adapted to 2DOF motorcycle suspension system

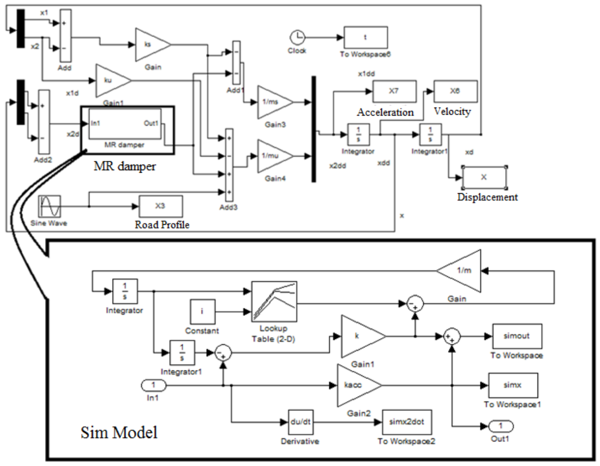


Figure 3 The Simulink Diagram for MR motorcycle suspension system

Figure 3 shows the overall system incorporating the application of MR model to the conventional passive motorcycle suspension system. This mathematical model approach for MR motorcycle suspension system is developed using Matlab *Simulink*.

4.0 BOUC-WEN MODEL FOR MR MOTORCYCLE SUSPENSION

Next, the two degree-of-freedom system from Figure 1 is now replaced with the system shown in Figure 4. Bouc-Wen model is adapted to the passive motorcycle suspension system and is labeled as F_{MR}. As in following to (G.Z. Yao 2002), the force in this system is given by,

$$F = c_0\dot{x} + k_0 x + \alpha z \qquad (4)$$

Where the evolutionary variable z is governed by

$$\dot{z} = -\gamma|\dot{x}|z|z|^{n-1} - \beta\dot{x}|z|^{n} + A\dot{x}, \qquad (5)$$

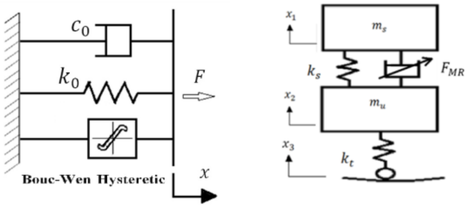


Figure 4 Bouc-Wen Model is adapted to 2DOF motorcycle suspension system

Where gamma γ, beta β and alpha A are parameters used to control the amplitude and shapes of the hysteresis loop. In addition, the force F due to the accumulator can be directly incorporated into this model as an initial deflection x_0 of the linear spring, k. Its dynamic equation is

$$m\ddot{x} + b\dot{x} + kx = k(d_e u - h) \qquad (6)$$

Where $h(t)$ represents the hysteretic state variable and $u(t)$ is the input voltage; n controls the transition from elastic to plastic response as follows.

$$\dot{h}(t) = \alpha\dot{u} - \beta|\dot{u}(t)|.h(t).|h(t)|^{n-1} - \gamma\dot{u}|h(t)|^{n} \qquad (7)$$

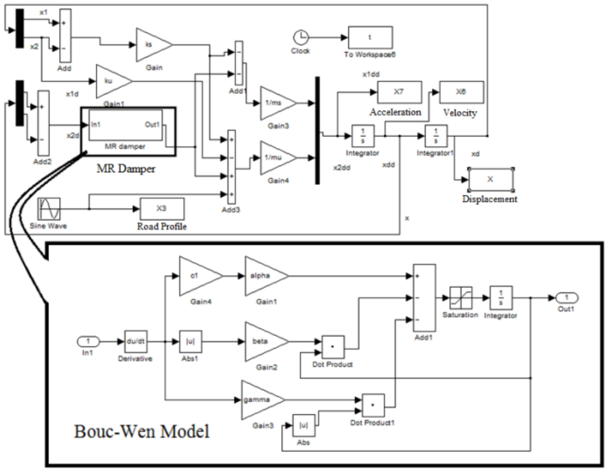


Figure 5 The Simulink Diagram for MR motorcycle suspension system using Bouc-Wen Model

5.0 MAGNETO RHEOLOGICAL AND CONVENTIONAL DAMPER PARAMETER

The validity of the MR motorcycle suspension is verified through computer numerical simulations. The physical parameters of the MR suspension system are as in Table 1. The road profile tested here shows various sine waves taken from (Fu-Kuang Yeh and Young-Yi Chen, 2012) which was used for bicycle suspension system and is similar to the motorcycle system, as shown in Figure 6.

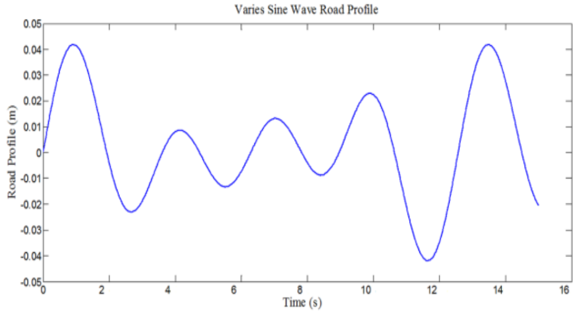


Figure 6 Road Profiles varies of sine waves (Fu-Kuang Yeh and Young-Yi Chen, 2012)

Figure 7 below shows the FRF for MR suspension using the Sim *et al.* model. The results of this model are quite similar to those of the Bouc-Wen model. Three current levels are tested and discussed for the Sim *et al.* model. Like its predecessor, the same basic parameters from the OEM system are now used for the MR damper. This has aided in determining the relative level of displacement versus the time content between the MR damper and the OEM damper. The simulation results in Figure 7 show the transmissibility for the MR suspension using the Sim *et al.* model. The transmissibility plot shows the effectiveness of vibration isolation in terms of the ratio of amplitude of sprung and unsprung displacement motion transmitted through the MR damper which acts as an isolator of the amplitude from the displacement excitation. The MR Sim *et al.* model for the suspension system is designed to replace the OEM damper. The electric current applied to the MR model caused the formation of particle chains in the fluid that provides and increases the resistance to flow in the form of controllable yield stress. The input current tested are 0.2A, 0.7A and 1A. The results can be explained as when the current increases; it will reduce the amplitude of the sprung mass. However, looking at Figure 7, for the unsprung mass, there are no major changes as the model has not considered damper to the tyre. However, it can still be seen that there is a slight decrease in the amplitude which is caused by the implementation of the MR suspension.

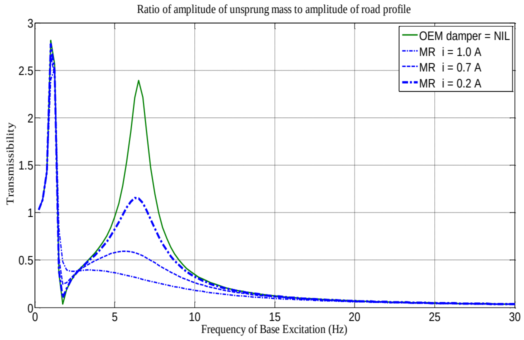


Figure 7 FRF comparisons between OEM and MR suspension system using Sim *et al.* model

The MR Bouc-Wen model for the suspension system is designed to replace the conventional damper. This aids in determining the relative level of displacement versus time content between the MR and OEM dampers. The simulation results in Figure 8 show the transmissibility for the MR suspension using the Bouc-Wen model. The transmissibility shows the effectiveness of the isolation of the vibration in terms of the ratio of amplitude of the sprung and unsprung displacement motions transmitted through the MR damper which acts as an isolator to the amplitude of the displacement excitation. Several values of electric current are applied to the MR model, which cause the formation of particle chains to the fluid that provides an increased resistance to flow in the form of controllable yield stress. The current input tested for 0.1A, 0.2A, 0.4A, 0.5A, 0.7A, 0.8A and 1A. The results can be explained in that when the current increases, it will reduce the amplitude of the sprung mass. Whereas, by looking at Figure 8, at the unsprung mass, there are no major changes as the model is not considered damper to the tyre. However a slight decrease to the amplitude can be seen, which is caused by the implementation of the MR suspension system.

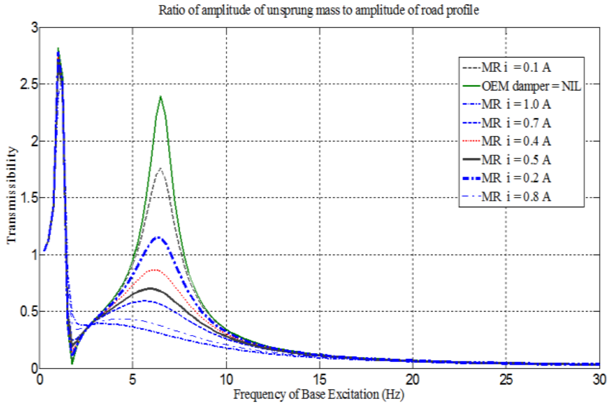


Figure 8 Transmissibility for OEM motorcycle Suspension and MR damper using the Bouc-Wen model

The input excitation of various sine waves was tested for the OEM and MR Sim *et al.* damper, shown in Figure 9. The input current was tested for 0.1A, 0.3A, 0.5A, 0.8A and 1A. As before, the results can be explained in that when the current increased, it will reduce the vibration of the sprung mass. Whereas by looking at the OEM damper, there are no major changes and far from reaching the zero equilibrium position. It can be seen that the OEM system did not change because the composition and parameters are fixed. In contrast to the MR system that uses the Sim *et al.* model, it can control vibration in the motorcycle suspension with a certain current level. In other words, this system is more flexible and gives an advantage to the MR system.

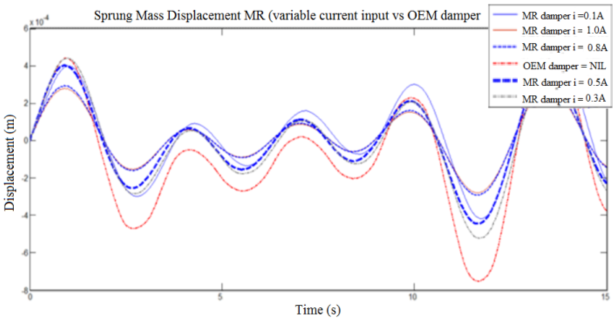


Figure 9 Various sine waves with variable current input using the Sim *et al.* Model

The current input tested here is 0.1A. Figure 10, shows the results between both models, in which the characteristic of the Bouc-Wen model have been tuned to obtain a better result. The best result for this simulation was obtained with Alpha, a of 33.6, Gamma, γ of 1.46 and Beta, β of 4.15. This figure also illustrates that the vibration time settlement for both MR dampers is reduced to 3 seconds for the Bouc-Wen model and 8 seconds for the Sim model. The better performance of the Bouc-Wen model makes it one of the most popular models among the MR application. By comparing these two mathematical models, it can be concluded that the Bouc-Wen model gives the best estimation for the hysteretic characteristic.

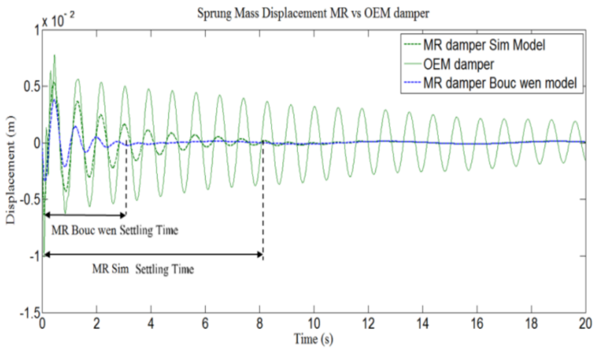


Figure 10 The Oscillation for the MR Bouc-Wen damper, MR Sim *et al.* damper and OEM Damper for current 0.1A

6.0 CONCLUSIONS

The MR for motorcycle suspension using the Bouc-Wen and Sim *et al.* models have shown their capability and reliability to suppress the vibration disturbance from the varies of sine waves excitations. All the results show that the MR motorcycle suspension is able to resist the rough oscillations and provide better ride time settlement which gives better handling and comfort for both the rider and passenger. By comparing these two MR models, it can be concluded that the Bouc-Wen model gives the best result. The designed model is run for several input currents ranging from 0.1A to 1.0A. The most effective current input is obtained and it is suggested here that an applied current from 0.2A to 0.75A would be comfortable for a 150kg motorcycle.

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