Analysis and Testing of the Dynamic Characteristics of Rotor Worktable

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Abstract. The finite element modelling, mesh generation and modal analysis of the rotor worktable are carried out by combining the analysis technology of finite element software in this paper. Then, the software analysis results and the actual experimental results are compared and analyzed, so as to get the causes of error, which can provide good basic data for the use of the rotor table in the future that could better meet the needs of scientific research and teaching.

1. Introduction

As a kind of power equipment, rotating machinery is widely used in production and life\textsuperscript{[1]}. As an important part of rotating machinery, the normal operation\textsuperscript{[2]} of the whole equipment will be affected or even determined by the performance of Flexible rotor. In the process of the actual research on the performance of the rotor, it is usually necessary to use the experimental instrument such as the rotor workbench that facilitate the various experiments on the rotor\textsuperscript{[3][4]}. But in the actual experiment, the results of rotor experiment are affected by the service life, the degree of wear, the vibration of rotor rotation\textsuperscript{[5][6]} and other factors of rotor table. Therefore, it is particularly important to be familiar with the structure and performance of rotor worktable.

Modal analysis is a modern method to study the dynamic characteristics of structures\textsuperscript{[7]}, which is mainly used to determine the vibration characteristics of structures or machine components. For the modal analysis of rotor vibration characteristics, a lot of research have been done by domestic scholars. The modal analysis error of flexible rotor system of Maglev motor under nonlinear contact are analyzed and verified by Ziyuan Huang\textsuperscript{[8]}. The modal analysis of magnetically suspended rotor that verified by relevant experiments is carried out by Kelei Li\textsuperscript{[9]}. The safe area of working speed of flexible rotor of high-power high-speed permanent magnet motor is analyzed by Guanghui Du\textsuperscript{[10]} through modal analysis.

In this subject, the results of the modal analysis of the rotor table that is carried out by combining the analysis technology of the finite element software are compared and analyzed with the calculation results of the actual experiment that would obtain the cause of the error, which would provide good basic data for the use of the rotor workbench in the future and some reference for the design and analysis of the rotor workbench.
2. Simulation model modeling of rotor working table

2.1. Rotor table modeling
The rotor table is basically composed of base, oil cup, oil bearing support, oil cup, eddy current sensor mounting support, counterweight plate and DC motor. In this paper, SolidWorks software is used to model inv 1612 multifunctional flexible rotor worktable. The assembly drawing of parts is shown in Figure 1.

![Fig.1 Overall assembly drawing of rotor table.](image)

2.2. Finite element modeling of rotor table
First, the model built in Solidworks must be saved as .x_t file format, and then the file must be imported into ANSYS finite element software. According to the actual situation of the rotor worktable, the rotor worktable is fixed and restrained (fixed support is added on the base to limit all degrees of freedom of points, edges or faces, but no load is added. The whole rotor table is simplified to be composed of one material, and the material parameter settings are shown in Table 1:

|        | Material                  | 45 Steel |
|--------|---------------------------|----------|
| Elastic modulus | 210GPa                     |          |
| Damping ratio   | 0.3                        |          |
| Density        | 7850kg/m                   |          |

The finite element mesh generation of the rotor workbench is carried out in the modal module. The mesh generation is automatic, and the mesh size is appropriate. The finite element mesh model is shown in Figure 2.

![Fig.2 Finite element mesh model of rotor table.](image)

2.3. Analysis of post-processing results
Since the low-order modes of the rotor worktable have practical reference value for the dynamic characteristic analysis of the rotor worktable, the first six \(n = 6\) modes of the rotor worktable are
obtained by using ANSYS 16.0 software, and the natural frequencies of each order are shown in Table 2. In the table: n - Order of mode; \( \omega \) - Natural frequency of rotor table.

| n  | 1    | 2    | 3    | 4    | 5    | 6    |
|----|------|------|------|------|------|------|
| \( \omega \) | 140.28 | 140.43 | 262.73 | 494.44 | 495.7 | 909.3 |

The first six modes of the rotor can be clearly seen in the modal analysis module of ANSYS, and its vibration mode diagram can be analyzed. In the vibration mode of the first-order natural frequency of the rotor table, it can be seen that it has longitudinal bending vibration, which is mainly shown that the downward bending of the counterweight shaft, as shown in Figure 3; in the second-order mode, it also shows longitudinal bending vibration, with large deformation and upward bending of the heavy shaft, as shown in Fig. 4; in the third mode, it has torsional bending, as shown in Figure 5; in the fourth mode, it bends longitudinally, which is mainly manifested in the large deformation and downward bending of the shaft of the eddy current sensor on the right side of the counterweight plate, as shown in Figure 6; in the fifth mode, it has longitudinal bending vibration, which is mainly manifested in large eddy current deformation and upward bending of the counterweight plate on the right side of the sensor shaft, as shown in Fig. 7; it has transverse bending vibration in the sixth mode, as shown in Figure 8.
3. Experimental analysis

3.1. Experiment Scheme

This test is mainly to test the dynamic characteristics of rotor worktable by hammering method. Compared with other methods, hammering method has obvious advantages, simple operation and easy control.

Firstly, according to the experimental instructions of the rotor workbench, the rotor workbench is connected with computers that need to set the parameters. Then the rotor workbench should be hit by hammer in turn and check the response attenuation signal should be checked. Finally the frequency value and damping value of the current waveform in the spectrum diagram should be observed and recorded.

3.2. Composition of experimental system

The system is mainly composed of rotor worktable, force hammer, INV1601B vibration teaching, experimental instrument and so on. The INV1601B vibration teaching experimental instrument and hammer used in the experiment are shown in Fig. 9 and Fig. 10 respectively.
3.3. Experimental results and analysis

Tab 3. Spectrum peak list.

| No. | Frequency (Hz) | Amplitude spectrum (Peak) | Damping ratio |
|-----|----------------|---------------------------|---------------|
| 1   | 19.04297       | 15.79974                  | ----          |
| 2   | 49.80469       | 1309.072                  | 1.21%         |
| 3   | 99.60938       | 19.10921                  | ----          |
| 4   | 107.4219       | 16.856                    | ----          |
| 5   | 109.375        | 16.51903                  | ----          |
| 6   | 111.8164       | 16.04238                  | ----          |
| 7   | 149.9023       | 102.9708                  | 0.34%         |
| 8   | 250            | 75.21978                  | 0.27%         |
| 9   | 349.6094       | 34.44186                  | 0.18%         |
| 10  | 449.707        | 82.59216                  | 0.12%         |

In the experimental data in Table 3, the 10th order natural frequencies during rotor bench test are listed. Their trend is also gradually increasing, while the damping ratio is gradually decreasing, which is in line with the actual situation. However, due to the limitations of experimental operation, experimental equipment and professional level, only five damping ratios are measured, which is a pity.

4. Conclusion

(1) Through the modal analysis of the dynamic characteristics of the rotor table, the vibration and deformation of the first six modes are different. With the increase of frequency, the deformation is basically bending from left to right.

(2) Through comparison, it can be found that there is a deviation between the simulation experimental results and the actual results, which can be seen from the difference between the natural frequency of the simulation results and the natural frequency of the experimental results. Although the simulation has tried to imitate the actual situation, it still deviates from the actual situation. For example, the simulation is based on the integration of rotor worktable, which is different from the actual situation. In addition, the rotor workbench used in the laboratory is a device that has been used for some time, which has been worn and will also affect the experimental results. But in general, this provides good basic data for the future use of the rotor worktable, and also provides a certain reference for the research of the rotor worktable.

Reference

[1] Xiaojing Ma, Mai Timin Aini, Yaling Yan, et al. (2012) Experimental study on vibration characteristics of single disk flexible rotor. Machine Tool & Hydraulics, 40: 34-36.

[2] Yan Wang, Jisheng Ma, Haiqi Zheng, et al. (2012) Dynamic characteristic analysis of gear bearing system with flexible rotor. Vibration. Journal of Vibration, Measurement & Diagnosis, 32: 51-55.

[3] Changsheng Zhu, Chuan Mao. (2019) Experimental study on vibration reduction characteristics of concentric squeeze film damper with partial contact between inner and outer rings of oil film. Journal of Vibration Engineering, 32: 116-122

[4] Shengxi Jia, Longxi Zheng, Wangqun Deng, et al. (2018) Dynamic balance test system of flexible rotor without test weight mode. Journal of Vibration, Measurement & Diagnosis, 38: 1108-1113+1287-1288.
[5] Jie Hong, Cheng Chen, Yongfeng Wang, et al. (2018) Vibration characteristics test of high speed flexible rotor system under sudden unbalanced excitation. Journal of Aerospace Power, 33: 15-23.

[6] Yanlei Gao, Yong Li, Deyou Wang. (2001) Experimental study on vibration characteristics of flexible rotor. Aeroengine, :21-24.

[7] Bin Yang, Jianping Tan, Jianxiong Yao, et al. (2013) Dynamic characteristic analysis of fault flexible rotor system. Journal of Mechanical Transmission, 37: 106-109.

[8] Ziyuan Huang, Bangcheng Han, Yinfeng Zhou, et al. (2014) Modal analysis of flexible rotor system of Maglev motor under nonlinear contact. Proceedings of the CSEE, 34: 2438-2444.

[9] Kelei Li, Zhenyu Xie. (2008) Modal analysis of magnetic levitation rotor based on ANSYS. Journal of Mechanical & Electrical Engineering, :1-3.

[10] Guanghui Du, Na Huang, Fengge Zhang, et al. (2017) Modal analysis of flexible rotor system of high power and high speed permanent magnet motor. Transactions of China Electrotechnical Society, 32: 101-107.