Design and Experimental Study of Vibration Reducing Experimental Device for Magneto-rheological Elastomer

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Abstract. The current automotive suspension system is fixed due to its rigidity and damping, so the damping effect is not adjustable, which affects the ride comfort. Trying to use magnetorheological elastomer as the core material of the suspension system, the theoretical model of the vehicle vibration damping experimental device excited by vertical vibration is established. According to the theoretical model, the experimental device of automobile vibration reduction system is designed, and the comparison experiment of vibration reduction effect under different conditions is carried out by using the device. The results show that the magnetorheological elastomer is effective in the automobile vibration damping system, and the magnetic field strength is the most important factor affecting the vibration damping effect.

1. Introduction
At present, the damping system in most vehicles is mainly composed of elastic components and rigid components, and its characteristic parameters are fixed, so the vibration damping effect cannot be adaptively adjusted according to the running condition and the road surface condition. On this issue, domestic and foreign scholars have proposed that the vibration reduction effect can be adjusted by the method of active suspension and semi-active suspension, because the active suspension which has complicated structure, high cost and large power consumption requires a high-precision servo mechanism, complex equipment and large external power sources. The semi-active suspension system has defects such as small adjustment range and uncontrollable adjustment ability. For example, Sun Jianming[1] studied the characteristics of existing active suspensions. It is proposed that the application range of active suspension is limited due to high cost, complicated structure and large power consumption, and the LMS control strategy method is adopted to reduce the cost. Zhu Hua[2] analyzed the characteristics of several suspensions in the development trend of semi-active suspensions, and pointed out that their commonality is small adjustment range and low control precision. In order to overcome the complex defects, Kou Farong designed a vehicle suspension system basing on electric hydrostatic actuation, and simplified the suspension structure. In order to solve these contradictions, improve the real-time operational stability and ride comfort of the vehicle. This paper proposes a new type of smart material which is Magneto-rheological elastomer as the main component of automotive vibration damping system. The shear modulus of this material is controlled by the strength of the magnetic field, while the shear modulus affects the stiffness and damping of the material. Therefore, it has an application basis that realizes adjustable vibration damping effect. Based on the above research status, it is proposed to apply magneto-rheological elastomer to automobile vibration reduction[3-4]. For this purpose, an experimental device has been developed and an experimental study on vibration damping effect has been carried out.
2. Design of Automobile Vibration Reduction Experimental Device Based on Magneto-rheological Elastomer

2.1 Theoretical model of automobile vibration reduction experimental device

Automotive vibrations include vertical vibration, pitch vibration, roll vibration, and lateral vibration. As the first step in the study of magneto-rheological elastomers for vibration reduction, this paper studies only vertical vibration, and its simplified theoretical model[5] is shown in Figure 1.

Assumption: The equivalent damping and equivalent stiffness of the part of the magneto-rheological elastomer vehicle suspension system are respectively $C$, $K_s$. The quality of the body and wheels is $m_b$, $m_w$. The acceleration of the body and the wheel is $\ddot{x}_b$, $\ddot{x}_w$. According to Newton’s second law, the equation of motion of the system can be obtained as:

$$m_b\ddot{x}_b = -C(\ddot{x}_b - \ddot{x}_w) - K_s[x_b(t) - x_w(t)]$$  \hspace{1cm} (1)

$$m_w\ddot{x}_w = -C(\ddot{x}_b - \ddot{x}_w) + K_s[x_b(t) - x_w(t)]$$

$$- K_s[x_w(t) - x_g(t)]$$  \hspace{1cm} (2)

The input stimulus uses a periodic signal whose function is $\omega(t)$.

$$\dot{x}_g(t) = -2\pi f_x x_g(t) + 2\pi \sqrt{G_0 U_0} \omega(t)$$  \hspace{1cm} (3)

In the formula: x- Road displacement
$g$- Road roughness coefficient
U- Vehicle forward speed
F- Natural frequency of the system
Combine formula (1) ~ formula (3), we write the system motion equation and the system input excitation equation in the form of a matrix, which is the state space equation of the system.

$$\dot{X}(t) = AX(t) + FW(t)$$  \hspace{1cm} (4)

In the formula: $X(t)$ - System state vector, $X(t) = [\dot{x}_g(t), \ddot{x}_w(t), x_b(t), x_w(t), x_g(t)]^T$;
According to this model, to know the vibration reduction effect of the suspension system, it is only necessary to compare the displacement and speed of the vibration before and after the vibration reduction, compare $x_a$ and $x_b$, OR $\dot{x}_a$ and $\dot{x}_b$.

According to the mechanical properties of the magneto-rheological elastomer and the theoretical model structure, the equivalent damping and equivalent stiffness of the theoretical model under different magnetic field strengths are calculated as shown in Table 1.

Table 1. Equivalent damping and equivalent stiffness under different magnetic fields

| Parameter name                                      | Numerical value |
|-----------------------------------------------------|-----------------|
| Magnetic field strength                            | 0 MT 250 MT 500 MT |
| Equivalent damping $C / N \cdot (m \cdot s^{-1})^{-1}$ | 543.5 1086.7 1753.5 |
| Equivalent stiffness $K_s / (N \cdot m^{-1})$       | 9846.2 18067.2 27546.8 |

The equivalent damping and equivalent stiffness are substituted into the theoretical model, and the rms evaluation method is used to evaluate the damping effect of the theoretical model. The root mean square values under different magnetic field strengths are shown in Table 2.

Table 2. Root mean square acceleration of acceleration under different magnetic field strengths

| Magnetic field size | Body acceleration | Suspension travel | Tire dynamic displacement |
|---------------------|-------------------|-------------------|--------------------------|
| 0 MT                | 1.43              | 29.12             | 11.98                    |
| 250 MT              | 2.68              | 23.05             | 11.68                    |
| 500 MT              | 1.23              | 21.23             | 16.78                    |
2.2 Mechanical structure design of automobile vibration reduction experimental device
Based on the theoretical model of the vehicle vibration reduction experimental device, the mechanical structure of the device is divided into three parts:

(1) Exciting structure
The excitation structure adopts an eccentric cam mechanism, through which the periodic motion is generated as an input excitation signal of the automobile vibration damping experimental device, wherein the eccentricity of the eccentric is 2 mm, so the total stroke of the entire device is 4 mm. The eccentric wheel is connected to the AC speed regulating motor, and the vibration frequency of the device is controlled by the rotation speed of the AC motor.

(2) Magneto-rheological elastomer suspension system damping structure
The general working modes of magnetorheological elastomers are shear and extrusion. The general working modes of magnetorheological elastomers are shear and extrusion. When the direction of the force is perpendicular to the direction of the magnetic field passing through the magnetorheological elastomer, it is called the shear mode. When the direction of the force is parallel to the direction of the magnetic field passing through the magnetorheological elastomer, it is called the extrusion mode. The working mode of the magnetorheological elastomer in the damping system designed in this paper adopts the shear mode, and its controllability and adjustment range are better than the extrusion mode.

(3) Data acquisition structure
The author judges the vibration damping effect of the experimental device by comparing the accelerations $\ddot{x}_a$ and $\ddot{x}_b$ before and after the vibration reduction. Therefore, an acceleration sensor is used and connected to the vibration measuring plane.

![Structure of automobile vibration reduction experimental device](image)

1. AC adjustable speed motor 2. Accelerometer 3. Magneto-rheological elastomer

Figure 2. Structure of automobile vibration reduction experimental device

Designed automobile vibration damping experimental device structure is shown in Figure 2. According to the theoretical model, the equivalent sprung masses of 3, 4, and 5 are shown in the figure below, 1, 6 Equivalent unsprung mass.

2.3 Design of Data Acquisition System for Automobile Vibration Reduction Experimental Device
The signal to be collected by the experimental system is the voltage signal output by two acceleration sensors. After they are collected, signal conditioning, A/D conversion, signal processing and analysis, vibration signal data storage and image output are required. In order to achieve these functions, using DSP TMS320F20 815 as the core, design and develop the data acquisition card, and compile the signal processing program, communicate with the computer through RS232, read the vibration signal in the SRAM into the computer, save it as data file, and then draw out before and after vibration reduction. The vibration image is analyzed based on the image to analyze the vibration reduction effect. The functional block diagram of the developed capture card is shown in Figure 3.
CCS3.3 as a software development tool, programming to achieve signal acquisition start, A/D conversion, data processing and analysis, save and other operations. According to the system characteristics and functional requirements, the FFT is used to transform the signal. After FIR filtering and spectrum analysis, the vibration signal to be acquired is selected, the data is saved in the SRAM, and the data is read to the computer through the serial communication software[6-7]. In addition, real-time control of system processes and monitoring via image display is required during the acquisition process.

3. Experimental Analysis of Magneto-rheological Elastomer Automobile Vibration Damping Device

Based on the designed experimental device, we carried out experimental research on the system damping effects of different thickness magneto-rheological elastomers, different excitation frequencies and different magnetic field strengths. The root mean square value evaluation method is used to judge the data before and after vibration reduction, analyze the vibration reduction effect, and further explore the key factors affecting the vibration reduction effect, and improve and perfect the experimental system. The experimental content includes the following three aspects.

3.1 Testing of the same magneto-rheological elastomer thickness and excitation frequency, and vibration damping effect under different magnetic fields

The excitation frequency used in the experiment, the speed of the AC motor is 150r/min. The magneto-rheological elastomer has a thickness of 3mm. Comparison curve of vibration acceleration before and after vibration reduction under different magnetic fields is shown in Figure 4. The root mean square value is shown in Table 3.
Figure 4. Comparison curve of vibration acceleration before and after vibration reduction under different magnetic field strengths

Table 3. Acceleration (output voltage) rms at different magnetic field strengths

| Magnetic Field Strength | Before Damping | After Damping | Damping Ratio |
|-------------------------|----------------|---------------|---------------|
| 0 MT                    | 0.091162       | 0.093216      | 19.78%        |
| 120 MT                  | 0.090662       | 0.069829      | 25.09%        |
| 180 MT                  | 0.066751       | 0.066751      | 26.57%        |

As can be seen from Figure 4 and Table 3, the change of the magnetic field has a great influence on the vibration damping effect of the magneto-rheological elastomer. When the magnetic field increases to a certain extent, the influence of the magnetic field on the damping capacity is weakened.

3.2 Vibration damping test of magneto-rheological elastomers with different thicknesses under the same excitation frequency and magnetic field

The AC motor used in the experiment has a rotational speed of 150 r/min and the magnetic field strength is 120 mT. Table 4 lists the root mean square values of the acceleration at different thicknesses.

Table 4. Acceleration root mean square value of magneto-rheological elastomers with different thicknesses

| Thickness | 3 mm          | 6 mm          |
|-----------|---------------|---------------|
| Before damping | 0.093216    | 0.091162      |
| After damping   | 0.069829    | 0.066851      |
| Damping ratio   | 25.09%       | 26.61%        |

Visible from Table 4, the effect of the increase in the thickness of the magneto-rheological elastomer on its damping capacity is not affected by the strength of the magnetic field; however, as the thickness increases, the damping capacity increases accordingly. From the structure of the experimental device, due to the increase in thickness, the magnetic field passing through the middle...
part of the magneto-rheological elastomer is not large on both sides, and the equivalent damping and stiffness in the middle are not as large on both sides, so the shear strength in vibration is not as good. On both sides, these weaken the damping effect of the magneto-rheological elastomer.

3.3 Damping effect of the same elastomer thickness and magnetic field and different excitation frequencies

The magneto-rheological elastomer used in the experiment has a thickness of 6 mm and a magnetic field strength of 180 mT. The root mean square value of the acceleration at different excitation frequencies is shown in Table 5. Experiments show that the change of excitation frequency has little effect on the damping capacity of magneto-rheological elastomer, which indicates that the damping capacity of magneto-rheological elastomer is affected by its own structure, damper structure and magnetic field. The influence of other external factors is large.

Table 5. Root mean square value of acceleration at different excitation frequencies

| Frequency | Before Damping | After Damping | Damping Ratio |
|-----------|----------------|---------------|---------------|
| 150 r/min | 0.093096       | 0.067429      | 27.88%        |
| 200 r/min | 0.100574       | 0.071282      | 28.91%        |

Discuss: Three sets of contrast experiments show that the change of the magnetic field has the greatest influence on the damping effect of the magneto-rheological elastomer, but the magnetic field strength needs a suitable range, not the bigger the better. The second most important factor is the thickness of the magneto-rheological elastomer, again the excitation frequency. In addition, from the effect of thickness change, the damping effect is not proportional to the change in thickness, which indicates that the damping effect is highly correlated with the structure inside the magneto-rheological elastomer, but due to the existing experimental conditions. The limit does not reflect this associated impact. One possible explanation is that the internal structure of a 6 mm thick magneto-rheological elastomer is not as strict as 3 mm. The chain arrangement affects the vibration damping effect of the magneto-rheological elastomer.

4. Conclusion

As a new type of smart material, magneto-rheological elastomer has broad prospects in vibration damping applications. However, its application research on vehicle vibration reduction is still at a very preliminary stage. The author establishes a vehicle vibration damping model based on magneto-rheological elastomer, and then establishes an experimental device according to the characteristics of the model, and performs multiple sets of contrast experiments under different conditions to test and verify the vibration damping effect under different conditions. In the comparative analysis, it is concluded that the magnetic field strength is the most critical factor affecting the damping effect, and different magnetic field strengths can obtain different damping effects. Research indicates, the magnetic field strength is the most important factor affecting the application performance of magneto-rheological elastomer. In the future, the application of magneto-rheological elastomer should be further explored and tested in the internal structure of magneto-rheological elastomer and the influence of magnetic field changes. Analysis, combined with the actual application, makes the experimental research gradually move to practical application.

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