Flow Analysis of Magnetic Fluid around a Permanent Magnet in Magnetic Fluid Damper

Xiaorui Yang[1], Qingxin Yang[1,2], Wenrong Yang[1], Bing Guo[1], Lifei Chen[1]*

[1]State Key Lab of Reliability and Intelligence of Electrical Equipment, Hebei University of Technology , Hebei University of Technology, Tianjin, China, 300130 *Email: wryang@hebut.edu.cn
[2]Tianjin Key Laboratory of Advanced Electrical Engineering and Energy Technology, Tianjin Polytechnic University, Tianjin, China, 300387

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Background

Vibrations may reduce the comfort, safety, dynamic accuracy and properties of machines. In order to solve the vibration problem of compact structure and smaller energy dissipation, this research proposes a passive magnetic fluid damper. Magnetic fluid is a stable colloidal dispersion that the magnetic nanoparticles, for example Fe3O4, uniformly disperse in a carrier liquid by surfactant. In a gradient magnetic field, the magnetic fluid can be magnetized and subjected to magnetic field force.

Contents

- The magnetic fluid damper works mainly based on the self-suspension characteristics of the permanent magnet in the magnetic fluid. The reciprocating movement of the permanent magnet in magnetic fluid can absorb energy to decrease vibration.
- This paper has built the energy dissipation model considering the magnetic field and liquid flow.

Conclusion

- Based on the second-order buoyancy principle of magnetic fluid, this paper proposes a kind of magnetic fluid damper. The energy dissipation has been calculated and the numerical model has been built. In the model, the damping fluid is ester-based magnetic fluid.
- By theoretical calculations, the factors affecting the energy dissipation of the magnetic fluid damper mainly include the size of permanent magnet and the magnetic field of permanent magnet. Numerical analysis results show that the energy dissipation of the damper will be enhanced when the size of the permanent magnet increases in a certain range. It also can be found that the flow consumption play a decisive role rather than the magnetic field energy dissipation. In addition to consume energy, the magnetic field will also affect the flow of magnetic fluid.
- The magnetic fluid damper is very sensitive to inertia with small size, low cost, and suitable for low-frequency vibration of about 0.5Hz.ult in decreased work hardening effects.

Fundamental

Structure

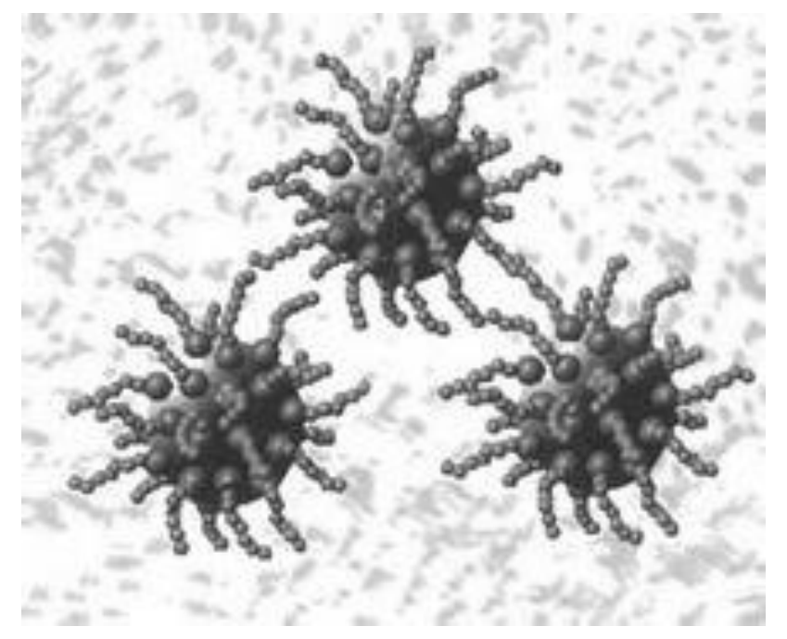

Fig. 1 Microstructure of magnetic fluid

Magnetic fluid is a stable colloidal dispersion of single domain magnetic nanoparticles in a carrier fluid. In a gradient magnetic field, a permanent magnet is suspended in the magnetic fluid by the second-order buoyancy due to the magnetic force.

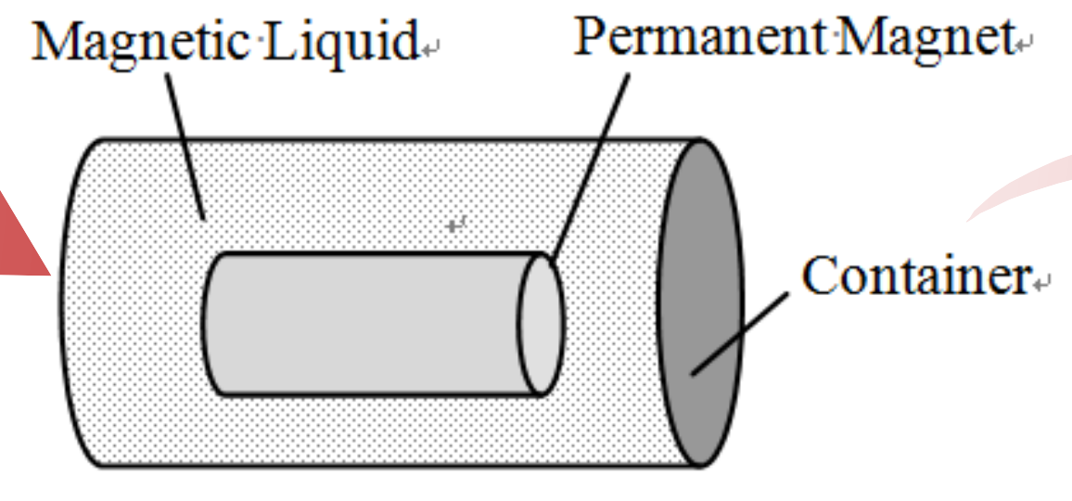

Fig.2 Sketch of the magnetic fluid damper.

Based on the second-order buoyancy of the magnetic fluid, the permanent magnet will be suspended in the lower middle of the container, When the damper is subjected to an external vibration, the permanent magnet reciprocates and drives magnetic fluid to viscous flow and absorb vibration energy.

Experimental Procedures

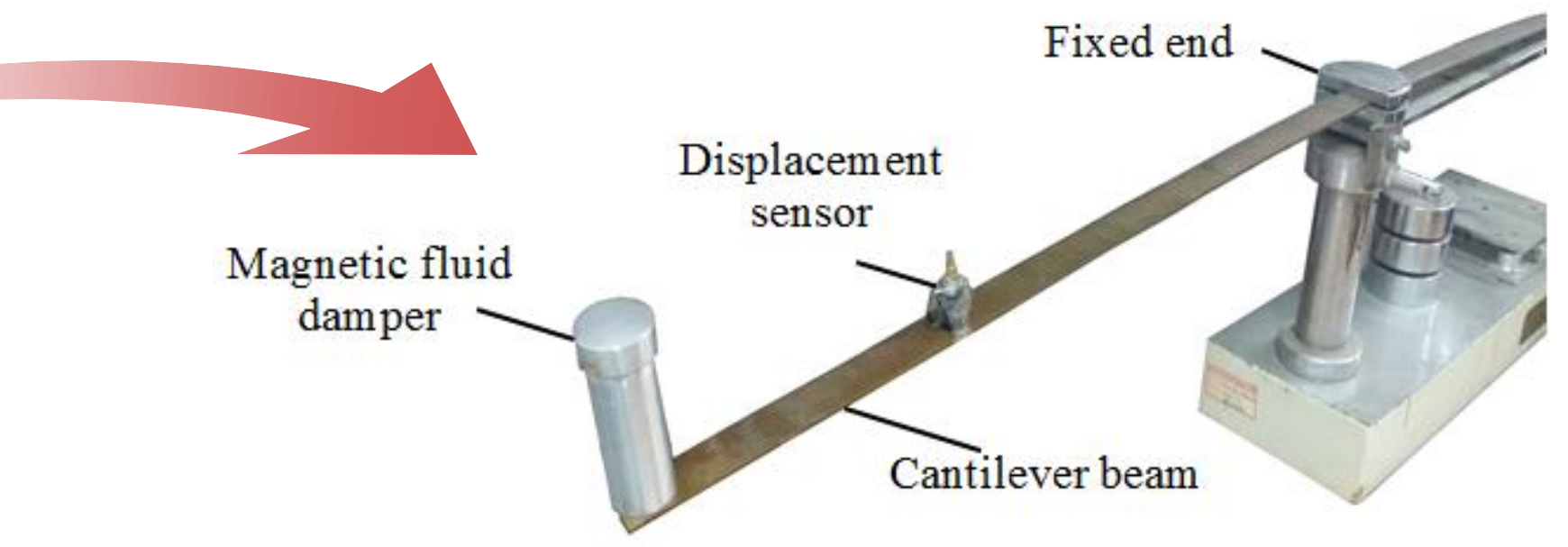

Fig.3 The experimental device

The cantilever beam vibration system is established. The magnetic fluid damper is fixed on the free end of the beam. The length can be adjusted by fixed end to obtain different frequency. The magnetic fluid damper is attached to the end of cantilever to absorb the vibration energy

Flow analysis

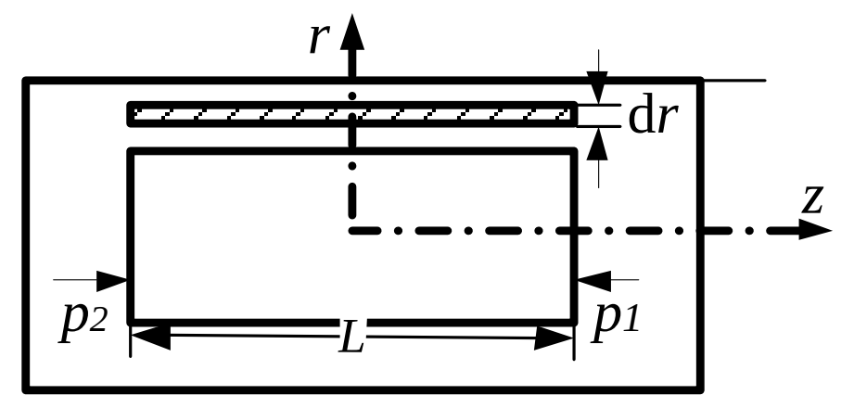

Fig.4 The analysis model of the damper

Taking the magnetic fluid between container and magnet as research object, the flow equation of the magnetic fluid is as follows:

$$0=-\frac{\partial p}{\partial z}-\boldsymbol{f}_{\eta,z}+\boldsymbol{f}_{\mathrm{m},z}$$

$$0=-\frac{\partial p}{\partial r}$$

$$0=-\frac{\partial p}{\partial \theta}$$

$$\text{where}\begin{cases}\boldsymbol{f}_{\eta}=\eta_{\mathrm{H}}\nabla^{2}\boldsymbol{v}+\frac{1}{3}\eta_{\mathrm{H}}\nabla(\nabla\cdot\boldsymbol{v})\\ \nabla\cdot\boldsymbol{v}=0\\ \boldsymbol{f}_{\mathrm{m}}=\mu_0 M\nabla H\\ \mu_0 M=(\mu-\mu_0)H\end{cases}$$

Boundary conditions:

$$v_{\mathrm{z}}=\dot{x}_{\mathrm{m}},\quad \text{for}\quad r=R_1$$
$$v_{\mathrm{z}}=0,\quad \text{for}\quad r=R_2$$

Mass conservation equation:

$$\int_0^r 2\pi r v_z \mathrm{d}r+S_{\mathrm{m}}\dot{x}_{\mathrm{m}}=0$$

The v_z can be deduced:

$$\frac{\mathrm{d}v_{\mathrm{z}}}{\mathrm{d}r}=\frac{K_1}{r}+\frac{r}{2R_1\eta_H}\left(\ddot{x}_{\mathrm{m}}\rho_{\mathrm{m}}R_1-2\tau\right)-\frac{(\mu-\mu_0)}{\eta_H}\int_{R_1}^{r}\frac{1}{r}\int_{R_1}^{r}rH_z\frac{\mathrm{d}H_z}{\mathrm{d}z}\mathrm{d}r\mathrm{d}r$$

$$K_1=\frac{1}{\frac{2R_2^{\,2}}{R_2^{\,2}-R_1^{\,2}}\cdot\ln\frac{R_2}{R_1}+\ln\frac{R_2}{R_1}-1}\dot{x}_{\mathrm{m}}$$

Energy dissipation of incompressible fluid per unit time is as

$$W=\eta_{\mathrm{H}}\int_{R_1}^{R_2}\left(\mathrm{d}v_z/\mathrm{d}r\right)^2\cdot 2\pi L\left(r-R_1\right)\mathrm{d}r$$
$$=W_1(\dot{x}_{\mathrm{m}},R_1,R_2,L)+W_2(H_z,\dot{x}_{\mathrm{m}},R_1,R_2,L)$$

$$W_1=2\pi\eta_H L\left(\dot{x}_{\mathrm{m}}\text{-}K_1\ln\frac{R_2}{R_1}\right)^2\left(R_1^{\,2}+R_2^{\,2}\right)+\frac{8\pi\eta_H L}{R_1+R_2}\left(\dot{x}_{\mathrm{m}}-K_1\ln\frac{R_2}{R_1}\right)+2\pi\eta_H LK_1^{\,2}\ln\frac{R_2}{R_1}$$

$$W_2=2\pi\eta_H\int_0^L\mathrm{d}z\int_{R_1}^{R_2}\frac{2\pi\left(\mu-\mu_0\right)}{\eta_H}\int rH_{\mathrm{z}}\frac{\mathrm{d}H_{\mathrm{z}}}{\mathrm{d}z}\mathrm{d}rF\mathrm{d}r$$

$$F=\left(\mu-\mu_0\right)\int_{R_1}^{R_2}rH_z\mathrm{d}H_z/\mathrm{d}z\mathrm{d}r/\eta_H r-2\left(\dot{x}_m-\frac{2rK_1}{R_2^{\,2}-R_1^{\,2}}\ln\frac{R_2}{R_1}+\frac{K_1}{r}\right)$$

Results

Magnetic Field Analysis

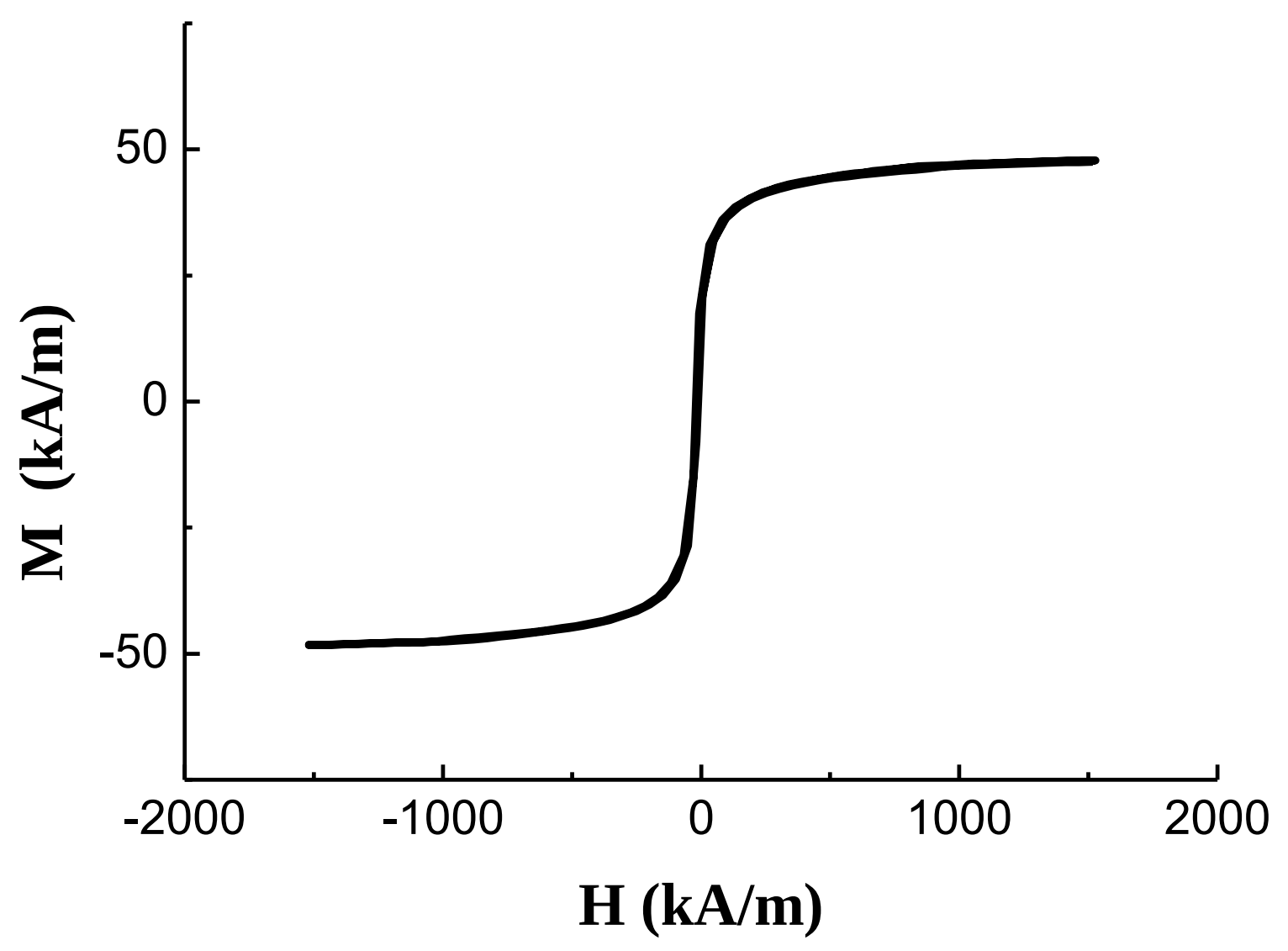

Fig.5 Magnetization curve of the magnetic fluid

The magnetic fluid has superparamagnetic properties, and there is no residual magnetism and coercive force after demagnetization

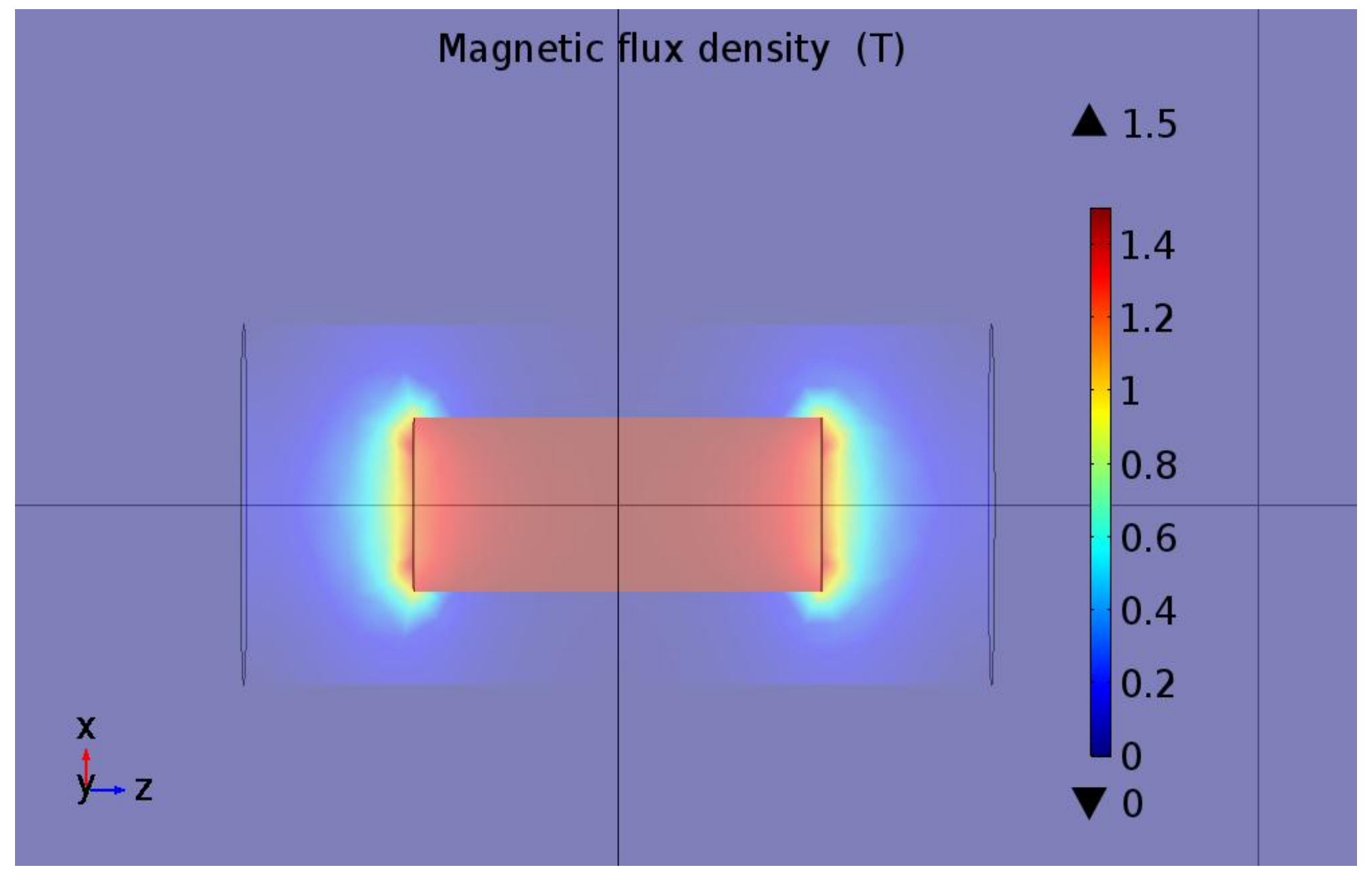

Fig.6 Magnetic field distribution of the permanent magnet in the damper.

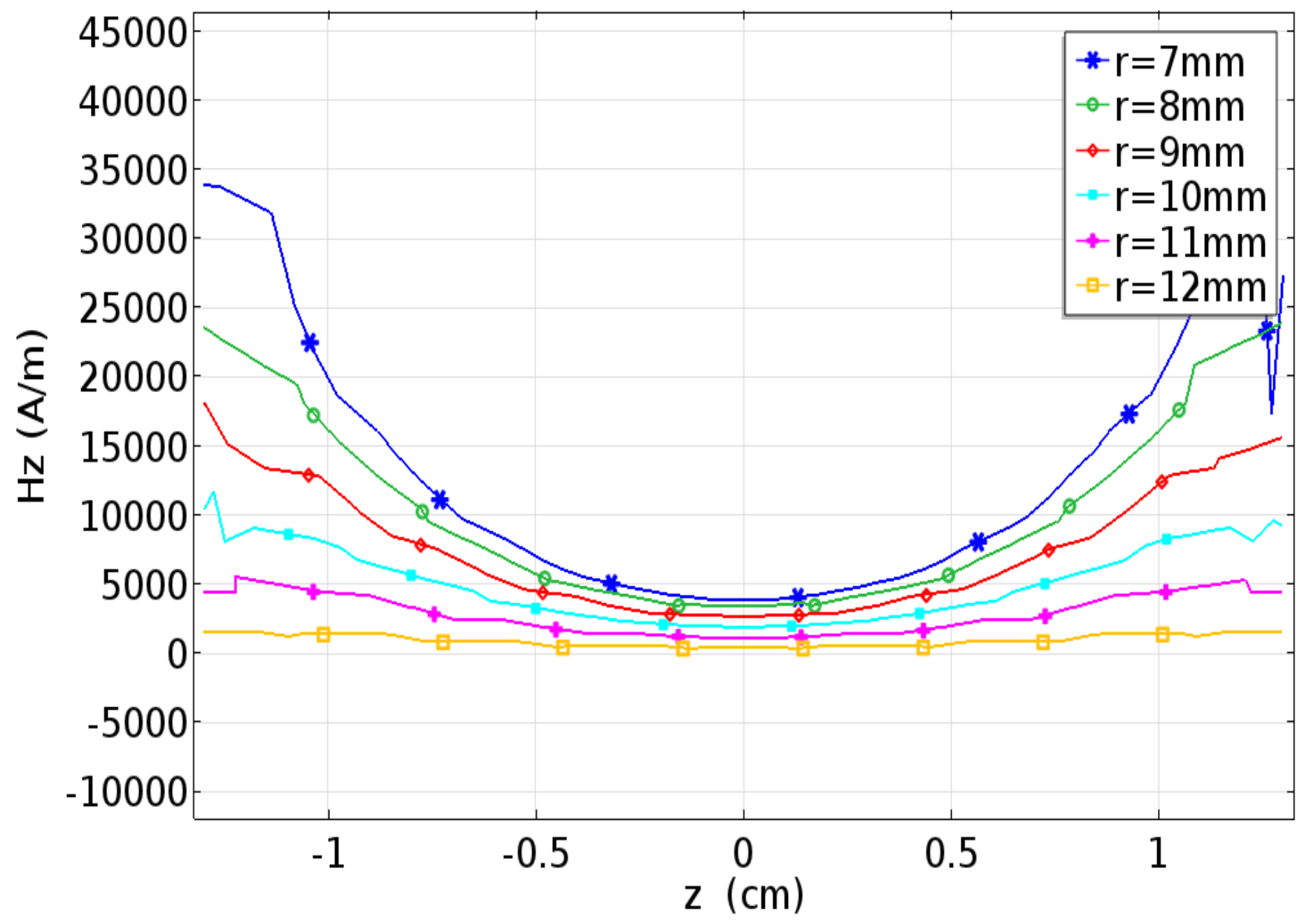

Fig.7 H_z distribution in the gap along z axis

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According to the simulation results, H_z has little changed away from surface of the permanent magnet. If the length of the permanent magnet is larger than the diameter, the magnetic field gradient is close to zero. In this case, the energy dissipation caused by the magnetic field is rather small.

Energy Dissipation

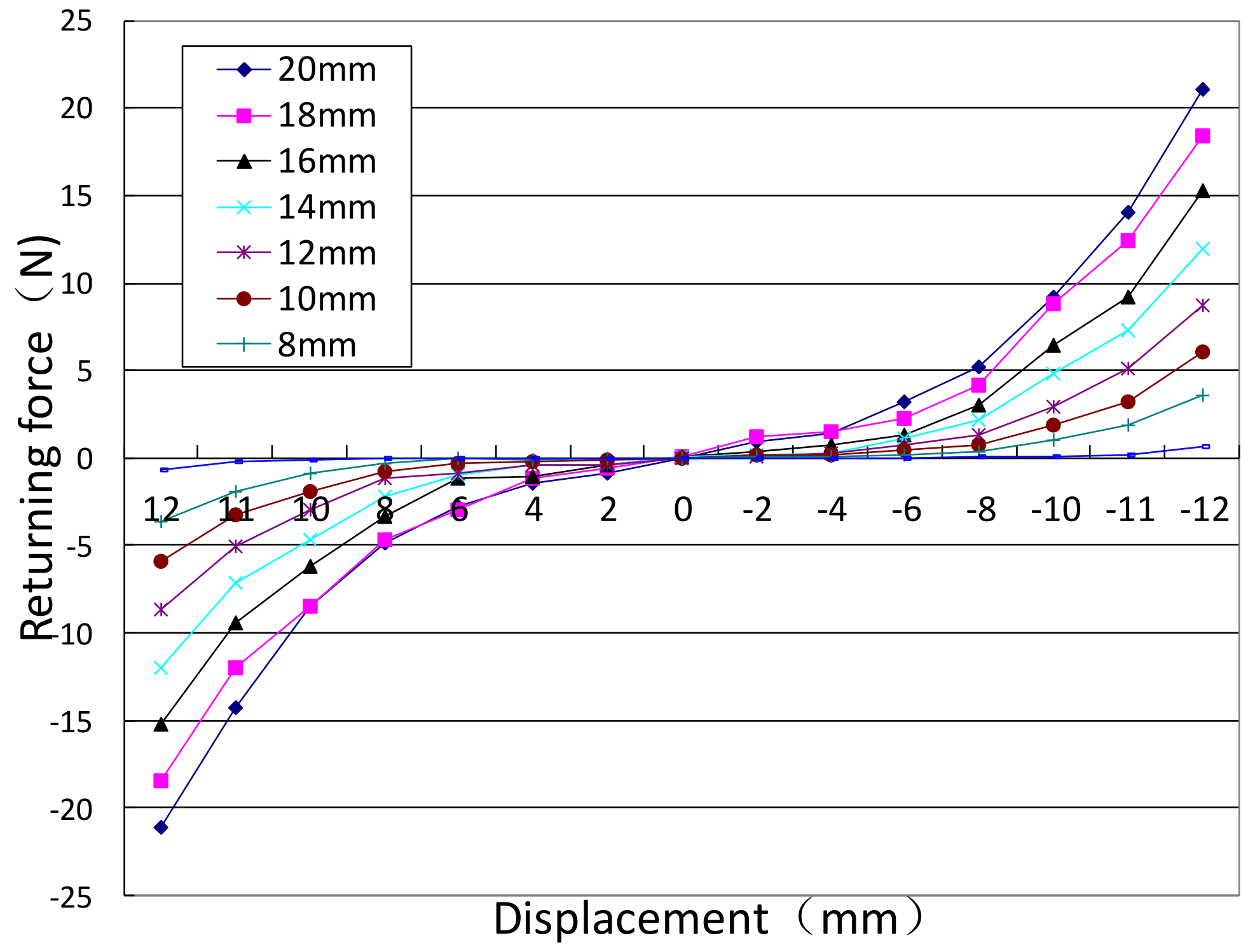

Fig. 8 The relationship between returning force and displacement of permanent magnet at L=30mm

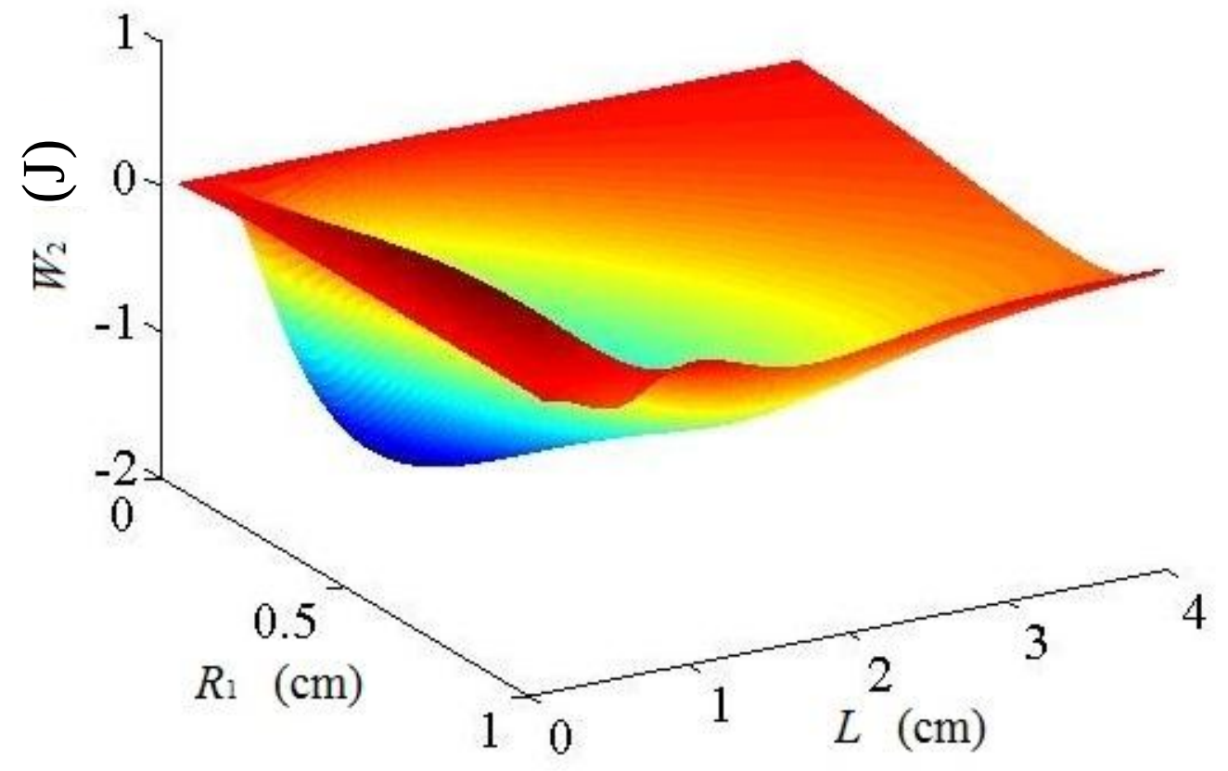

Fig.9 Magnetic field energy dissipation W_2

The energy dissipation of the damper is mainly due to the flow dissipation of the liquid.

The energy dissipation caused by magnetic field has little effect on the whole energy dissipation.

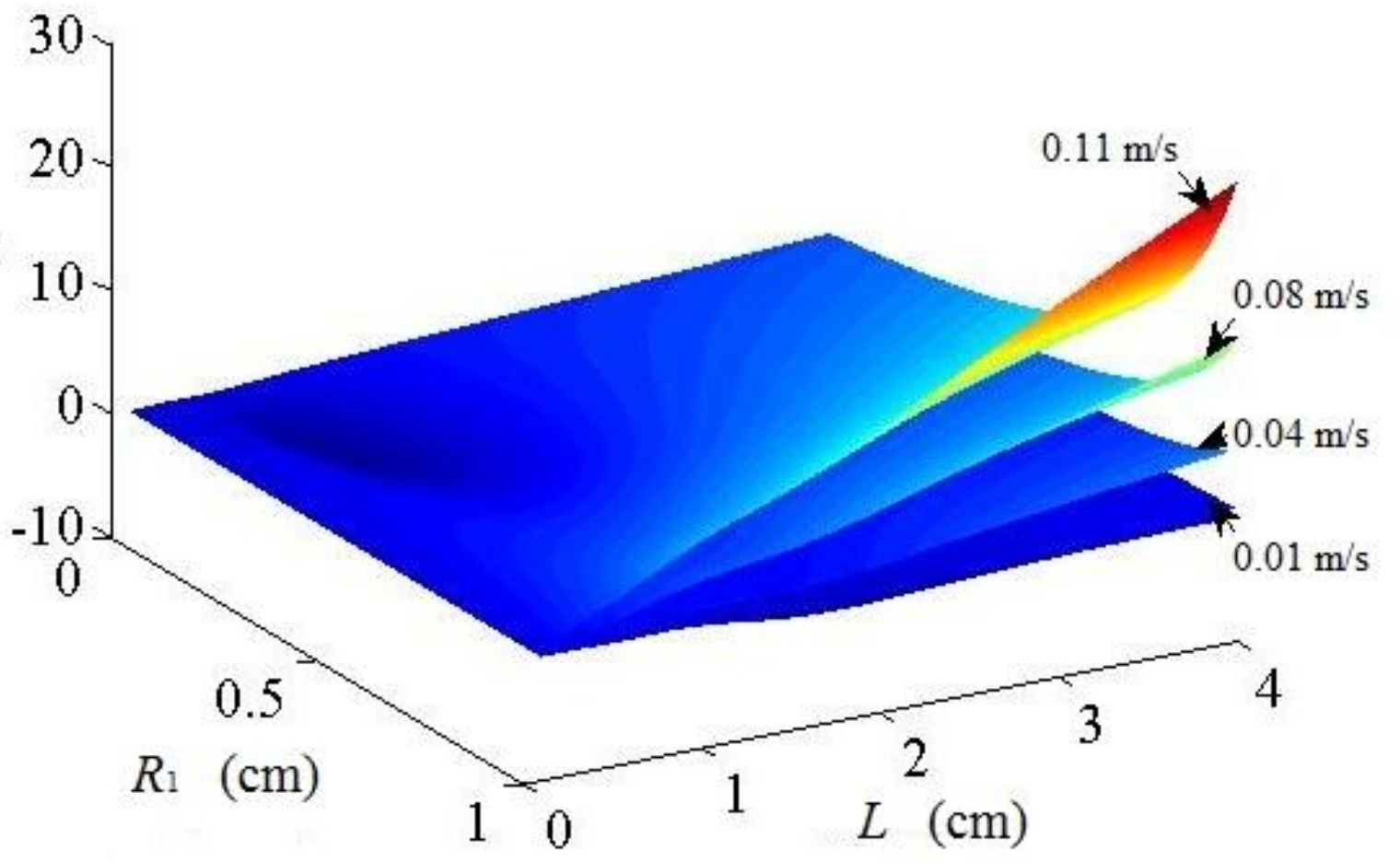

Fig.10 Energy dissipation W of the damper

The negative values act as lubrication for reducing the energy dissipation for the damper.