Design of circular particle damper for turbopump

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Abstract: A circular particle damper attached to the turbopump of the liquid rocket engine is designed. The models of the turbopump with and without the particle damper are built with finite element method to evaluate the damping effect on the vibration of the turbopump. In the simulation, the equivalent structural damping ratio is used to describe the damping performance of the particle damper. Numerical results show that the particle damper can reduce the vibration of the turbopump significantly, and has less effect on the dynamic characteristics of the turbopump.

Key words: particle damper; turbopump; damping

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0 Introduction

In the ground test, the vibration level of the turbopump is very high, and usually leads to broken of some pipes. The turbopump works in the severe environment, such as low- and high-temperature environments, and the factors causing the strong vibration of the turbopump are complicated. In order to suppress the strong vibration of the turbopump, the methods of damping are needed.

Particle damper is a passive damping structure for achieving high structural damping by the use of a particle-filled enclosure attached to the vibrating structures[1]. Damping is achieved by dissipation of the kinetic energy. Particle damping involves energy absorption and dissipation through momentum exchange, friction, and shear deformations. The advantage of particle damper over the traditional damper is that particle damper is inexpensive, simple and able to provide effective damping over a wide range of frequencies. In addition, particle damper is robust and can operate in environments that other traditional dampers cannot. The dynamics of the particle damper is very complex though the structure is simple. There are some analytical models to describe the particle damper′s damping characteristics[2-6], which focus on the damper attached to a beam. However they are not suit to use in practice. Because these models are built based on the

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simple beam and also cannot agree well with the experiment results.

In this work, the circular particle damper attached to the turbopump is designed. In order to investigate the damping effect on the turbopump with the circular particle damper, the finite element model of the turbopump is built. The structural damping of the materials is introduced to describe the damping mechanism of the particle damper. The modal analysis and frequency response analysis for the turbopumps with and without the particle damper are performed to make a comparison for the dynamic characteristics and vibration amplitudes of the turbopumps.

1 Particle damping

A schematic drawing of particle damper is shown in Fig.1. The particle damper has tremendous potential to provide suppression of vibration in a wide frequency range. The particles can be made with many materials, such as metal, lead, plastic, ceramic and so on. The size of the particles can also be diverse, which usually has the diameter of 0.05~5 mm. The cavity is used to contain the particles, which usually has the shape of circular cylinder.

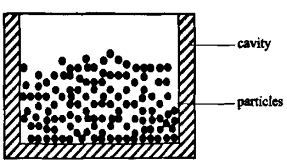


Fig.1 Schematic drawing of a particle damper.

In contrast to viscoelastic materials which dissipate the stored elastic energy, particle damping mainly arises from the collisions between the particles, and between the particles and the walls of the cavity. As a result of these collisions, momentum is exchanged between the structure and the particles. Additional energy dissipation occurs due to frictional losses. High damping can be achieved by absorbing the kinetic energy of the structure as opposed to many traditional methods of damping where the elastic strain energy stored in the structure is converted to heat. For example, a very high value of maximum specific damping capability (~50%) was observed in Friend and Kinra's experiment [1]. The particle damper is an attractive alternative in passive damping with proven effectiveness and insensitivity to temperature and degradation.

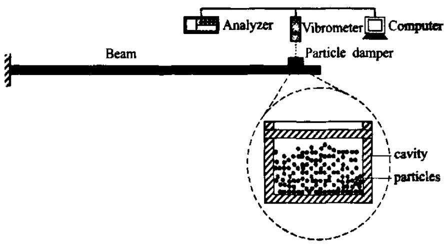


Fig.2 Usual experimental setup for the particle damper.

The experimental setup to test the characteristics of the particle damper is usually proposed by many researchers as Fig.2. The particle damper is attached at the free end of the cantilever and the vibrometer is used to catch the displacement response of the beam. The responses of the displacements are similar to that shown in Fig.3. In Fig.3, the real and dotted lines represent the response of the beam with and without the particle damper respectively. Using this setup, the damping characteristics of the particle damper with different kinds or different diameters of particles can be studied experimentally.

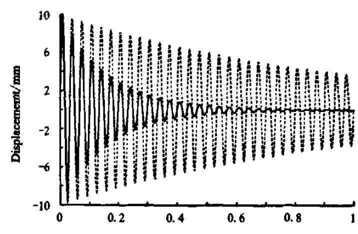
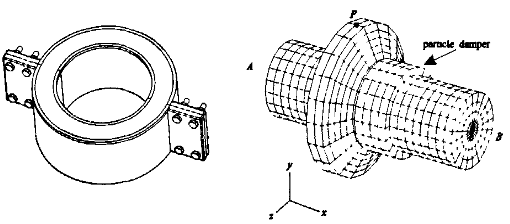


Fig.3 Displacement responses for the beam
Real line: with particle damper; dotted line: without particle damper.

2 Circular particle damper design and analysis

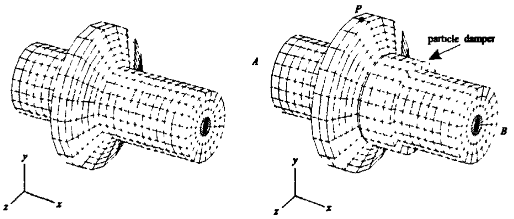
In this study, the particle damper is used to suppress the strong translational vibration of the turbopump. The particle damper is designed considering the geometry of the turbopump. The cavity geometry of the particle damper is shown in Fig.4. The cavity is composed with three parts. The iron particles will be put into the cavity. The outer diameter, inner diameter and the height of the particle damper are 240 mm, 200 mm and 100 mm respectively.



(a) external appearance　　(b) internal structure

Fig.4 Cavity configuration of the circular particle damper

The finite element model of the turbopump without the particle damper is given in Fig.5 (a). In the ground test, the translational vibration of the turbopump was strong. In order to reduce the vibration of the turbopump, one particle damper is attached on the surface of the turbopump (as shown in Fig.5(b)).



(a) without particle damper　　(b) with particle damper

Fig.5 Finite element model of turbopump

In the simulation, the density, elastic modulus and structural damping ratio of the turbopump are 7800kg/m^3, 2.1GPa and 0.001, respectively. The equivalent structural damping ratio of the particle damper near the 2000Hz is assumed to be 0.1. The mass of the particle damper is 1.4 kg, which is 0.66% of the turbopump mass (212.9kg).

One end of the turbopump (A) is fixed and the other (B) is simply supported, which are shown in Fig.5(b) as A and B. The first four natural frequencies of the turbopump with and without the particle damper are calculated. The results are listed in Table 1. As can be seen from Table 1, the natural frequencies are approximate for the turbopump with and without the particle damper, which is a litter lower in the former. So, there is little influence on the dynamic characteristics of the turbopump caused by the particle damper.

Tab.1 Natural frequencies of the turbopump with and without the particle damper.

Mode	Frequency/Hz	
	Without particle damper	With particle damper
1	1130	1127
2	1202	1200
3	1986	1978
4	2765	2762

The centre point of plane C is excited in the Y direction to investigate the damping performance of the particle damper on the vibration of the turbopump. The plane C is the middle plane of the turbine and perpendicular to the axis of the turbopump (as shown in Fig.5 (b)) The exciting frequency is near 1125 Hz (1100–1150Hz) because the first bending frequencies for the turbopump with and without the particle damper are 1127Hz and 1130Hz respectively. The representative point P (as shown in Fig.5 (b)) is chosen to show the results. Both of the models with and without the particle damper are analyzed to make comparisons. The frequency responses of the acceleration of the point P are shown in Fig.6 and Fig.7. As can be seen from the figures, the maximum acceleration amplitudes of the point P in X direction for the turbopump with and without the particle damper are 216g and 333g respectively; the maximum acceleration amplitudes of the point P in Y direction for the turbopump with and without the particle damper are 344g and 528g respectively. The vibration level of the turbopump with the particle damper is nearly 65% of without the particle damper. The results show that the particle dampers can greatly suppress the vibration of the turbopump.

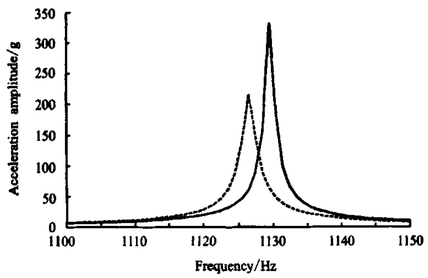


Fig.6 Accelerations of point P in X direction
Real line: without particle damper;
dotted line: with particle damper.

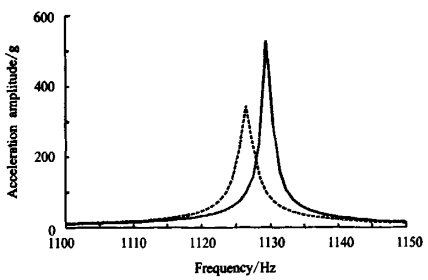


Fig.7 Accelerations of point P in Y direction. Real line: without particle damper; dotted line: with particle damper.

3 Conclusions

A passive circular particle damper to reduce the vibration of the turbopump is designed and analyzed. In the simulation, the structural damping ratio is introduced to describe the damping mechanism of the particle damper. Further experimental study will be done to reach the assumed damping ratio in the paper by arranging the particles, such as choosing the diameters of the particles and the mixing ratio of different kinds of particles.

References:

[1]Friend R.D., Kinra V.K. Particle impact damping. Journal of Sound and Vibration, 2000, 233(1): 93-118.

[2]Olson S.E. An analytical particle damping model. Journal of Sound and Vibration, 2003, 264(5): 1155-1166.

[3]Mao K, Wang M Y, Xu Z. DEM simulation of particle damping. Powder Technology, 2004, 142 (2-3): 154-165.

[4]Duncan M R, Wassgren C R. The damping performance of a single particle impact damper. Journal of Sound and Vibration, 2005, 286(1-2): 849-861.

[5]Liu W, Tomlinson G R, Rongong J A. The dynamic characterization of disk geometry particle dampers. Journal of Sound and Vibration, 2005, 280(3-5): 849-861.

[6]Xu Z, Wang M Y, Chen T. Particle damping for passive vibration suppression: Numerical modeling and experimental investigation. Journal of Sound and Vibration, 2005, 279(3-5): 1097-1120.

[7]刘占生, 李存生, 黄智勇, 等. 涡轮泵转子弯扭耦合振动与分岔特性研究[J]. 火箭推进, 2007, 33(5): 11-17.

涡轮泵环形颗粒阻尼器设计

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摘　要：设计了一种用于液体火箭发动机涡轮泵减振的环形颗粒阻尼器。为研究颗粒阻尼器的减振性能，基于有限元法建立了附加颗粒阻尼器以及不加颗粒阻尼器的涡轮泵模型，计算过程中采用结构阻尼系数来描述颗粒阻尼器的阻尼特性。仿真结果表明，颗粒阻尼器能够显著降低涡轮泵的振动，并且对涡轮泵的动态特性影响很小。

关键词：颗粒阻尼器；涡轮泵；减振

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参考文献：

[1]Farhangi S, Yu T, Rojas L. Gas-Gas injector technology for full flow combustion cycle application[R]. AIAA 1999-2757.

[2]Tucker P K, Klemt M D, Smith T D. Design of efficient GO_2/GH_2 injectors[R]. A NASA, industry and university cooperative effort, AIAA 1997.

[3]Marshall W M, Pal S, Santoro R J. Benchmark wall heat flux data for a GO_2/GH_2 single element combustor[R]. AIAA 2005-3572.

[4]杜正刚，金平，杨立军，蔡国飙，等. 气-气喷注器流量特性实验研究[J]. 航空动力学报，2007，22(3)：500-504.

[5]汪小卫，金平，杜正刚，蔡国飙. 氢/氧气-气喷注器冷流掺混与燃烧比较的仿真研究 [J]. 航空动力学报，2008，23(9)：1737-1742.

[6] 孙宏明. 液氧/甲烷发动机评述 [J]. 火箭推进，2006，32(2)：23-31.

[7]杨 V，安德松 W W E. 液体火箭发动机燃烧不稳定性[M]. 北京：科学出版社，2001，P37.

[8]蔡国飙，张化照，庄逢甘. 氢氧发动机推力室化学反应流场计算 [J]. 北京航空航天大学学报，1998，24(6)：671-675.

[9]董刚，黄鹰，陈义良. 不同化学反应机理对甲烷射流湍流火焰计算结果影响的研究[J]. 燃料化学学报，2000，28(1)：49-54.

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