Research of NOPD Technology Applied on Vibration Reduction of Rotor Compressor

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ABSTRACT

Vibration of compressor shafting system can cause the uneven air gap between the stator and the rotor, which will intensify the electromagnetic vibration of the motor. Traditional damping technique is not available for vibration and noise control due to the high temperature and high pressure conditions inside the compressors. In order to reduce the vibration of the compressor's shafting, a technique named Non-obstacle Particle Damping (NOPD) is used and some special NOPD shock absorbers are designed for shafting vibration reduction. According to the structure of an inverter compressor, 4 NOPD shock absorbers with different numbers of filled-in particles and cavity materials are made and installed to the rotors. Results of compressor vibration test show that the vibration of the compressor with NOPD shock absorbers installed is reduced apparently in contrast with the compressor without NOPD shock absorber. And the more particles are filled in, the better effect of vibration reduction is achieved.

1. INTRODUCTION

Compressor's shafting vibration is one of the main sources. It will cause uneven air gap between the stator and the rotor, and then intensify the electromagnetic vibration. For a high temperature and high pressure condition inside the compressor, traditional damping technique is not available. In order to reduce the vibration of the compressor's shafting, a technique named Non-obstacle Particle Damping (NOPD) is used. NOPD is a tiny particle damping technology proposed by Panossian in 1990s. NOPD has the advantage of small additional quality, less change in structure, stable damping properties and uneasy to age under extreme temperature conditions. This technique has been applied in field of architecture, machinery, and aerospace successfully, but it had never been used in compressor before.

In the aspects of theory, Jianglong Fang established a quantitative model of energy dissipation of non-obstructive particle damping according to the molecular dynamics theory. It was found that the energy dissipation power of the particle damping increased with the increase of particle diameter, number of particles, material density and vibration intensity. Kai Zhang made a research of the relationship between damping effect of NOPD and movement pattern of particles based on the rheological properties of vibrating particles.

In practical application, GangHua Yu designed a multi-layer composite plate by NOPD technology, and confirmed effectiveness of NOPD technology in suppressing sound radiation of plate structures. XiangDong Zhang analyzed the possibility of applying particle damping technology to building structures, and provided guidance for the location and installation method.

2. PRINCIPLE OF NOPD APPLIED IN VIBRATION REDUCTION

2.1 Principle of Vibration Energy Dissipation

Vibration reduction principle of NOPD is making some cavities on the vibration source filled with tiny particles. For inelastic collision and friction between the particles, particles and wall surface of cavity, the vibration energy of the system will be converted to internal energy. For low frequency, friction between the particles, particles and wall surface of cavity takes main effects. For high frequency, collision takes main effects.

According to the theory of energy dissipation, energy dissipation of particle dampers can be classified as collision energy dissipation and friction energy dissipation. For any two particles i and j, collision energy dissipation equation is

$$\Delta E_e = \frac{1}{2}\frac{m_i m_j}{m_i + m_j}(1-e^2)\left|\Delta v\right|^2 \tag{1}$$

In this equation, m_i and m_j is the mass of particles i and j, e is the restitution coefficient of collision, and Δv is the relative velocity between two particles before collision. Friction energy dissipation can be obtain with equation

$$\Delta E_f = \mu\left|F_{Xij}\delta_t\right| \tag{2}$$

where μ *is* coefficient of friction, F_{Xij} is the normal contact force between two particles, and δ_t is the relative displacement between two particles. If we take j as the wall surface of cavity in equation (1) and (2), energy dissipation between particle and wall surface of cavity can be obtained. So the total energy consumption of the system is

$$E_{loss} = \sum \Delta E_e + \sum \Delta E_f \tag{3}$$

2.2 Influence Factors of NOPD

According to the equation (1), (2), (3), it can be find that the effect of NOPD depends on the particles' mass, number, restitution coefficient and relative displacement. Generally, NOPD has a better effect with more particles and bigger mass of particles. As the volume of cavity is restricted, it just can be filled with limited number of particles. So the particles should be as small as possible, and the density should be as big as possible. Then we can fill the cavity with particles as many as possible. But the cavity cannot be filled to full to ensure the particles have enough motion space.

3. NOPD SHOCK ABSORBERS DESIGN FOR COMPRESSOR SHAFTING

Fig.1 shows the typical structure of the shafting. It is made up of cylinder, absorber, cylinder cover, rotor and some other parts. When compressor is running, the rotor will rotate with high speed by electromagnetic force. It can cause a violent vibration. If the air gap is not even, the vibration will be aggravated. So NOPD shock absorbers are better to be fixed on the rotor as shown in fig.2. Considering the rotor balance, the structure of NOPD shock absorber is designed as a cylindrical ring with a certain height. There are some cavities with different patterns at one side of cylindrical ring. And these cavities will be filled with a lot of particles.

In order to find good design parameters, four NOPD shock absorbers are designed for a 6 poles 9 slots inverter compressor in this paper. The structure and parameters of samples are list in table 1. According to the analysis about influence factors of NOPD, the density of particles should be as big as possible. So the metal particle is a good choice. But not all metal particles are suitable, for the rotor is magnetic and some magnetic metal particles cannot be used as they cannot move freely in cavity. So we use copper particles. Another factor is the number of particles. It should be as more as possible. In order to fill in particles as much as possible, it is need to make cavities as much as possible. It means the proportion of cavities volume should be as much as possible. Two types pattern of cavity were made. One is cylindrical cavity (Sample 1-3), and the other is flabellate cavity (Sample 4). The former is convenient to process, but has less volume. The later has more volume, but is hard to process, and have to be made by 3D printing.

Figure 1: Schematic of shafting

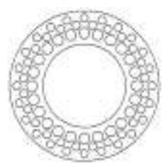
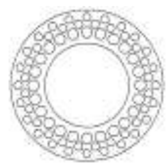
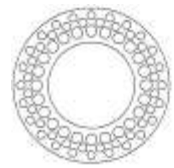
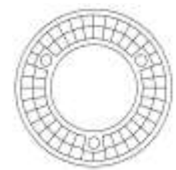
Figure 2: Photo of NOPD shock absorber sample attached on rotor

4. VERIFICATION OF NOPD SHOCK ABSORBERS

4.1 The Effect of NOPD Shock Absorbers

Vibration test of 4 compressors installed NOPD shock absorbers and a compressor without NOPD shock absorbers were made at working conditions of 3210 r/min、4800 r/min, 5100 r/min, 5400r/min, 5700 r/min, 6000 r/min, 6900 r/min. Two accelerometers of three-directions located at shell around motor and cylinder. The results of test are shown from fig.3to fig.6. Figure 3shows the vibration results in axial-direction around motor, and figure 4 shows the vibration results in circumferential-direction around motor. Figure 5shows the vibration results in axial-direction around cylinder, and figure 6 shows the vibration results in circumferential-direction around cylinder.

Table 1: Structure and parameters of NOPD shock absorbers

Items	Sample 1	Sample 2	Sample 3	Sample 4
Pattern				
Material of Shock Absorber	copper	copper	nylon+30%glass fibre	nylon+30%glass fibre
Depth of cavity(mm)	8	17	17	17
Proportion of Cavities Volume (%)	26.7	31.2	31.2	51.8
Proportion of Particles Volume (%)	16.7	25.7	25.7	42.6
Proportion of Residual Cavities Volume (%)	37.5	17.6	17.6	17.6
Diameter(mm)	0.5	0.5	0.5	0.5
Material of Particles	copper	copper	copper	copper

It can be found that the vibration of compressor without NOPD shock absorber is higher than all 4 compressors mounted with NOPD shock absorber apparently at all working conditions and in all directions except circumferential-direction around motor. Even in the circumferential-direction around motor, vibration of compressors with NOPD shock absorbers Sample 1 and Sample 4 are still less than compressor without NOPD shock absorber at working conditions of 4800 r/min, 5700 r/min, 6000 r/min, 6900 r/min. So the NOPD shock absorbers are useful in vibration reduction of shafting and compressor in practice.

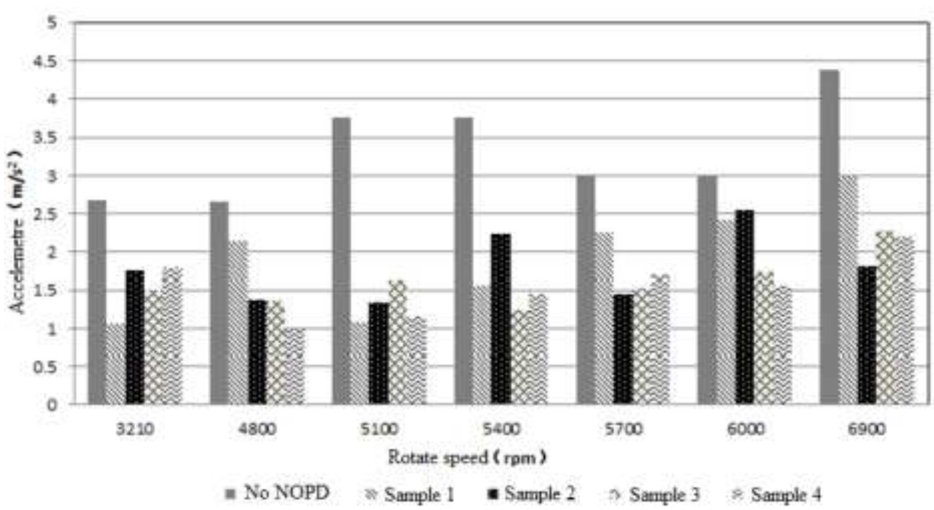


Figure 3: Test results in axial-direction around motor

4.2 The Influence of Particles Number

In this paper, 4 kinds of NOPD shock absorbers with different patterns were made. According to the Table 1, Sample 1 and Sample 2 have the same patterns of cavities and materials of cylindrical rings, but different cavity volume proportion and number of particles. The height of Sample 2 is higher than Sample 1, and the cavities depth of Sample 2 are deeper than Sample1. So there are more particles filled in the cavities of Sample 2. Sample 3 and Sample 4 have the same height, the same materials of cylindrical rings and the same depth of cavities, but the patterns of cavities are different. The volume of Sample 4 is much larger than Sample 3. So much more particles can be filled in. Then we make a contrast between Sample 1 and Sample 2, Sample 3 and Sample 4 to identify the influence of particles number.

Subtract the vibration value of Sample 1 from Sample 2 and normalize the result. It was show in Figure 7. The positive means that the vibration of Sample 2 is larger than Sample 1. Make a same operation on vibration values of Sample 3 and Sample 4, and show the results in Figure 8. It can be found from Figure 8 that vibration reduction effect of Sample 4 with more particles was better than Sample 3 apparently. But this situation didn't happen between Sample 1 and Sample 2 apparently. It could be that the number of particles filled in Sample 4 is 16.9% more than Sample 3. And the number of particles filled in Sample 2 is just 9% more than Sample 1. It is not more enough to obtain a better effect.

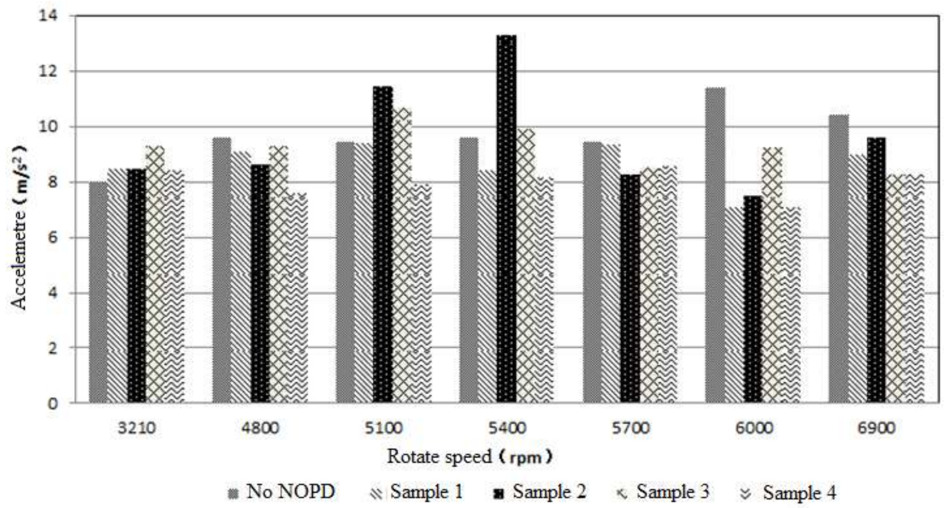


Figure 4: Test results in circumferential-direction around motor

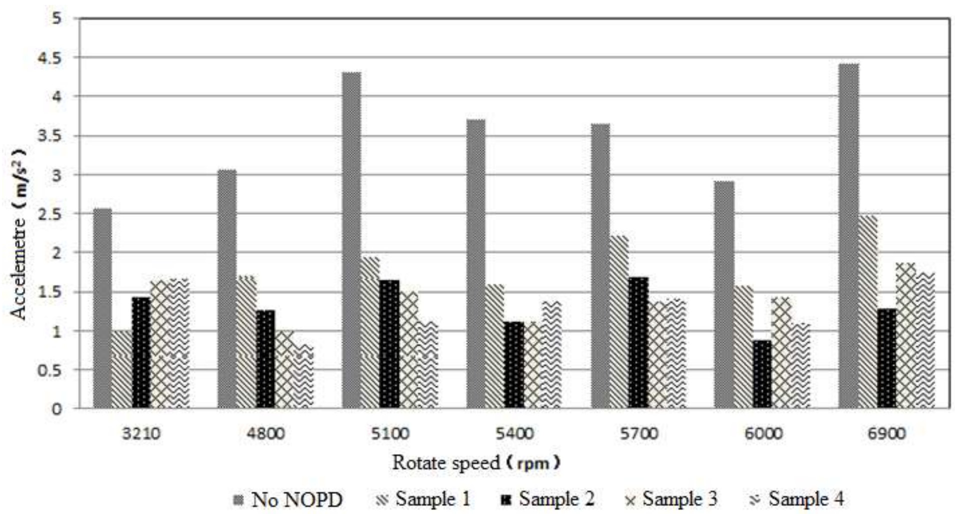


Figure 5: Test results in axial-direction around cylinder

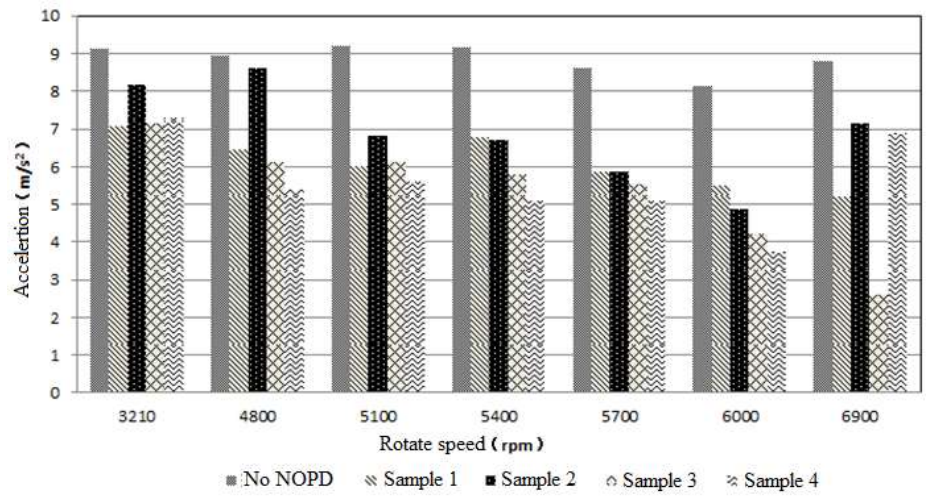


Figure 6: Test results in circumferential-direction around cylinder

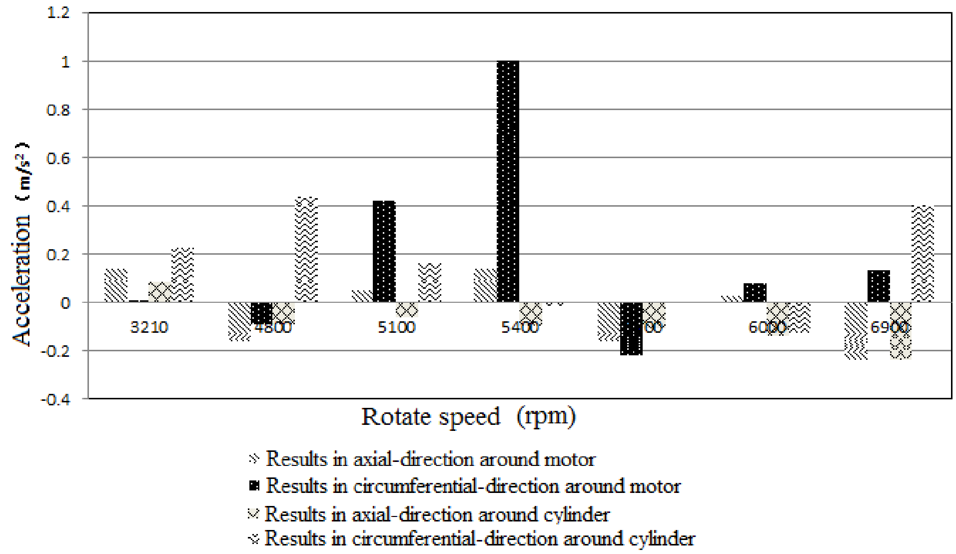


Figure 7: Normalized vibration difference between Sample 1 and Sample 2

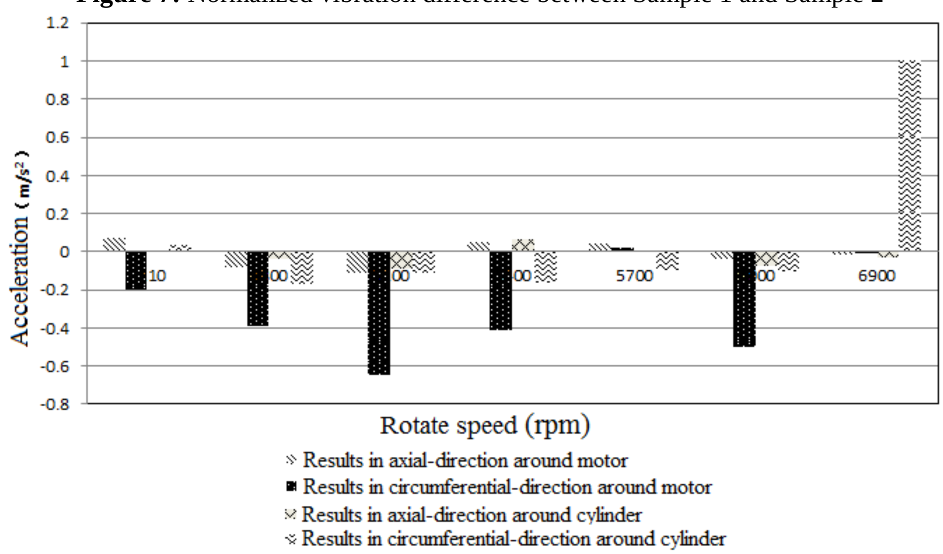


Figure 8: Normalized vibration difference between Sample 3 and Sample 4

4.3 The Influence of Additional Mass Caused by Existing of Shock Absorbers

As the existing of NOPD shock absorbers, an additional mass were added on the shaft. So there is maybe a doubt that whether the vibration reduction is caused by NOPD shock absorbers or the additional mass. Although we did not make a vibration contrast between compressor with NOPD shock absorbers with no particles filled in and compressor without NOPD shock absorber, but we can also confirm that whether there is a relationship between additional mass and vibration reduction by comparing the effect among Sample 2, Sample 3 and Sample 4. These 3 samples have different weight. According to the figure 8, it can be found that Sample 4 is weightier and better effect than Sample 3. Then we make a figure 9 like figure 8 to compare the vibration between Sample 2 and Sample 3. It can be found that Sample 2 is weightier and mainly worse effect than Sample 3. So we can make a tentative conclusion that there is less relationship between additional mass and vibration reduction.

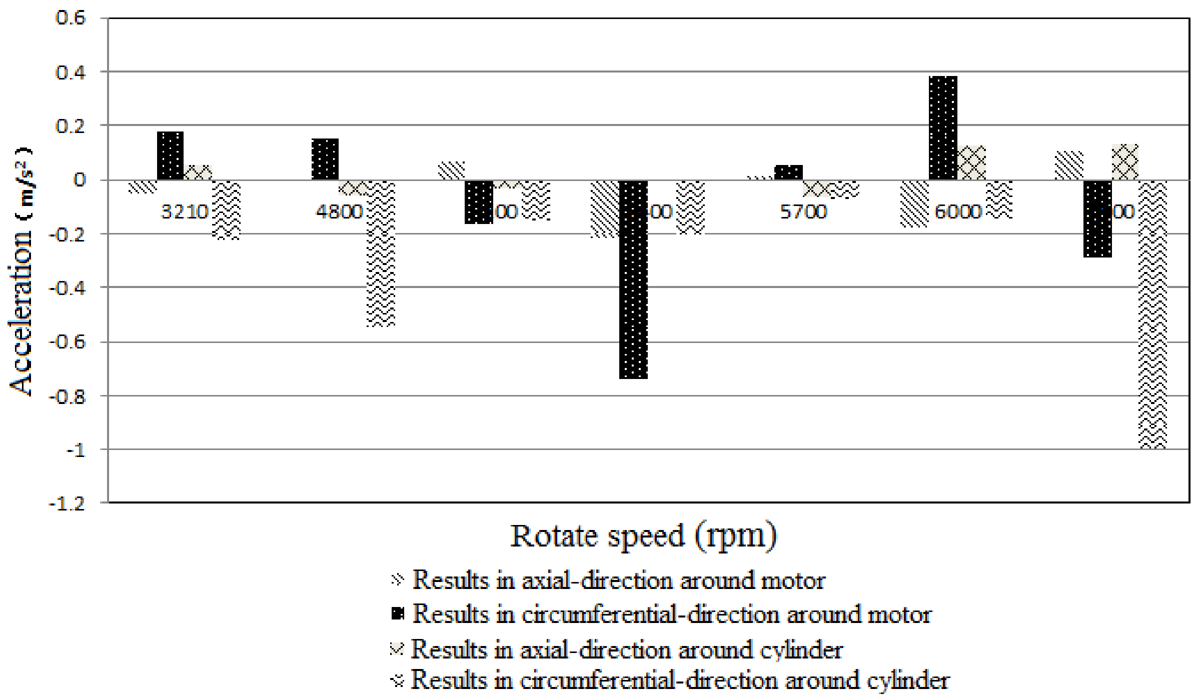


Figure 9: Normalized vibration difference between Sample 2 and Sample 3

5. CONCLUSIONS

A technique named Non-obstacle Particle Damping (NOPD) is applied on compressor shafting. And 4 different structures of NOPD shock absorbers were made and mounted on the rotor. Vibration test results show that the NOPD shock absorbers have a good effect in vibration reduction of shafting and compressor and the effect is related to the number of particles. Generally, the more particles filled in the cavity, the better.

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