An Experimental Study on Damping Characteristics of Mechanical Snubber for Nuclear Power Plant Piping Systems

T. Chiba, H. Kobayashi
Nuclear Power Division, Ishikawajima-Harima Heavy Industries Co., Ltd., 1, Shin-nakahara-cho, Isogo-ku, Yokohama 235, Japan

K. Kitamura, K. Ando, R. Koyanagi
Research Institute, Ishikawajima-Harima Heavy Industries Co., Ltd., Kohtoh-ku, Tokyo 135, Japan

Summary :

Damping ratio is one of the most important parameters in seismic analysis of nuclear power plant facilities. A study group titled SDREP (Seismic Damping Ratio Evaluation Program) was established to clarify the damping ratio which is used in the seismic analysis of piping systems, and vibration tests were conducted systematically to investigate the damping characteristics of thermal insulator, oil snubber, rod restraint, spring hanger, and frame type restraint. From the results of these study, damping characteristics of thermal insulator and above-mentioned seismic supports were clarified, and the prediction formula of design damping ratio of piping systems was obtained. The study was presented in 5th SMiRT paper of K 11/3 and 6th SMiRT papers of K 6/4, 6/5 and 13/4.

In recent year, a mechanical snubber gets to use commonly as a seismic support of piping system in nuclear power plants, but it was not tested in SDREP.

The objectives of this study are

1) to clarify the damping characteristics and the dynamic stiffness of mechanical snubber,
2) to take the damping characteristics of mechanical snubber into the damping evaluation method obtained in SDREP.

Therefore, following vibration tests were conducted.

1) Component test
   As a first step, mechanical snubbers were excited with sinusoidal wave, and damping ratio and dynamic stiffness were measured at several loading levels.
2) Piping model test
   Second, a 8" diameter x 16 m length 3-dimensional piping model simulating the supporting conditions of actual piping systems was tested. Damping ratio and mpde shapes of piping model with mechanical snubbers were measured at several supporting conditions and response levels.

From the results of these tests, the damping characteristics and the dynamic stiffness of mechanical snubber can be summarized as follows :

1) The damping effect of mechanical snubber is as strong as that of oil snubber.
2) Mechanical snubber contributes effectively to the damping of piping system, and it is indicated that the damping characteristics of mechanical snubber is applicable to the damping evaluation method obtained in SDREP.

1. Introduction

The damping characteristics of piping system should be discussed as a matter of combined effects of piping and supports. In SDREP (Seiamic Damping Ratio Evaluation Program), a series of vibration tests, which consisted of component test, simplified piping model test and scale model test were conducted to investigate the damping characteristics of thermal insulator, spring hanger, oil snubber, rod restraint and frame type restraint, and reported. 1),2),3),4) On the basis of the data obtained in SDREP, the damping effect of these components were clarified and prediction formula of damping ratio for piping system were developed. However, this work did not include the discussion and test of mechanical snubbers which get to use recently as seismic supports in nuclear power plants.

In this study, the authors performed component test and piping model test on mechanical snubbers with the aims:

1) to investigate the damping characteristics and the dynamic stiffness of mechanical snubber,
2) to develop a prediction formula for damping effect of mechanical snubbers,
3) to clarify the difference of damping effect between the oil snubber and the mechanical snubber.

2. Component Test

2.1 Test contents

A mechanical snubber is made of body and joints at its both ends. Hence, damping is expected to occur at both the body and the joints. The method used in this test, therefore, was to excite a snubber with its joints using a hydraulic excitor and to measure the damping effect as well as the dynamic stiffness of the snubber.

Two types of mechanical snubbers widely used in nuclear power plants were tested and its specifications and construction are shown in Table 1 and Fig. 1.

Mechanical snubbers (rated load 0.6, 1.0 and 3.0 ton) were excited with a sinusoidal wave. Displacement amplitudes and load were measured simultaneously as shown in Fig. 2. The test was conducted under following conditions.

Frequency : 1, 2, 3, 4, 5, 10. 15, 20, 25 Hz
Load : 0.1P, 0.3P, 0.5P, 0.75P, 1.0P, 1.1P
where P denotes the rated load of snubber.

2.2 Test results

From the results, load-displacement plot known as Lissajous pattern were obtained. A typical plot is shown in Fig. 3.

The dynamic stiffness of the mechanical snubber was determined from the ratio of the displacement amplitude to the load amplitude. The dynamic stiffness of the mechanical snubber is shown in Fig. 4. As seen from Fig. 4, the mechanical snubber has two types of dynamic stiffness depending on the frequency. In the region of lower frequency than the snubber's natural frequency, the dynamic stiffness increases with the reaction force, which is derived primarily from the inertia of the rotating flywheel and the internal brake. At higher frequency region, the dynamic stiffness is almost constant and of the spring type with the reaction generated from the spring of the ball screw, while the flywheel does not rotate in this region. It is also seen that the dynamic stiffness tends to increase with the reaction force because the effect of gaps become relatively smaller as displacement increases.

The damping effect was evaluated in terms of the energy which was determined from the area enclosed by the Lissajous pattern. The dissipation energy per cycle is shown in Fig. 5. The damping effect of a mechanical snubber is assumed to occur due to the friction of the internal brake and due to the friction and impact of the ball screw, bearing and other rotating parts. The damping increase with the reaction force and decreases with the frequency.

On the basis of the data obtained in this test, it is possible to express the mechanical snubber's dissipation energy per cycle as a function of the reaciton force and the frequency by the regression analysis as shown in the following formula.

$$\log \Delta E = 1.33 \log R - 1.04 \log f + 0.31 (\log f)^2 - 0.28 \quad \text{..............(1)}$$

where, ΔE : dissipation energy (Kg.mm)

R : reaction force (Kg)

f : frequency (Hz)

As shown in Fig. 5, the damping effect of mechanical snubber was compared with that of oil snubber which was obtained in SDREP. (2) From the comparison, it is found that a mechanical snubber tends to have damping characteristics similar to those of an oil snubber and a damping effect of mechanical snubber is more reaction-dependent and, is larger than that of an oil snubber at high loading level. The evaluation formula is similar in form to that of oil snubber. The only difference is in the coefficient.

3. Piping model Test

3.1 Test contents

In order to verify the applicability of the formula (1), a piping model test was conducted. The model was a 8" dia. x 16 m length 3-dimensional piping system shown in Fig. 6. And piping model was supported by the mechanical snubber used in the component test.

This test consisted of the following two types of testing :

1) Sinusoidal Sweep Test

   The model was excited with a sinusoidal wave using a hydraulic excitor to find its natural frequency, vibration mode and damping ratio.

   The test was conducted under conditions of 1 to 25 Hz in range (up and down) 0.025 Hz/sec in rate, and 3 loading levels.

2) Snapback test

   snapback test was performed to obtain the free vibration curve and to get the natural frequency and the damping ratio. Initial load application points are shown in Fig. 6. Levels of initial load are 3 and the test was made three times at each level.

The test conditions are indicated in Table 2. Damping ratio was calculated by the half power method and the logarithmic decrement method for each mode.

3.2 Damping evaluation method for piping systems (2)

In SDREP, the evaluation method was develped to predict the damping ratio of a piping system. The damping ratio of a piping system with a mechanical snubber using the evaluation method is obtained as follows :

$$h_i = \frac{\Sigma \Delta E_{ij}}{4\pi E_i} \quad \text{..(2)}$$

where, h_i : damping ratio of piping system in the i-th mode

E_i : total strain energy of the piping system in the i-th mode

$E_i = 1/2.KX^2$

K : stiffness matrix of piping system

X : displacement vector of piping system

ΔE_{ij} : dissipation energy by mechanical snubber at point j in the i-th mode obtained from equation (1).

3.3 Test result

As results of piping model test, the measured damping ratio vs. displacement plots are shown in Fig. 7 and Fig. 8. The data were summarized with respect to the relation of damping ratio to response displacement, not to reaction force, since the snubber reaction is proportional to the response displacement of the piping model.

piping systems supported with restraints which have practically small damping effect were found to have damping ratio of 0.2 to 0.3%.

As seen from Fig. 8, the damping ratio was about 5% at 2.5 mm displacement in the mode which the mechanical snubber works effectively. Some damping effect was seen in the mode in which the mechanical snubber does not work effectively as shown in Fig. 7. It may be brought about by impact and friction in joints of the mechanical snubber.

Figure 8 shows the camparison between the damping ratio obtained from model test and that calculated by the damping evaluation method described 3.2 The test results were found to agree well with those calculated by the damping evaluation method described in 3.2. It was also found that the damping ratio reduced with increasing displacement amplitude presumably because of the following reason : The dissipation energy in a snubber increases in proportion to displacement shown in the damping evaluation formula (1), while the strain energy in the piping system is proportional to the second power of displacement described in 3.2. Hence, the damping ratio of piping system supported by a mechanical snubber descreases with the response displacement. Piping systems with oil snubbers showed the same tendency.

4. Conclusion

This study clarified the damping characteristics and the dynamic stiffness of mechanial snubber as follows :

1) In the component test, two types of mechanical snubbers were tested to investigate their damping effects and dynamic stiffnesses. It was found that dynamic stiffness change with loading level even at the same frequency.

2) From the component test the following formula was obtained as an experimental formula for the dissipation energy of mechanical snubber.

   $\log \Delta E = 1.33 \log R - 1.04 \log f + 0.31 (\log f)^2 - 0.28$

   where, ΔE : dissipation energy (Kg.mm)

   R : reaction force (Kg)

   f : frequency (Hz)

   This formula indicates that the damping effect of mechanical snubber increases with reaction force and decreases with frequency.

3) The damping effects of mechanical snubber are almost the same as and, at high reaction level, even larger than those of oil snubber.

4) The comparison between the results of the piping model tests and those calculated by the evaluation formula of mechanical snubber is made. The calculation value are in good agreement with the test results. From these comparison, one can conclud that the proposed prediction formula for the damping effect of the mechanical snubber is

applicable to the damping evaluation method developed in SDREP.

Acknowledgment

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Reference

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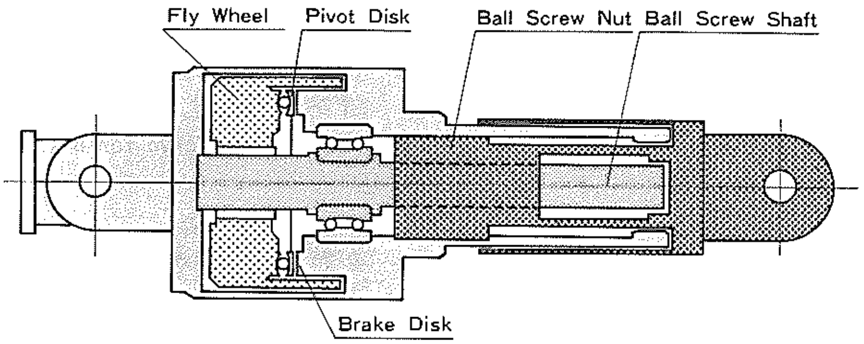
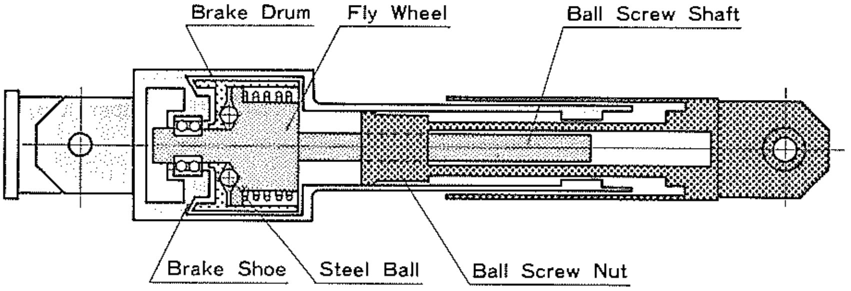
(3) Shibata, H., et al., "Test and Evaluation about Damping Characteristics of Hanger Supports for Nuclear Power Plant Piping Systems", 6th SMiRT, Paper K 6/4, Aug. 1981.

(4) Shibata, H., et al., "An Experimental Study of Damping Characteristics with Emphasis on Insulation for Nuclear Power Plant Piping Systems", 6th SMiRT, Paper K 6/5, Aug. 1981.



a Type



b Type

Fig. 1 Section of Mechanical Snubber

Table 1 Specification of Mechanical Snubber

Rated Load (Ton)	Stroke (mm)	No. of Mechanical Snubber	
		A Type	B Type
0.6	125	2	2
1.0	125	2	2
3.0	125	2	—

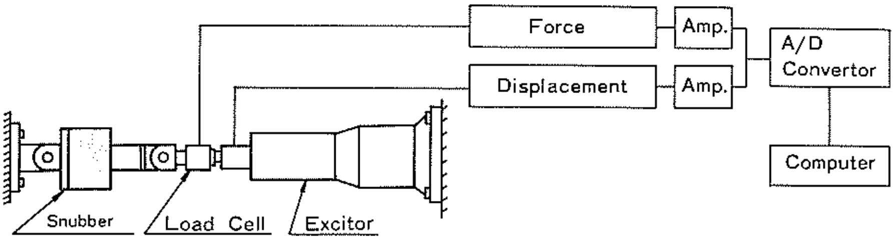
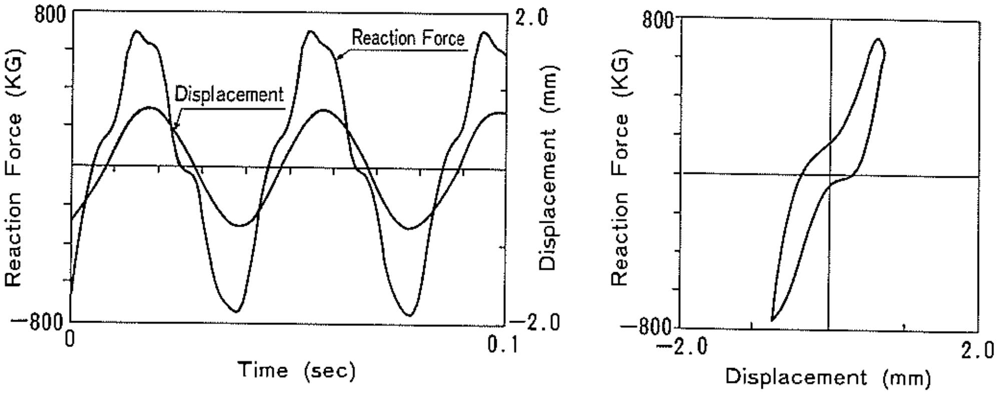


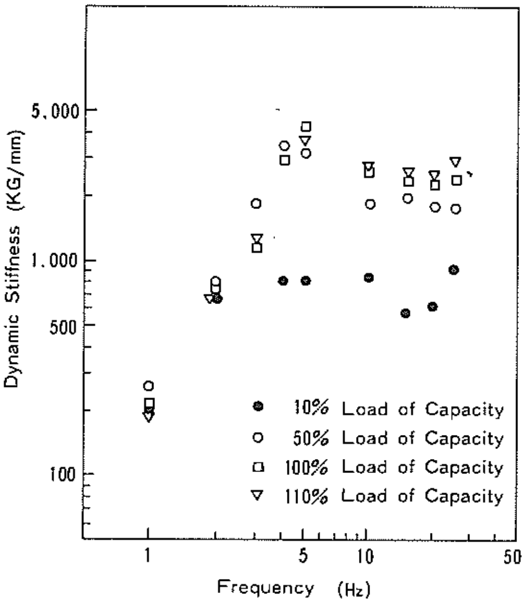
Fig. 2 Schematic Sketch of Component Test



(a) Time History

(b) Lissajous Pattern

Fig. 3 Typical Result of Component Test



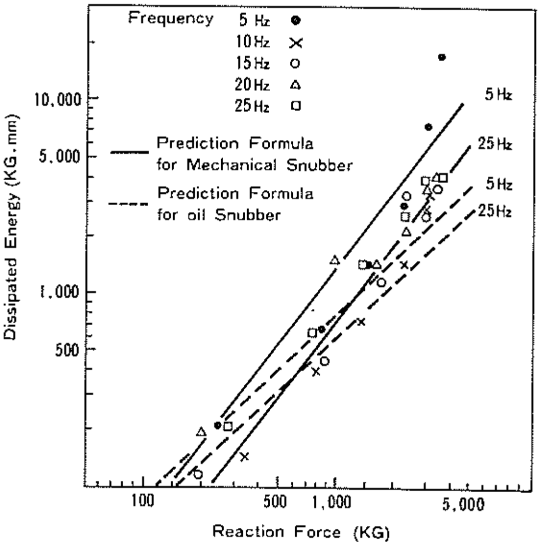


Fig. 4 Dynamic Stiffness
(3 Ton Mechanical Snubber)

Fig. 5 Energy Dissipation Per Cycle
(3 Ton Mechanical Snubber)

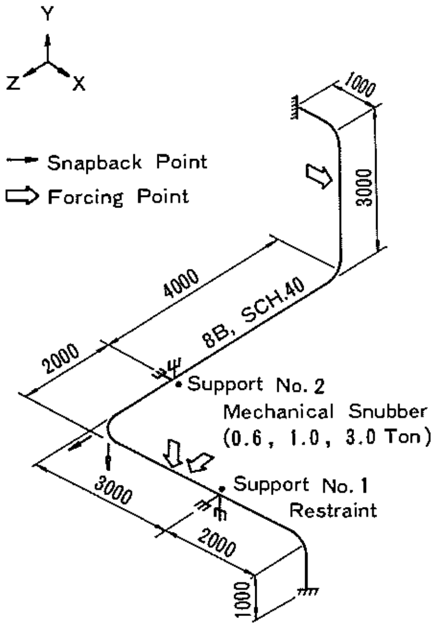


Fig. 6 Piping Model

Table 2 Test Condition of Pipe Model Test

Test Case	Support Condition	
	Support No. 1	Support No. 2
1	Frame Type Restraint *	Frame Type Restraint *
2	Frame Type Restraint *	0.6 Ton Mecha. Snubber
3	Frame Type Restraint *	1.0 Ton Mecha. Snubber
4	Frame Type Restraint *	3.0 Ton Mecha. Snubber

* Damping Effect is negligible small

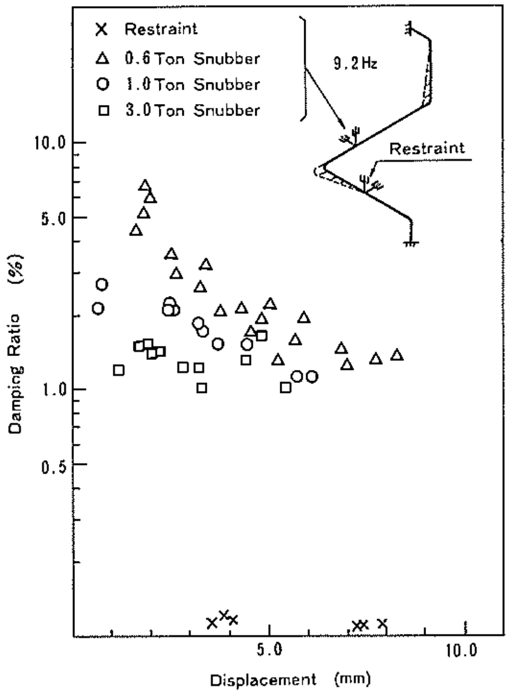


Fig. 7 Damping Effect of Mechanical Snubber (1st Mode)

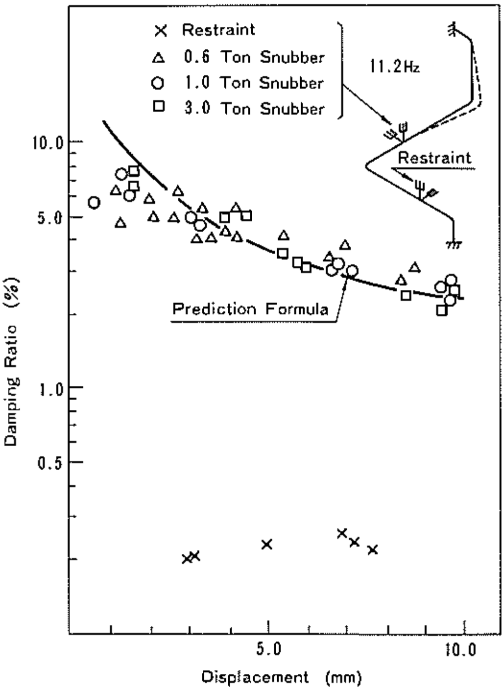


Fig. 8 Damping Effect of Mechanical Snubber (2nd Mode)