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PARTICLE DAMPING FOR VIBRATION AND NOISE REDUCTION

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Abstract

The purpose of this paper is to report an application of particle damping technique for noise reduction of a desk-top industrial machine. We applied the particle damping technique to a desk-top banknotes processing machine as a task to substantially reduce its noise (by 6 dB(A)) to the level of a standard requirement when it is in operation in an office environment.

1. INTRODUCTION

The purpose of this paper is to report an application of particle damping technique for noise reduction of a desk-top industrial machine. Particle damping is a technique of providing damping with granular particles embedded within small holes in a vibrating structure [1,2]. The particles absorb kinetic energy through particle-to-wall and particle-to-particle frictional collisions. Because of its extreme simplicity, high effectiveness and low cost, it has a tremendous potential for vibration and noise suppression in a broad range of applications [3,4]. While particle damping techniques have been investigated in recent years [5-7], their successful applications are scarcely reported in literature [2,3]. In a recent development, we applied the particle damping technique to a desk-top banknotes processing machine as a task to substantially reduce its noise (by 6 dB(A)) to the level of a standard requirement when it is in operation in an office environment. The objective of this paper is to bring attention of the particle damping technique to the academic and industrial communities to further stimulate development in its fundamental investigations and broad applications in many more fields for vibration and noise reduction. In this technology area, literature is very scarce and a comprehensive design method is yet available.

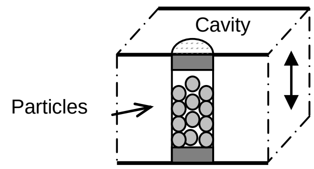


Figure 1. A schematic of a particle.

2. THE BANKNOTE PROCESSING MACHINE

A commercial banknote processing machine of desk-top type is usually operated in a bank office. It is used to process individual banknotes into a bundle of a specific number of bills. It has a number of process steps, including counting, aligning, packing, and wrapping. The particular machine under our investigation uses a cam mechanism running at a rotation speed as high as 11,500 rpm. At the full speed, it produces an excessive level of noise - 89 dB(A) measured at a distance of 0.5 m. Our task is to find a solution to substantially reduce the noise level to meet the standard environmental requirement preferably with vibration dampers of low cost.

3. PARTICLE DAMPERS

Of the various discrete dampers that are available, particle dampers are known to have a tremendous potential to provide suppression of large level broadband vibrations [1,2]. They are passive devices with very low cost. It is a relatively simple concept where metal or ceramic particles or powders of small size (~0.05 - 0.5 mm in diameter) are placed inside cavities within or attached to the vibrating structure (see a schematic of Fig. 1). In contrast to viscoelastic materials which dissipate the stored elastic energy, particle damping treatment focuses on dissipation of the *kinetic energy*. Particle damping involves energy absorption and dissipation through momentum exchange between moving particles and vibrating walls, friction, impact restitution, and shear deformations. It is an attractive alternative in passive damping with proven effectiveness and insensitivity to temperature and degradation [1-3].

4. PARTICLE DAMPING TREATMENTS

Our plan of noise reduction calls for damping treatment on three major structural elements of the machine. The machine under study here has a main body-structure, a cam-shaft, and a folk-shaft. During operation, the cam-shaft creates precipitating motions of the folk-shaft, causing strong vibrating forces on the shafts, bearings, and folk mechanisms. The vibrations not only directly produce noise, but also force the body structure and other components connected to it to vibrate. Thus, the cam-shaft and the folk-shaft are considered as source elements of vibration, while the body structure is the main source of noise emission. The shafts and the main structure are castings of an aluminum alloy which has little inherent material damping. Our experiment indicates that the damping ratio of the material is approximately at 10^{-4}. It is determined that the damping property should be substantially enhanced with particle damping treatments.

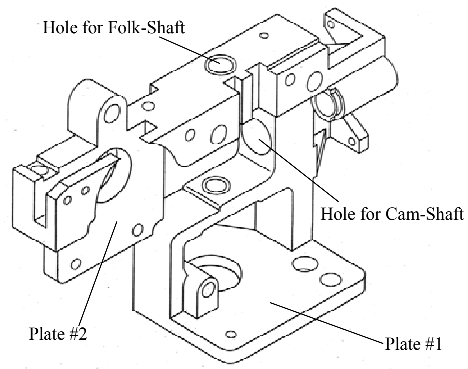


Figure 2. The main body-structure.

Our particle damping method is to use a single or multiple holes drilled in the concerned structure and to fill the hole(s) with tungsten-carbide particles of small size. The size of the particles is typically less than $1/5$ of the hole's diameter and is usually in the range of 0.05-5 mm [1-6]. The tungsten particles of our use have a size of approximately 0.5 mm in diameter. The main structure of the machine is shown in Fig. 2. During the machine operation, the structure is under a broadband vibration, as illustrated by the power spectrum of the acceleration response of measurement (Fig. 3). It is indicated that there are a large number of frequency components in the response, ranging between 30 - 12,500 Hz.

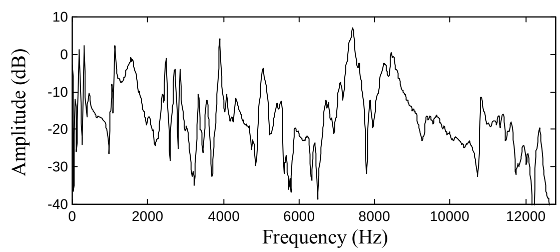


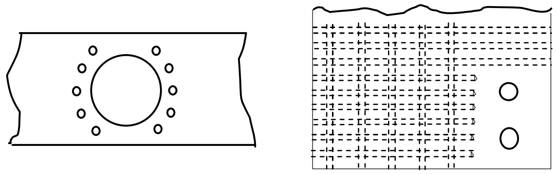
Figure 2. Amplitude of acceleration response in operation.

The body-structure has two plate-type elements with a size of $110 \times 97 \times 7$ and $70 \times 80 \times 10$ $(mm)^3$ respectively in width, length and thickness. It is expected that these two plates would be the major elements of noise generation and emission. Thus, it is determined to apply particle damping at the following three major areas on these two major elements:

- *Near the shaft holes.* The cam-shaft and the folk-shaft are supported by the plate-type elements through bearings in the holes on the elements. It is expected that the particle damping would be effective if the particles are embedded near the holes. Therefore, ten holes of 3 mm in diameter were drilled near the cam-shaft hole and the folk-shaft hole respectively as shown in Fig. 4(a). Each hole is 20 mm in depth and is filled with the tungsten carbide particles.

- *In the plate-elements.* Both plate-elements of the body structure have a relatively large area. Multiple deep-holes were drilled in the longitudinal and the latitudinal directions as shown in Fig. 4(b). These holes are distributed with various depths so to avoid the other functional surfaces on the structure. The diameter of the holes is 4 mm and the holes are fully filled with the particle material.

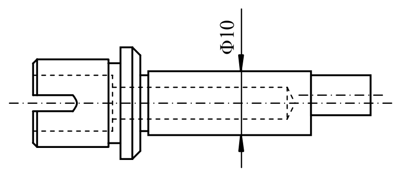
- *In addition, there are some areas of non-load bearing on the body-structure.* Thirty holes of 3 mm in diameter were placed over these areas with their locations judicially selected.



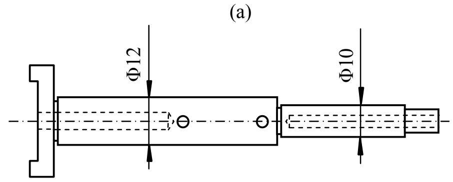
(a) (b)

Figure 4. Locations of particle dampers on the body-structure: (a) Near the shaft hole; (b) In the plate body.

As discussed earlier, the cam-shaft and the folk-shaft are the major contributing elements for the noise. Therefore, they should also be treated for damping enhancement. Since either shaft bears relatively low load, the central core of the shaft becomes a good location for embedding particles. In the central segment of the cam-shaft of 10 mm in diameter, a hole of 6 mm in diameter is made with 32 mm in depth, as shown in Fig. 5(a). For the folk-shaft, a 6 mm diameter hole is placed in its middle section of 12 mm in diameter, while a 5 mm diameter hole is placed in its right section of 10 mm in diameter (Fig. 5(b)). In this fashion, both shafts are treated with the particles filled within these axial holes.



(a)



(b)

Figure 3. Embedding particles in the shafts: (a) The cam-shaft. (b) The folk-shalt.

5. TEST RESULTS

In order to evaluate the effects of the particle damping, two kinds of tests were conducted. First, a vibration test is made on the body structure for the cases with and without the particle treatment respectively. The test configuration is shown in Fig. 6. The body structure is excited at a location near the cam-shaft hole, with a broad frequency band up to 12.8 kHz. The response of the body structure is measured at three different locations as indicated in Fig. 6. The measured acceleration responses are shown in Figs. 7 - 9 for the cases with and without the particles respectively. In examining these responses, we conclude the following:

The original body structure (without the particle damping) has a high level of response especially in the middle frequency range of 4,000 - 6,000 Hz. The particle damping treatment of the body structure made a significant improvement in reducing the vibration response. Particularly in the middle frequency range of 4,000 - 6,000 Hz, the damping effect is the highest and remarkable. At a number of resonance frequencies in this range, the particle damping exhibits a reduction of the response amplitude by as high as 40 dB!

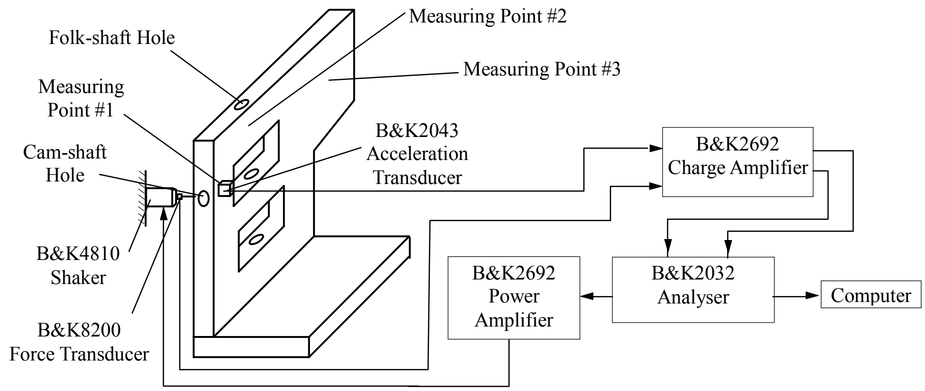


Figure 4. Test configuration of the body-structure.

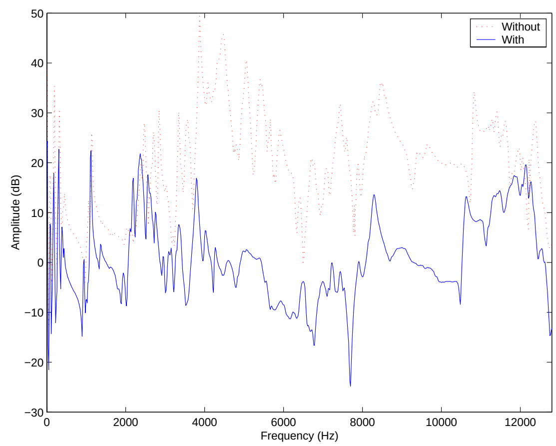


Figure 5. Acceleration response at measurement point #1 without andwith the particle damping treatments.

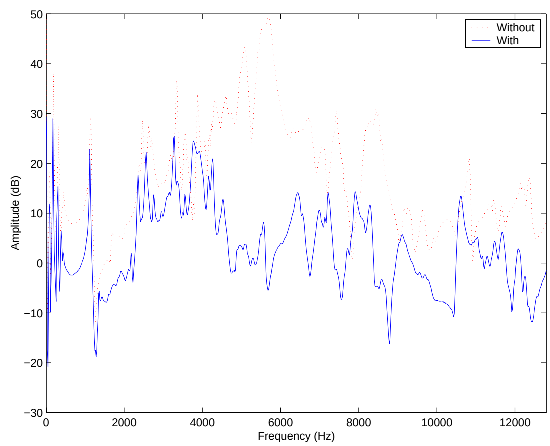


Figure 6. Acceleration response at measurement point #2 without and with the particle damping treatments.

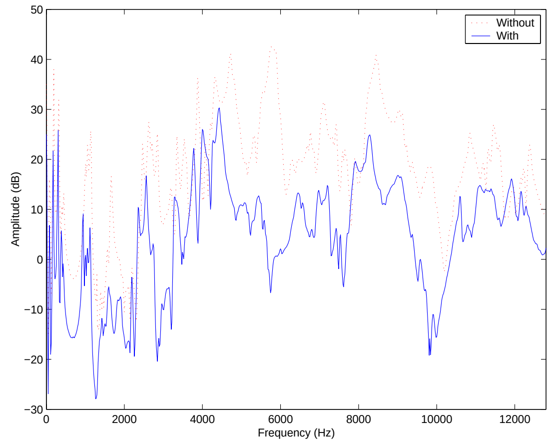


Figure 7. Acceleration response at measurement point #3 without and with the particle damping treatments.

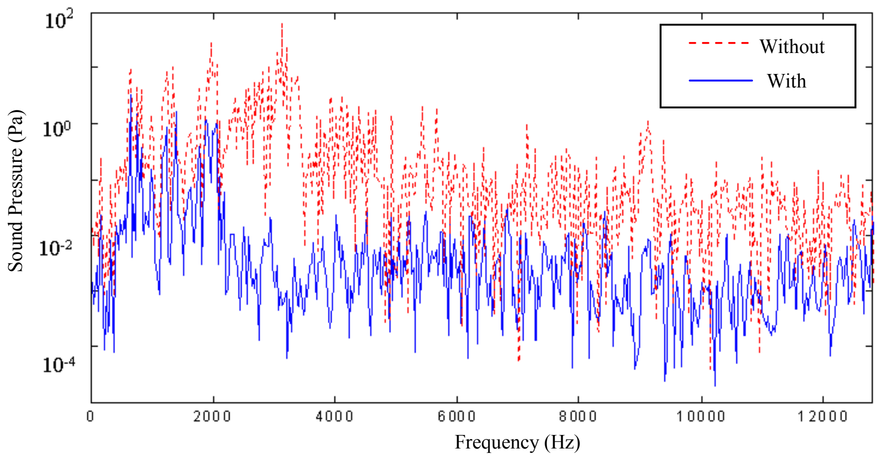


Figure 8. Measured sound pressure without and with the particle damping treatments.

The particle material provides a highly remarkable damping effect in the relatively high frequency range (from 2 - 12 kHz), while the vibration reduction in the lower range of 0 - 2 kHz is modest. This shows that this particular treatment of the body-structure may have some trade-offs. In this application, we have largely relied on our experience and heuristic guidelines. Another set of tests was conducted during normal operation of the machine with measurements of its noise. Four different arrangements of the damping treatments are made and evaluated: (1) the cam-shaft treatment only, (2) the folk-treatment only, (3) both the cam-shaft and the folk-shaft are treated, and (4) the shafts and the body-structure treatments together. The effects of these different treatments on noise reduction are as follows.

- With only the cam-shaft is treated with the particle damping, the noise level is reduced by 1.5 dB(A) from the original 89 dB(A) to 87.5 dB(A).

- If only the folk-shaft is treated, a similar reduction of 1.5 dB(A) in the noise level is achieved.

- When particle damping is applied to both shafts, the noise is reduced by 2.0 dB(A).

- Finally, in treating the body-structure and both shafts with the particle dampers, a combined effect of noise suppression is 6.0 dB(A), reducing it from the original 89 dB(A) to 83 dB(A). The final noise spectrum is compared with that of the original machine in Fig. 10. It is observed that these treatments of particle damping are especially effective in the middle and the high frequency range above 2,000 Hz.

6. CONCLUSIONS

In this paper we have described a successful application of particle damping for noise reduction. Based on the experience gained in working with particle dampers, we believe that important classes of vibration and noise problems can be solved with this simple technique. It is hoped that this report will help stimulate more developments in particle damping technology, especially towards understanding damping behavior characteristics to facilitate its design [6, 7, 8].

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