CONTENTS

AUTHORS

15th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2011, Prague, Czech Republic, 12-18 September 2011

INVESTIGATION OF THE EFFECTS OF TEMPERATURE VARIATIONS ON THE MAGNETORHEOLOGICAL DAMPER BEHAVIOUR

İsmail Şahin
Akyazı Vocational School, Sakarya University, Akyazı, Sakarya, Turkey
Zekeriya Parlak, Tahsin Engin
Dept. of Mechanical Engineering, Sakarya University, Sakarya, Turkey

ABSTRACT

Magnetorheological (MR) dampers have received a great deal of attention due to their being a potential technology to conduct semi-active vibration control and it has become vitally important to describe the dynamic responses of these devices in an effective manner in order to develop successful control algorithms. To this end, a considerable effort has been devoted in the literature to study the factors affecting the dynamic behaviour of MR dampers. And, so far, excitation displacement, velocity, and current have been shown to be the primary factors. However, MR dampers can experience large variations in temperature due to self-heating of the damper as well as heat addition to the MR fluid because of the magnetic coil on the piston head. The change in fluid temperature may result in a decay in fluid viscosity and thus, a decrease in the post-yield damping of the damper. Also, heated gas in the accumulator may yield an additional increase in the stiffness of the damper. To study these effects, a low-force and a low-stroke MR damper was built and tested at the Applied Fluid Mechanics Laboratory of University of Sakarya. And, it has been observed that temperature was at least as important as velocity on the damper behaviour.

Keywords: Magnetorheological damper, temperature, design of experiment.

1. INTRODUCTION

MR dampers have attracted a great deal of attention in the recent years as an important component of semi-active suspension systems. Due to their variable damping feature, mechanical simplicity, robustness, low power requirement, and fast response, these dampers have found many application areas in practice such as aircraft, building, bridge, off-road vehicle suspensions and so on. And, as for any mechanical system, control of these highly non-linear devices is of crucial importance and has been an area of interest for many researches. In order to develop successful control algorithms, dynamic behavior of the MR damper needs to be described in an effective manner. To this end, a considerable effort has been devoted in the literature to study the factors affecting the dynamic behavior of MR dampers. And, so far, excitation displacement, velocity, and current have been shown to be the primary factors. However, MR dampers can experience large variations in temperature due to self-heating of the damper as well as heat addition to the MR fluid because of the magnetic coil on the piston head. The change in fluid temperature may result in a decay in fluid viscosity and thus, a decrease in the post-yield damping of the damper. Also, heated gas in the accumulator may yield an additional increase in the stiffness of the damper.

Although there are numerous designs in controllable MR fluid devices, only limited analytical and experimental studies have been conducted on heat transfer analysis of such devices. To study the effects of heat generation in the MR damper, Alonso and Comas [1] proposed an analytical method that accounts for the thermal effects as well as fluid compressibility, chamber deformation, and fluid capitation to quantify the damping force of a generic twin-tube shock absorber for an automobile. They compared the results from the model with those from simpler models (which do not include thermal effects) and validated against the results from real shock absorber and observed a good agreement for the damping force. He and Zheng [2] studied the interaction between viscous heating and damping force in a fluid viscous damper. And, they proposed a thermodynamic model for the damper, which includes a dynamic equation and the thermal balance equation. Numerical results indicated that temperature rise mainly caused shifts of resonant frequencies and larger amplification factors at resonances. Breese and Gordaninejad [3] performed a theoretical study on predicting the temperature increase of MR dampers experiencing a sinusoidal input motion. A theoretical model was proposed to estimate the temperature of MR dampers.

As a later study, similar to this, Breese and Gordaninejad at all. [4] developed a theoretical model based on Bingham plastic model to estimate temperature history of the MR dampers. The governing equation included the MR fluid viscosity as a function of temperature. They compared the numerical solutions with experimental results and observed an excellent agreement. Recently, Şahin at al.[5] attempted to characterize the temperature dependent behavior of an MR damper. After conducting the experiments, they used Bouc-Wen model to examine the trends of the models parameters to see how the model parameters were changing with temperature so that they would be able characterize some physical phenomena of the damper such as post-yield damping, stiffness, and yield force. However, they concluded that as Bouc-Wen model included differential terms meaning that it could not yield unique solutions, Bouc-Wen was not a useful tool to assess the temperature dependency of the damper. To date, most of the studies dealing with parametric modeling of MR dampers have only focused on excitation displacement, velocity and current [6,7,8]. Although some efforts have been devoted to study the effect of temperature recently, still there is limited number of parametric models incorporating the effect of temperature in the literature. Also, the present studies still cannot answer the question “To what extend is temperature affecting the dynamic behavior of the MR damper”? In this study, the effect of temperature on the dynamic behavior of the MR damper was characterized by experimental design method and then results were discussed.

2. MR DAMPER DESIGN

For the define to effect of temperature on MR damper, a low-force and a low-stroke MR damper was built and tested at the Applied Fluid Mechanics Laboratory of University of Sakarya. MR dampers operate on the following basic principle: a high-pressure fluid is forced through a small duct, resulting in a drop in pressure of the outgoing fluid. The pressure drop across a valve is caused by energy loss in the fluid due to plasticity and viscosity. MR fluid flows through a gap in the piston head at aimed design of MR damper. Most devices that use controllable fluids can be classified as having either fixed poles (pressure-driven mode) or relatively moveable poles (direct-shear mode). Examples of valve mode devices include servo-valves and dampers. Examples of direct-shear mode devices include clutches, brakes, chucking and locking devices. Figure 1 shows a schematic for the prototyped MR fluid damper under consideration.

The chambers that are separated by the piston head are filled with MR fluid, whereas the accumulator, which is used for compensating the volume changes, induced by the movement of the piston rod to the up and down, is filled with the pressurized nitrogen gas. During the motion of the MR damper’s piston rod, fluid flows through the annular gap opened on the piston head. Inside the piston head, a coil is wound around the bobbin shaft with a heat-resistant and electrically insulated wire. When electrical current is applied to the coil, a magnetic field develops around the piston head. The outer face of the MR damper was heat-sealed to prevent the heat transfer between the damper and the ambient.A K-type thermocouple was soldered on the piston head to measure the temperature of the MR fluid. The soldering point is 2 mm distant from the annular flow gap on the piston head. During the tests, the readings from both the inside and outer face of the damper were recorded via IOTech PDQ30 data acquisition card instantaneously. Experimental data of the MR damper have been acquired under the sinusoidal excitations on a mechanical scotch-yoke type Roehrig 10VS damper dynamometer. The main components of the test set-up along with the test damper are shown in figure 2. The shock machine has its own software to collect data from the data card and use them to plot force versus time, force versus displacement and force versus velocity graphs for each test. A programmable GWinstek PPE 3223 power supply is used to feed current to the MR damper.

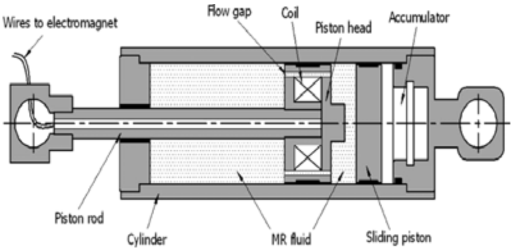

Figure 1. Schematic for the prototyped MR shock damper

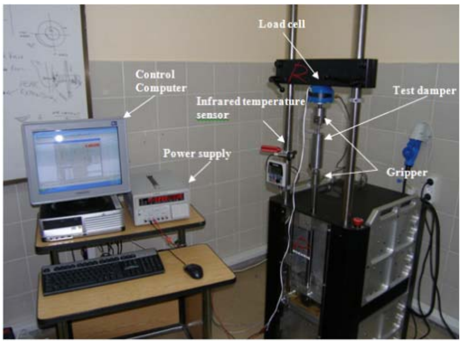

Figure 2. Photograph of the test machine with the damper under test

3. EXPERIMENTAL DESIGN

Experimental design method can be defined as assessment of variability of the outputs of a process by tuning the inputs of the process. It is also used to determine the primary test parameters, to have a better understanding of the behavior of the process, and to compare the parameters and/or interactions affecting the process. The objective in the MR damper design has been generally focused on predicting the dynamic response of the damper for given velocity and current values. In addition to the velocity and current, this study assesses the effect of temperature as a design parameter.

The other important step is how the tests are realized and an arrangement is used. It can't be specified that if tests are realized as randomly, which parameters will affect to what extent the results. Experimental array that determines as statically is used for this reason. The simplest experimental array to be able to considered is that having of two levels and three factors. Even though the tests that consider only two levels can be seen unimportant, it is found as suitable due to allowing tests that are realized with a number of factors at the same time and low cost. Three parameters interested that have two levels yield L8 orthogonal array that implies 8 (2^3) tests [9].

Thanks to the statistical method is to specified how both influences of each factor and interaction among the factors affect the results. Because of that, two tests are specified consisted of both values of maximum and minimum of each parameter. Each test is repeated three times and rebound and compression damper forces are measured at every test. Average of absolute values of compression and rebound forces are assumed effective force in the analysis. Specified parameters, compression and rebound forces, and their absolute values in L8 orthogonal array can be seen Table 1.

Table 1. Parameters and Test results of MR damper

V(m/s)	i(A)	T(°C)	F_1 (N)	F_2 (N)	F_3 (N)	Fmean (N)
0.05	0	10	187	187	200	191
0.05	0	85	142	134	132	136
0.05	0.9	10	858	867	855	860
0.05	0.9	85	674	684	676	678
0.2	0	10	461	454	476	464
0.2	0	85	174	170	165	169
0.2	0.9	10	1187	1196	1214	1199
0.2	0.9	85	778	791	793	787

The effect of each individual parameter and interaction between factors are calculated by assigning of each damper force in corresponding cell in L8 orthogonal array (Table 2). A good understanding of interaction between two factors is highly effective in interpreting the experimental results.

CONTENTS

AUTHORS

Table 2. L8 table of parameters of MR damper

		Parameter		***Parameter***		***Parameter***		***İnteraction***		***İnteraction***		***İnteraction***		***İnteraction***	
Nr	***F mean (N)***	***V (m/s)***		***i (A)***		***T (°C)***		***VI***		***VT***		***IT***		***VIT***	
1	***191***	191		191		191			191		191		191	191	
2	***136***	136		136			136		136	136		136			136
3	***860***	860			860	860		860			860	860			860
4	***678***	678			678		678	678		678			678	678	
5	***464***		464	464		464		464		464			464		464
6	***169***		169	169			169	169			169	169		169	
7	***1199***		1199		1199	1199			1199	1199		1199		1199	
8	***787***		787		787		787		787		787		787		787
Total	4483	1865	2618	960	3523	2713	1770	2170	2313	2476	2007	2364	2119	2237	2246
Nr	8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Mean	560	466	655	240	881	678	442	543	578	619	502	591	530	559	562
Effect		**188**		**641**		**236**		**36**		**117**		**61**		**2**	
Rank		**3**		**1**		**2**		**6**		**4**		**5**		**7**	

According to Table 2, the most significant parameter is current as expected (Rank=1). Besides, it can be seen temperature is more effective factor than velocity in considering the range of test temperature (Rank=2). Also, because of nature of MR damper, significance of interaction between velocity and temperature can be seen in Table 2, significance of other interactions are less than it. On the other word, if variation of temperature becomes at high values, effect of temperature should be considered to provide controllability of the MR damper. The variation of temperature is 75^o C in the table and in case that variation of temperature is high, temperature becomes more effective than velocity.

4. RESULTS

In the study, as a result of L8 tests realized by taking into consideration three factor that is effected response force of MR damper shown that temperature is more effective parameter than velocity in case of high temperature differences. Because of that, temperature should be considered in design and of dynamic model of MR damper. Also, ambient temperature is important in terms of heat transfer in tests that determine behaviors of the MR damper. Change of response force due to increasing of temperature can be fixed to be recalculated value of velocity in terms of control current. Control system should be built in considering of temperature of MR damper that works in real condition

5. ACKNOWLEDGEMENT

The authors gratefully acknowledge TUBITAK for making this project possible under Grant No:104M157 and 108M635.

6. REFERENCES

[1] Alonso M. and Comas A, Thermal model of a twin-tube cavitating shock absorber, Proc. IMechE Vol. 222 Part D: J. Automobile Engineering, 2008.

[2] He, L. and Zheng G.T., Effect of viscous heating in fluid damper on the vibration isolation performance, Mechanical Systems and Signal Processing 21, 3060–3071, 2007.

[3] Breese D. G. and Gordaninejad F., Heating of magneto-rheological fluid dampers: a theoretical study, Proc. SPIE 3671, 2; Univ. of Nevada/Reno (USA), 1999.

[4] Breese D. G., Ericksen E. O. and Gordaninejad F., Heat generation of magneto-rheological fluid dampers, Proc. SPIE 3988, 450, 2000.

[5] Şahin İ., Çeşmeci Ş., and Wereley N.M., Sensitivity Of Magnetorheological Damper Behavior To Perturbations In Temperature Via BoucWen Model, The 12th Int. Conf. on ER and MR Susp., Phi. USA. 2010.

[6] Spencer B. F., Dyke S. J., Sain M. K. and Carlson J. D., Phenomenological model of a Magnetorheological damper, J. Eng. Mech. ASCE 123 230–8, 1997.

[7] Jimenez R. and Alvarez-Icaza L. LuGre friction model for a Magnetorheological damper, Struct. Control Health Monit.12 91–116, 2005.

[8] Kwok N M, Ha Q P, Nguyen T H, Li J and Samali B, A novel hysteretic model for Magnetorheological fluid dampers and parameter identification using particle swarm optimization *Sensors Actuators* A 132 441–5, 2006.

[9] Şirvancı M., Kalite için deney tasarımı, Taguchi yaklaşımı, Literatür yayınları, İstanbul, Turkey, 1997.