PID controller for Semi-active Suspension System with Magnetorheological Fluid Damper

Mahdi Qahraman [1], Mohammed Jawad Aubad [2]

[1,2] Department of Mechanical Engineering, Faculty of Engineering, University of Babylon, Babylon Province, Iraq.

mehdi.brakas@student.uobabylon.edu.iq

Abstract. This paper study the magnetorheological fluid damper of controlled and uncontrolled of a semi-active suspensions system as an application under different rode profiles (step, sin, and random input) for the automotive. Bingham plastic model is adopted for the mathematical modeling and analyzes the hysteretic behavior of the MR fluid damper. The PID controller is used for the control processes. The study presented the dynamic response of the suspension system with MR damper with different road profiles and show the force-velocity, and response of body automotive. PID controller uses to improve the dynamic behavior of the MR suspension system by control on the damping force. The results have shown that the input current play an important role regarding the dynamic response and hysteric behavior by reducing the dynamic characteristics of the automotive suspension. Also, The PID controller has sooth effective to remove the vibration without any irregular behavior.

Keywords: PID controller, Magnetorheological Damper, Damping force, Semi-active suspension system.

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1. Introduction

The suspension system is a critical component of any automotive suspension system, which is played a very important role to save the stability of automotive and passengers. Suspension systems have different types of suspension systems, namely: passive, semi- active, and active that have been by many researchers who have study different design techniques and control algorithms[1−4]. Magnetorheological (MR) damper is an example of semi-active suspension system adaptive devices that have been the subject of extensive research into different dynamics applications in mechanical and civil engineering. A semi- active suspension system was proposed[5-8]. where MR damper used unemployed commercially in- vehicle shock absorbers, landing gear, vibration isolation systems, helicopter lag dampers, vehicle seat suspension systems, mounts, bearings, and military equipment. brake. Excellent strength to weight ratio of actuators and dampers using these fluids has recently led to an interest in its use in the interaction between man and machine, particularly used robots[9]. Magnetorheological brakes had been introducedas high-performance brakes which is simple system design and exclusion brake wear[10]

The base parameters used in the semi-active control entry is low power, good performance, fast response, simplicity interaction between mechanical and electrical parts. Low power requirements, safe to fail, and high level of reliability are the main advantages of MRF damper. The magnetorheological fluid is a typical smart material with unique magnetic and unique property characteristics that are mirrored in viscosity and stress yield under the magnetic field. The MR fluid has many Properties, one of these fluid properties is can working low temperatures range from -40°C to 150°C in MR damper [11]. MR fluids

properties are changes with the application of an external magnetic field[12].In absence of a magnetic field, an MR fluid behaves as a Newtonian liquid it is free-flowing like motor oil. the applied magnetic field is forming a chain structure that resists the movement, and this resist depended on the strength of the applied

magnetic field. Many different models have been studied the parameters of magnetorheological fluid and explain the effect of these parameters on the accuracy and to improve the behavior of models like Bingham, Bouc-Wen, Dahl, Luger, and hyperbolic tangent models. Because of the nonlinear behavior of the MRF damper, it is imported to develop a suitable controller for it to arrive at minimum power supply for maximum force. Therefore, so many types of controllers are used to control the MRF damper such as PID, Fuzzy, Skyhook, and LQR controllers [13-17].

M. A. Al-shujairi et, al [18] used the LQR controller to control the damping force by controlling the input current under different road inputs. M. Razali et, al[19] studied the dynamic response for small-scale MRF damper for orthotic shaking suppression applications. Sulayman L. Eshkabilov[20] presented a good review of the mathematical models used for different road excitations. Mohammad Saad et, al[21], used the PID controller with the Bouc- Wen model to scrutinize the performance of a semi-active suspension system. Mat Hussin Ab Talib[22] in his paper using intelligent PID controller with Bouc-Wen model for study the performance of MRF damper under different exaction to determent force- displacement and force-velocity Behavior. Zhao-Dong Xu et, al[23] proposed an on-line real-time control method with a Bingham model for a control current of MR damper The subtract matches the experiment data. Jann N. Yang [24] presented the safety ability of various types of hybrid control systemswith nonlinear buildings against near-field earthquakes. Mahmoud El-Kafafy [25] used the Bouc-wen model for MR damper with sliding mode control to force the MRF damper to follow the dynamic of an ideal sky-hock model. Nikoo K. Hazaveh et, al[26] studied three different algorithms to determent optimal control forces of MR damper including a discrete wavelet transform (DWT), a clipped-optimal control algorithm and a linear quadratic regulator (LQR) used with the Bouc-Wen model. Zakariyya H. A. et, al[27] designed a PID controller for a Motion control system. K. Dhananjay Rao et, al[28] designed Linear Quadratic Regulator (LQR) and PID controllers for Quarter car semi-active suspension system. Banna Kasemi et, al[29] used Fuzzy-PID controller to control the vibration of the car, and the controller structure determined by the methodology adopted on the experimental results. Miao Yu et, al[30] developed a human simulated intelligent control (HSIC) scheme to attenuate the unwanted vibration response of MR damper. Michele Ieluzzi et, al[31] developed and design control for the development process and overall performance for a semi-active suspension system of a heavy truck.

In this paper, the magnetorheological fluid damper of passive and controller semi-active suspensions system as an application under different rode profiles (step, sin and random input) has been studied. Bingham plastic model is used for the analysis and modeling of the hysteretic behavior of the MRF damper. The process is controlled by using a PID controller. The study presented in two branches, first the dynamic response of suspension system with MR damper with different road profiles and show force- velocity, the response of displacement, velocity, or acceleration body, for each case. Second, use the PID controller to improve the behavior of the MR suspension system. Each case applied different current inputs with changing in form factor with each current, and the result has shown that both current and form factors play an imported role on the dynamic characteristics and dynamic force for each exaction.

2. Modeling of the Quarter Car

Mathematical modeling of the quarter automotive suspension system can be described as two degrees of freedom used the basic laws of mechanics. The aims of a mathematical model of a quarter car are to describing the interactions between the suspension system, and the tire in a single corner of a vehicle. The figure 1 shown the quarter car model diagram. Table 1 defined the quarter car model parameter.

A quarter of the body of the car for the semi- active suspension system is being implemented using newton's law of motion. Some small powers (Including a backlit in the body and motion, flex in different links, the gear, and the garbage system,) to increasing the simplicity of the system and to exclusion the undesirable forces because of low density and then these were left out of order form. The mathematical equation for the quarter car model introduced

in equation (1) and (2)[18]:

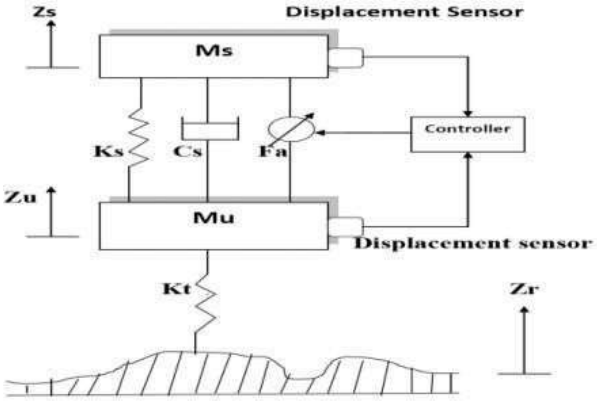

Figure 1. Quarter car model diagram of asemi-active system

$M_{\square}\ddot{\square} + K_{\square}(Z_{\square} + \ddot{\square}_{\square}) + \square(\dot{\square} + \dot{\square}\square) = \square_{\square}$ (1)

$\square_{\square}\ddot{\square} + \square(\ddot{\square}_{\square} + \ddot{\square}_{\square}) + \square_{\square}(\dot{\square} + \dot{\square}\square) + \square_{\square}(\ddot{\square}_{\square} + \ddot{\square}) = -\square_{\square}$ (2)

Where:

$\square_{\square}$ = sprung mass (kg)

$\square_{\square}$ = unsprung mass (kg)

$\square_{\square}$ = unsprung mass

$\square_{\square}$ = relative tire displacement (m)

$\square_{\square}$ = relative body displacement (m)

$\square_{\square}$ = sprung stiffness (N/m)

$\square_{\square}$ = unsprung stiffness (N/m)

$\square_{\square}$ = sprung mass damper (N.s/m)$\square_{\square}$=controlled damping force (N)

Table 1. quarter car data [20]

Parameter	value
sprung mass (Ms)	450 (kg)
unsprung mass (Mu)	68 (kg)
sprung stiffness (Ks)	28500 (N/m)
unsprung stiffness (Kt)	293900 (N/m)
sprung mass damper (Cs)	2700 (N.s/m)

3. Bingham plastic Model

Dynamic hysteria behaviors of MR fluid dampers have different models that use to modeling it . Bingham model is the simplest model for MR damper [32]. Using the Bingham model because it has better performance than another model, it is simple and easy to be controlled. It can be mathematical modeling for this system described by the following equation[18]:

$$\square_{\square\square} = \frac{2\square\tan^{-1}(\square.\dot{\square})}{\square} + \square_0\dot{\square} + \square_0\square + \square_0 \quad (3)$$

Where z is a displacement of MR damper, $\square_{\square}$ is the controlled force, $\square_{\square}$ is the constant force of MR damper, $\square_{\square}$ is the damping coefficients of the MR damper, $\square_{\square}$ is the stiffness of MR damper and $\square$ is the form factor. Bingham plastic model diagram is shown in figure 2 as an approximate introduction of the hysteresis loop expressed by (3), and a working form enhances the rounding of hysteresis loops of equation (3) to a large extent. The form factor enhances the accuracy of the hysteresis loops of equation (3) considerably.

Bingham model parameters are $\square_0$ is assumed to equal 40N ,for n take the following value for each current value [0, 5, 10, 20, 30]A and for $\square_{\square},\square_{\square}$ are both depended on the input current to MR damper. Their values are given as a function of the current as in following equation [18]:

$\square_{\square}(I)$= -910.09 $\square^3$+986.49 $\square^2$+663.56 I+52.19

$\square(I)$= 48.74 $\square^4$-106.39 $\square^3$+66.00 $\square^2$+1.43 I+0.53

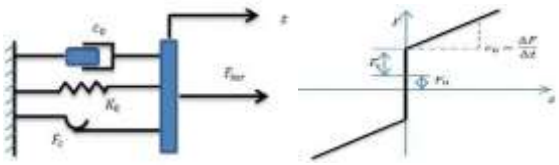

Figure 2. Bingham plastic model proposed

4. RESULTS AND DISCUSSION

4.1 Effect of Current

The MR damper mathematical model in equation (2) which was previously introduced has been simulated in MATLAB/SIMULINK and applied different road exaction. First, modified the Bingham plastic model by changing the form factor to improve MR damper performance. To

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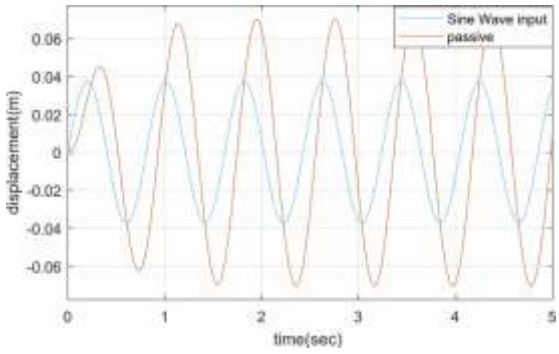
show the effect of increasing the input current as well as form factor which is compared with controller case later.

The uncontrolled characteristic of the suspension system with different types of excitation (step with 10cm amplitude, sin wave with 0.375 cm amplitude, and random with - 3.75cm to +3.75cm amplitude) can be shown in figures(4,5 and 6) to understand the effect of the current value on the dynamic response behavior for the body car displacement and to appear the influence of current value on suspension system without used control system.

Through the responses in figure (5), can be noted that the effect of values of current, when the values of current increase this leads to a change in the value of (Fc), it is a function of the current in the equation (4), lead to reduce value of overshot, and settling time.



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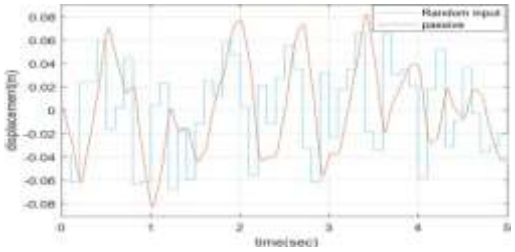
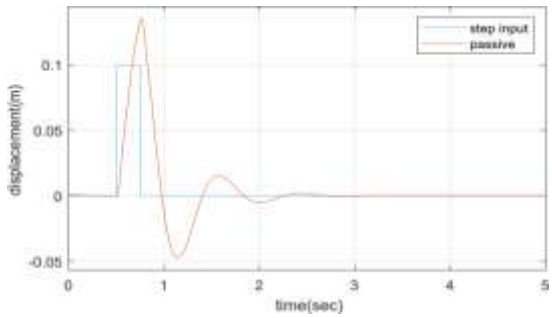


(c)

Figure 4. the passive state of. (a) step, (b) sin, (c) random.



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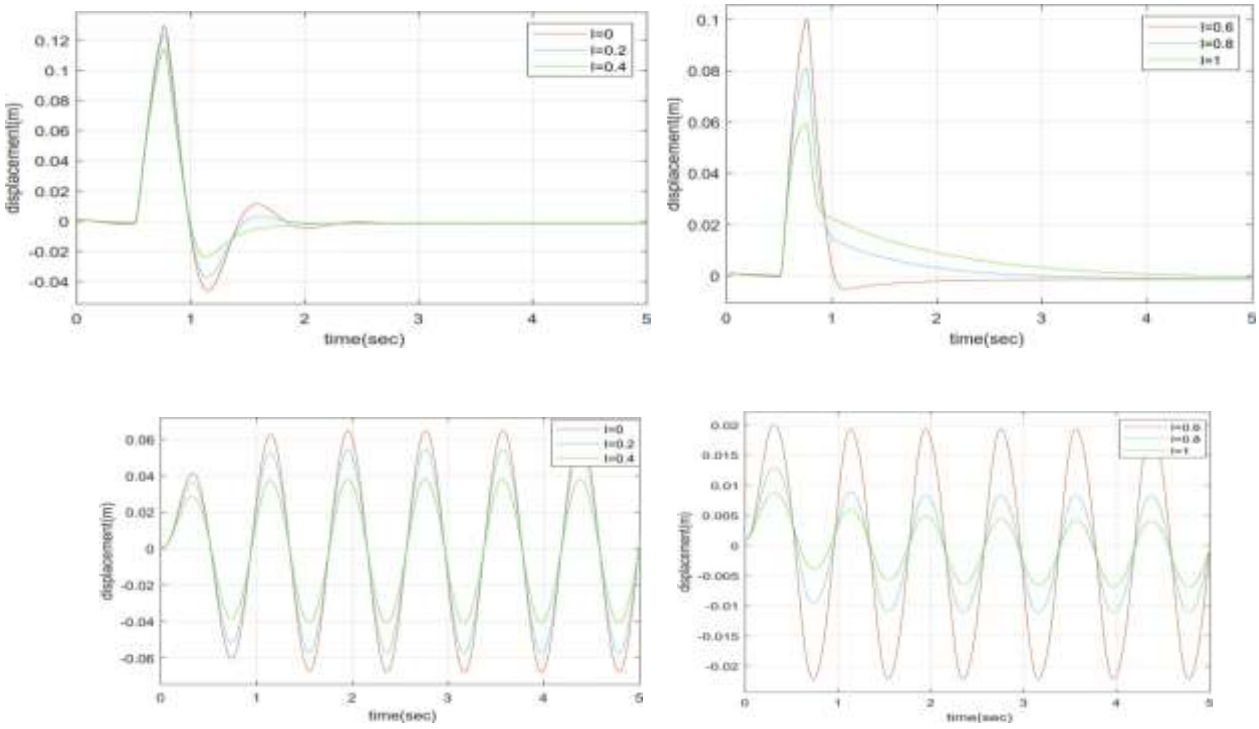

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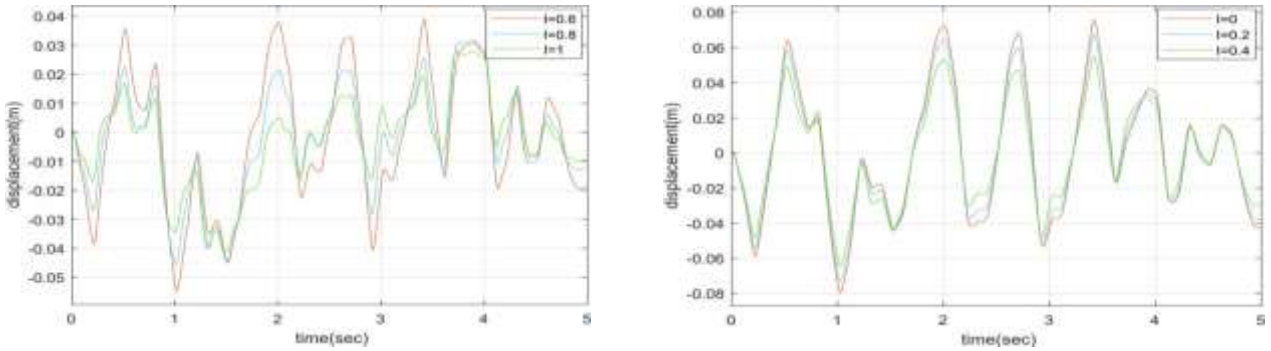
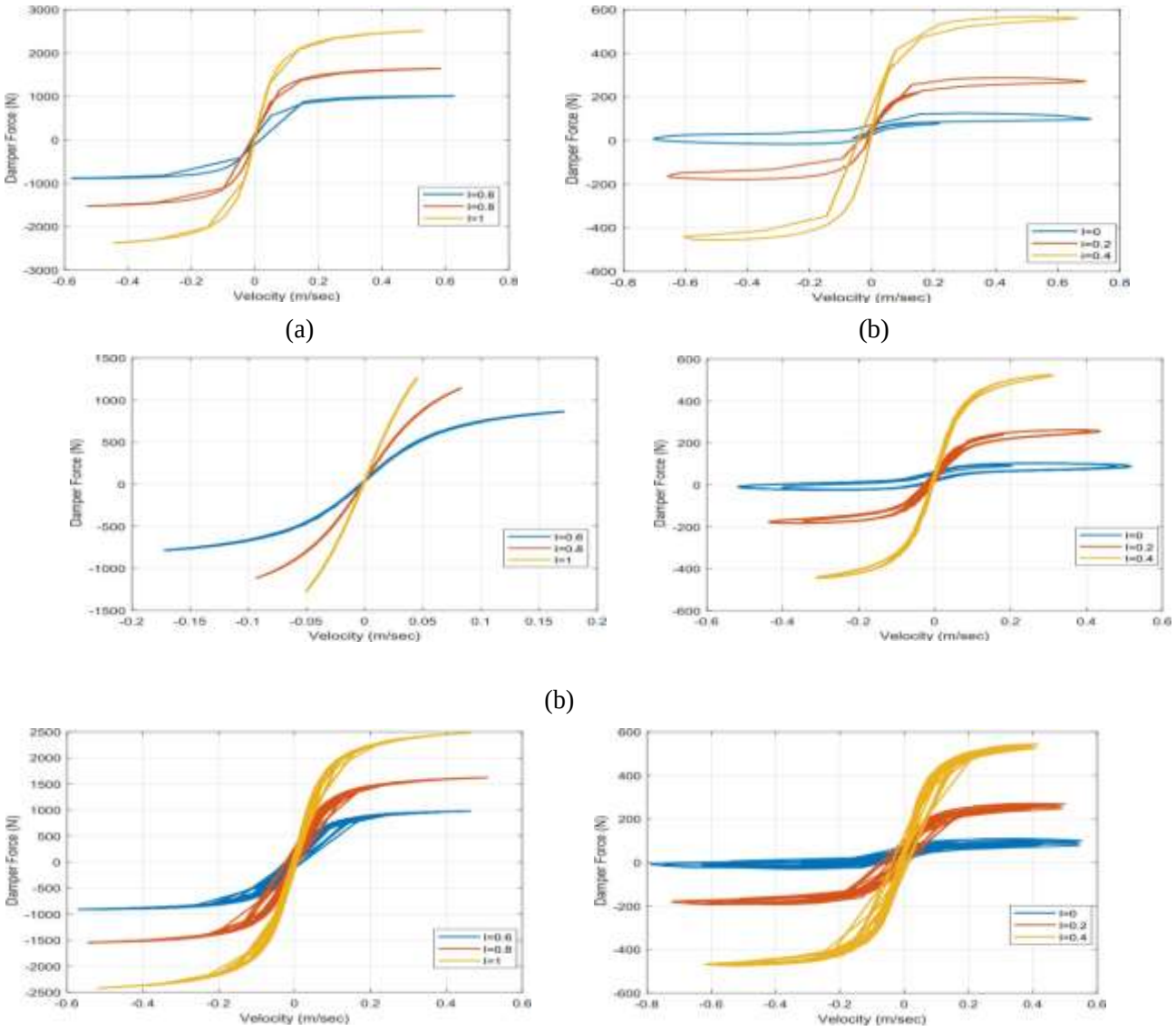


(c)

Figure 5. displacement of car body under step excitation with different input current . (a) step, (b) sin, (c) random.



(a)

(b)

(b)

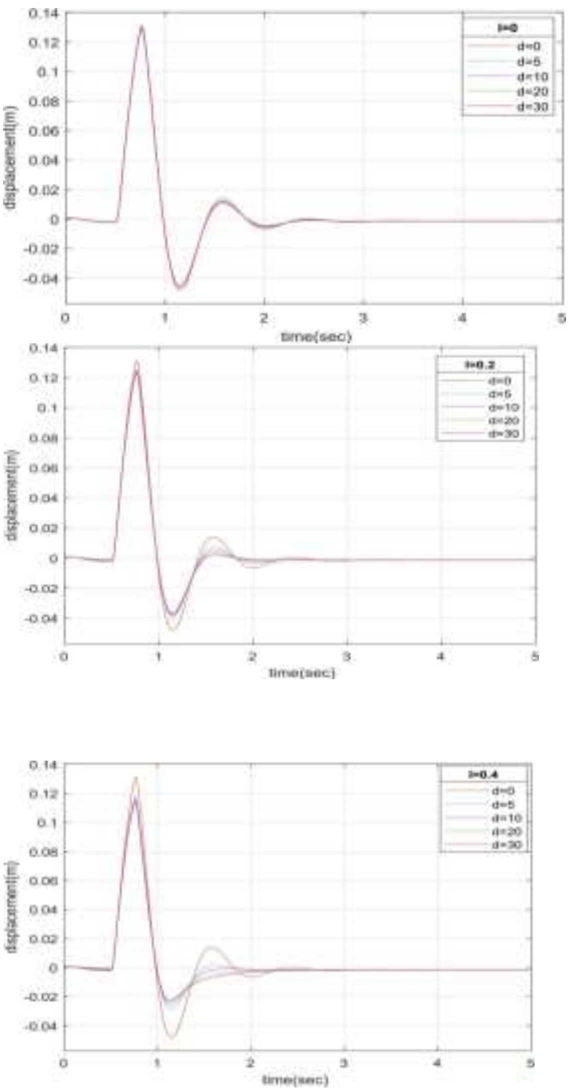
(c)

Figure 6. effect of current value on Damping force for defferent road profile . (a) step, (b) sin, (c) random

4. 2 Effect of Form Factor (d)

In this case , change the form factor (d) for different road profile (step, sin and, random) to show effect of this factor on the dynamic behavior of suspension system . Take a range of form factor [0, 5, 10, 20, 30] for each current value. Figure (7, 8,and 9), show the positive effect of the form factor (d) appears by reduced in the displacement generated (overshoot) in the body car that is produced from the external excitation but at the expense of an increase in settling time.

Figure 10, represent the effect of changing with current on the damping force, and its showed that the increasing of value of form factor d with current lead to increasing the damping force as result of this reduce the value of overshot and, settling time.



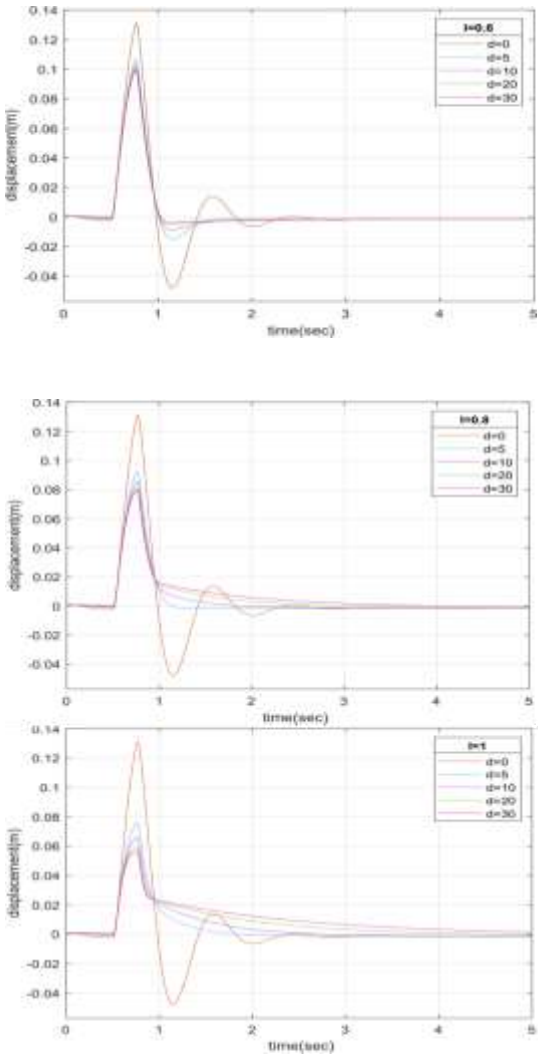
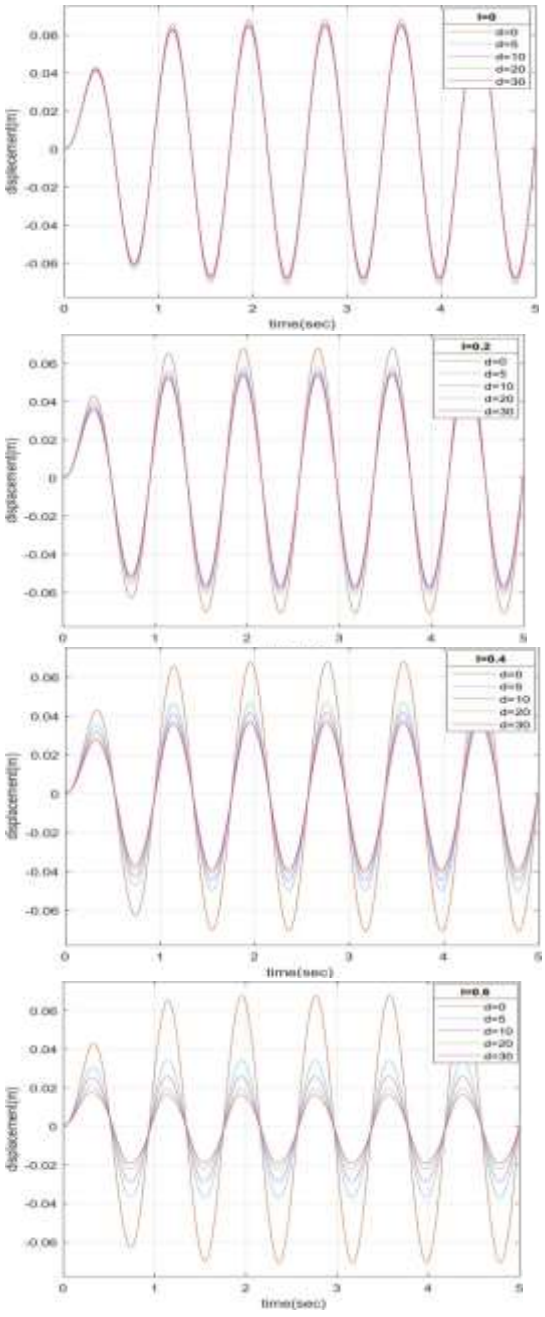


Figure 7. displacement of car body under step excitation with different input current with a change of the form factor.



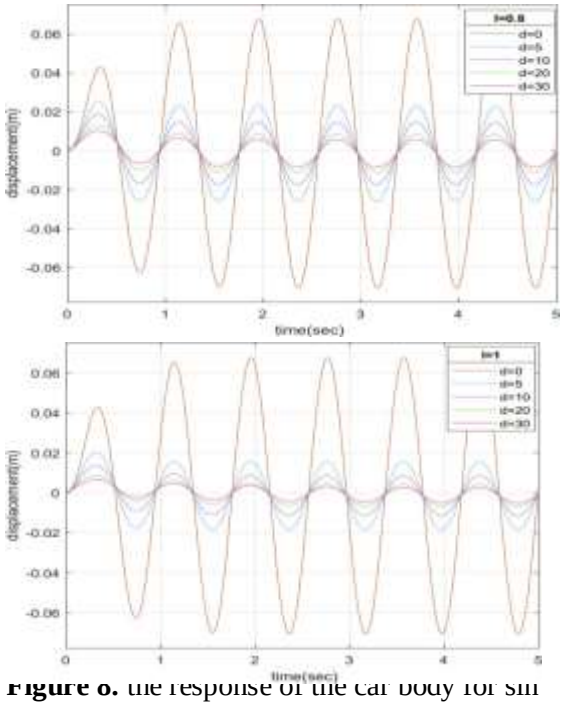
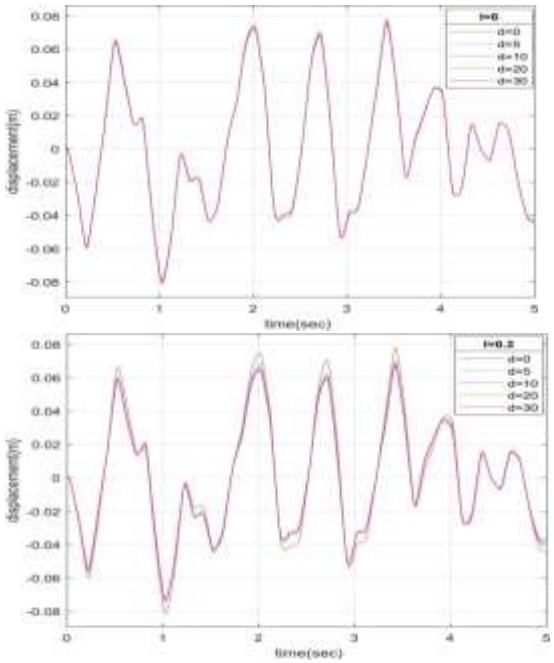


Figure 8. the response of the car body for sin input for different input current with a change in form factor.



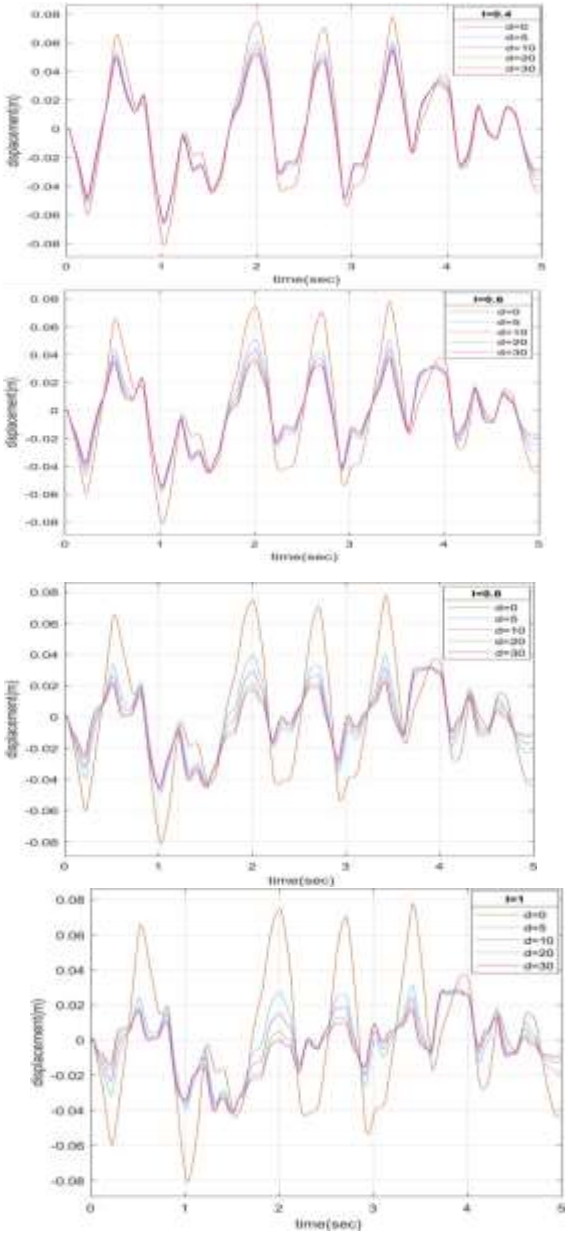
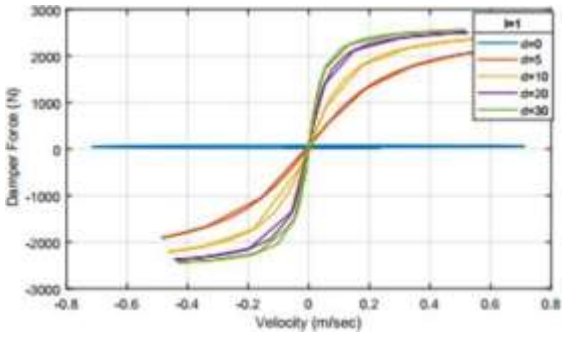
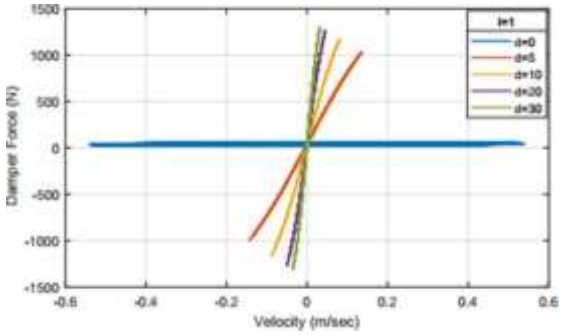


Figure 9. displacement of car body under random exaction for different current with changing in form factor



(a)



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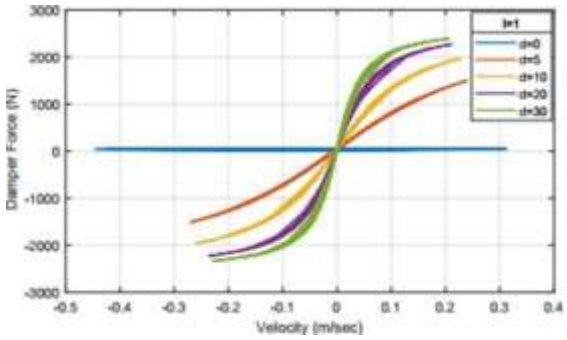


(c)

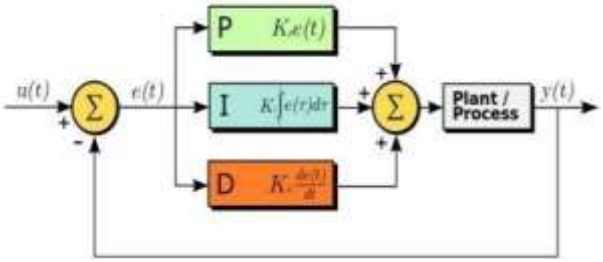
Figure 10. Effect of form factor d on damping force with damper relative velocity with the constant current value. (a) step, (b) sin, (c) random.

5. PID Controller

For controlled cases in this study using PID (proportional, integral and derivative) controller. The reason for using of PID controller is to simplify, excellent controlling performance, good robustness, and is easy to apply in a computer or microprocessor. Using Zigluer-Nicholas method of tuning to tuning the PID controller. The PID controller structure and diagram of the control system shown in Figure (8)

The controlled characteristics of the suspension system for different road exaction (step, sin, and random) as shown in figures(9 and 10) to understand the effect of the PID controller on the dynamic response behavior for the body car displacement and to appear the influence of PID controller on the suspension system.

The advantage of the PID controller appears by reduced the settling time of the body car but at the expense of an increase in displacement generated (overshoot), that is produced from the external excitation.



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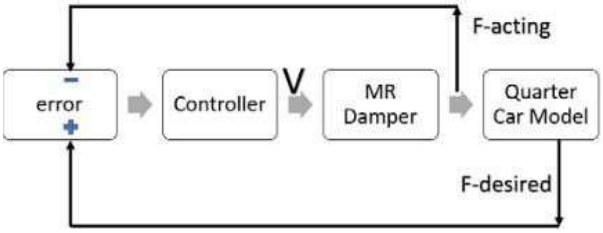
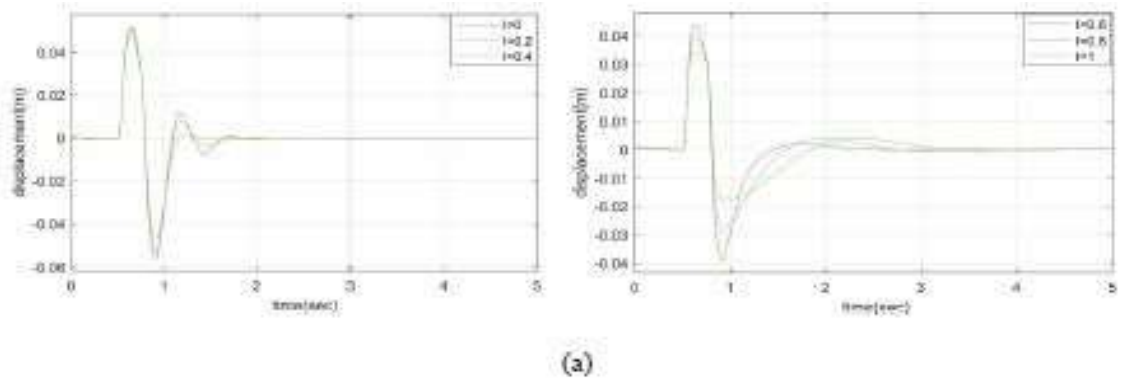


(b)

Figure 8. (a) PID controller configuration[30] **, (b)** Flowchart of the control system [24]**.**



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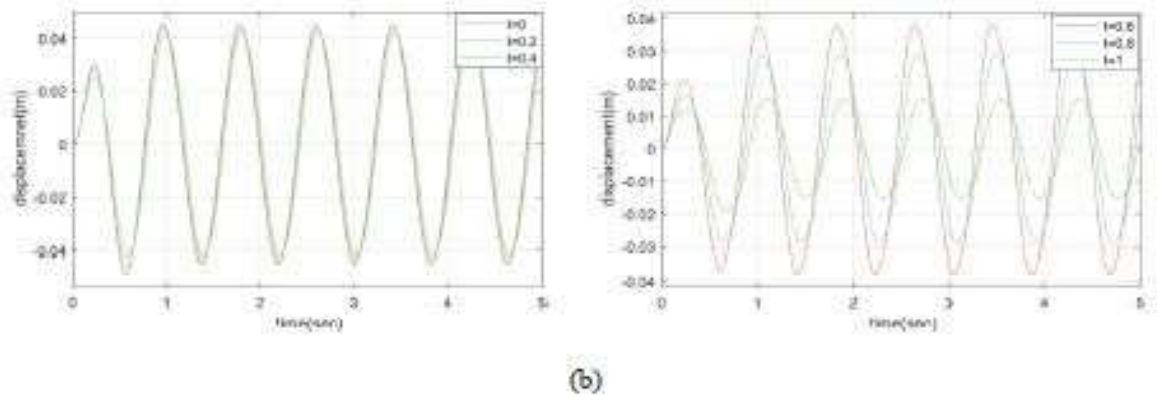

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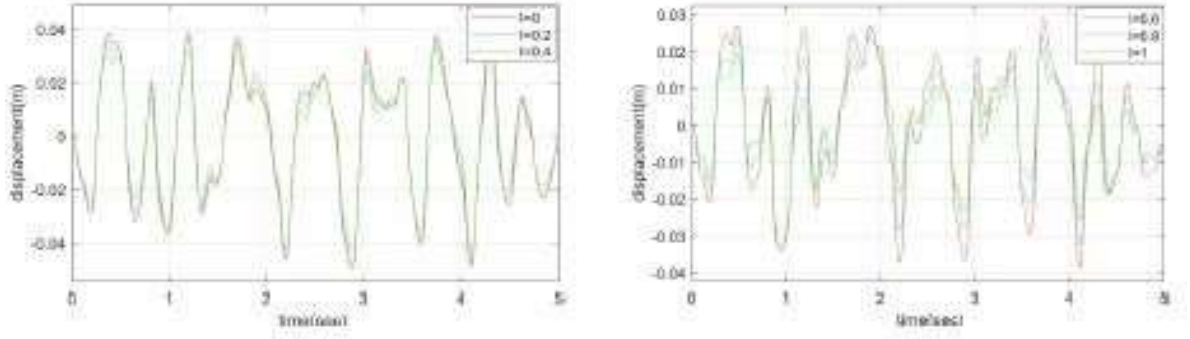

(c)

Figure 9 . the response of car body with different input current, (a) for step exaction, (b) for sin exaction, (c) for random exaction

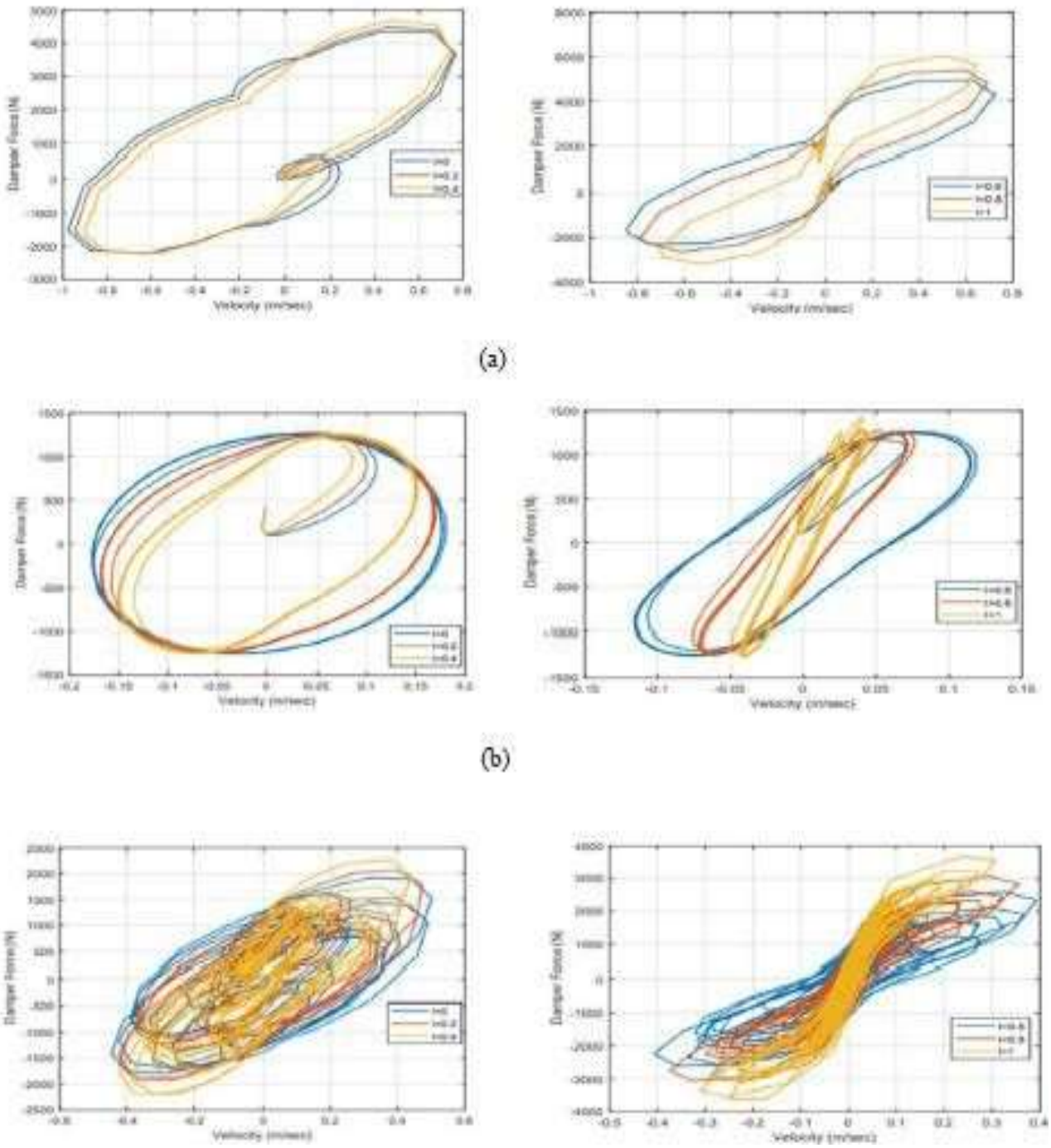

Figure 10. the damping force with defferent current in controller case . (a) step, (b) sin, (c) random

5. Conclusions

Many conclusion notes can be drawn from the analysis and results of the work. First, the developed simulation models of the hysteresis behaviors of MR fluid that using in a damper with mathematical formulations of Bingham model in MATLAB®/Simulink® for quarter car model with the previous parameter to designing shock and vibration damper. second, applied different road excitation (step, sin, and random), and the MR fluid damper offers a different damping force for each case. With different input current and saw the effect of them on the dynamic characteristic of a car body.

Finally, damping force can be controlled and in

this study we PID controller to control the MRF damper to enhance the performance of MR damper, enhance the passenger comfort, and increase the age of the vehicle. Compared with uncontrolled characteristic and controlled characteristic, which the controlling case give batter performance as compared with an uncontrolled case. So the PID controller gives better performance than modifying on Bingham model by changing in form factor.

6. Reference

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