

SIMULATION AND EXPERIMENTAL INVESTIGATION ON
MAGNETORHEOLOGICAL DAMPER CHARACTERIZATION USING SIXTH
ORDER POLYNOMIAL APPROACHED

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This technical report is submitted in accordance with the requirements of the
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COMFORMATION

I admit that have read this work and in my opinion this work was adequate from scope aspect and quality to award in purpose Bachelor of Mechanical Engineering (Automotive)

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DECLARATION

“I hereby, declare this report entitled “Simulation and experimental investigation on magnetorheological damper characterization using sixth order polynomial approached” is the result of my own research except as cited in the reference”

Signature:

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Date: 9th APRIL 2009

DEDICATION

To My Beloved Parents, who keep me continuously motivated with their great support and encouragement throughout my Bachelor Degree program.

ACKNOWLEDGEMENT

I would like to take this opportunity to thank God because with his permission I completely finished my final year project. By this chance, I would like to express my deepest gratitude to Dr Khisbullah Hudha for his kind effort in guiding me to perform project procedure and lending his hand for supporting in my project accomplishment.

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ABSTRACT

A study on this research is about simulation and experimental investigation on magnetorheological damper characterization using sixth order polynomial approached. Magnetorheological (MR) damper uses a kind of smart material which react with magnetic field namely magnetorheological fluid (MR Fluid). In this study, characterization of MR damper has been carried in different current based on force-velocity and force-displacement graph and it was validated with experimental result. The polynomial approached was used to get the nonlinear hysteresis behavior of MR Damper. Every coefficient a_i for current domain 0.25A until 2.0A gives the equation itself. So every coefficient a_i for current domain had been collected and became only one equation. Then, the sixth order polynomial model compared with inverse model to capture the difference of experimental result. Inverse model is not adequately captured the nonlinear hysteresis although the trend of its force versus velocity is still same with experimental result. Proposed polynomial model has best fit with experimental result and its curve closely same with experimental result.

ABSTRAK

Kajian dalam projek ini adalah mengenai penyelidikan simulasi dan eksperimen ke atas penggambaran peredam bermagnet menggunakan pendekatan kaedah polinomial turutan keenam. Peredam bermagnet merupakan peredam yang boleh dikawal kekerasannya dan menggunakan cecair yang mengandungi bahan yang kuat iaitu bertindakbalas apabila dikenakan arus elektrik dan bahan tersebut ialah cecair bermagnet. Dalam kajian ini, penggambaran peredam bermagnet dilakukan dengan menggunakan arus elektrik yang berbeza-beza berdasarkan daya-halaju dan daya-jarak dan ianya disahkan dengan keputusan eksperimen. Pendekatan polinomial ini digunakan untuk mendapatkan sifat histerisis tidak lurus peredam bermagnet. Setiap pekali a_i untuk arus elektrik 0.25A sehingga 2.0A memberikan persamaan tersendiri. Jadi setiap pekali a_i untuk domain 0.25A hingga 2.0A dikumpulkan dan dibentuk menjadi hanya satu persamaan. Kemudian, model polinomial turutan keenam di bandingkan dengan model songsang untuk mendapatkan perbezaan kedua-dua model tersebut dengan keputusan eksperimen. Model songsang tidak dapat menghampiri histerisis tidak lurus walaupun arah aliran bagi daya-halaju masih lagi sama dengan keputusan eksperimen. Model polinomial yang dicadangkan mempunyai kesesuaian yang terbaik dengan keputusan eksperimen dan lengkungannya juga sama dengan keputusan eksperimen.

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LIST OF SYMBOL

τ	=	Total stress
η	=	Viscosity of the fluid
f_c	=	Frictional force
\dot{x}	=	Piston velocity
c_0	=	Damping coefficient
f_0	=	Offset force
$k_1 = k_2 = c_1$	=	Linear solid material coefficient
F	=	Damper force
a_i	=	Experimental coefficient to be determined from the curve fitting
v_i	=	Damper velocity
n	=	Order
I	=	Current
$\dot{\gamma}$	=	Shear rate

CHAPTER 1

INTRODUCTION

1.1 Introduction of study

The purpose of this study is to orient the reader with the characteristics of magnetorheological damper using the sixth order polynomial approach to model the nonlinear hysteresis behavior. From this point forward, magnetorheological damper will be referred to simply MR damper. Sixth order polynomial approach has an advantage compare to the previous study in term of MR damper behavior that has been proved in this study. Since 1990's, Lord Corporation has been developed MR fluids which used in MR damper nowadays. Besides MR damper, MR fluids also used in other automotive part such as MR Brake which developed by researchers from Universiti Teknikal Malaysia Melaka. In MR damper scope, many researchers show their interest in semi-active suspension which used controllable damper to attenuate vehicle vibration.

There are several performance criteria in suspension control design. There are body acceleration, body displacement, suspension travel or deflection and wheel acceleration. Those criteria must be minimized of the magnitude to get the powerful performance of vehicle. The idea of active suspension system for vehicles was first suggested by Federspeil-Labrosse in 1954 (Hansen and Snyder, 1997) initiated by the progress in servo-mechanism technology for control force generation. Active suspension is the best performance and most popular installed in luxury car like Nissan Infiniti Q45 which the world's first production fully active suspension system

and Toyota Soarer UZZ32. The Chevrolet Corvette (Corbett, 2004) and Cadillac XLR (Raynal, 2003) are also the world's first vehicles equipped with Magnetic Ride Control. The Magnetic Ride Control is a magnetic-fluid based real-time damping. The system uses four wheel-to-body displacement sensors to measure wheel motion over the road surface and responds by adjusting the shock damping at speeds approaching one millisecond. By controlling the current to an electromagnetic coil inside the piston of the damper, the MR fluid's viscosity can be changed, resulting in continuously variable real-time damping.

Although active suspension gives the best performance in term ride comfort, it has several disadvantages as example need more power in moving the actuator and the price usually expensive. In contrast, semi-active suspension only needs less power in their operation. Semi-active suspensions were introduced in the early 1970's (Crosby and Karnopp, 1973). Semi-active suspension still becomes a passive suspension if the failure occurs in the system. Besides that, MR damper shows a unique characteristic which can be recognized as damper constraint. Force-velocity curve only lies in first and third quadrants Cartesian of coordinate and also can be recognized as S-Diagram. Experimental can be done with applied several current or voltage domain to get MR damper behavior. In order to find MR damper behavior, both parametric and non-parametric model has been developed from previous researchers. A proposed model still not valid if it carried out from simulation only, so the experimental was setup and carried out. The simulation result must approximately same with experiment result. The experimental results are evaluated in the damping force versus piston velocity domain and the damping force versus piston displacement domain.

1.2 Problem Statement

From previous studies on MR damper characteristic, it can be determined that the proposed model such as Bingham model and Bouq-Wen model is not approach the experimental result curve even though it still shows MR damper behavior. Bingham model is totally cannot capture the nonlinear hysteresis behavior, although

it fairly predicts only the magnitude of the damping force at a certain piston velocity. Bouq-Wen model is almost accurate and it followed the nonlinear hysteresis behavior of MR damper but it still cannot get more accurate hysteresis with experimental result. Inverse model approached is also the nonlinear hysteresis which compared in this study. Although the trend in $F-v$ curves same with Bouq-Wen model; the damping force for both models are difference. Accurate model is the difficult to obtain in capturing the MR damper behavior and this is the main problem exist. Furthermore, an inaccurate damper model will lead to inaccurate control strategy in predicting the optimum target force.

1.3 Objective

- i. To derive the mathematical model of MR Damper using sixth order polynomial equation.
- ii. To simulate the mathematical model in MATLAB-Simulink environment.
- iii. Experimental work of Magnetorheological (MR) Damper characterization
- iv. Model validation between Inverse Model and Polynomial Model with Experimental data.

1.3 Scope

This study was carried out using existing Delphi MR damper in term to investigate the MR damper behavior. Simulation study which the early prediction was carried out using MATLAB-Simulink environment. Experimental work was carried out using Suspension Test Machine to validate the simulation result is available in UTeM Autotronics Lab.

CHAPTER 2

LITERATURE REVIEW

2.1 Vehicle Suspension System

There are three main types of suspension; that is passive, semi-active, and active suspension which depend on the operation mode to improve vehicle ride. Normally, conventional passive suspension is effectively only in a certain frequency range and no on-line feedback action is used. Thus, optimal design performance cannot be achieved when the system and its operating conditions are changed. Passive suspension systems can only temporarily store or dissipate energy at a constant rate and the forces they generate depend on local relative motions. In contrast, active suspensions can be improve the performance of the suspension systems over a wide range of frequency and can adapt to the system variations based on on-line changes of the actuating force. However, active suspensions normally require large power supply, which is the main drawback that prevents this technology from being used extensively in practice.

Semi-active suspensions have received much attention since they achieve desirable performance than passive suspension and consume much less power than that of active suspensions. Especially, when some controllable dampers, such as magnetorheological dampers are available in practice recently, semi-active suspensions are more practical than ever in engineering realization. Semi-active controls with MR dampers for vehicles suspensions have also been studied by many researchers. Instead of low cost, low power requirement and competitive

performance to the active system, semi-active suspension is more getting attention compare to active suspension. Semi-active suspension is safer than active suspension because semi-active still can be reacted as passive damper if failure occurred. An undesired force could pull the tire away from road if failure of an active system occurs. Semi-active suspension can be adjusted mechanically or using the rheological properties of the fluid that is used in the damper. There have a solenoid in damper uses to control the damper force.

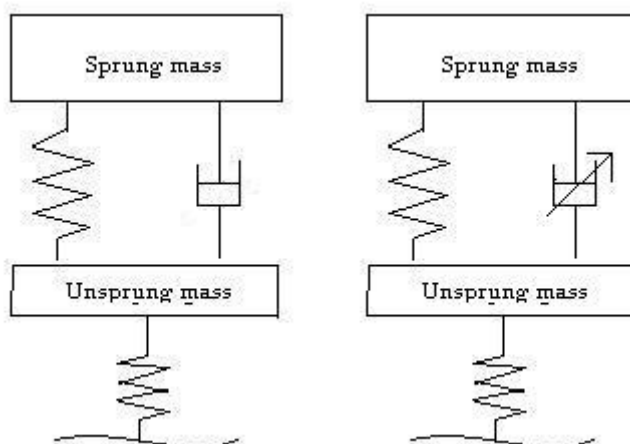


Figure 2.1: Passive suspension

Figure 2.2: Semi-active suspension

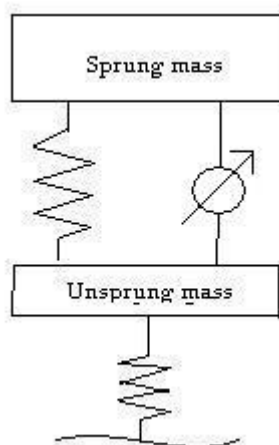


Figure 2.3: Active suspension

Some researchers study the controllable suspension performance when control strategy was applied in experiment. The result obtained will compare after that with the passive suspension. Here some result obtained with several performance criteria.

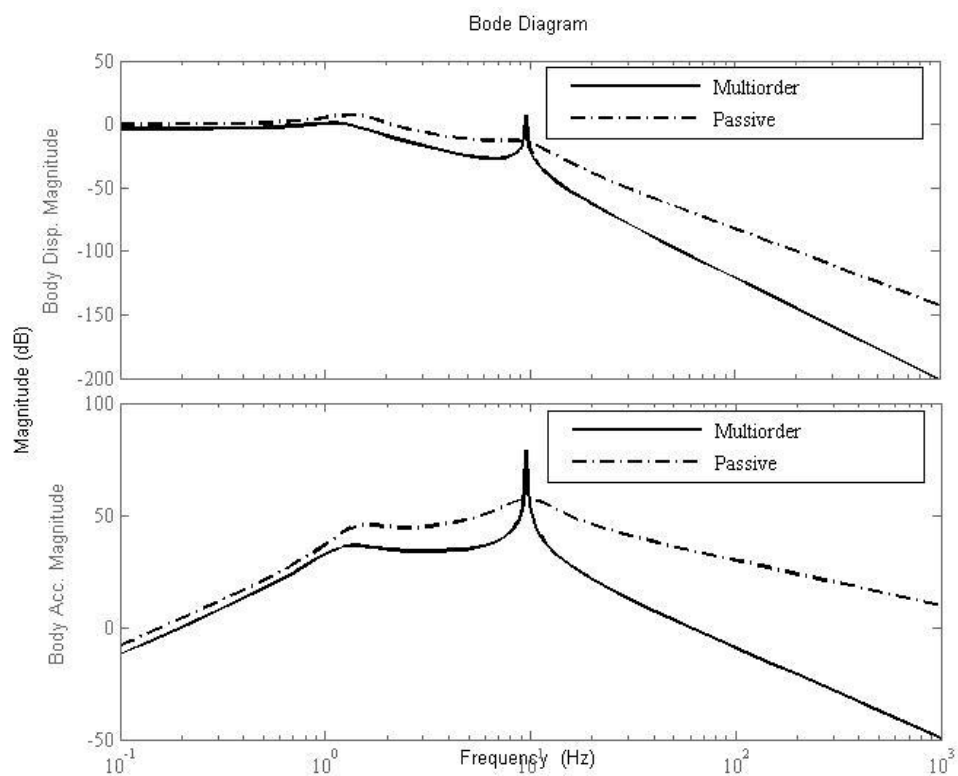


Figure 2.4: Bode plot of body displacement and body acceleration response
(Source: Manuscript)

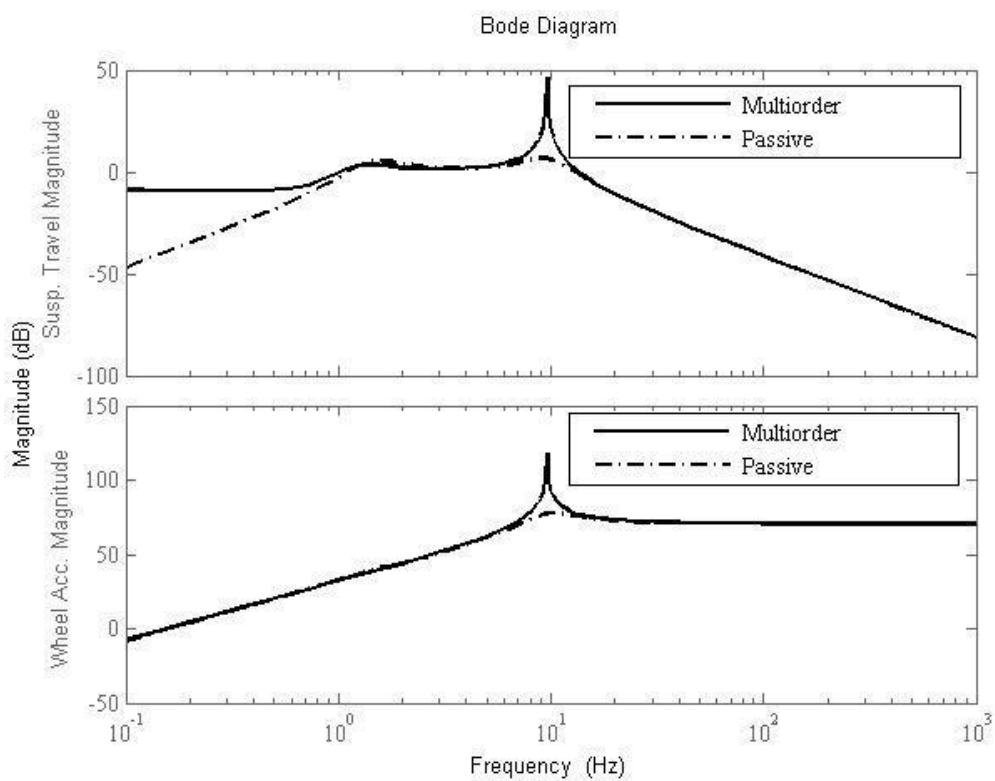


Figure 2.5: Bode plot of suspension travel and wheel acceleration response
(Source: Manuscript)

Figure 2.4 shows the performance of body displacement and body acceleration for passive suspension and controllable suspension using multiorder PI control. No improvement occurs at low frequency but after 10Hz, multiorder PI control shows the improvement.

Figure 2.5 shows the performance of suspension travel and wheel acceleration. The result obtained is contrast with sprung mass criteria which are the passive suspension shows the improvement at low and medium frequency for suspension travel criteria and medium frequency for wheel acceleration criteria.

2.2 Magnetorheological (MR) Fluid

Magnetorheological (MR) fluid includes into a class of smart fluids whose rheological properties such as elasticity, plasticity, or viscosity change in the presence of a magnetic field. MR fluid consists of a carrier fluid, typically a synthetic or silicone based oil, and ferromagnetic particles (20–50 μm in diameter). Normally MR fluids are free flowing with the consistency of motor oil. In the presence of a magnetic field, however, the particles align and form linear chains parallel to the field. The chains act to restrict fluid movement and solidify the suspension. Many different ceramic, metal and alloy compositions have been described and can be used to prepare MR fluids, as long as the particles used are magnetically multi-domain and exhibit low levels of magnetic coercivity.

The most common magnetic material useful in preparation of MR fluids is high purity iron (Fe) powder derived from decomposition of iron penta-carbonyl ($\text{Fe}(\text{CO})_5$). The carrier phase could be organic liquids or water. In the „off“ state, in terms of their consistency, MR fluids appear similar to liquid paints and exhibit comparable levels of apparent viscosity (0.1 to 1 Pa-s, at low shear rates). When an external magnetic field is applied (typically using an electromagnet), MR fluids undergo a considerable increase in their apparent yield stress.

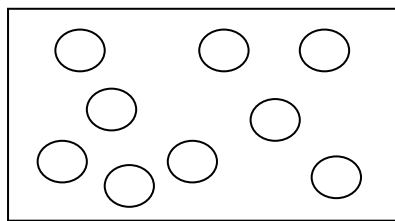


Figure 2.6: Without Magnetic Field

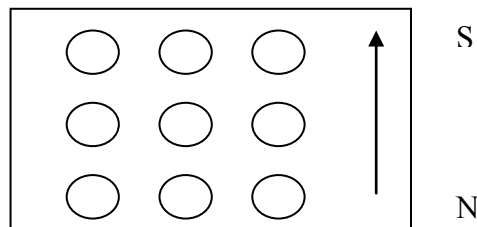


Figure 2.7: Magnetic field applied

There are three modes MR fluid can be used. These modes of operation are referred to as squeeze mode, shear mode and valve mode. A device that uses squeeze mode has a thin film on the order of 0.05cm of MR fluid that is crushed between paramagnetic poles of surface as shown in Figure 2.8.

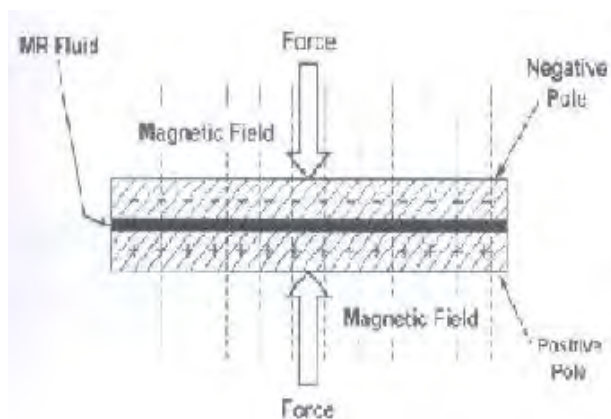


Figure 2.8: MR fluid used in squeeze mode

(Source: James C. Poynor)

Valve mode is the most widely used compared to other modes. MR fluid is used to impede the flow of MR fluid from one reservoir to another as shown in Figure 2.9.

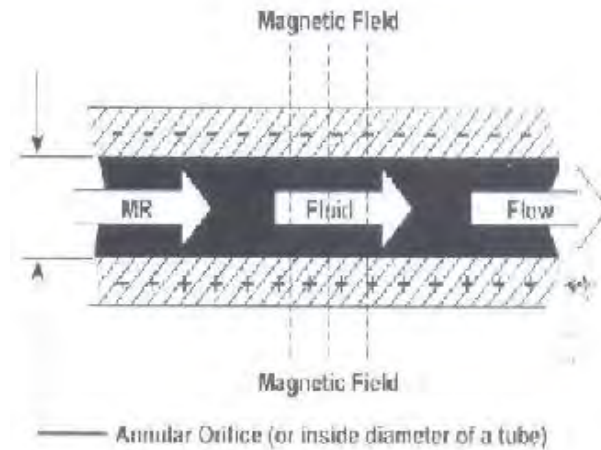


Figure 2.9: MR Fluid used in valve mode
(Source: James C. Poynor)

In shear mode, a thin layer which approximately 0.01cm to 0.04cm MR fluid is sandwiched between two paramagnetic moving surfaces. Shear mode usually useful for dampers that are not required to produce large forces or for brakes and clutches.

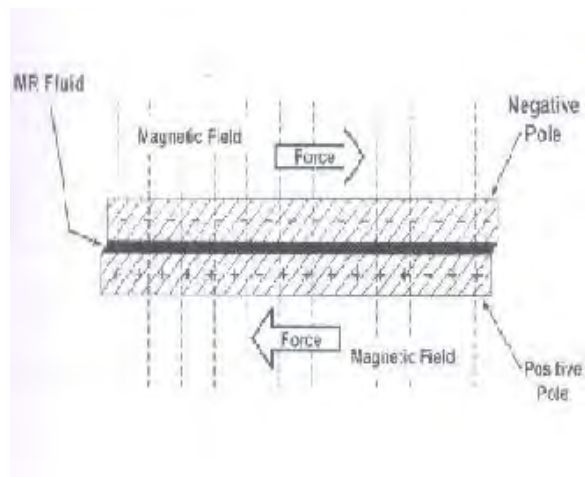


Figure 2.10: MR Fluid used in shear mode
(Source: James C. Poynor)

2.2.1 Applications of MR fluids

MR fluids are being predominantly used for developing applications in which active vibration control or transfer of torque or force is needed. Therefore,