Transactions of the 15th International Conference on
Structural Mechanics in Reactor Technology (SMiRT-15)
Seoul, Korea, August 15-20, 1999

Current Research and Development of Damping and Seismic Isolation Technology in Japan

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ABSTRACT: This paper summarizes recent research and development of damping and vibration control technology in Japan. As a chairman of the JSME Research Subcommittee of Damping which was founded in 1992, the author introduces current activities in the area of passive vibration control techniques, new damping materials, damping devices and the practical application to seismic design enforcement.
Seismic isolation systems and devices achieved significant anti-earthquake performances to various structures during the Southern Hyogo Prefectural Earthquake (Kobe Earthquake) on January, 1995. Thus, specific interests of this paper are also focused on the technical scope of the seismic isolation problems.

1 INTRODUCTION

The research and development related to the damping materials, damping devices and passive vibration control technologies in Japan have been significantly advanced in the past decade. As a typical example, the application of damping materials such as laminated damping steel sheet (LDSS) to the motor vehicle body and electrical home appliance have been highly progressed in Japanese industries. Also, in the field of earthquake engineering, various types of passive dampers having the capacity of high seismic energy absorption have been proposed for utility.

In 1989, the author and his colleagues from different universities and industries formed a Sub-committee of Damping Technologies in the Dynamics, Control and Measurement Division of JSME (Suzuki;1993). The particular attention of this committee is focused on the following topics.

(1) Damping characteristics of metal and nonmetal materials such as viscoelastic material (VEM), super plastic alloy (SPA), shape memory alloy (SMA) and laminated damping steel sheet (LDSS).

(2) Study and development on the applicability of newly proposed passive dampers and energy absorbers to the seismic and nonseismic structural design procedure.

(3) Vibration test and measurement methodology by which design-based damping value can be identified and evaluated.

Due to the stringent regulations by the Japanese Government to reduce environment pollution such as noise of motor vehicles, the research and development on damping materials have been rapidly spread among various Japanese vehicle industries. This trend has been further enhanced by the industries' understanding of the noise and vibration reduction in products can enhance the value in the market. With regard to the research and development of the damping technology, activities have been carried out among the committees. For example, Society of Damping Technology (SDT) was established to develop damping materials and demonstrate their application to the industrial sectors for the purpose of vibration and noise reduction

In the Damping '91 Conference at San Diego, the activities of SDT with current trend of the damping materials related technology in Japan were reported (Tokita et al.;1991). The report introduced some typical trends around damping materials technology. According to the report, appropriate damping effects were achieved either by addition of the damping materials such as free-layer bonding or by replacement such as LDSS. Figure 1 shows pie chart showing percentage use of yearly produced LDSS for various industrial products in Japan. Major users are the motor vehicle and electric appliance industries. Recently, the application to building structures and general machineries is also being increased.

In 1997, JSME held a symposium "New Damping Technology towards 21st Century" as one of the events for celebrating the centennial anniversary of the foundation. About 100 topics were presented from the academic sectors as well as from the industries.

This paper overviews the above mentioned current activities on this area by demonstrating several typical examples to nuclear technology as well as non-nuclear one.

2 DAMPING MATERIALS

Damping materials can be generally classified into following 4 categories.

(1) Viscoelastic materials such as rubbers, polymer compounds, silicone gels and many polymeric and glassy materials.

(2) High damping alloys which are developed for getting high damping capacity to practical construction purposes.

(3) Composite materials which are manufactured as a combination of two or more materials. Examples of such systems include metal matrix composites, nonmetal matrix composites and sandwiched or surface-treated materials such as LDSS.

(4) Damping functional materials. Characteristics of these material can be functionally controlled depending on temperature and excited frequency.

Many research and development works regarding these materials have been carried out and presented during past years. Here, study on characterization of viscoelastic materials and application of LDSS are overviewed.

2.1 Characterization of viscoelastic materials' behavior

Characteristics of viscoelastic materials is strongly influenced by temperature and frequency change. Viscosity of the materials decreases with increasing temperature, while it increases with rising frequency of excitation. Therefore, these polymeric materials are expected to possess a wide variety of high damping, thermal stability and strength. Figure 2 illustrates typical damping and strength behavior in accordance with temperature. Feasible damping effect can be achieved at certain "transition " temperature region between glassy and rubber states.

In order to characterize the damping behavior of these materials, mathematical modeling of the state equation is particularly important. Standard models of the equation hitherto utilized are generalized Maxwell model and Voigt model which are represented by eqs.(1) and (2), respectively.

$$\sigma = E\varepsilon + \mu \frac{d\sigma}{dt} \tag{1}$$

$$\frac{d\varepsilon}{dt} = \frac{1}{E}\frac{d\sigma}{dt} + \frac{\sigma}{\mu} \tag{2}$$

where σ, ε, E and μ mean stress, strain, modulus of elasticity and coefficient of viscosity. However, these modelings have the limitation for practical use since the variation of E and μ with frequency is much more rapid than is usually observed in real materials.

Recently, new model was proposed to represent viscoelastic behavior (Bagley, R.L. et al.1983). By applying this model, the state equation of stress-strain relation can be expressed by

$$\sigma(t)=E_0\,\varepsilon(t)+\mu D^q[\varepsilon(t)] \tag{3}$$

In this equation, $D^q[\varepsilon(t)]$ means "fractional integral" which is determined by

$$D^q[\varepsilon(t)]= \frac{1}{\Gamma(1-q)} D\left[\int_0^t \frac{\varepsilon(\xi)}{(t-\xi)^q} d\xi\right] \tag{4}$$

where $\Gamma(\cdot)$ is Gamma function and q is fraction such as 1/2, 2/3, 2/5 etc. and D means operator of differentiation. Shimizu applied this model to silicone gel materials (Shimizu, N., 1997) and Sunakoda utilized it to characterize viscoelastic damper for the plant structures.

2.2 Application of LDSS

Generally, LDSS can be divided into two types; (1) constrained layer type and (2) unconstrained layer type. In the former type, resin layer having high viscous damping is sandwiched between two steel sheets and in the later type resin layer is bonded on single sheet as shown in Fig. 3. Although both of two types can provide high damping ability to the panel-like structures by utilizing viscosity of resin materials, their damping mechanism is completely different. In the constrained type, high damping can be achieved by shear deformation of the resin layer, while in the unconstrained type, vibration energy can be absorbed by expansion and contraction of the resin layer.

Nippon Steel Corporation experimentally investigated and clarified the characteristics of LDSS as follows (Kadowaki;1996).

(1)Three layered constrained LDSS has higher damping capacity than the unconstrained type, but the weight is about half of unconstrained type.

(2)Vibration response level of LDSS panel is remarkably suppressed at higher frequency range and no appreciable reduction at low frequency range.

(3)Spotwelding given to the nodal of LDSS panel affects the damping.

In view of the practical application, a vibration test was conducted on vehicle oilsump using LDSS. From the results, a remarkable damping effect was observed when comparing to the conventional steel oilsump. Figure 4 shows a bar chart which compares the response of oilsump with or without LDSS.

3 SEISMIC ISOLATORS AND DAMPERS

3.1 Seismic isolator

On January 17, 1995, the huge Southern Hyogo Prefectural Earthquake (Kobe Earthquake) occurred at Hyogo Prefecture, Awaji island and Osaka Prefecture. The total number of damaged houses and buildings were about 400,000 including about 100,000 completely collapsed buildings. The most severe damages were observed on large number of buildings along the seismicity Ⅶ (by Japanese Meteorological scale) zone in Kobe City. However, two big buildings constructed on the seismic base isolators near the region were not damaged. On the contrary, the maximum response was reduced to less than 30% by the way of seismic isolator systems.Figure 5 demonstrates the configurations of "high damped laminated rubber"(HDLR) and "laminated rubber with lead plug"(LRLP). According to the recent technical information through the Building Center of Japan (BCJ), the number of proposals for obtaining the authorization to construct isolated buildings have remarkably increased after the Kobe Earthquake. During the fiscal year 1995, more than 80 isolated buildings were approved by the BCJ for construction on base isolators.

The base isolator systems to the building floor on which important or expensive structures and equipments such as central work stations to be installed have also been developed in Japan. Figure 6 shows an example of the base isolator proposed by Kajima Corporation (Harada et al.;1989). This ball bearing base isolator (BBBI) consists of a large main ball bearing, several small sub-ball bearings and a bowl-shaped base. At the time of the Kobe Earthquake, this base isolator system has worked quite effectively in the computer room of the existing bank building in Osaka City.

Many types of floor isolators have been developed by the industries and construction companies.

3.2 New types of dampers and absorbers

In order to maintain high performance of structures, machineries, equipments and piping systems, many types of damping devices such as elasto-plastic damper, adaptive damper, electro-rheological damper, viscoelastic damper, granular damper have been proposed. Some of them were developed by the Japanese industries such as Hitachi, IHI, Mitsubishi and others and several dampers were developed by the joint projects among the governmental, the academic and the industrial sectors.

A typical example of the corporative works for developing damping devices is a national project monitored by NUPEC (Nuclear Power-plant Engineering Commission) under the sponsorship of MITI. In this project, two stages of seismic proving tests were carried out for the nuclear piping with damper systems by using two-dimensional large size shaking table at Tadotsu, Kagawa Prefecture. In the first stage, test was carried out on the piping system having conventional supports; hydraulic dampers and mechanical snubbers. While in the second stage, testing was made on the piping systems with supports which were developed by the industries as seismic energy absorbers. The energy absorbers such as elasto-plastic absorber (EAB) developed by Hitachi and lead excursion damper (LED) developed by Mitsubishi were used. Figure 7 shows the configurations of the EAB (Namita;1995).

Through this project, it was confirmed that nuclear pipings having conventional supports could maintain enough strength against the most severe design seismic excitations. It was also recognized that newly developed energy absorbers such as EAB and LED could be introduced in place of conventional supports for plants in the near future. The number of the conventional snubbers can be tremendously reduced since individual EAB or LED can absorb much more seismic energy.

Magnetic dampers can be recognized having many advantages such as good linearity, thermal stability and good reliability over conventional mechanical dampers. Toshiba's group recently proposed a new type of vibration absorber based on a magnetic spring and damper system (Aida et al.;1995). In this damper, a pair of double cylindrical magnets face with each other across a certain gap. One magnet fixed to the target structure and another to the moving mass of the dynamic absorber. Figure 8 describes an outline of this damper, and Fig. 9 shows an example of application of the magnetic damper to rotation machineries.

Electro-rheological fluid (ER fluid) is known as a class of highly functional fluid whose apparent viscosity can be varied in response to the applied electric field. ER fluid has attractive characteristics since the viscosity can vary over a wide range and its response is as rapid as in several milliseconds. It is known that the ER fluid is utilized in mechanical damping components such as a shock absorber system, a squeeze film damper bearing, a dynamic damper and an engine mount (Morishita et al.;1995). Figure 10 shows an example of the ER damper.

4 FUTURE SCOPE OF DAMPING TECHNOLOGY

Future scope of damping technology in Japan will be to develop higher capacity damping materials and devices which can be applied to the structures and mechanical systems. New materials which will be hopefully applied as damping materials could be invented by both of academic and industrial sectors based on the eager desire in the area of the 21st century's technologies such as space engineering and bio-technology.

4.1 Adaptive damping materials

Any vibration damped material which could be effective over a wide frequency range will be one of the hopeful materials. If the damping characteristics of the specific material can be controlled depending on the excitation level, the material can be applied for the anti-vibro structure design.

From this viewpoint, thixotropic materials are note worthy substances because they can liquefy when they are stirred or shaken and can return to original state after being left it free. By utilizing this specific characteristics, it is possible to make the damping device whose capacity can be controlled with respect to the vibration intensity. A passive adaptive damping device using the thixotropic material was designed by the scientists of Hitachi Co.Ltd. (Matsuda et al.;1995). The configuration of the damper is illustrated in Fig. 11. Figure 12 shows an example of the test results of this damper. In this figure, change of dynamic characteristics of the damper such as natural frequency and damping ratio to the base excitation is presented.

4.2 Multi-functional adaptive damper

Towards the 21st century's, multi-functional adaptive technologies are expected to be required in various engineering fields. The "multi-functional damper" can adaptively select active, passive or hybrid operation control mode according to the specific demand.

The author and his colleagues proposed a kind of this adaptive damper, i.e.,the "mechatro damper" shown in Fig. 13 (Sunakoda et al.;1995). It consists of a "mechanical" ball screw and nut element and an "electrical" D.C. servo motor with a gear amplifier. This damper can control damping forces by applying SMC (slide mode control) algorithm for the use of VSS (variable structure system). Figure 14 shows the frequency response characteristics for the hybrid mode system in which apparent advantage compared to the conventional passive systems can be recognized.

5 CONCLUSION

A brief survey and overview to the progress of damping researches and technologies in Japan was presented, particularly, focused on seismic and nuclear structure engineering. It should be carefully noticed that similar works and more developed investigations are carried out in overseas such as United States and European countries. Mutual exchange of the informations related to the damping technology still has to be put forward and cooperative works including international conference on the damping problems should be promoted.

Reference

1. Suzuki, K., "A brief survey of research works about vibration damping", *Trans. JSME, Ser.C,* 59-566, 1993, pp. 2908-2914.
2. Tokita, Y. & H. Okamura, "The society of damping technology in Japan and its activities", *Proceed. of Damping '91 Conf.,* 1, 1991, pp.1-16.
3. Bagley, R.L., "On the fractional calculus model of viscoelastic behavior", *J. Rheology*, 30-1, 1986, pp.133-155.
4. Shimizu, N., "Dynamic characteristics of viscoelastic vibration system", *Trans. JSME, Ser.C,* 61-583, 1995, pp.166-170.
5. Kadowaki, N., "The recent study on properties of vibration damping steel sheets and its applications", *Trans. of Annual Conf. on Vehicle Dynamics, JSME,* 1996, pp.76-81.
6. Harada, M. et al., "Base isolation system for earthquake protection of precision machinery system", *PVP-Vol. 182, ASME 1989,* 1989, pp.142-155.
7. Namita, Y. et al., "Development of seismic design method for piping system supported by elasto-plastic damper", *Trans. JSME, Ser.C*, 60-590, 1995, pp.3874-3880.
8. Aida, Y. et al., "Dynamic vibration absorber using magnetic spring and damper", *PVP-Vol.312, ASME 1995*, 1995, pp.439-445.
9. Morishita, S. & Y.K. An, "On dynamic characteristics of ER fluid squeeze film damper", *Trans. JSME, Ser.C,* 61-591, 1995, pp.4245-4250.
10. Matsuda, H. et al., "A study on passive adaptive vibration control elements by using thixotropic materials", *Trans. JSME, Ser.C*, 61-588, 1995, pp.3217-3221.
11. Sunakoda, et al., "Semiactive seismic isolation system by using mechatro damper", *Proceed. of 2nd Inter. Conf. on MOVIC*, pp.41-46, July 1994.

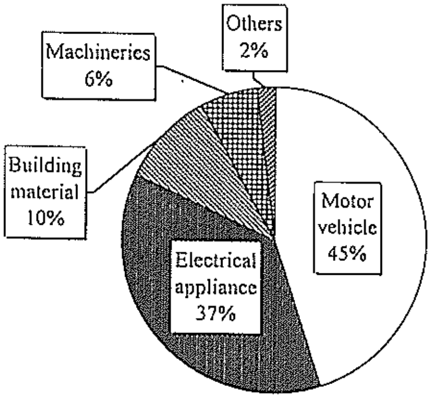

Figure 1 Percentage of produced LDSS application

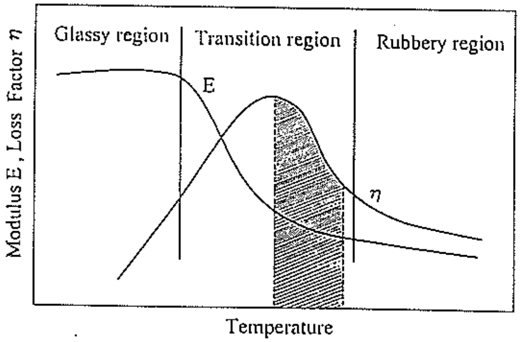

Figure 2 Damping and strength behavior of viscoelastic material

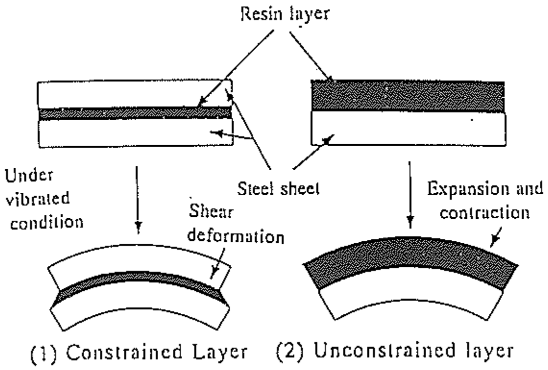

Figure 3 Schematic configurations of LDSS

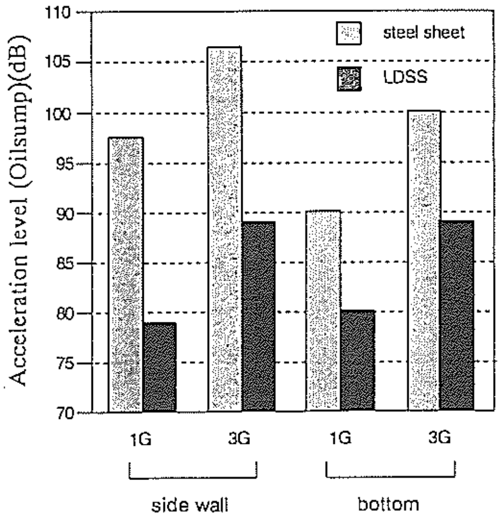

Figure 4 Response of vehicle oilsump with / without LDSS

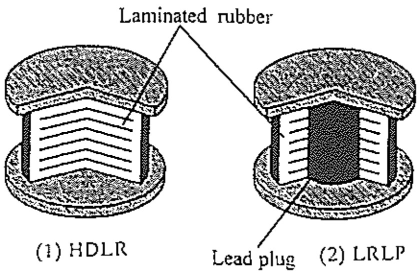

Figure 5 Schematic views of HDLR and LRLP isolators

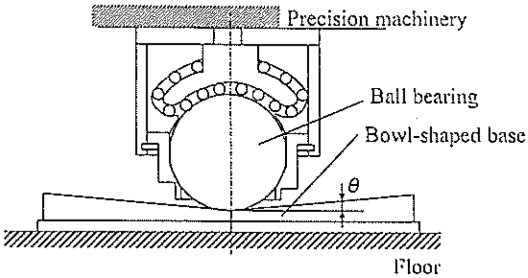

Figure 6 Ball bearing base isolator (BBBI)

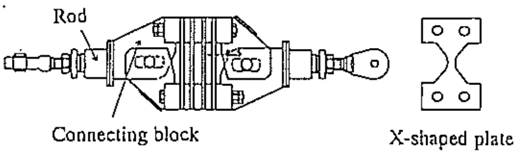

Figure 7 Configuration of EAB

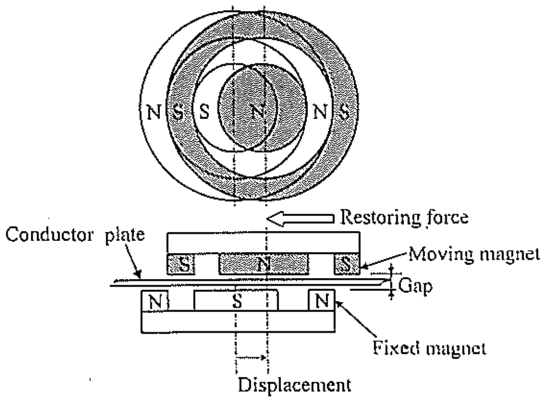

Figure 8 Magnetic damper system

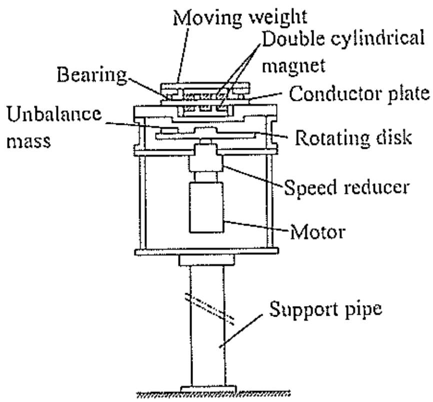

Figure 9 Magnetic damper mounted on rotating machinery

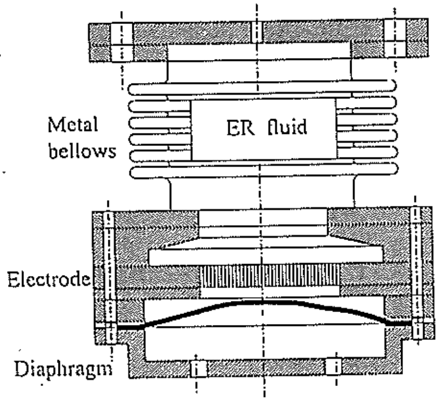

Figure 10 Electro rheological fluid damper
("ER damper")

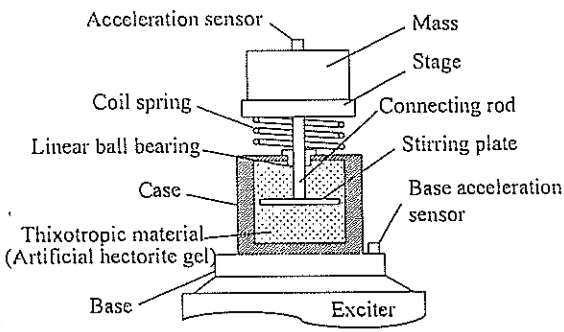

Figure 11 Passive adaptive damper
("thixotropic damper")

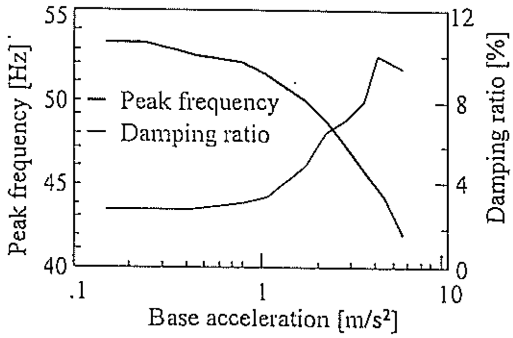

Figure 12 Vibration characteristics of "thixotropic damper"

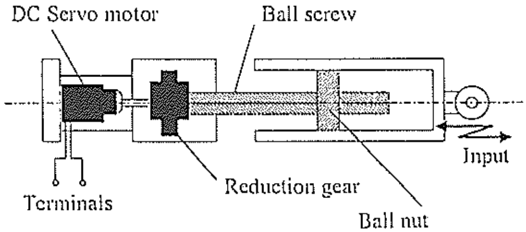

Figure 13 Multi-functional adaptive damper ("mechatro damper")

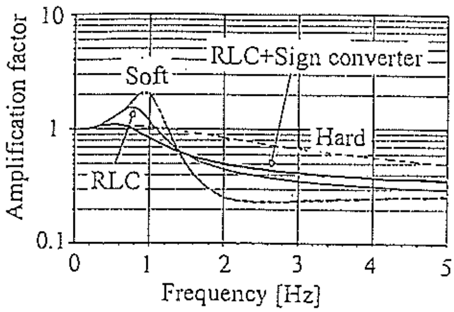

Figure 14 Frequency response characteristics of the "mechatro damper"