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doi:10.4028/www.scientific.net/AMM.663.158

Simulation on Force Tracking Control of a Magnetorheological Damper under Impact Loading

Alif Zulfakar bin Pokaad[1,a], Md Radzai bin Said[2,b], Fauzi bin Ahmad[2,c]
and Mohd Nazeri Kamaruddin[1,a]
[1]Faculty Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama,
Bukit Beruang, 75450, Malaysia
[2]Faculty of Mechanical, University Technical Malaysia Malacca, Hang Tuah Jaya,
Durian Tunggal, 76100, Malaysia
[a]alif_zul85@yahoo.com, [b]radzai@utem.edu.my, [c]fauzi@utem.edu.my,
[d]nazeri.kamaruddin@mmu.edu.my

Keywords: Magnetorheological damper, force tracking control, PI controller and impact loading.

Abstract. This paper focuses on the design of the control structure which consists of inner loop controller employed for MR damper under impact loading by using computer simulation. The simulation is done by using MATLAB 7.0. The structure of the inner loop control for the proposed MR damper model uses a simple PI control to achieve the desired force. In this simulation, the MR damper model that has been validated with the experimental result is used to simulate the actual force that produced by MR damper. The performance of inner loop controller to track the actual force produced by MR damper by obtaining the several input functions which are half wave of sinusoidal, saw-tooth, square and random functions of desired force with the variation in pendulum mass of 15 kg and 20 kg are investigated. It can be seen clearly that under several input functions, the proposed polynomial model with PI controller has the good ability to track the desired damping force under impact loading.

Introduction

Energy absorb devices are critical issued when the subject face with the dynamic or impact loads such as vehicle accident and earth-quake. The energy absorb device is the main part that reduced the transmitted energy from the impact loads into the subject by making the more contact time between the energy absorb device and impact loads. There are two types of energy absorb which are passive and active energy absorb. The different between passive and active energy absorb devices is the elasto-plastic region. The elasto-plastic region is constant for the passive energy absorb and impossible to control with the real time. But the active energy absorb device has variation elasto-plastic region that can control by the real time of the impact.

Magnethorheological damper is one of the active devices. Magnetorheological (MR) fluids fall into a class of smart fluids which rheological properties (elasticity, plasticity, or viscosity) change in the presence of a magnetic field. In the presence of a magnetic field, the particles align and form linear chains parallel to the field direction. With a properly designed magnetic circuit, the apparent yield stress of the MR fluid will change within milliseconds [1]. A significant amount of work on developing electromagnetic circuits for damper coil has lead to design an electromagnetic system that require low voltages and exhibit fast response times [2,3].

Previous studies on shock reduction are actively accomplished using smart fluid which has reversible properties with applied magnetic fields. Lee et al. investigated a magnetorheological (MR) damper to reduce shock transmitted to a helicopter including its dynamics model and controller strategy [4]. MR damper application for shock reduction in weapon mechanism has also studied by Ahmadian et al. [5]. Song et al. proposed the shock damper to reduce impact by means of acceleration decrement of the damper [6]. Other application was the use of MR damper in driver seat for shock attenuation. Investigation on the potential benefits of MR damper in reducing the incidence and severity of end-stop impacts of a low natural frequency was performed by McManus et al. [7]. However, the previously mentioned studies did not investigate the force tracking control in modelling the MR damper characteristics under impact loading.

The contribution of this work is to study the effectiveness of the PI control to track the force produced by MR damper by following the trend and value of desired force. This investigation is important to determine whether the MR damper model subjected to impact loading can be adapted with PI controller or not. This paper has shown that PI controller has good capability to track the force produced by MR damper by following the trend and value of desired force. For future works, the advance controller can be used to generate the desired force in order to reduce the impact of dynamic loading.

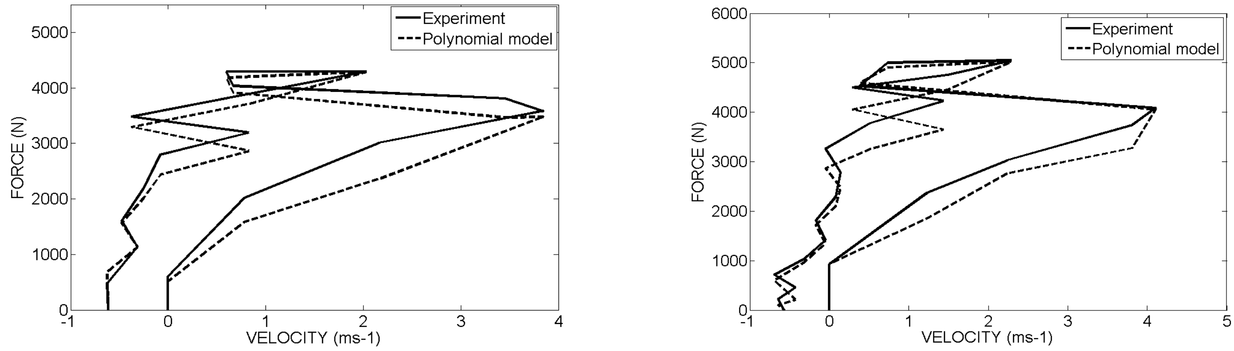
MR Damper Model

The modelling of Magnetorheological (MR) damper under impact loading is developed by using a polynomial method which has been validated with the experimental results as shown in Fig. 1. The polynomial model is developed based on curve fitting from experimental results and consists of a three regions namely fluid locking, positive and negative acceleration regions. The details on how the value of MR damper damping force from experimental to be implemented into the modelling had been described in our previous research [8]. The general formula of force transmitted by MR damper under impact loading is shown below:

$$F(t) = \alpha_m f_d(I,t) \tag{1}$$

$$v(t) = \beta_m v_d(I,t) \tag{2}$$

where $F(t)$ and $v(t)$ are force and velocity of MR damper with real time, α_m and β_m is dimensionless parameter, I is input current, f_d is damping force at mass of pendulum 25 kg and t is time during impact loading.



(a) (b)

Fig. 1: Characteristics comparison for MR damping force between experimental and modelling (a) 15 kg pendulum mass, and (b) 20 kg pendulum mass (Force against Velocity) [8]

Force Tracking Control

In this section, the inner loop control for the proposed MR damper model is performed in simulation study. The inner loop control structure of the proposed MR damper model use a simple PI control as shown in Fig. 2 which illustrates a closed-loop control system to achieve a desirable damping force generated by the outer loop control. The PI controller is formulated as follows,

$$u(t) = k_p e(t) + k_i \int e(t) \partial t \tag{3}$$

$$e(t) = F_d(t) - F_a(t) \tag{4}$$

where F_d is the desired damping force and F_a is the actual damping force. Meanwhile, *e*(*t*) is the force error between the desired damping force and the actual damping force and *u(t)* is a command current.

In this simulation study, the parameters of K_p and K_i are chosen by using the sensitivity. It can be illustrated by looking the Fig. 3 where the lowest RMS value for the force error are pointed at 0.0515 and 0.0015 for K_p and K_i respectively at each pendulum mass. So the optimum value of K_p and K_i are set to 0.0515 and 0.0015 respectively.

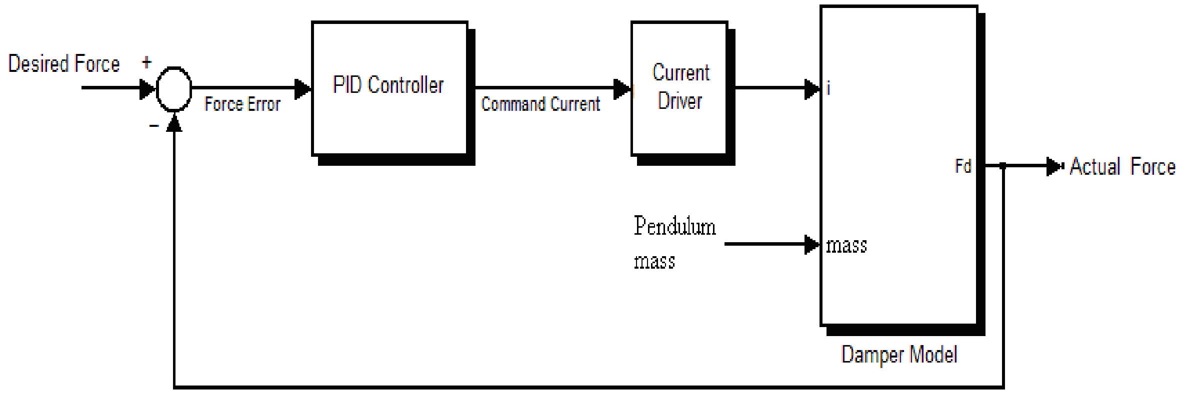


Fig. 2: Graph RMS Force error versus K_p at each pendulum mass

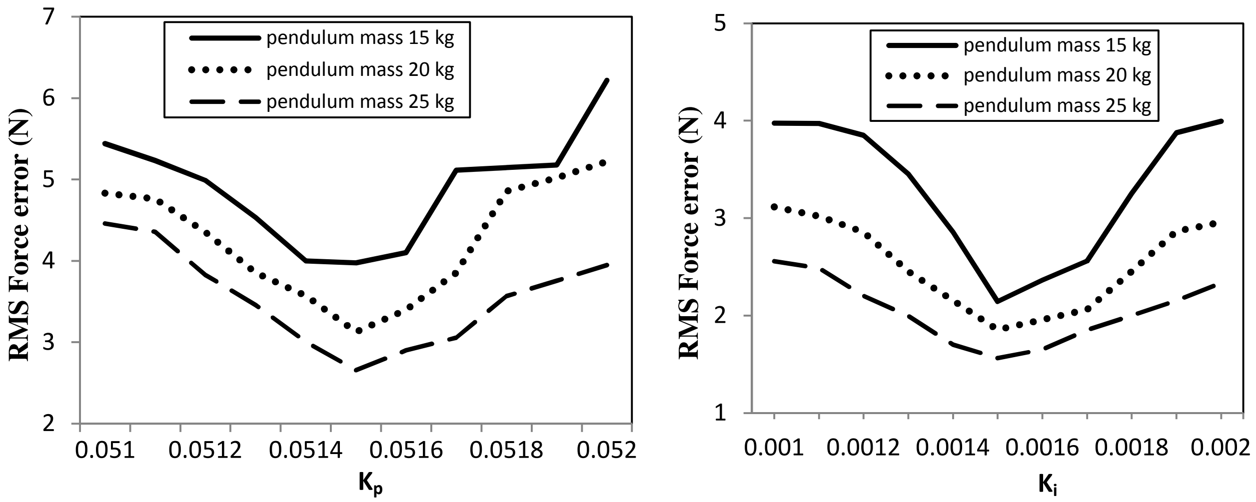
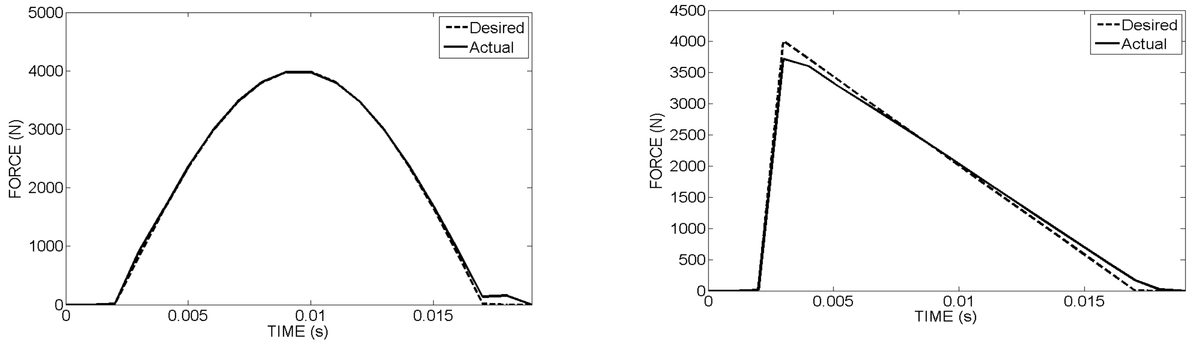


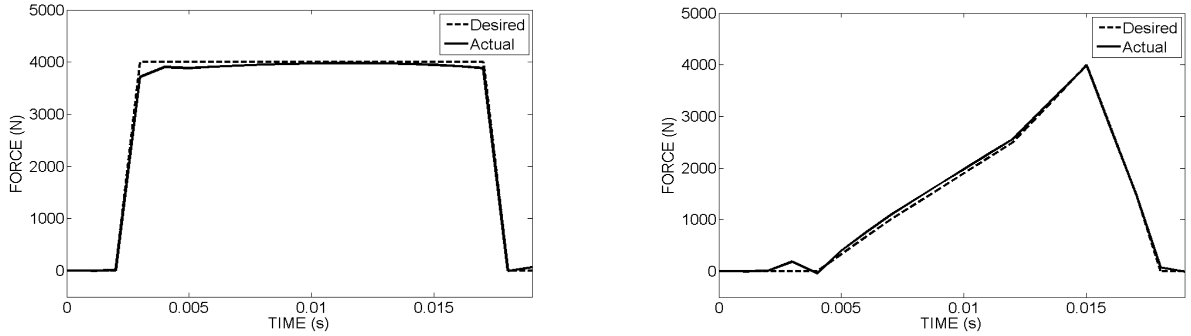
Fig. 3: Graph RMS Force error versus K_i at each pendulum mass

Simulation Result

The simulation study is executed in MATLAB-SIMULINK environment for half wave of sinusoidal, saw-tooth, square and random functions of desired force with the variation in pendulum mass of 15 kg and 20 kg. In this simulation, the desired force is set to positive value and generates in contact time, t_c of pendulum mass during collision. The desired force is set to positive value since the model of MR damper is under impact loading and only has positive velocity of MR damper. As shown in Fig. 4 and 5, the proposed inner loop control has the ability to track the desired damping force of the MR damper and able to closely follow the trend of the desired force in the form of sinusoidal, saw-tooth, square and random function with the variations in pendulum mass of 15 kg and 20 kg respectively.

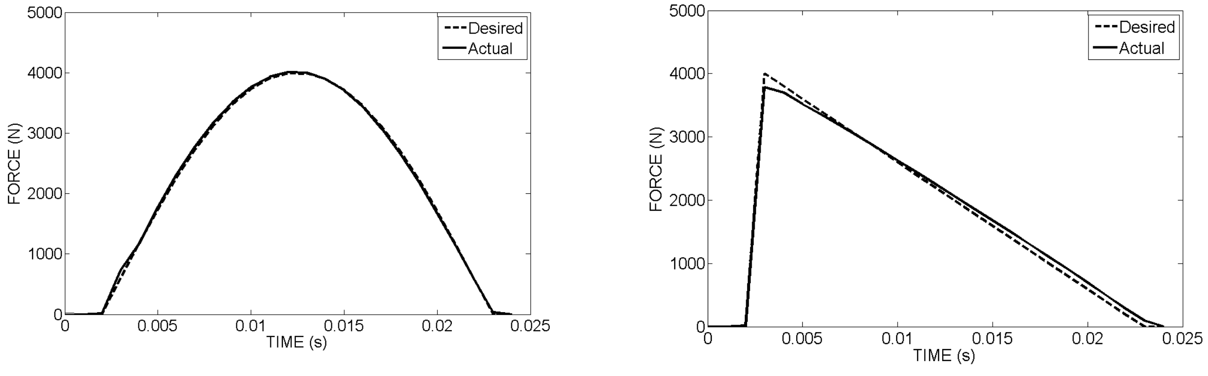


(a) sinusoidal (b) saw-tooth

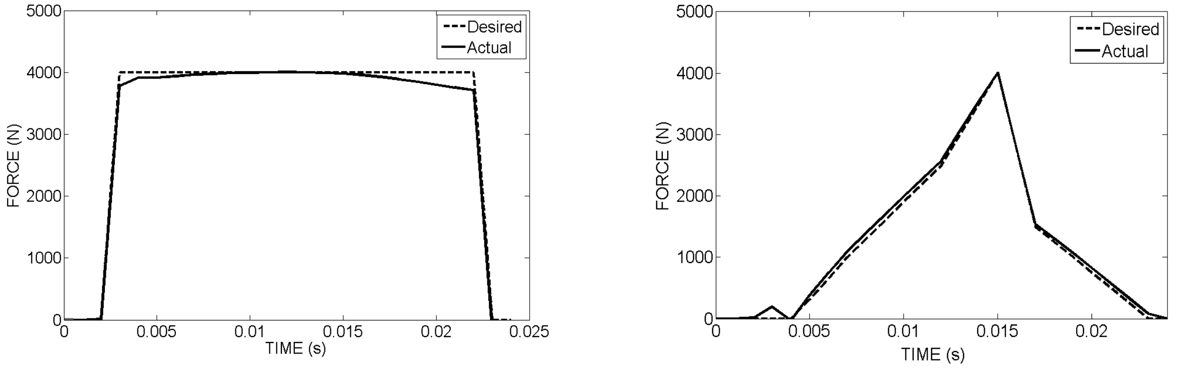


(c) square (d) random

Fig. 4: Simulation results of force tracking control at the mass of pendulum 15 kg



(a) sinusoidal (b) saw-tooth



(c) square (d) random

Fig. 5: Simulation results of force tracking control at the mass of pendulum 20 kg

As shown in Fig. 5, the inner loop controller almost perfect to follow the pattern and the value of force in sinusoidal and random shape (desired force). Saw-tooth and square shapes force, the inner loop controller has the small differential in terms of the peak force value but the force pattern of inner loop controller is similar with the desired force. The small differential is occurred due to the optimize values of K_p and K_i do not reach the peak value of desired force in terms of saw-tooth and square shapes desired force. But the differential is too small and acceptable to guarantee that the proposed inner loop controller has the good potential to track the desired force in variable shapes of desired force.

Conclusion

In this research, the controllability of the proposed model is investigated in simulation study by realizing a simple closed-loop PI control. In the simulation study, several types of desired damping force including half wave for sinusoidal, saw-tooth, square and random function of desired force in the variation of pendulum mass of 15 kg and 20 kg have been treated to the inner-loop block diagram. The sensitivity study is used in order to determine the optimize values for K_p and K_i respectively. From the simulation results, it can be seen clearly that under several input functions, the proposed polynomial model tracks the desired damping force well.

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