Dynamic characteristics and influencing factors of azimuth axis of a new antenna pedestal

WEN Guang1, CHENG Ming2*, TANG Xianchun2, JIANG Xinhui2, ZHANG Xuerong2

1School of Intelligent Manufacturing, Chengdu Technological University, Chengdu 611730, China
2Chengdu Radio Special Equipment Factory (state owned 633 factory), Chengdu 611730, China
Wg66360336@126.com

Abstract: Based on the finite element method, the dynamic characteristics of the azimuth axis of an antenna pedestal were studied. With the help of modal analysis module of finite element software, the modal natural frequency and modal shape of the structure were obtained, and the influence of structural size parameters on its dynamic characteristics was also investigated. Through the research, it can be concluded that the first six natural frequency values of the azimuth axis are 220.21, 220.24, 1178.2, 1519.9, 1531.3, 1531.3 Hz. And the first six modes are shown as follows: the first and second order is the swing mode of the axis, the third order is the up and down stretching mode of the azimuth axis, the fourth order is the torsional vibration mode of the azimuth axis, and the fifth and sixth order are the first bending vibration mode of the azimuth axis. The first and second order natural frequencies of the axis decrease with the increase of size parameters \(d_2\), \(l_1\) and \(l_2\), and increase with the increase of size parameters \(d_1\), \(d_3\) and \(d_4\). The analysis results provide a theoretical basis for the optimization of the dynamic performance of the azimuth axis.

1. Introduction
The azimuth axis is an important part of the antenna support, which is mainly used to adjust and determine the antenna orientation. It mainly bears the periodic torsional load in the work. The antenna needs to rotate constantly when searching for the target, and the dynamic characteristics of the structure have a certain influence on its search accuracy. It is very necessary to carry out the dynamic characteristic analysis for the antenna support structure design. Azimuth axis is one of many mechanical parts. In the past mechanical parts and even the whole machine structure design, relevant engineering researchers have done a lot of detailed and effective analysis around its dynamic characteristics. In literature [1], taking the output shaft of a reducer as the research object, the transient dynamic analysis was carried out by using the finite element method. Through the analysis, the parts of the structure with greater stress under the impact load were found, and the dynamic response of the structure under different impact loads and rotating speeds was studied. In literature [2], the dynamic characteristics of a machine tool were analyzed by using the structural unit. It is found that the machine tool with trilateral body has better dynamic characteristics. In literature [3] and [4], the dynamic characteristics of machine tool spindle were analyzed by simulation analysis method, and the dynamic characteristic parameters such as natural frequency and vibration mode were obtained. In literature [5], the metal structure of a truss gantry crane was taken as the research object, modal analysis and
harmonic response analysis on the metal structure were carried out, and the natural frequency and vibration mode parameters of the structure were obtained. In literature [6] and [7], considering the stiffness of the joint surface, the dynamic characteristics of the ball screw feed system under the premise of were respectively analyzed. In literature [8], the dynamic characteristics of a vane type hydraulic swing cylinder were simulated and analyzed by using Matlab / Simulink software. Through the analysis, the main factors affecting the response speed and stability of the swing cylinder were found. In literature [9], the structural dynamic characteristics of a motorcycle frame and frame mounted engine were analyzed by using experimental and analytical methods. It is found that the dynamic characteristics of the frame structure were greatly affected by the engine. Based on the response surface theory, the dynamic characteristics of CNC machine tools in the machining space were studied in literature [10], and the influence degree of the displacement changes of moving parts in each direction on the dynamic characteristics of the machine tool was calculated. In this paper, based on the theory of finite element dynamic characteristics analysis, the dynamic characteristics of a new antenna support azimuth axis were analyzed by using modal analysis module, and the influence of structural size parameters on its dynamic characteristics was also investigated.

2. Structural sketch of the azimuth axis
The research object of this paper is azimuth axis of a new antenna support. Its structure is shown in Fig. 1. The azimuth axis is a stepped shaft, which mainly bears the torque caused by motor starting during operation. The shaft is made of Q345 steel, and its material characteristic parameters are shown in Tab. 1.

![Fig. 1 Structural diagram of azimuth axis](image)

| Characteristic parameters | Density/Kg/mm³ | Elastic modulus/MPa | Poisson's ratio |
|--------------------------|---------------|---------------------|----------------|
| Values                   | 7.85×10⁻⁶     | 2.1×10⁵             | 0.3            |

According to the modeling principle of the finite element software ANSYS, the finite element model of the azimuth axis was established by using APDL language. The solid 45 element was selected to simulate the azimuth axis, and the whole axis was meshed by sweeping. The divided finite element model is shown in Fig. 2. There are 37311 elements and 47160 nodes in the whole model.
3. Modal analysis of the azimuth axis

There are many kinds of structural dynamic characteristics analysis based on finite element method, such as modal analysis, harmonic response analysis, transient dynamic analysis and so on. Among them, modal analysis is mainly used to analyze the natural vibration characteristics of the structure, so as to obtain the structural natural frequency, modal shape and other dynamic characteristics parameters, which lays the foundation for the subsequent structural dynamic characteristics analysis.

According to the dynamic analysis theory, the dynamic equation of the azimuth axis can be described as:

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

In the above formula: \([M]\) represents mass matrix; \([C]\) represents damping matrix; \([K]\) represents stiffness matrix; \([u]\) represents node displacement vector; \([\ddot{u}]\) represents node acceleration vector; \([\dot{u}]\) represents node velocity vector; \([F(t)]\) represents node load vector.

In the modal analysis, the dynamic equation of the azimuth axis can be simplified as follows if the damping and external load of the azimuth axis are neglected.

\[ [M]\{\ddot{u}\} + [K]\{u\} = \{0\} \] (2)

After the finite element model was established in ANSYS software, according to the actual working conditions of the azimuth axis, the fixed installation surface was constrained, and the Lanczos Method was used for modal analysis of the azimuth axis. Considering that the lower order modes of the structure have great influence on its dynamic characteristics, only the first six modes of the azimuth axis were extracted in this paper. Tab. 2 shows the natural frequencies of the first six modes of the azimuth axis, and the corresponding modal shapes are shown in Fig. 3.

| Order | 1    | 2    | 3    | 4    | 5    | 6    |
|-------|------|------|------|------|------|------|
| Frequencies/Hz | 220.21 | 220.24 | 1178.2 | 1519.9 | 1531.3 | 1531.3 |
From the modal natural frequency analysis results in Tab. 2, it can be seen that the first and second order modal natural frequencies of the azimuth axis are closer to the working frequency. Therefore, the first and second order modal natural frequencies should be the key frequencies to be focused on in the design.

It can be seen from the azimuth axis mode shape diagram in Fig. 3 that the first six modes are shown as follows: The first and second modes are the swing mode of the azimuth axis, the third mode is the up and down stretching mode of the azimuth axis, the fourth mode is the torsional mode of the azimuth axis, and the fifth and sixth modes are the first bending mode of the azimuth axis.

4. Influence analysis of structural size parameters
In order to further study the influence of structural size parameters of azimuth axis on its dynamic
characteristics, in this paper, the structural size parameters of the azimuth axis in different values were selected for modal analysis, and the changes of the key modal natural frequencies, that is, the first and second order natural frequencies of the azimuth axis with the size parameters were observed. When taking values, only one of the structural size parameters was changed, and the values of other parameters remained unchanged. The values of structural size parameters of different models are shown in Tab. 3, and the curves of natural frequencies of key modes with parameter values drawn are shown in Fig. 4.

| Parameters | \(d_1\) | \(d_2\) | \(d_3\) | \(d_4\) | \(l_1\) | \(l_2\) |
|------------|---------|---------|---------|---------|---------|---------|
| Values 1   | 200     | 175     | 120     | 80      | 100     | 480     |
| Values 2   | 202     | 177     | 122     | 82      | 102     | 482     |
| Values 3   | 204     | 179     | 124     | 84      | 104     | 484     |
| Values 4   | 206     | 181     | 126     | 86      | 106     | 486     |

(a) curve of the first natural frequency with \(d_1\)  
(b) curve of the second natural frequency with \(d_1\)  
(c) curve of the first natural frequency with \(d_2\)  
(d) curve of the second natural frequency with \(d_2\)  
(e) curve of the first natural frequency with \(d_3\)  
(f) curve of the second natural frequency with \(d_3\)
Fig. 4 Variation curve of natural frequency of key modes of azimuth axis with dimension parameters

It can be seen from Fig. 4 that when the same parameter value changes, the change trend of the first and second order natural frequencies of the azimuth axis is consistent. With the increase of dimension parameters $d_1$, $d_3$, and $d_4$, the natural frequencies of key modes of azimuth axis increase. With the increase of dimension parameters $d_2$, $l_1$, and $l_2$, the natural frequencies of key modes of azimuth axis decrease.

5. Conclusions
In this paper, the finite element software ANSYS was used to analyze the dynamic characteristics of the azimuth axis of a new antenna support, and the influence of the structural size parameters of the azimuth axis on the dynamic characteristics was also studied. The main conclusions are as follows:

(1) The natural frequencies of the first six modes of the azimuth axis are: 220.21, 220.24, 1178.2, 1519.9, 1531.3, 1531.3 Hz, and the first six modes are mainly manifested as follows: the first and second order is the swing mode, the third order is the up and down stretching mode, the fourth order is the torsional vibration mode, and the fifth and sixth order are the first bending vibration mode.

(2) The natural frequencies of the key modes of the azimuth axis are positively correlated with the structural parameters $d_1$, $d_3$, and $d_4$, and negatively correlated with the structural size parameters $d_2$, $l_1$, and $l_2$.

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