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Experimental Research on Dynamic Characteristic of the Vehicle Magnetorheological Damper

Zhang Jin-qiu, Zhang Lei, Peng Zhi-zhao* and Zhang Yu

Abstract—**In this study, the mechanism of a disc gap magnetorheological fluid damper (MRD) used in heavy vehicle was introduced. As a study object, the mechanical characteristic and the dynamic response characteristic of the MRD were investigated through experiments. The results of the experiments suggest that with the increase of current value, the damping force and the power consuming ability of the MRD increase. What's more, the MRD response time decreases as the piston velocity and temperature increases, and increases as the value of step current amplitude increases.**

Index Terms—**MRD, mechanical characteristic, dynamic response characteristic, experiment**

I. Introduction

THE magnetorheological fluid dampers(MRD) are fabricated to be outstanding structure vibration control devices based on the rapid and reversible orheological effect of magnetorheological fluid(MRF). With the characteristic of damping force controllability, MRDs are used widely in many engineering fields [1], [2]. Investigations indicate that semi-active vehicle suspension systems based on MRDs are effective to improve the maneuverability and ride performance compared with passive suspensions [3], so vehicle MRDs have gained considerable attention in recent years.

Damping force and response time are the most important performance indexes for the MRDs' dynamic characteristics, which decide MRDs' application and control quality [4]. Generally, we expect MRDs to have greater controllable damping force and lower response time to achieve better real-time control effects. Related studies show that, the damping force of MRDs differs greatly because of the different size parameters and structures, and the response time ranges from tens milliseconds to hundreds milliseconds depending on different testing conditions [5]-[8]. In order to analyze the dynamic characteristic of a disc gap MRD used in heavy vehicle suspension, mechanical experiment and response time testing experiment were applied to the MRD. The experiment results and influencing factors of damping force and response time were discussed.

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II. Structure and Mechanism of MRD

The piston of a disc gap MRD used in a heavy vehicle suspension, which is composed of the piston body, the iron core and the excitation unit, is shown in Fig 1. Apply current to the coil and magnetic field will generate in the disc gap. When the piston moves, the MRF enters disc gap under pressure and approaches or leaves the centre of the gap. In this time, change the current value to regulate the magnetic field vertical to the direction MRF flows and magnetorheological effect will occur, so the damping force can be controlled continuously. The structure of MRD is shown in Fig. 2. The main size parameters the MRD are listed in Table 1.The MRF used for experiments is the suspensions of carbonyl iron particles with the quality percentage of 80% and the carried fluid of MRF is a kind of shock absorption liquor.

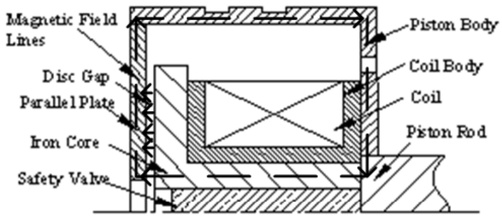

Fig. 1. The structure of piston

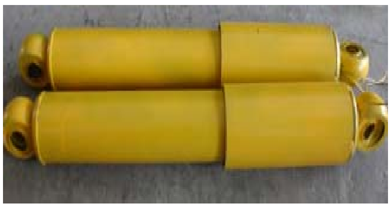

Fig. 2. The structure of piston

TABLE I
MAIN SIZE PARAMETERS OF THE MRD

Size Parameters	Value
Diameter of piston body(mm)	50
Diameter of piston rod (mm)	25
Height of piston body(mm)	35
Height of disc gap(mm)	1
Diameter of disc gap(mm)	40
Total turns of coil	300

III. Mechanical Experiment

A. *Experiment Procedure*

We use the IST (Instron Structural Testing Systems) shown in Fig. 3 to complete the MRD mechanical experiment. During the experiment, the current of the MRD coil ranges from 0 to 0.75A while the velocity of the piston changes from 0.05m/s to 0.13m/s. The amplitude of the IST is ±50mm.Use the position vs force curves to analyze the MRD's mechanical characteristic.

Fig. 3. Experiment system

B. *Results Analysis*

The position vs force curves are shown in Fig. 4 and Fig. 5.The curves from interior to exterior are when the current is 0A, 0.25A, 0.5A and 0.75A. From the results we can get that:

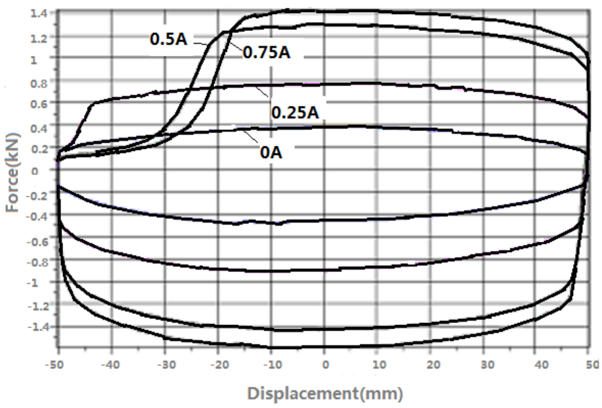

Fig. 4. 0.05m/s

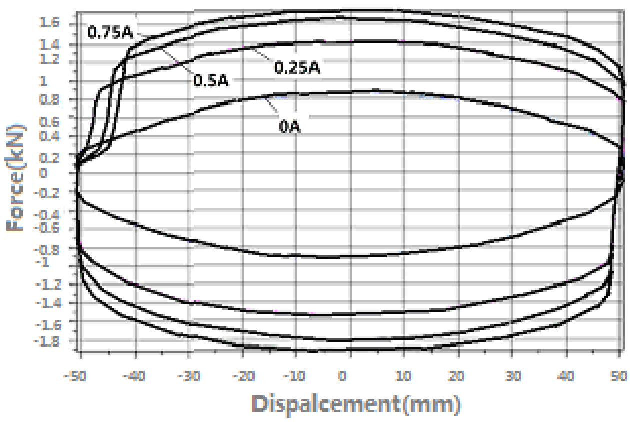

Fig. 5. 0.13m/s

Firstly, as the current increases, the damping force and power consuming ability increase as well. When the current was 0.75A, the controllable damping force is about 1200N.

Secondly, with the increment of current, the increasing trend of damping force becomes lower. That is because the ferromagnetic particles of MRF are reaching magnetic saturation points, which prevents the further increment of MRF shearing yield strength.

Thirdly, there are some aberrations in the position vs force curves. What's more, the curve aberrations under magnet field are more obvious than that without magnet field. The reason is that there is some air-stroke in the MRD. When magnet field is applied, MRF's fluidity becomes much lower, and air inside MRD is mainly compressed during this period. So the velocity MRF flows inside piston is very low and the damping force decreases suddenly as a result. When the MRD is applied, high-pressure inactive gas should be charged to compensate the air-stroke.

IV. Response Time Test Experiment

A. *Definition of MRD Response Time*

Numbers of experiment data shows that when the piston of the MRD is moves uniformly as the step current increases or decreases, the changing process of damping force can be described as a exponential form. According this, when the piston moves uniformly, the time from the current starts to change driving by control instructions until the value of damping force reaches 63.2% the margin of two steady states of damping force is defined as the MRD response time in this study.

As shown in Fig. 6, the MRD response process experiences the process from control instruction to current, magnetic field, MRF's shearing yield strength and damping force. So the response time of the MRD includes four components, i.e. the response time of power(τ_{power}), the electromagnetic response time(τ_{em}), the response time of MRF(τ_{MRF}) and the structure response time of the MRD (τ_{damper}) accordingly.

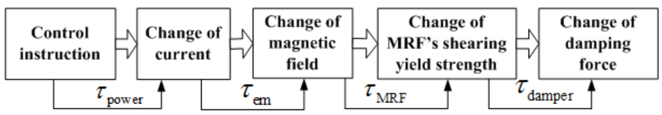

Fig. 6. Response Process of MRD

B. *Experiment Procedure*

MRD's response process is the controllable damping force changes with mutative current essentially, so we must try to keep the viscous damping force constant through piston rod's uniform motion during the test. Fig. 7 and Fig. 8 are the mechanism and structure of MRD response time testing system, which is composed of hydraulic system, MRD, sensor unit, control unit and data acquisition unit. When the MRD's piston rod performs uniform motion, the position sensor gets the position data. The controller instructs current-driven power to generate step current at specific displacement points. The force sensor measures the change of damping force driven by step current, which can reflect the MRD response time. During the test, we choose the piston velocity, amplitude of step current and temperature as control variables, as listed in Table 2. In Test 3, we use a thermostated container to heat the MRD.

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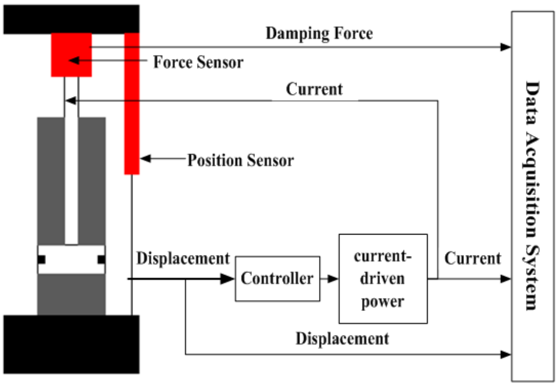


Fig. 7. Mechanism of Testing System

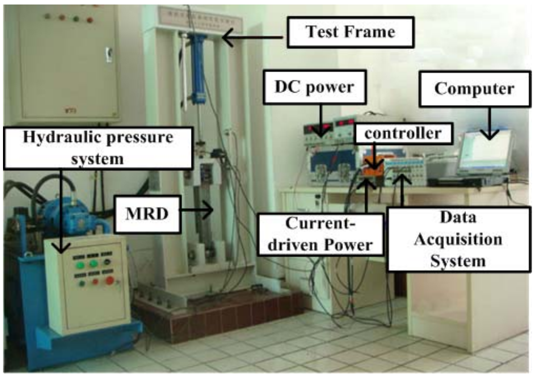


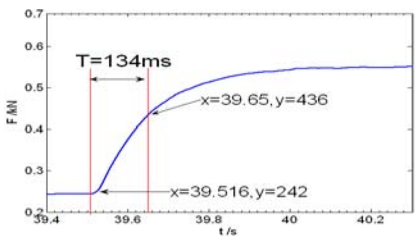
Fig. 8. Structure of Testing System

TABLE II
TEST CONDITIONS

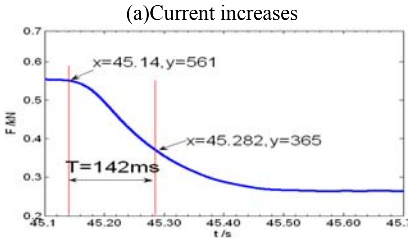
Condition	Piston velocity (m/s)	Step current (A)	Temperature (°C)
Test 1	0.01 0.02 0.04	0-1,1-0	22
Test 2	0.04	0-1,1-0; 0-1.6,1.6-0 0-2,2-0	22
Test 3	0.04	0-1,1-0	22 50 80

C. Results Analysis

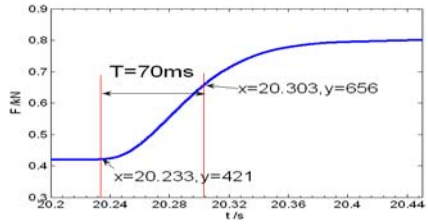
The results of Test 1 are shown from Fig. 9 to Fig.11. Considering the limited space of the page, we just provide the values of response time in Test 2 and Test 3 instead of the original test data, as shown in Fig. 12 and Fig.13. What need to note is that all the results are tested in MRD's compression stroke.



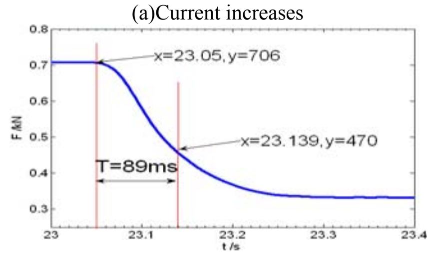
(a)Current increases



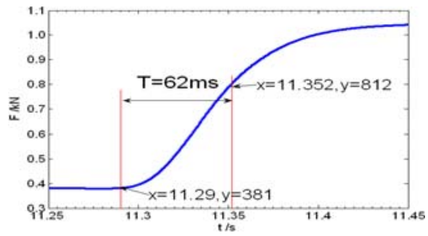
(b) Current decreases
Fig. 9. 0.01m/s of Test



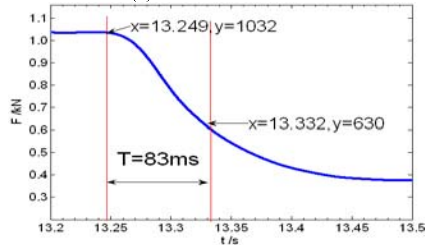
(a)Current increases



(b) Current decreases
Fig. 10. 0.02m/s of Test 1



(a)Current increases



(b) Current decreases
Fig. 11. 0.04m/s of Test 1

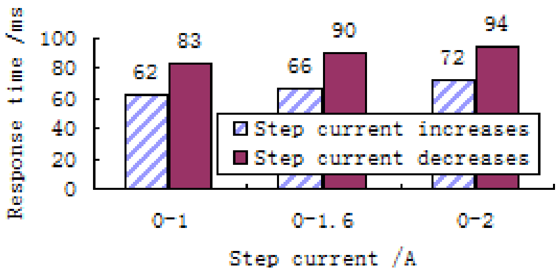


Fig. 12. Results of Test 2

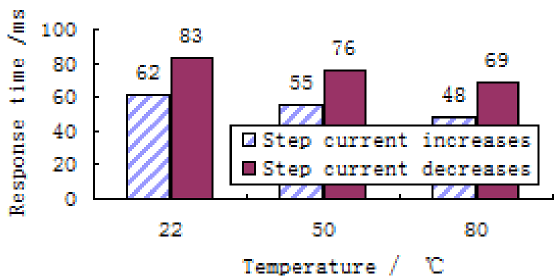


Fig. 13. Results of Test 3

From the test results above, we can conclude that:

Firstly, in test conditions above, the MRD response time ranges from 48ms to 142ms, which indicates that the MRD has a relatively rapid response.

Secondly, the response time decreases with the increment

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of piston velocity when the other factors keep the same. While, some related researches claim that as the velocity increases, the response time increases as well, which are opposite to ours [9], [10]. That may because in the tests above, the MRD has some additional stiffness and the test velocity is too low to overcome the influence of additional stiffness to response time. The lower the velocity is, the influence of additional stiffness to damping force will be more obvious, and the longer time will be needed for the damping force to reach a steady value by the drive of step current.

Thirdly, when the step current ranges from 0 to 2A, the response time increases with the increment of the step current amplitudes. That is because the excitation components such as coil body and iron core are conductors, eddy current will generate in the conductors with the drive of time-varying current. Faraday law of electromagnetic induction tells that the time-varying current of the coil will inspire time-varying magnetic field and the eddy effect will happen. The time-varying current will generate magnetic field as well. As the directions of the magnetic field inspired by eddy current and the magnetic field inspired by coil current are always opposite, the eddy effect prevents the increment of the magnetic field in MRD's disc gap and the result of which is that the change of the magnetic field in disc gap is always slower than that of core current [8]. As the amplitude of step current increases, the acting time of time-varying current increase as well, so the eddy effect will becomes more serious, which cause the increment of the response time.

Fourthly, the increment of temperature makes the response time becomes lower. The reason is that as the temperature increases, the viscosity of MRF becomes lower [11], which makes it easier for the ferromagnetic particles of MRF to move and form a steady chain-like structure rapidly. As a result, the response time decrease accordingly.

Fifthly, when other experimental conditions are the same, the MRD response time when the step current increases is always lower than that when the step current decreases. That is because of the ferromagnetic material's hysteresis, i.e. the time for material being magnetized is always lower than that demagnetizes.

V. Conclusion

In this study, the structure and mechanism of a disc gap MRD was introduced, and the dynamic characteristic experiments including mechanical experiment and response time testing experiment were implemented. Based on the experiment results and analysis, we can conclude that:

1) The damping force and power consuming ability increases with the increment of current, and when the current was 0.75A the controllable damping force was about 1200N, which show the MRD designed has an advanced mechanical characteristic. But there were some aberrations in the position vs force curves because of the air-stroke.
2) The MRD response time ranges from 48ms to 142ms in test conditions. During the test, the response time decreases as the piston velocity and temperature increase, and increases as the value of step current amplitude increases. And what's more, the response time when the step current increases are always lower than that when the step current decreases.

In order to improve mechanical characteristic of the MRD, inactive gas should be charged to compensate the air-stroke. What's more, aiming at achieving a better real-time control effect of the semi-active control systems based on MRDs, the method to design and fabricate rapid response MRDs should be investigated. On the other hand, to compensate the time-delay throng control strategies is another feasible way.

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