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DEVELOPMENT AND APPLICATION OF HIGH DAMPING ALLOYS FOR NOISE AND VIBRATION CONTROL

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Abstract

High damping alloys are finding more and more applications in several industrial fields as a passive technique in vibration and acoustic attenuation. Manganese-copper based alloys are the most potential high damping alloys. In order to improve the damping stability and workability of the traditional Manganese-copper based alloys, M2052 high damping alloy has been developed, which shows the superior damping behavior and the high mechanical properties. In the present work, the properties and the application trials of the alloy are introduced.

1. INTRODUCTION

Vibration damping is usually considered in the design stage of structures through increasing the structure mass, preventing occurrence of resonance, and supplementing damping devices. However, those damping measures seem to be incompatible to the overwhelming development of much compacter and more efficient instruments and vehicles. Damping materials, which themselves have the capacity of damping vibrations, are called the most effective way to damping out vibration in structures. Viscoelastic damping materials, such as rubber, plastics and polymers, have been developed that show the high damping capacity. However the low rigidness and limited durability have impeded the wide-field application of such damping materials. On the other hand, high damping alloys, which show the mechanical properties of alloys but a damping capacity much higher than the normal metallic materials, have been studied through extending the internal friction mechanism of metals or alloys [1].

Fig.1 compares the tensile strength and damping capacity for the usual engineering alloys and some of the HIDAMETS, which have a damping capacity larger than 10% [2]. According to the dominant damping mechanisms, high damping alloys can be classified into composite type (gray cast iron and Zn-Al alloy), magnetostrictive type (Fe-Cr, Fe-Al alloys), dislocation type (Mg alloys) and interfaces type (Mn-Cu alloys) [3]. Among those damping alloys the higher damping capacities of Mn-Cu alloys are accompanied with the superior mechanical properties, and some alloys (SONOSTON, INCRAMUTE alloy) have been developed for practical usages [4]. Recently, M2052 damping alloy (nominally Mn-20Cu-5Ni-2Fe at. %) has been developed for a good balance between the damping capacity and strength and workability [2]. Fig. 2 shows the photos of some mechanical parts and the thin sheet, as well as wire. In contrast to some other high damping alloys, M2052 alloy has a superior workability, adequate for applications in vehicles, precision instruments and many mechanical structures. In the present paper, the mechanical properties and damping behavior of the alloy are introduced. Besides, FEM and experimental vibration analysis results of a M2052/steel composite plate model are shown in order to characterize the damping capacity of the elementary damping alloy parts to the base structure. Furthermore, some application examples of M2052 alloy reported recently in Japan are listed.

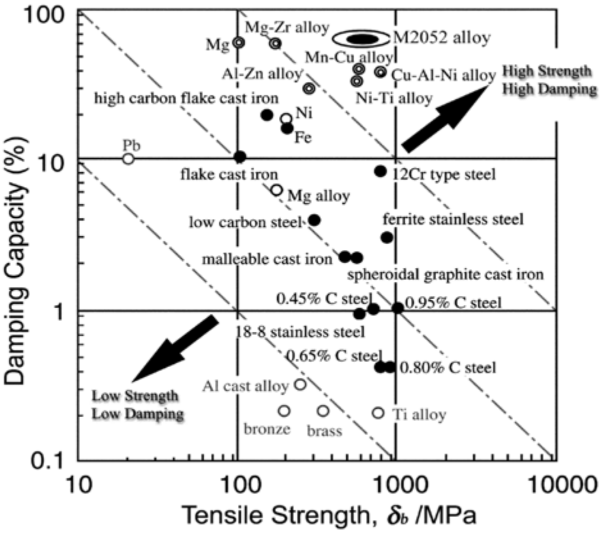

Fig. 1. Strength and damping capacity of some normal alloys and damping alloys.

Fig. 2. Photos of the mechanical parts, thin sheet and wires made from M2052 damping alloy.

2. PROPERTIES OF M2052 HIGH DAMPING ALLOY

Table 1 shows the mechanical properties of M2052 damping alloy. The Young's modulus and Poisson's ratio are obtained in compression test of cylinder samples of 8mm in diameter. Yield and tensile strengths of the alloy have verified the adaptability to serve as the ordinary structural parts. The balance between the mechanical properties and damping capacity of M2052 alloy can be adjusted through adequate heat treatments for specific applications.

Table 1 The mechanical properties of the M2052 damping alloy

Young's Modulus E /GPa	Poisson's Ratio ν	Yield Strength σ_s /MPa	Tensile Strength σ_b /MPa	Elongation ψ /%	Reduction of Area ϕ /%	Impact Energy IE /J
66.97	0.301	300	540	32	62	105

A dynamical mechanical analyzer (DMA) was used to ascertain the temperature dependent damping behavior in the 3-point bending deformation mode. Sheet samples in the dimension of 1×10×60mm were heated from 173K to 473K at a heating rate of 3K/min. Fig. 3 shows the changes of Young's modulus E and $tan\phi$ of M2052 alloy with temperature, in 0.1, 1 and 10Hz and at the strain amplitude of 1.8×10^{-5}. The minimum Young's modulus appears at 346K, which corresponds to the phase transformation temperature T_t of γ_{Mn} phase [5]. Below this critical temperature, the damping capacity increases obviously with the lowing of temperature and presents two damping peaks, indicated as DP_t and DP_m respectively. The main damping peak (DP_m) shows strong frequency dependence, shifting to higher temperatures with the increased frequency. Dynamic hysteresis model can be used to describe this behavior, and the stress-aided movement of interfaces in the alloy is accompanied with the overcoming of local barriers by thermal activation. The activation energy for the interfaces responsible for the main damping peak in the M2052 alloy is calculated by the peak shifts to be 4.88×10^{4}J/mol. No temperature shift has been observed in damping peak (DP_t) with the changes of frequency, but the damping capacity shows a slight decrease with increased frequency. The damping behavior accompanying the transformation is usually attributed to the stress-induced amount of low-temperature phase, and the damping capacity is proportional to heating rate and reversibly to the vibration frequency [3].

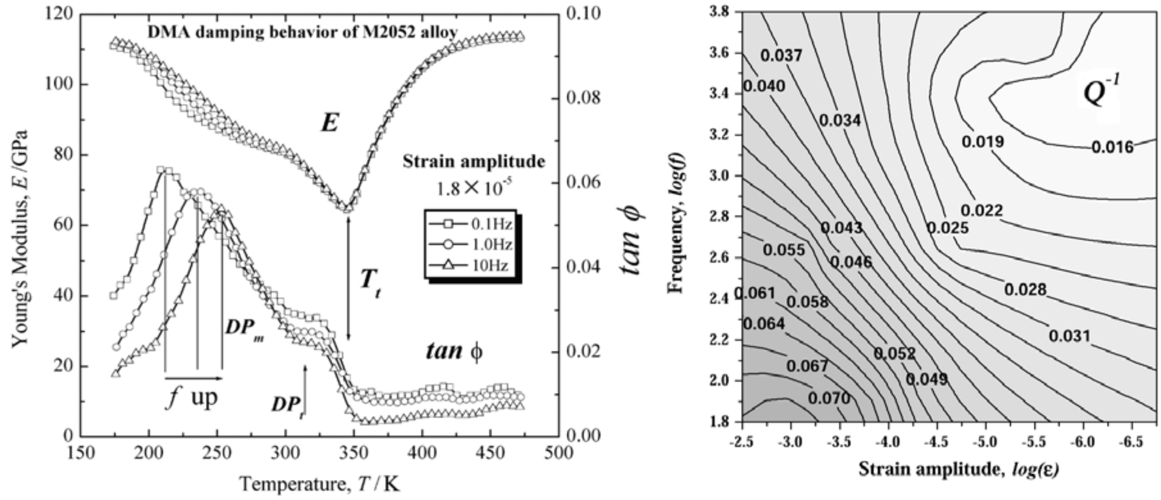

Fig. 3. Temperature dependent changes of *E* and *tanφ* of M2052 alloy, measured at a strain amplitude of 1.8×10^{-5} with DMA method (left). And the contour map format showing of influence of both strain-amplitude and frequency, measured on the resonant frequencies for a vibration beam sample excited at centre position (right).

In order to verify the damping capacity of high damping alloy used in a structure, the cantilever vibration of the SUS 304 steel sheet in the dimension of 2x35x400mm was simulated with FEM method. The resonant frequency is about 5Hz and the maximum displacement of the sheet is calculated. Figure 4 show the vibration sheets partially substituted by M2052 damping alloy sheet. The length of the damping alloy sheet is 1/3 of the whole length of the steel sheet, the position of the damping alloy sheet and the width of that are changed in different levels. As shown in Figure 5, when the position of the damping alloy sheet is shifted apart from the fixing side of the cantilever vibration sheet, the damping effect of the inserted damping alloy sheet is decreased obviously, and the largest decrease is found in the position changes from 1/3 to 1/2 or from 1/2 to 2/3. On the other hand, when the width of damping alloys sheet that is at the fix side of the steel sheet is increased step by step, the damping effect of the alloy sheet is found to become larger. The damping effect is nearly proportional to the width of the damping alloy sheet, and this phenomenon is different to that occurred in the case of position change. Those results indicate that usage of damping alloys in a structure is rather important in order to make full use of the damping capacity of the damping alloys.

There are a lot of resonant vibration modes in a structure or a solid material. Depending on the position and dimension of the applied damping alloy, the vibration amplitude of the structure varies extensively. Fig. 6 shows a steel plate model which is revealed to have 6 bending vibration modes by FEM simulation. When the centre of the steel plate is inserted with M2052 damping alloy disc the vibration amplitude of the plate is found to decrease to different degrees upon each vibration mode. The dimension of the steel plate is $150\text{x}100\text{x}10^{t}$mm, and that of the damping alloy disc is $\phi50\text{-}\phi15\text{x}10^{t}$mm. The Young's modulus of the steel plate and damping alloy disc is adopted as 210GPa and 70 GPa, respectively. The damping ratio of 0.002

and 0.1 is applied respectively. Fig. 7 shows the strain amplitude decrease at mode 2 (~2500Hz) and mode 3 (~3800Hz) when the dimension of damping alloy disc is changed. It is observed that the increased damping alloy disc volume could certainly make a larger decrease in strain amplitude, and a larger disc area seems much more effective than the disc thickness. By comparing mode 2 with mode 3, it is obvious that mode 2 shows the larger damping effect for the steel plate with the insertion of damping alloy disc than mode 3.

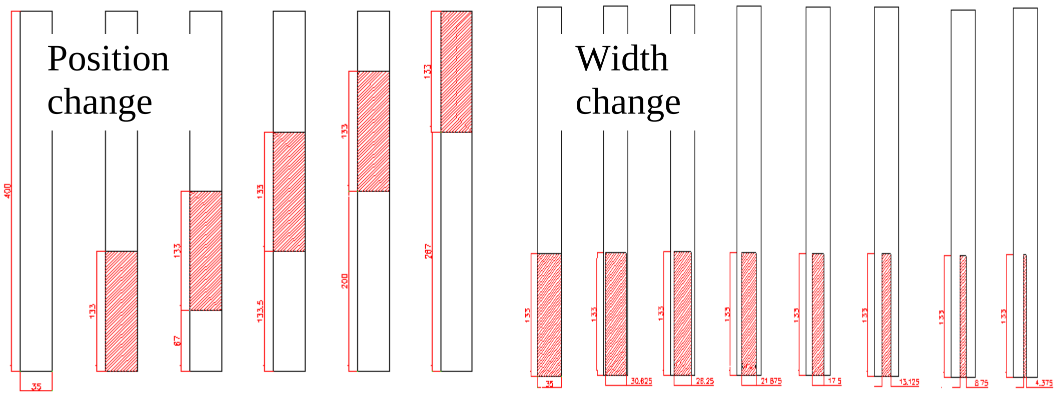

Fig.4. Cantilever vibration models of a stainless steel sheet substituted by M2052 damping alloys sheet in different positions and widths.

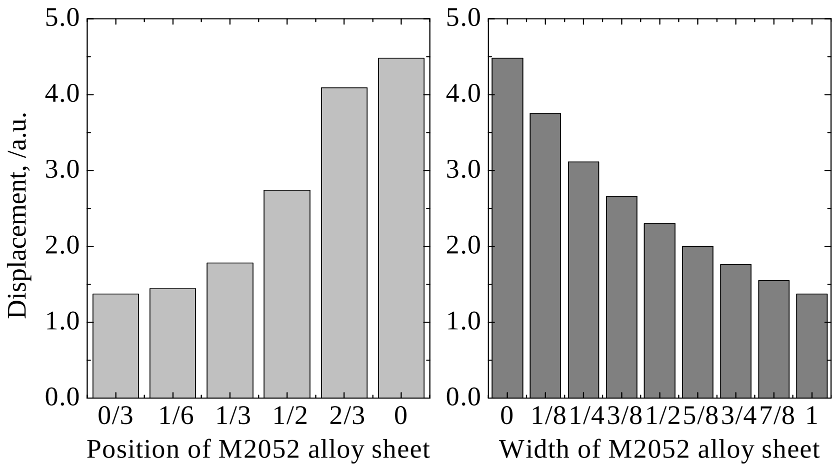

Fig. 5. The calculated displacement of the cantilever steel sheet, changed with the partial application of M2052 damping alloy sheet.

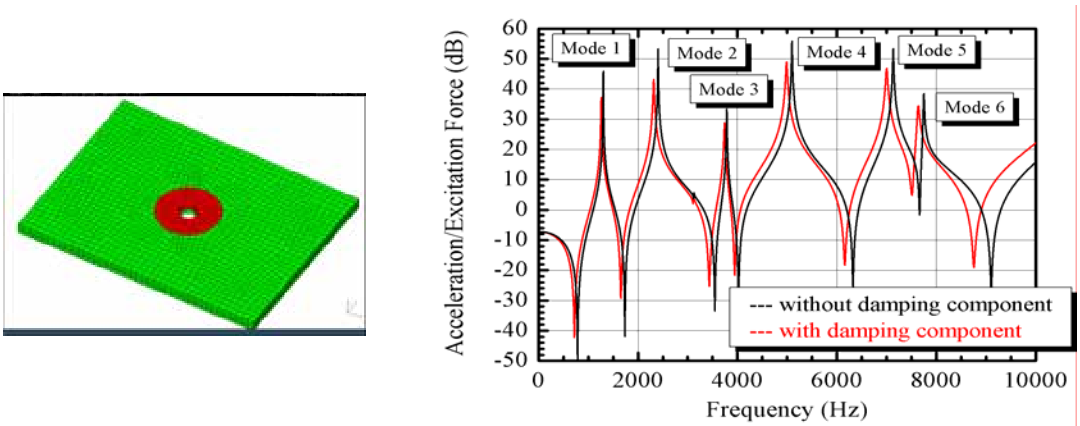

Fig. 6. FEM simulation model of a steel plate with an inserted M2052 damping alloy disc and the strain amplitude decrease at each vibration mode caused by the insertion of damping alloy.

On the other hand, at a certain dimension (ϕ50-ϕ15x10^{t}mm) of the damping alloy disc the material properties of the damping alloy are found to influence the strain amplitude of the plate extensively. Fig. 8 shows the contour map of strain amplitude (dB) at each vibration mode when Young's modulus and loss factor of the damping alloy is changed. The increased Young's modulus and loss factor definitely decrease the vibration response even the decrease magnitude is different for each vibration mode. Mode 4 and 5 show the most sensitive decrease and Mode 3 and 6 show nearly no decrease in vibration response. Moreover, when the material has a large damping capacity (η=0.1) the increase of Young's modulus in the region of <100GPa causes an obvious damping effect in the steel plate. In contrast when the Young's modulus is 70GPa the increase of loss factor of damping alloy in the region of >0.01 shows the larger damping effect.

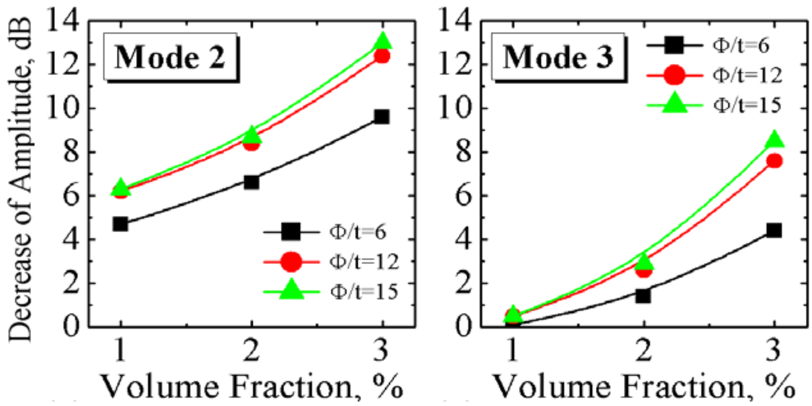

Fig. 7. The calculated decrease of strain amplitude in dB of the steel plate with insertion of damping alloy disc in varied dimensions.

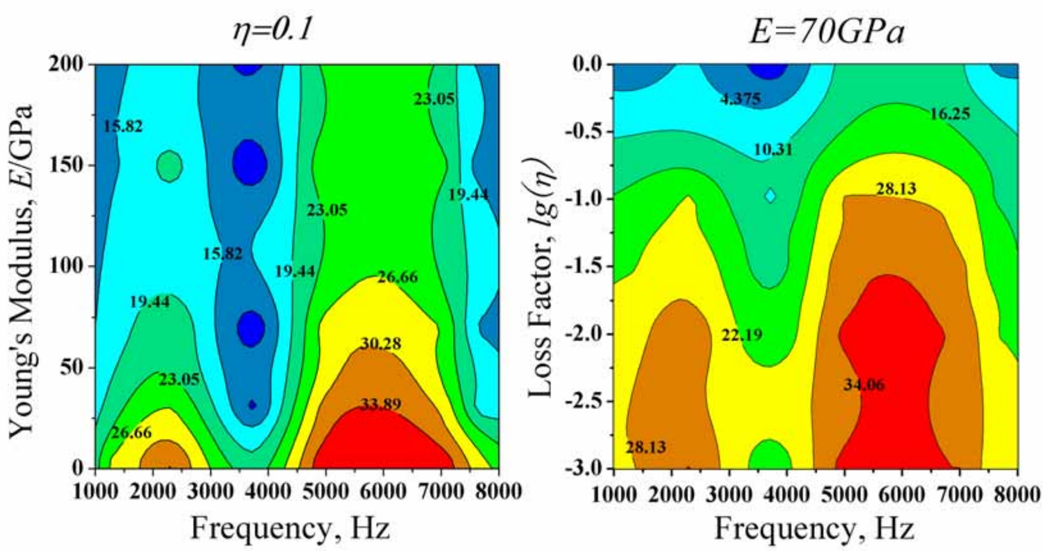

Fig. 8. FEM calculted strain amplitude of the steel plate at different vibration modes. The changes of strain amplitude is shown with the variaion of Young's modulus and loss factor of the damping alloy disc.

3. APPLICATION EXAMPLES OF M2052 HIGH DAMPING ALLOY

3.1 Mounting parts for working machinery

Cast iron or steel mounts and bolts are used for fixing working machinery to the ground. In order to avoid the vibration interruption to the working accuracy, rubbers or polymer sheets are usually applied as a combination with the mounting parts. However, those sheets only works to level the machinery and have scarce effect in vibration damping since the sheets are highly pressed by the machine weight. Yoshida applied M2052 high damping alloy in a grinding machine as the mounts and bolts, as shown in Fig.9 [6]. A grinding machine of one ton weight was installed to the ground via 4 mounts and bolts, all of which were made from steel and M2052 high damping alloy, respectively. Vibration test was conducted by the impulse hammering method, by exciting vibration in the rear of machine column and detecting the displacement between the grinding wheel and the working table with an eddy current sensor. It was found that the strongest receptance peak occurred at 25Hz, and the magnitude of the response was decreased to about 1/6 when the mount and bolt material was changed from steel to M2052 high damping alloy.

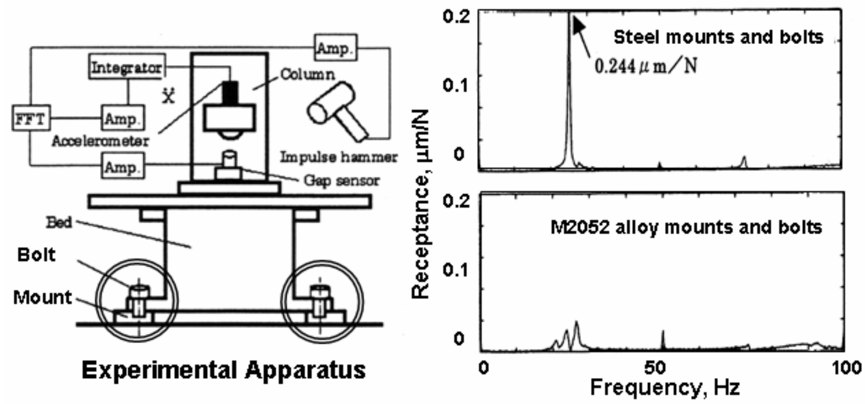

Fig. 9. Damping effect of mount and bolt material in a grinding machine.

3.2 Cutting tool holders in working machinery

"Chattering" or "shifting" phenomena occurred during surface working of metallic materials extensively affect the surface precision of the worked parts. Since both phenomena are associated with the vibration of the operating cutting bit, high rigidity tool holder and notched holder were applied to improve the working precision through damping the vibration of the working bit. However the results were found to be unrealistic since the high rigidity material and notched structure had only shifted the resonant vibration frequency and had not damped the vibration effectively. Koya et al. applied M2052 high damping alloy as the cutting tool holder in a spring neck working machine [7]. Fig. 10 shows the tool holders made from conventional high rigidity SCM435 steel and M2052 high damping alloy, respectively. At the same working conditions, the surface roughness of the worked Al alloy is reduced considerably to less than 0.5μm with the M2052 alloy holder. It was found that the resonant vibration at 2500Hz in the case of steel holder was reduced obviously, and that damping effect of M2052 alloy holder was responsible to the high surface precision of worked parts.

3.3 Connection pipe for radiation detector

The energy resolution of γ-ray radiation detectors is considerably deteriorated by the microphonic noises, caused by nitrogen bubbles and refrigerator driving. M2052 alloy was used as the cryostat outer-pipe in a radiation detecting apparatus, and observed to decrease the noise level to 50% and increase the energy resolution for a Co-60 γ-ray by about 10%, in comparison to same part made by an aluminum alloy [8]. Fig. 11 shows the structure of a mobile type radiation detector. The cooling media is transported through inner pipe of No. 8 while the vibration occurred in the refrigerator (No.27) is transmitted to the detector section through connection pipe (No. 35). The damping capacity of the connection pipe is important to the transmitted vibration in the detector. As compared with an Al alloy outer pipe the vibration amplitude in the detector section is obviously reduced with the application of M2052 high damping alloy.

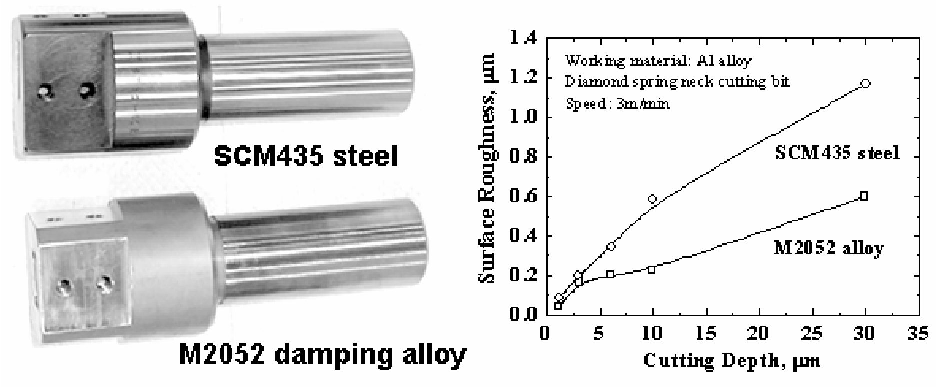

Fig. 10. Surface roughness improvement by different cutting tool holder in the spring neck working system.

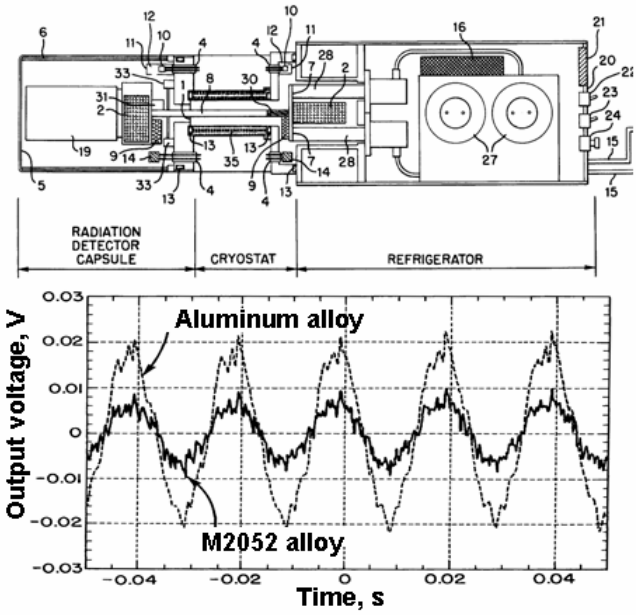

Fig. 11. Vibration transmission through the connection pipe in different pipe materials in a mobile radiation detector system.

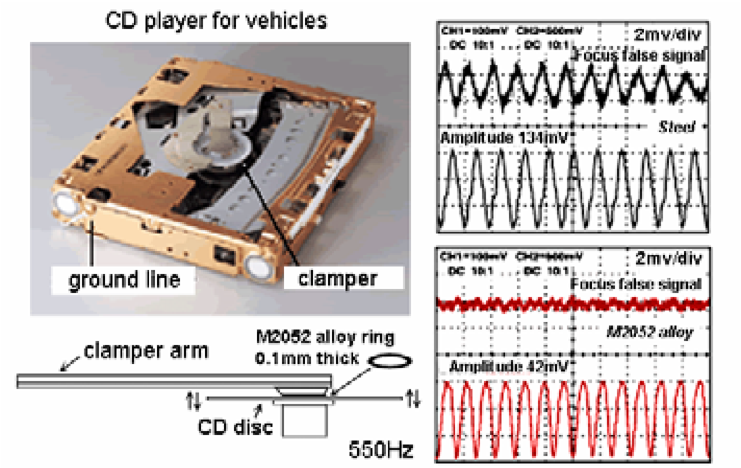

Fig. 12. Application of M2052 alloy ring in the CD player for vehicles and the effect of reducing focus error signal.

3.4 Damping rings applied in CD player for vehicles

The audio quality of CD players is sensitive to vibration interruptions, which cause the focus false signals. Especially in the CD player for vehicles, vibration damping for the rotating CD disc seems quite necessary. In the development of RS-D7χ CD player for vehicles, Pioneer Company applied M2052 alloy ring of 0.1mm thick on the CD disc clamper, as shown in Fig. 12 [9]. It was reported the focus error signal caused by the vibration at 700Hz was obviously reduced with the application of M2052 alloy ring. The focus error signal is found to be reduced to 1/3 as compared with the case without damping ring.

4. CONCLUSIONS

Among damping materials, high damping alloys show not only a certain level of damping capacity, but also the adequate mechanical properties and workability. Therefore high damping alloys can find a much wider application field, especially in the high strength or high vacuum environment. M2052 high damping alloy possess the necessary property features as structure parts, in addition to the superior damping capacity. Some practical applications of the alloy confirm its ability to damp out the unwanted vibrations and reduce the noise level of the whole structure or instruments. It should be noted that damping capacity of high damping alloys must be suitable to the concrete application conditions, where strain amplitude and static load may influence the behaved damping capacity of the alloy considerably.

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