

Research and Development of Mechanically Adjustable Fluid Viscous Damper

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Abstract. In this study, a new type of mechanically adjustable fluid viscous damper is developed for specific requirement. According to its operating principles, the output force of the damper is derived based on N-S equation. As a third-generation fluid viscous damper, the damping coefficient can be adjusted by controlling the angle of external valve. The theoretically and numerically predicted results are compared with sample tests, showing a fairly good agreement with each other. The developed damper can meet the requirements of engineering experiment and may provide a technical reference for further product development.

Introduction

At first, the fluid viscous damper was applied to provide the percussion counter-force in the course of launching artillery and spacecraft. At present, it has been widely used in many industries, such as construction, transportation, energy and so on, which provides a specific function for the protection of the structure. During the course of development, the mechanism of damping and the problems arose in engineering have become a hot topic in research and design.

In the 1980s, with the financial assistance from NSF(National Science Foundation, United States), the State University of New York at Buffalo started the research of the viscous damper and mainly aimed at the damping mechanism, damping materials and thermodynamic properties. After that, a series of related products have been developed by companies such as Taylor[1], FIP[2], ALGA and Kajima. Domestically, several colleges have been carrying out the systematic research and manufacture of viscous dampers from the early 1990s, such as Southeast University[3], Tongji University[4], Shanghai Jiao Tong University[5], Guangzhou University [6] and so on.

At present, viscous fluid damper has been developed from the first generation to the third generation which built-in low-viscosity media. Its damping mechanism is based on the N-S equation and no quantitative analysis has been formed by the scholars yet. According to experimental needs, this paper put forward a new viscous damper. Due to its external valve, its damping coefficient is adjustable. A performance test of the sample has been carried out to verify the numerical analysis.

The design of mechanically adjustable damper

In accordance with multiple cases of experiment, the viscous damper is required to be adjustable for different parameters. When taking the convenience and economy of the experiment into account, a kind of adjustable damper is needed. However, it is difficult to find suitable products from the market. In this condition, this paper proposed a simple adjustable damper based on the principle of traditional damper.

For a traditional viscous damper, the damping coefficient is constant after the product was made. It is determined by the viscosity of the internal medium and the geometric dimensions of the fluid channel. Furthermore, the damping coefficient of the product is related to the Reynolds number which is its inherent characteristic. For this reason, damping coefficient can be adjusted by changing the Reynolds number. The damper used in this research is based on the traditional damper

and the external damping channel is added on both sides of the piston. In addition, the middle part of the channel is provided with a valve. When adjust the opening angle of the valve, the section parameters of the damping structure can be controlled to realize the adjustability of the damping parameter. Then the relationship between flow control and damping parameters of valve will be calibrated by experiment.

According to the needs of the experimental system and combined with the structure of the adjustable damper, an adjustable damper was designed as shown in Figure 1. The variation of damping coefficient is realized through two pipes. When the external valve is closed, the viscous liquid flow only by the pipes, therefore, the corresponding damping coefficient is the biggest. The throughput of the oil hole will be increased by adjusting the external valve, and the damping coefficient will reduce accordingly.



Fig. 1 The sample of adjustable fluid viscous damper

The basic theory of damper

The Determination of Shape Parameters of Damper. Considering the condition of the application of damper, its displacement range is from 0 mm to 500mm, damping coefficient range is from 0 to $1\text{N}/(\text{mm s}^{-1})$ and maximum speed is not less than 750mm/s . The structural form of damper and the size of cylinder are shown in Figure 2 and Table 1.

A_0 , A_1 and A_2 represent section area of inlet flow in the cylinder, slit area and orifice area. According to the geometric parameters, they are $1.568 \times 10^{-2}\text{m}^2$, $2.006 \times 10^{-4}\text{m}^2$ and $9.05 \times 10^{-6}\text{m}^2$.

The working fluid of the damper is methyl silicone oil, whose density is generally between 930kg/m^3 and 975kg/m^3 and viscosity coefficient (μ) is $0.963\text{N}/(\text{mm s}^{-1})$. The flow in the cylinder can be divided into three zones, which are inlet-flow area, slit area and orifice area and the corresponding velocities are 0.02m/s , 1.0m/s and 10m/s . The Reynolds numbers in the three regions are 1.6, 0.4 and 24. It can be seen that the Reynolds number is much smaller than the critical Reynolds number in each region of the viscous fluid of the damper, so they meet the laminar flow model.

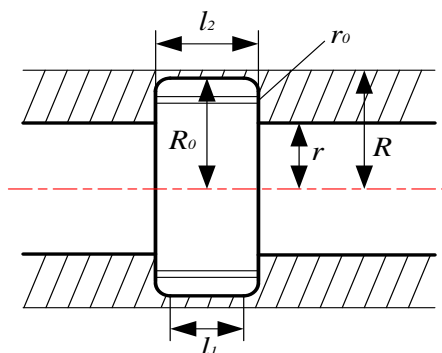


Fig. 2 The parametric diagrams of damping structure

Tab. 1 The geometric parameters of cylinder

Dimensions	Value
Inner diameter of the cylinder R / mm	80.0
Radius of the piston rod r / mm	37.5
Radius of the orifice r_0 / mm	1.2
<i>Maximum radius of the piston rod</i> R_0 / mm	79.6
Gap length l_1 / mm	35.0
Length of the orifice l_2 / mm	64.0

The Relationship Between Characteristics of Damper. Assuming that the fluid in the cylinder meets the continuity equation:

$$v_0 A_0 = v_1 A_1 + v_2 A_2 \quad (1)$$

Where v_0 is the velocity of fluid in the main body of the cylinder, v_1 is the velocity of fluid in the slit and v_2 is the velocity of fluid in the orifice.

The fluid in the slit between the piston and the cylinder wall can be simulated by Poiseuille flow between infinite parallel plates and the distribution characteristics of the flow can be obtained by the N-S equation. The maximum and mean velocities of flow in the slit are:

$$v_{\max 1} = -\frac{b^2}{8\mu} \frac{dp_1}{dx} \quad v_1 = \frac{2}{3} v_{\max 1} \quad (2)$$

Where b is the distance between the two plates and $b=0.4\text{mm}$. dp_1/dx is the pressure gradient between slits.

The fluid in the orifice can be simulated by Poiseuille flow in pipe and the distribution characteristics of the flow can be obtained by the N-S equation. The maximum and mean velocities of flow in the orifice are

$$v_{\max 2} = -\frac{r_0^2}{4\mu} \frac{dp_2}{dx} \quad v_2 = \frac{1}{2} v_{\max 2} \quad (3)$$

Assuming that the pressure on the left and right of the piston is evenly distributed, so the pressure difference (Δp) is equal and can be written as

$$\Delta p = \int_0^{l_1} \frac{dp_1}{dx} dx = \int_0^{l_2} \frac{dp_2}{dx} dx \quad (4)$$

From Eq. (4), the relationship between the pressure on the left and the right side of the piston, the slit length of the cylinder and the length of the orifice is given by

$$\frac{dp_2}{dx} = \frac{l_1}{l_2} \frac{dp_1}{dx} \quad (5)$$

When substitute Eq. (3), (4) and (5) into the continuity equation, Eq. (1) can be simplified:

$$\frac{dp_1}{dx} = \frac{v_0 A_0}{\frac{b^2 A_1}{12\mu} + \frac{r_0^2 A_2 l_1}{8\mu l_2}} \quad (6)$$

Thus, the pressure difference between the left and right side of the piston is

$$\Delta p = \left| \int_0^L \frac{dp_1}{dx} dx \right| = \frac{v_0 A_0}{\frac{b^2 A_1}{12\mu l_1} + \frac{r_0^2 A_2}{8\mu l_2}} \quad (7)$$

From Eq. (7), the force on the piston can be written as

$$F = \Delta p \times \Delta A = \frac{v_0 A_0 \pi (R_0^2 - 2 \times r_0^2 - r^2)}{\frac{b^2 A_1}{12\mu l_1} + \frac{r_0^2 A_2}{8\mu l_2}} \quad (8)$$

Assuming that the damper with methyl silicone meets the characteristics of viscous damping, the relationship between the velocity of the piston and the force on the piston is $F=cv$. Combining the velocity of the piston and the force on the piston, the damping coefficient of the damper can be obtained by

$$c = \frac{A_0 \times \Delta A}{\frac{b^2 A_1}{12\mu l_1} + \frac{r_0^2 A_2}{8\mu l_2}} \quad (9)$$

Where $\Delta A = \pi (R_0^2 - 2 \times r_0^2 - r^2)$

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The numerical simulation of damper. According to the performance of the damper, it is assumed that the velocity of the piston is 0.01885m/s. Basing on Eq. (9), the corresponding damping coefficient can be calculated as 2296N/(mm s⁻¹). The performance parameters of damper are shown in Table 2.

The damper is numerically simulated by ANSYS, and the result of force on the piston is 37.07kN. Among them, the pressure drag is 36.81kN and the friction resistance is 0.26kN. The pressure contour and velocity vector chart are shown in Figure 3 and Figure 4.

Tab. 2 The Results of performance parameters of damper

Parameters	Value
Forces on the piston(kN)	43.28
Velocity of fluid in the slit(m/s)	1.10
Velocity of fluid in the orifice(m/s)	8.20
Pressure difference at both ends(Pa)	2.8×10 ⁶
Pressure gradient in the slit(Pa/m)	8.0×10 ⁷
Pressure gradient in the orifice (Pa/m)	4.4×10 ⁷

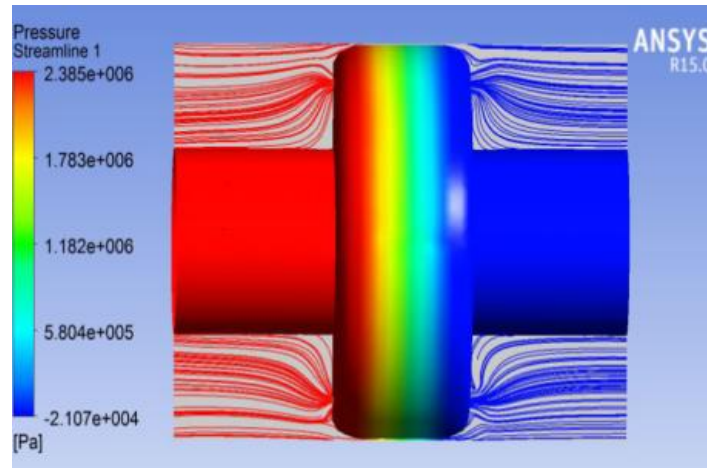


Fig. 3 The pressure contour

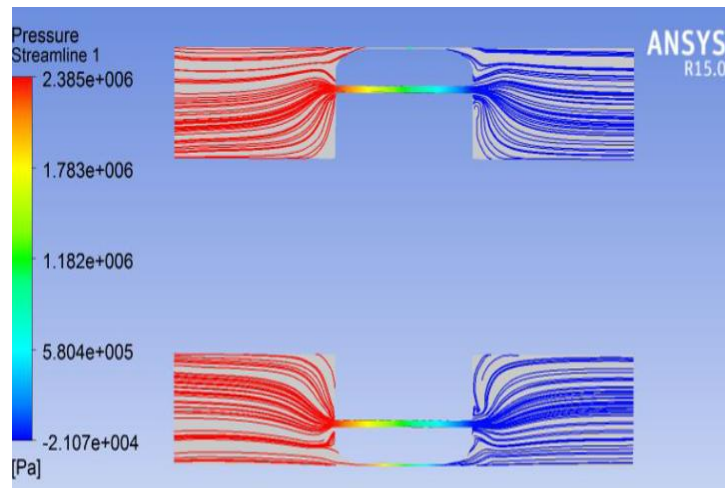


Fig. 4 The velocity vector chart

The test of damper's parameters

In order to determine the performance of the adjustable damper, the sample was tested on the test bench. The damper is imitatively loaded by the test bench, and the corresponding parameters are obtained. Through the testing that determines the parameters and sets the technical target:

- Loading frequency: 0.5, 1.0, 2.0, 3.0 Hz
- Loading law: harmonic function
- Maximum dynamic displacement: $\pm 150\text{mm}$
- The accuracy of dynamic test: $< 1\%$

As for the mechanical properties of the viscous damper, if the frequency of the ejector pin's reciprocating motion is less than 3Hz, taking into account the existence of a certain nonlinear effect, the damping force can be expressed as

$$F=cv \quad (10)$$

Where, c is the damping constant of damper, $\text{N}/(\text{m s}^{-1})$; v is velocity coefficient that ranges from 0.3 to 1.0, when $v=1$, it is linear damping; and v is the relative velocity of the piston relative to the cylinder, m/s .

According to the different position of the adjustable valve, the corresponding relationship of the thrust, the driving speed and the damping coefficient is shown in Figure 5. The regression results that between angles which adjusted by the valve and damping coefficient is shown in Figure 7. In the usage, the damping parameter can be adjusted according to the relationship of Figure 6, so as to meet the requirement.

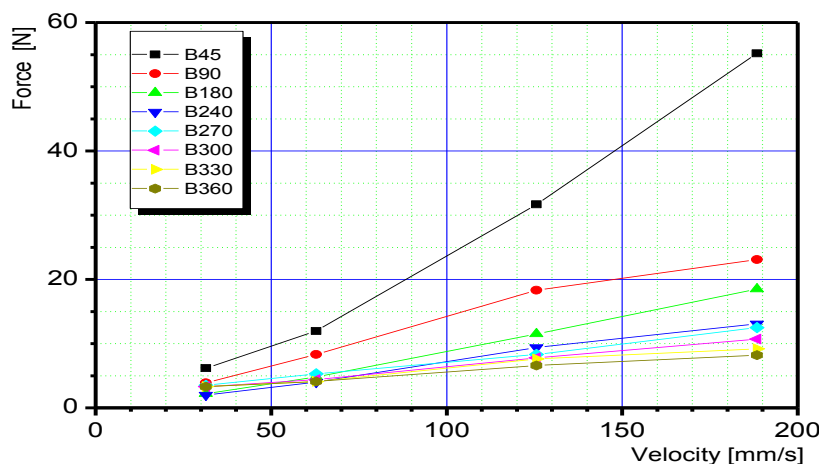


Fig. 5 The relationships between the resistance and the piston movement speed is measured in different angles of the valve

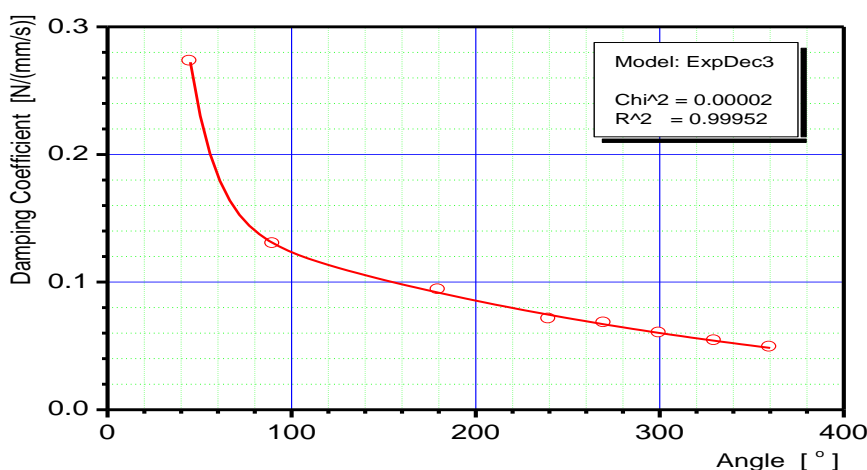


Fig. 6 The regression results of the relationship between different angles of the valve and damping coefficient.

Conclusion

Based on the principle of traditional viscous damper, a damper with new structural is proposed, which can be used to adjust the damping parameters in accordance with the requirement. The adjustable damper, which developed in this paper, sets up a section of the oil circuit with the valve on both sides of the piston and extended the model of fixed oil hole on piston in traditional viscous damper. Thus, it is very suitable for the experiment which needs to adjust the damping parameters frequently. The main work and conclusions of this paper are as follows:

- The external oil valve can achieve a continuous adjustment of damping coefficient, which can meet the experimental requirements;
- Through the N-S equation, the output force of the third-generation of viscous fluid dampers can be accurately simulated;
- Numerical simulation by Fluent and theory are basically the same;
- Through experimental verification, the damping coefficient of the damper varies exponentially with the opening angle.

According to the design of the damper in this paper, it can also be extended:

- Changing the mechanical valve into a solenoid valve, which is more adaptive to the automatic control system;

- According to the requirement, the area ratio of the cylinder and the external pipe of the damper can be designed to change the range and the maximum value of the adjustable damping coefficient;
- Setting the one-way valve in the orifice of the piston can get the nonlinear characteristic damper.

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