Modal Analysis of Ball Screws in AOI Equipment

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Abstract

Ball screw is an important transmission component in the mechanical industry. During the rotation process, certain vibration, noise and deformation will occur under the action of external force. In this paper, the finite element analysis software ANSYS Workbench is used to analyze the modal of the ball screw in the linear module of AOI equipment of LUSTER LightTech Group. The analysis shows that the first six-order mode of the ball screw is a bending mode, the even-order mode is very close to the natural frequency of the previous step, and the vibration mode of the middle part changes significantly. However, the first six natural frequencies are greater than the motor resonance frequency, which provides a design reference for the motor's assembly.

Keywords

AOI , Linear Module, Ball Screw, Modal Analysis , Bending Mode.

1. Introduction

During long-term operation, mechanical components will generate vibration, noise and deformation due to external forces. Vibration is an important part of structural dynamics research. Vibration is easy to cause resonance and fatigue, which greatly reduces the service life of components [1]. As the basis of dynamic analysis such as response spectrum analysis, transient dynamic response analysis and harmonic response analysis, modal analysis can extract the natural frequency and main vibration mode of structural vibration, and provide design reference for structural fault location, diagnosis and optimization design[2].

As an important transmission component, the ball screw is widely used in AOI inspection equipment. Its performance is directly related to the stability and reliability of the inspection equipment. The ball screw is generally connected with a power component such as a stepping motor, a servo motor, or a DD motor, and the vibration generated by the motion not only causes the transmission component to wear, affects the motion accuracy. But also once it is close to the motor frequency, it is easy to cause resonance. Therefore the motor needs to avoid the main vibration frequency of the ball screw in the adjustment stage. The modal analysis of the ball screw is performed by ANSYS Workbench to obtain its natural frequency and vibration mode, which can provide a basis for the setting of the speed of the stepping motor, and be beneficial to the stable operation of the AOI check equipment.

2. Basis of Modal Analysis

The object itself has a natural frequency and mode shape. The purpose of the modal analysis is to calculate the dynamic characteristics (natural frequency and mode shape) of the object to provide a design basis for the structural design. Common methods for obtaining modal methods include theoretical calculation methods, numerical simulation methods, and experimental analysis methods. Among them, the numerical simulation method is widely used in modal analysis because of its simple calculation, low cost and high computational efficiency. In the numerical simulation method, the finite element method has the advantages of simple and reliable calculation and high calculation precision. In this paper, the modal analysis of the ball screw is analyzed by the finite element analysis software ANSYS. In linear systems, the general differential equation for the free motion of a mechanism is:

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{F(t)\} \tag{1}$$

Among them,[M] is the mass matrix of the structure as a whole; [C] is the damping matrix of structure; [K] is the stiffness matrix of the whole structure; {F(t)} is the external force vector acting on the structure; {x} is the displacement vector of the structural node, and $\{\dot{x}\}$ and $\{\ddot{x}\}$ are the first and second derivatives of {x}.The mode shape and natural frequency of the structure are independent of the external environment, therefore, the influence of damping on vibration is not considered, and the equation of motion of the structure can be rewritten as:

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=0 \tag{2}$$

The displacement vector function of the above formula is $\{x\}=\{X\}\sin(\omega t+\Phi)$, after deriving and substituting a with the above formula, can get the result is:

$$([K]-\omega 2[M])\{X\}=\{0\} \tag{3}$$

After solving the above formula, the square root of the eigenvalue is the natural frequency, and the corresponding vibration mode is obtained after being brought in.

3. Ball Screw Modal Analysis

This paper takes the ball screw of a brand linear module as the research object, the nominal diameter of the screw shaft D=15mm,lead Ph=100mm, screw stroke Ls=350mm, and the supporting method is one end fixed at one end free. To improve the quality and efficiency of the grid, Simplify the ball screw and use Solid Works to create a 3D model as shown in Fig. 1. After introducing the model into ANSYS Workbench, the material density was set to 7850 kg/m3, the elastic modulus was 2.1E11Pa, and the Poisson's ratio was 0.3.

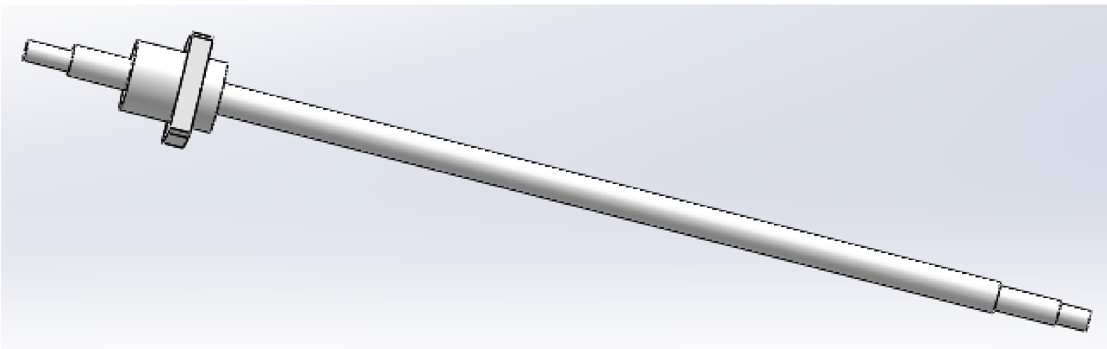


Fig 1. Ball screw model assembly drawing

In finite element analysis, the quality of the mesh determines the speed and accuracy of the analysis. If the mesh is too sparse, the calculation accuracy will be too low. If the mesh is too dense, the calculation will increase, and even the calculation result will not convergeIn ANSYS Workbench there are automatic meshing, tetrahedral mesh, hexahedral mesh, sweep mesh, etc[3]. In this paper, we use the free mesh and control grid cell size to divide the mesh, and finally get the mesh model of the ball screw as shown in Fig. 2.

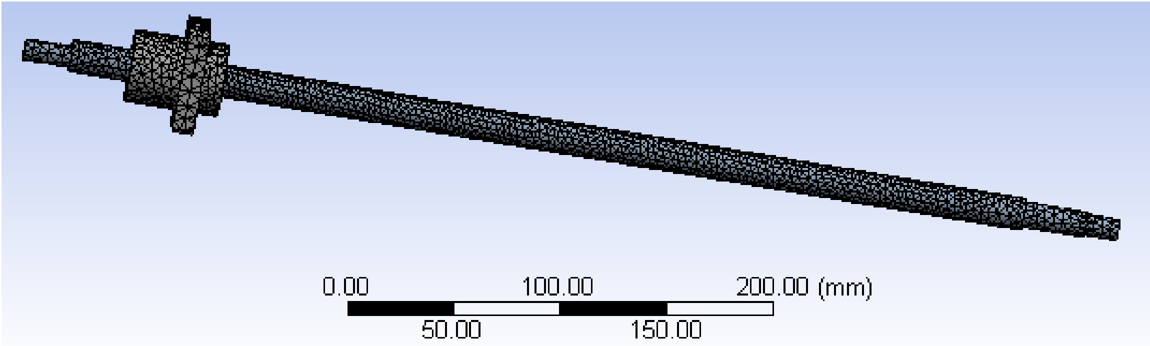


Fig 2. Ball screw grid model

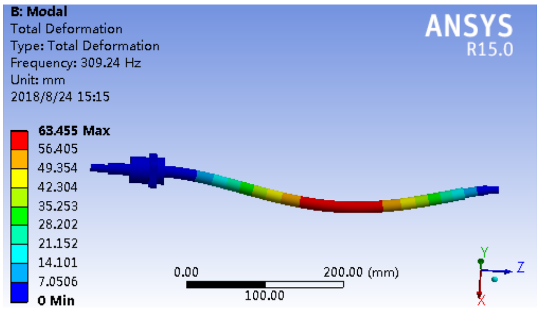
In order to ensure the accuracy of the calculation results, after the meshing is completed, the ball screw is restrained according to the actual working condition in Modal, wherein the movement of the two end faces of the screw rod on the x, y, and z axes and the radial and cutting are performed. The rotation of the direction, the other degrees of freedom of the constraint nut except the movement in the x-axis direction.

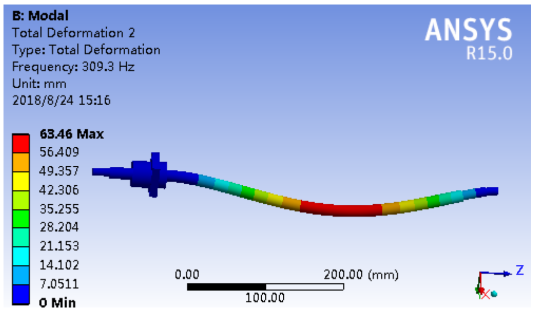
In the modal analysis, there are high-order modes and low-order modes. The high-order modes are complex, the calculation is large, the modal data is far away from the vibration frequency and difficult to verify; the low-order mode has small stiffness, small calculation, and dynamic characteristics. The position in the analysis is more prominent. Therefore, the natural frequencies and vibration modes of the first six modes are shown in Table 1 and Fig. 3.

Table 1. The first six modes natural frequency of the ball screw

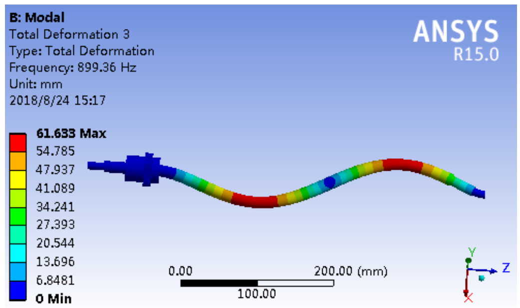
Order	1	2	3	4	5	6
Frequency/Hz	309.24	309.3	899.36	899.57	1789.8	1790.3

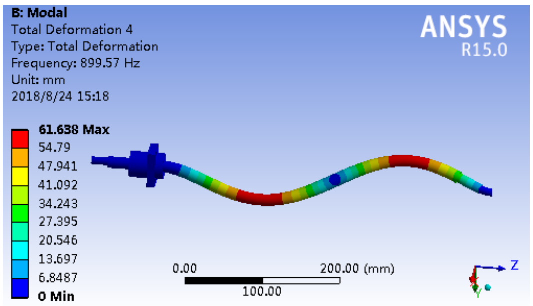
It can be seen from Table 1 that the natural frequency of the ball screw is 309.24 Hz to 1790.3 Hz, and the resonant frequency of the stepping motor with a general step angle of 1.8 is about 180 Hz-250 Hz [4]. The natural frequency of the ball screw avoids the resonance frequency region of the motor and does not resonate. It can be seen from Fig. 3 that the first six modes of the ball screw are bent, the first-order mode is represented by one bend along the x-axis direction, and the second-order mode is represented by one bend along the y-axis direction, third order. The modal representation is a quadratic bend along the x-axis, the fourth-order mode is a quadratic bend along the y-axis, and the fifth-order mode is a cubic bend along the x-axis, the sixth-order mode Expressed as three bends along the y-axis. Moreover, the bending of the middle part of the screw is more serious than other parts, and should be the weak part of the screw. It can be seen from Table 1 and Figure 2 that the even-order mode is very close to the natural frequency of the previous order and the corresponding mode is orthogonal, which can be approximated as the result of the same-order mode coupling [5].



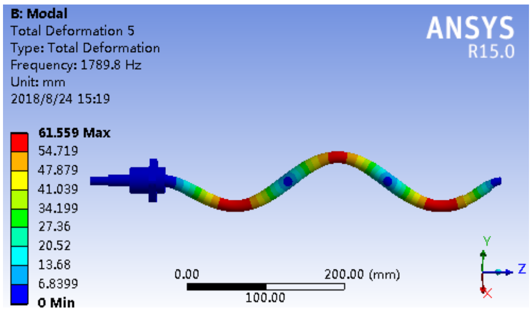


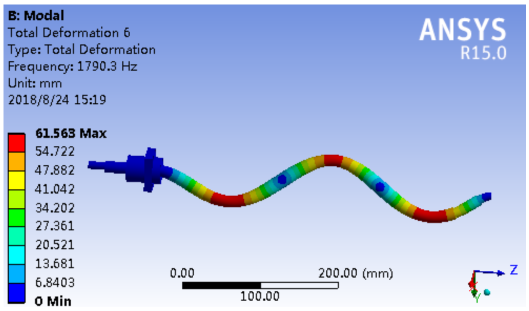
(a) The first order mode shape (b) The second order mode shape





(c) The Third-order mode shape (d) The Fourth order mode shape





(e) The Fifth order mode shape (f) The sixth order mode shape

Fig 3. The first six modes shapes of the ball screw

4. Conclusion

This paper uses 3D modeling of the ball screw on the module in the AOI equipment and using the finite element method for modal analysis, obtaines the first six modes shapes and natural frequencies of the ball screw and provides a reference for the installation and commissioning of the motor and also provides a basis for the vibration performance analysis of the ball screw. Research shows that the middle position of the screw is its weak part. In the future, we can consider optimizing the design of materials, heat treatment, grinding and other methods to enhance its linearity, surface roughness and surface hardness. Thereby increasing the fatigue strength of the screw, stiffness, stability, increase the life of the linear module.

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