Modeling and Simulation Technology of Dynamic Vibration Absorber for Sheet Metal Parts

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***Abstract*—In order to control the vibration of the specific frequency in the process of sheet metal parts, the dynamic vibration absorber is designed. First of all,obtain the target frequency which need to be controlled through modal analysis and determine the installation position of vibration absorber according to the vibration diagram; then get the equivalent mass and equivalent stiffness of the main system , and deduce the parameters of dynamic vibration absorber based on theory; make frequency response analysis on the sheet metal parts before and after the installation of dynamic vibration absorber in the Abaqus software to get the vibration displacement curve of reference point. The simulation results show that the amplitude of the vibration displacement of the reference point is obviously decreased after the installation of the dynamic absorber, which verifies the effectiveness of the vibration absorber.**

***Index Terms*—dynamic vibration absorber, sheet metal parts, Abaqus simulation, equivalent mass method**

I. INTRODUCTION

Sheet metal parts are widely used in many fields, such as aerospace, with the advantages of light weight, compact structure, material saving and so on. Because of the low rigidity of the thin plate parts, it is easy to produce vibration in the machining process. The most direct effect of vibration is produce displacement between the tool and the workpiece, and can reduce the surface quality of the workpiece. Thus control vibration can effectively improve the workpiece processing, and has vital significance to the stability of processing.

Dynamic vibration absorber is a kind of vibration reduction device, its basic structure includes the quality components, stiffness components and damping components. The absorber works as a subsystem attached to the target vibration damper, the reaction force generated by the subsystem in the resonance can reduce the vibration of the main system. Because of its simple structure, easy to implement, obvious effect of vibration reduction and high stability, the dynamic vibration absorbers are widely used in various industries.

The theory of dynamic vibration absorber has a great development in the last century [1], the development trend from single degree of freedom to multi degree of freedom [2], [3], passive to active [4], [5], the frequency range from single to multi [6], [7]. In recent years, domestic and foreign scholars have done a lot of research on the application of vibration absorber, Chen Guo designed a spring type dynamic vibration absorber used in piping system, the experimental results show that the resonant frequency reduced more than 90%, which has a significant effect [8]. Zhang Wulin established a double vibrator multi frequency dynamic vibration absorber based on single oscillator model to break through the traditional limitations of single frequency vibration absorbing. The simulation verifies the good performance of absorber [9]. Qu Hongfei designed a damping vibration absorber to control the vibration of a marine pump motor [10]. Dynamic vibration absorbers have also been widely used in tool damping [11], [12].

In order to control the vibration of sheet metal parts, a passive dynamic vibration absorber is designed based on dynamic vibration absorption theory in this paper, and the performance of the vibration absorber is verified by simulation analysis.

II. MODELING AND MODAL ANALYSIS TECHNOLOGY OF SHEET METAL PARTS BASED ON SIMULATION

In order to verify the performance of the dynamic absorber, it is needed to be applied to the sheet metal parts and apply a load, obtain the response of a point on the sheet before and after the installation of dynamic vibration absorber to draw a comparision. In this paper, a vibration frequency of a sheet metal part is set as the target vibration reduction frequency, and take the displacement response of the point on the sheet as parameter to compare.

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In this paper, the finite element model of the sheet is established by ABAQUS software. The sizes of the sheet are: length a=800mm, width b=600mm, thickness l=5mm. Aluminum Alloy ZL205A is selected as sheet material, the physical parameters of the material are: elastic modulus E=68GPa, shear modulus G=26GPa, Poisson's ratio μ =0.33, density ρ =2820kg/m^3. Define the sheet's length direction as X axis; the width direction as Y axis; the thickness direction as Z axis. The boundary condition is that the bottom is fixed, remaining are free edges, then mesh the body. The model is established as shown in Fig. 1.

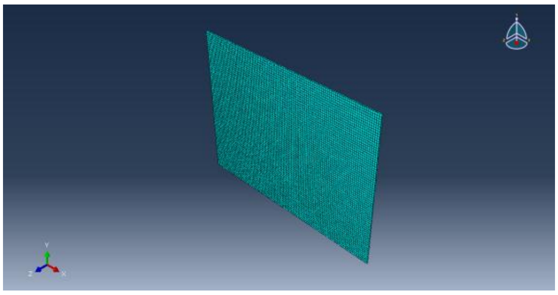

Figure 1. The bottom fixed sheet model

Use ABAQUS software to carry out the modal analysis of the sheet, and obtain the first 30 order natural frequencies. The first 10 order natural frequencies are shown in Table I.

TABLE I. THE FIRST 10 NATURAL FREQUENCY OF THE BOTTOM FIXED SHEET

Modal order	Frequency/[Hz]
1	11.53
2	22.59
3	55.40
4	73.08
5	89.10
6	126.59
7	137.66
8	201.84
9	209.92
10	221.73

Fig. 2 is the modal vibration mode of the sheet corresponding to the first order natural frequency.

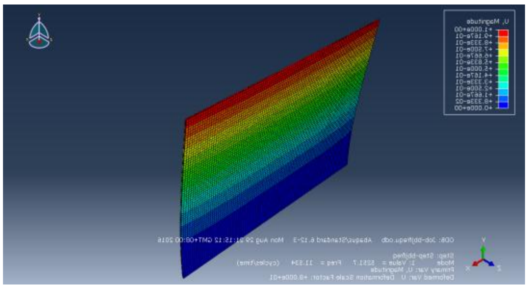

Figure 2. The first order modal vibration mode

It can be seen from Fig. 2 that the first order modal vibration mode of the sheet mainly manifested in the Z direction. Considering the direction of the force loaded and the installation of vibration absorber, in this paper, the first-order natural frequency (f=11.53Hz) is selected as the target vibration frequency.

III. Parameter Determination and Analysis Technology of Dynamic Vibration Absorber

A. *Theoretical Analysis of Dynamic Vibration Absorber*

The dynamic vibration absorber is usually mounted directly on the target vibration system. Its working mechanism is the vibration of main system will lead to the vibration of absorber, the movement of dynamic vibration absorber will produce reactive force and transmit to main system to control the main system's vibration to a certain extent. The additional dynamic absorber is called a subsystem, which is composed of a two degree of freedom system with the main vibration system. The simplified model is shown in Fig. 3.

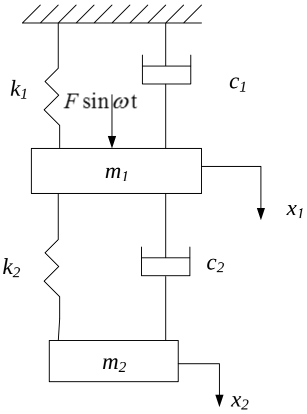

Figure 3. Two degree of freedom system model

Where F is the load; m_1、k_1、c_1 are the mass, stiffness and damping of the main system; m_2、k_2、c_2 are the mass, stiffness and damping of the dynamic vibration absorber; x_1、x_2 respectively represent the displacement of the main system and subsystem.

$$\begin{gathered} m_1\ddot{x}_1+(c_1+c_2)\dot{x}_1-c_2\ddot{x}_2+k_1+k_2x_1-k_2x_2=F \\ m_2\ddot{x}_2-c_2\dot{x}_1+c_2\dot{x}_2-k_2x_1+k_2x_2=0 \end{gathered} \tag{1}$$

Fix-point theory is developed in the last century when research the optimal design of dynamic vibration absorber. It is a method of using the specific point, which has nothing to do with the damping, in frequency response function curve to design a vibration reduction device [13].

After a long period of development and promotion, the fix-point theory obtains the optimal design formula of the dynamic vibration absorber. Thereinto, the inherent frequency of the main system and the dynamic vibration absorber need to satisfy the optimal conditions of homology

$$\gamma=\frac{\omega_2}{\omega_1}=\frac{1}{1+\mu}\ . \tag{2}$$

Damping ratio ζ need to satisfy the optimal damping condition

$$\zeta = \sqrt{\frac{3\mu}{8(1+\mu)^3}}. \tag{3}$$

Thereinto, μ represents the mass ratio of the dynamic absorber and the main system.

B. *Parameter Determination of Absorber Based on Equivalent Mass Method*

As mentioned above, the installation position of the dynamic absorber is on the top of the sheet where the first order mode shape is more obvious, and the quality of the dynamic absorber depends on the mode quality of the target controlled frequency mode. This paper uses equivalent mass method to obtain the equivalent quality of thin plate. The principle is to attach a specific quality in the installation position of dynamic vibration absorber, and obtain the frequency. According to the change of the frequency before and after the additional quality, the equivalent quality of the sheet can be get.

$$m = m'\omega^2 / (\omega_1^{\ 2} - \omega_2^{\ 2}). \tag{4}$$

In which, ω_1 represents the natural angular frequency of the main system, ω_2 represents the natural angular frequency of the system which has installed the dynamic vibration absorber. The m' represents the additional quality, according to

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}. \tag{5}$$

The equivalent stiffness can be obtained

$$k = m\omega_1^{\ 2}. \tag{6}$$

According to the equivalent mass method, a mass weighs 0.6768kg is attached to the installation location of the additional dynamic vibration absorber, then obtain the first-order natural frequency of the sheet which has additional quality as f' =10.639Hz. According to (4), can reach the equivalent quality as *m*=3.861kg, according to (6), can reach the equivalent stiffness as *k*=20277.59N/m.

Ref. [14] proved that the damping effect of absorber increases with the mass ratio, but when the mass ratio is more than 0.1, the growth of the damping efficiency will slow down. And for the consideration of additional weight can't be too large and the limiting installation space, the quality ratio is set as μ =0.1. The quality of the dynamic vibration absorber is: *m1*=0.3861kg; according to (2), (3), can reach the stiffness is: *k1*=1425.86N/m; the damping is: *c1*=9.4 (N.s/m).

IV. An Example Verification Based on Finite Element Simulation

A. *A Sheet Coupled Model for Additional Dynamic Absorber*

Because the performance of the first order modal shape is obvious in the Z direction, and we can see from Fig. 2 that the maximum amplitude position will appear at the top of the sheet. It will have better damping effect if the dynamic vibration absorber is installed in the location where has a relatively large amplitude. Therefore in this paper, the dynamic vibration absorber is installed in the upper end of the sheet at the node14236. The main parts of dynamic vibration absorbers are the quality unit, elastic unit and damping element, Fig. 4 is a sheet model which has installed dynamic vibration absorber. Establish a reference point RP1 face toward the installation node, then establish a quality point at the reference point and give it quality as the mass unit of dynamic vibration absorber, connect quality point and node with a spring damping as elastic element and damping element.

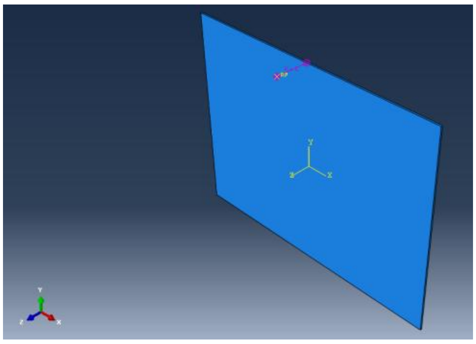

Figure 4. Coupled model of dynamic vibration absorber and sheet

B. *Vibration Reduction Effect Analysis*

Applying harmonic load can stimulate the modal vibration mode more obviously. So a Z axis direction harmonic excitation is applied at a node in the center of the sheet, the amplitude is 2N and frequency range is 1~100Hz. Fig. 5 is the displacement frequency response curve of the node 14265 before and after installation of the dynamic vibration absorber.

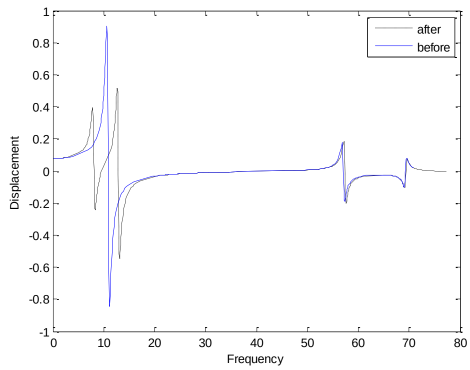

Figure 5. The amplitude frequency response of node 14265 before and after installation of the dynamic vibration absorber

From Fig. 5 can be seen that before the application of dynamic vibration absorber, a peak emerge in the displacement frequency curve of node 14265, and the peak corresponding to the first order natural frequency of the 11.534Hz, Which indicates that the applied harmonic excitation has stimulated the first order vibration mode well. After the application of dynamic vibration absorber, the displacement amplitude decreased significantly in the vicinity of the first order natural frequency, and produced two smaller peak. The maximum peak decreased from 0.905 to 0.516, this means the vibration displacement reduced by 42.7%, and the damping effect is obvious.

The dynamic vibration absorber designed in this paper can effectively restrain the vibration of the first natural frequency of the sheet, and the effective bandwidth is about 3Hz.

Change installation position of the dynamic vibration absorber from maximum amplitude point to the center of the sheet, keep the other conditions are the same, obtain displacement amplitude of node 14236 when the two positions were installed with dynamic vibration absorber vibration separately, the curve is shown as Fig. 6.

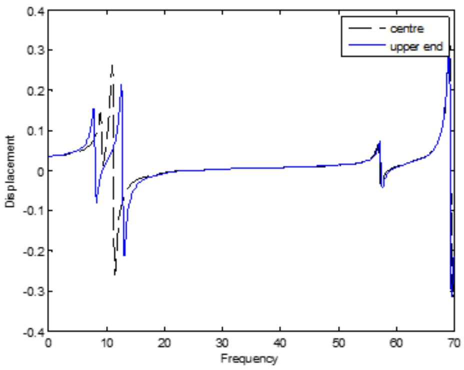

Figure 6. Displacement of node14236 when vibration absorber was installed in different position

From Fig.6, we can see that the amplitude displacement of the node 14236 is relatively small when the vibration absorber is installed at the maximum point of the vibration mode, it shows that the dynamic vibration absorber installed in the larger amplitude point can get a better effect.

V. Conclusion

This paper researched the working principle and design method of the dynamic vibration absorber. Select the sheet metal as a model, then use ABAQUS software to establish finite element model and do modal analysis. Aimed at the first order natural frequency of the sheet, a dynamic vibration absorber is designed based on the equivalent mass method. By coupling model of sheet and dynamic vibration absorber, then perform frequency response analysis to obtain the vibration displacement of the reference node, the results of the study show that

1) The dynamic vibration absorber can effectively reduce the vibration amplitude near the first order natural frequency, the absorption effect is obvious and the absorption bandwidth is wide.
2) The applied force whose direction is consistent with the direction of the vibration mode can effectively stimulate the vibration mode, and the vibration suppression effect is better when the dynamic vibration absorber is installed at the maximum vibration amplitude point.

In addition, use multiple vibration absorbers to control the complex vibration need to be studied in the future.

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