Research and Application of Flutter Suppression Technology for Aeroengine Case Machining

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Abstract. The magazine is an important part of the aero-engine, its main role is to bear the load and mass inertia force generated by the engine in the work. The design and manufacturing level of the magazine is of great significance to improve the aero-engine’s quality. Engine magazine belongs to a thin-wall cylinder part with large size, complex shape and high processing precision. Due to its thin wall rigidity difference, the processing quality is easy to reduce caused by the vibration of machine tools and other processing system, and cannot meet the requirements. According to the absorption principle of TMD (Tuning Mass Damper), an auxiliary fixture is designed to transfer the magazine processing vibration energy to the auxiliary fixture to reduce the vibration of the processing system and to improve the processing quality. Through ANSYS analysis, the maximum vibration amplitude of the magazine was reduced by 60% by using this fixture. Therefore, the fixture can significantly reduce the vibration in the processing and have good effect on improving the quality of the processing. The auxiliary fixture has the advantages of simple installation, simple disassembly, and strong scalability.

Keywords: Engine magazine; Vibration suppression; Tuning mass dampers; Auxiliary fixtures; General finite element analysis.

1. Introduction

Aero engines are the power core of the aircraft, and the powerful thrust is used to push the aircraft forward. The magazine is an important part of the aero-engine, and its main role is to bear the load and mass inertia force generated by the engine at work. The design and manufacture of aero-engine magazine is of great significance to improve the quality of aero-engine products. In order to realize the function of the aero-engine, the magazine mostly adopts a thin-walled, overall slewed structure in design. The materials used are mainly titanium alloy, superalloy, etc., which have high hardness and processing difficulty. Especially, the deformation problems produced in machining process directly affect the machining quality of the aero-engine magazine. The typical engine case is shown in figure 1. The magazine structure is complex, and many features of islands, bumps, holes, grooves, tendons and other characteristics are distributed around the groove. The walls are thin, and the shape changes dramatically, which causes the difficulty in the machining process. The deformation problem caused by the magazine machining process is another difficulty in the magazine processing. According to the conventional process, the external error along the edge of the magazine slot is more and more bigger. This deformation error will cause the vibration of engine blade operation and directly affect the performance and service life of the whole aero engine.
Vibration is an inevitable problem in the machining process. The source of vibration is generally the vibration of the machine tool or the machining center, and the contact vibration between the processing workparts and the cutting tool system. This vibration will not only affect the surface quality of workpieces but also greatly reduce the life of cutting tools and machine systems. The cause of vibration is greatly related to the characteristics of the machine tool, workparts, processing methods, processing routes, which makes the suppression of processing vibration an important problem to improve the magazine processing quality, and the vibration suppression problem in the part processing process is also an important problem to improve the processing quality of parts.

From the principle of system vibration control, vibration suppression can be divided into three methods: vibration isolation, vibration reduction and vibration absorption. The vibration isolation is a vibration reduction method that isolating the vibration isolation between the vibration source and the workpiece or processing center that makes vibration reduction. The vibration isolation research should study and establish the system dynamics model and draw the conclusions. Karadayi [1] established a nonlinear vibration separator model firstly. On this basis, the Venkatesa [2] proposed a method for optimizing the system parameters. Tang Jinyuan [3] obtained the kinetic theoretical equations for three nonlinear stiffness using energy iterations. Damping method use the damping structure on the main structure to reduce the vibration energy of the system [4]-[6]. The damper materials are usually non-metallic materials, rubber, etc, and vary depending on the vibration reduction scenario. Vibration absorption is the 3rd. damping method that attaching the damping system transferring the vibration energy to the damping system by suitable frequency modulation technique [7]. The method has been a hotspot among vibration suppression scholars. Our project’s solution belongs to vibration absorption method. Processing fixture is designed according to vibration absorption principle of tuning mass damper to achieve the purpose of suppressing processing vibration [8].

2. Vibration Absorption Principle of the Tuning Mass Damper
The damping principle of Tuning Mass Damper (TMD) is to attach TMD as a substructure to the main structure forming a new system, transferring the vibrational energy of the main structure to the damper, thus suppressing the vibration of the main structure. The shock absorption performance of the TMD lies in the accurate frequency modulation. With the self-vibration frequency on the damper similar to the main structure, then the vibration of the substructure will be very strong, producing an external fierce reverse force on the main structure, thus reducing the vibration of the main structure. TMD is a second-order mass spring damping system, shown in figure 2.

The motion equation of the system is:

\[ m_1x_1''(t) + c[x_1'(t) - x_2'(t)] + (k_1 + k_2)x_2(t) - k_2x_2(t) = F_1\sin (\omega t) \quad (1) \]

\[ m_2x_2''(t) + c[x_2'(t) - x_1'(t)] - k_2x_1(t) - k_2x_2(t) = 0 \quad (2) \]

Where, the \( m_1, c_1, k_1 \) are the mass, damping ratio and spring stiffness of the main structure, \( m_2, c_2, k_2 \) represents the spring mass damping device mass, damping ratio, and spring stiffness, respectively.

Using fixed point theory, when the main system parameter has certain mass and does not consider the main system damping, the optimal parameter of the damper is as follows:

The optimal inherent frequency ratio of the damper is:

\[ \frac{\omega_d}{\omega_n} = \frac{1}{1 + \mu} \quad (3) \]

Optimal damping ratio of the dampers:

\[ \zeta = \sqrt{\frac{3\mu}{8(1 + \mu)^3}} \quad (4) \]

Among them:

\( \omega_n \) - Natural frequency of the dampers
$\omega_n$ - Inherent frequency of the main structure

$\mu$ - Mass ratio of the damper to the main structure, namely $m_2 / m_1$

It can be seen from equation (3) that as long as the mass $m_1$ of the auxiliary fixture is determined, the mass ratio of the damper to the main structure $\mu$ is also determined. Since the inherent frequency of the main structure $\omega_n$ is determined, it is only necessary to optimize the inherent frequency of the damper without changing the quality of the auxiliary fixture to satisfy the optimal inherent frequency obtained by the equation (3) calculation. According to equation (4), the optimal damping ratio $\zeta$ of the postdamping device is determined when $\mu$ is determined.

Tuning mass dampers have been applied to a wide variety of engineering realities due to their better vibration damping effect and have been shown to be a good vibration damping device. Since the 1970s, applications have been used to tuned mass dampers in natural vibrational disasters, such as earthquakes, typhoons, with the most famous example, the Hancka Building in Boston, United States. Guangzhou landmark building Guangzhou Tower was installed by 4 tuning mass dampers in 2009, each weighing 600 tons. The Hangzhou Bay Cross-Sea Bridge, which opened in 2007, installed a 120-tonne tuned mass damper to resist seawater impact and side typhoons. Taipei's 101 Tower has the single largest tuning mass damper in China of 660 tons.

3. Finite Element Analysis of the Magazine Processing System

Figure 1 shows a magazine part of a turbofan engine from GE, some part parameters is: material 2219 aluminum alloy, elastic modulus 73GPa, Poisson ratio 0.3, density 2700kg/m³, mass 93.54kg, diameter 2.086m, height 0.6772m, thinnest thickness 5mm, thickness up to 53mm. The inherent frequency and modal vibration results are obtained using the Block Lanczos method in ANSYS.

3.1. Magazine Grid Division

The grid division adopts the fast grid division method, moderate smoothness degree, 5 delicacy degree, the magazine is divided into 746850 nodes and 388760 positive tetrahedron units. The post-mesh model is shown in figure 3.

3.2. Boundary Condition Setting

According to the actual part processing process and process parameters, considering the machine tool, cutting tool, fixture and other processing system, in order to reduce the processing deformation as far as possible, the analyzed boundary conditions are determined as the zero displacement constraint of the bottom surface plate (the constraint surface is close to the 4 opening ends of the magazine, a total of 8 faces). As shown in figure 4.
3.3. Mode Analysis and Harmonious Response Analysis

The modal analysis calculation using ANSYS workbench, obtains the 10th order mode of the magazine and its corresponding frequency as shown in Table 1.

| Modal Order | Natural Frequency (Hz) | Modal vibration type | Modal Order | Natural Frequency (Hz) | Modal vibration type |
|-------------|------------------------|----------------------|-------------|------------------------|----------------------|
| 1           | 223.28                 |                      | 6           | 253.38                 |                      |
| 2           | 227.55                 |                      | 7           | 300.69                 |                      |
| 3           | 245.97                 |                      | 8           | 304.26                 |                      |
| 4           | 248.82                 |                      | 9           | 320.66                 |                      |
| 5           | 252.98                 |                      | 10          | 347.84                 |                      |

To determine the main type of the subject, the harmonic response analysis is performed based on the modal analysis. The alternating load of the harmonic response analysis varies from 200Hz to 400Hz, with the solution scheme interval set to 20Hz. Figure 5 shows the amplitude-frequency response figure of the magazine processing process. According to the chart, the amplitude of the timing magazine with...
the frequency near 230Hz is maximum, and the vibration type corresponding to this frequency is the main vibration type of the magazine. Corresponding to the order 2 vibration type of the magazine in Table 1, as shown in figure 6.

It can be seen from figure 5 that the amplitude of the magazine near the frequency 350Hz is also large, and to better design the vibration type corresponding to the frequency as the auxiliary vibration type, as shown in figure 7.

4. Auxiliary Fixture Design

Through ANSYS workbench harmonic response analysis, the main vibration type is shown in figure 6. This vibration type is not conducive to the installation of the fixture, the auxiliary vibration type of the magazine should also be considered to design the fixture. Consider two vibration type, the basic structure of the fixture is determined as octagon\(^{9,10}\).

To make fixture simple and easy to assemble, no additional clamping mechanism is designed, a self-tightening mechanism is choosed. That is, the torsion spring torsion to make the fixture and workpiece tightly bonded together. As shown in figure 8, No.1 is a magazine. In order to reduce damage to the contact between the magazine and the fixture, a rubber washer 2 is added between the magazine and the rubber plate 6 is directly in contact with the rubber washer. A total of 16 same plates ensure full contact between the magazine and the fixture. At the same time, in order to ensure the close contact between the magazine and the clamping, the torsion spring 7 is added between the long bolt 8 and the pressing plate, which makes the pressing plate in close contact with the magazine together under the action of the torsion spring torsion. The calculation equation of the torque force is:

\[
F = \frac{E \pi d^4 \varphi}{3670 D n L} \tag{5}
\]
Among them:

E- elastic modulus (Mpa), torsion spring material is 65Mn spring steel with an elastic modulus 198,000 Mpa;

d- torsion spring diameter (mm), the design angle is 5mm;

\( \varphi \) - torsion angle of the torsion spring, the design angle is 50°;

L- torsion spring arm length (mm) for 60mm;

D- torsion spring middle diameter mm, with a design size of 25mm;

n- effective number of torsion springs and the design number of 12.

5. Modal Analysis of the Magazine Fixture System

In order to check the vibration suppression effect of the fixture, the magazine-fixture processing system is used as the whole by finite element analysis software for modal analysis to observe the amplitude of the magazine before the fixture, so as to verify the effect of the fixture on the vibration suppression in the processing of the magazine[11]-[13].

The magazine and fixture system is simplified and removes the unrelated structure and relationship to the analysis before importing the ANSYS workbench, as shown in Figure 9.

After importing ANSYS workbench, the modal analysis of the magazine-fixture processing system is analyzed, with the specific steps as the previous analysis.

The frequency response diagram of the calculated magazine-fixture processing system is shown in Figure 10. Compared to Figure 5, the maximum frequency response amplitude of the magazine is 100 \( \times 10^{-8} \)m, decreased by 60% by 250 \( \times 10^{-8} \)m, before the uninstalled fixture.

6. Conclusions

- Based on the vibration absorption principle of the spring mass damper, an auxiliary fixture is designed to reduce the machining vibration of the magazine. The fixture consists of rubber gaskets, T frames, press plates, torsion springs and some common standard parts. It has the advantages of obvious damping effect, simple installation, convenient maintenance and adapting to different vibration reduction scenarios.
- The final ANSYS analysis results show that the magazine machining vibration amplitude is reduced by 60%.
- For the vibration damping of the processing system for thin-wall parts using the TMD principle, the quality of the system, the size of the damping, the shape and structure of the fixture on the effect of vibration suppression will be studied in the future work.

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Figure 9. Analysis model of processing system. Figure 10. Frequency response of processing system.
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