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나노 다공성 입자의 콜로이드 서스펜션을 이용한 기계적 감쇠기구에 대한 연구

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Study on Mechanism of Mechanical Damping System Based on The Colloidal Suspension of Nano-Porous Particles

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Abstract

Damping systems have been widely used to various industrial structures and are mainly hydraulic and pneumatic devices nowadays. In this work, a novel damping system based on the colloidal suspension in the field of nanotechnology is investigated. The colloidal suspension consists of lyophobic working fluid and hydrophobic-coated porous particle. The mechanism of mechanical energy dissipation in damping system based on the colloidal suspension with nano-porous particles is different from that of the existing hydraulic damping system. The absorbed energy of the damping system using colloidal suspension can be calculated through the mechanical equilibrium condition by the superficial tensions of liquid-gas interface in the hydrophobic surface in nano-porous particles. The results from an analytic approach have a reasonable agreement with experimental results.

Key Words : Colloidal suspension, Surface tension, Nano-porous particle, Energy dissipation

1. Introduction

Damping systems have been widely used to various industrial structures and are mainly hydraulic devices nowadays. The novel concept of heterogeneous structure that Eroshenko had proposed can accumulate and dissipate the mechanical energy, and this kind of structure is called colloidal damper [2]. This kind of colloidal damping system can be replaced with hydraulic damping system as an anti-vibration structure in all of industrial field. Although related studies have been made on static experiments and introductory theoretical investigation [2-4], there seems to be no diverse application of analytic approach for the prediction of the performance of colloidal damping system.

The absorbed energy of the damping system using colloidal suspension can be estimated through the mechanical equilibrium condition by the superficial tensions of liquid-gas interface of the hydrophobic surface in nano-porous particles. This research presents the method of prediction about the dissipated

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energy and the energy dissipation efficiency of the colloidal damping system through the analytic approach using the conditions governing mechanical equilibrium of capillary system, which is consisted with fluid and particles having nano-sized passages. The results from an analytic approach have a reasonable agreement with the previous experimental results [3].

2. Analytical approach for colloidal damping system

2.1 Relation between pressure and volume variation of nano porous particle

The performance of the colloidal damping system is determined by the amount of dissipated-energy to that of absorbed-energy during compression phase of a total cycle. In order to estimate the performance of colloidal damping system, variation of the absorbed volume of the working fluid should be calculated with respect to loading external pressure. Before the relationship with the variation of the absorbed volume to the external pressure is determined through the mechanical equilibrium of capillary system in porous particle with nano-sized passage, there are several assumptions to be considered. These assumptions are following:

- A total cycle from compression to relaxation of colloidal damping system is isothermal process.
- Air in porous particle is considered as an ideal gas.
- The working fluid is considered as an incompressible one.

The governing mechanical equilibrium of capillary system in porous particles with the nano-sized passage can be expressed as follows [5]:

$$P_{ext}=\left(\frac{-2\sigma\cos\theta}{R}\right)+P_{air} \tag{1}$$

where, P_{ext} is the external pressure loaded, and P_{air} is the pressure in the cavity of porous particles. And, σ, θ, and R are superficial tension, angle of liquid-gas interface in the solid surface, and radius of capillary system, respectively.

Using the equation of state of ideal gas for isothermal process, the following relation between pressure and volume for two different states of ideal gas can be obtained.

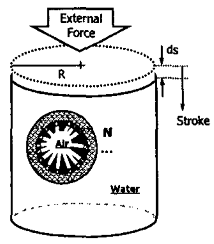

Fig. 1 Basic model of colloidal damping system

$$P_{air}=P_{ATM}V_{ATM}\frac{1}{V_{air}} \tag{2}$$

As shown in Fig. 1, the volume of the cavity of a porous particle can be expressed using the equation (2) and variation of the absorbed volume (ΔV).

$$V_{air}=V_{ATM}-\frac{\Delta V}{N} \tag{3}$$

where, N is the total number of porous particles. Then, the governing mechanical equilibrium of capillary system in a porous particle with nano-sized passages can be expressed from the equation (3).

$$P_{ext}=\left(\frac{-2\sigma\cos\theta}{R}\right)+P_{ATM}V_{ATM}\frac{1}{V_{ATM}-\frac{\Delta V}{N}} \tag{4}$$

where, $V_{ATM}$is the volume of porous particle including nano-sized passage and cavity. The relation with variation of the absorbed volume to the external pressure can be determined through the above equation.

2.2 Compression phase in energy dissipation cycle of colloidal damping system

The compression phase can be divided into two steps like step A, and B in Fig. 2 (a) with respect to the radius of capillary system. One (step A) is the period when the working fluid penetrates a nano-sized passage of the porous particle; the other (step B) is the period when the working fluid fills a cavity of the porous particle after the nano-sized passage. For the step A, the angle of liquid-gas interface in the solid surface changes from 90° to 180° with loading the external pressure, and the radius of capillary system is that of the passage of a porous particle. For the step B, the radius of capillary system is that of the cavity of a porous particle, and the angle of liquid-gas interface in the solid surface is considered as 180° regardless of loading the external pressure. And the working pressure in these steps of the capillary system in a porous particle is the external pressure.

2.3 Relaxation phase in energy dissipation cycle of colloidal damping system

The relaxation phase can be divided into two steps like step C, and D in Fig. 2 (b) with respect to the radius of capillary system. One (step C) is the period when the working fluid flows off a cavity of the porous particle to nano-sized passage; the other (step D) is the period when the working fluid passes through a nano-sized passage of the porous particle. For a step C, the radius of capillary system is that of the cavity of a porous particle, and the angle of liquid-gas interface in the solid surface is considered as 180° regardless of loading the external pressure. For a step D, the angle of liquid-gas interface in the solid surface changes from 90° to 180° with loading the external pressure, and the radius of capillary system is that of the passage of a porous particle. And the working pressure in these steps of capillary system in a porous particle is the pressure in the cavity of particle.

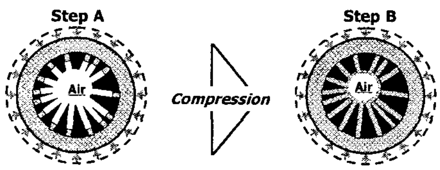

Fig. 2(a) Compression phase:Patrition of a total cycle in colloidal damping system for analytic approach

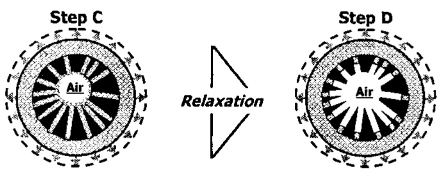

Fig. 2(b) Relaxation phase:Patrition of a total cycle in colloidal damping system for analytic approach

Table 1 Dimension of nano-porous particles

[nm]	P1	P2	P3	P4	P5
Dia. of passage	10	20	30	7	7
Dia. of particle	20E3	20E3	20E3	20E3	40E3
Dia. of cavity	15.8E3	15.8E3	15.8E3	6E3	12E3
Stroke	11.2E6	13.7E6	14.1E6	11.2E6	11.2E6
Dia. of pistom	20E6	20E6	20E6	20E6	20E6

3. Resuts through analytic approach

The performance of colloidal damping system can be estimated using the governing mechanical equilibrium of capillary system in a porous particle with nano-sized passages. The particle dimensions of colloidal damping systems applied by the analytic approach are shown in Table 1.

The energy dissipation efficiency from the colloidal damping system is defined as the ratio of the dissipated energy during the total cycle to the absorbed energy during compression phase as follows:

$$\eta \equiv \frac{\textit{Dissipated energy during the cycle}}{\textit{Absorbed energy during compression phase}} = \frac{E_{dissipation}}{E_{compression}} \quad (5)$$

3.1 Comparison for various passage diameters in nano-porous particle

The analytic approach using the governing mechanical equilibrium condition is applied with three different dimensions of porous particles. P1, P2, and P3 have 10nm, 20nm, and 30nm as the diameter of fluid passages in porous particles respectively, and the particle diameter is constant as 20 μm. Figure. 3 (a) and (b) show the comparison of results between analytic approach and experiment for various fluid passage diameters. As these results are compared with the experiment for the same cases in Ref. [3], the maximum pressure is different from each other. But the hysteresis curve has the similar tendency with decreasing the diameter of fluid passages.

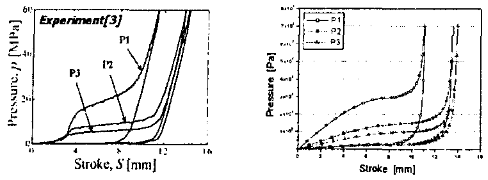

Fig. 3 Comparision between experimental[3] & analytic results for various passage diameters of nano porous particle in colloidal damping system

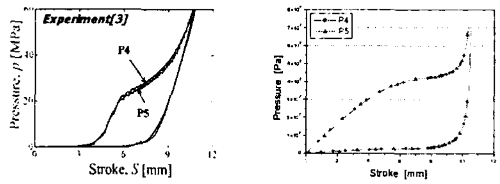

Fig. 4 Comparision between experimental[3] & analytic results for various diameters of nano porous particle in colloidal damping system

3.2 Comparison for various diameters of nano-porous particles

In order to evaluate the effect of the diameter of porous particles on the efficiency of colloidal damping system, the analytic approach based on the governing mechanical equilibrium condition is applied with two different dimensions of porous particles. P4 and P5 have 20 μm and 40 μm as the diameter of the porous particle respectively, whose fluid passage diameter is constant as 7nm. Figure. 4 (a) and (b) show the comparison of results between analytic approach and experiment [3]. The hysteresis curves for different diameter of porous particle in colloidal damping system have the similar tendency with those of the experiment [3]. It can be confirmed with these results that the diameter of porous particle cannot affect to the energy dissipation efficiency of colloidal damping system.

4. Conclusions

This research can be summarized as follows:

Firstly, this research proposes the analytic method to evaluate the performance of colloidal damping system with nano-porous particles. In order to confirm the analytic approach for colloidal damping system, these results are compared with those of experimental results [3]. And, the results from an analytic approach have a reasonable agreement with experimental results.

Secondly, it is confirmed through this research that the energy dissipation efficiency of colloidal damping system can be affected significantly by the fluid passage diameter of porous particle. On the other hand, the diameter of the porous particle has no influence upon the energy dissipation efficiency of colloidal damping system.

Lastly, this research shows that the performance for colloidal damping system using nano-porous particle can be predicted using the analytic calculation based on the mechanical equilibrium in capillary system.

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