Finite Element Analysis of High-speed Rotary Fixture of CNC Machine Tool

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Abstract. As an important functional component of CNC lathes and turning-milling machining centers, high-speed rotary fixtures play an important role in machining. Because the high-speed rotary clamp has the characteristics of large plate structure and high working speed, huge centrifugal force will be generated during rotation, which leads to the safety problem of unreliable clamping during work. In this paper, the geometric model of the high-speed rotary fixture is established, the contact mode of the key parts of the fixture is defined, and the mechanical properties of the high-speed rotary fixture under the condition of centrifugal force are analyzed by the finite element analysis method; and the different structural sizes, The influence of materials and working speed on the stress and strain of the fixture plate body is studied. Lay the foundation for subsequent fixture structure optimization and failure analysis.

Keywords: high-speed rotary fixture, finite element analysis, centrifugal force, mechanical properties.

1. Introduction

Modern manufacturing technology is developing in the direction of high efficiency, high precision and flexibility, which puts forward the requirements of high speed, high precision and flexibility for machine tool fixtures [1]. In CNC machine tools, the high-speed rotary fixture is the most commonly used functional component, which is the interface between the machine tool spindle and the workpiece [2-3]. In machining, it plays the role of transmitting the torque, rotational speed and rotation accuracy of the machine tool spindle to the workpiece [4]. High-speed rotary fixtures are being widely used due to their high speed, high transmission efficiency, compact structure, and large clamping force [5]. However, due to the high speed of the fixture, the clamp is often accompanied by huge centrifugal force when working, resulting in the loss of clamping force and the unreliable clamping of the fixture, which limits the further development of high-speed rotary fixtures [6-7]. In addition, the structural size and material of the clamp disc body will also have a huge impact on the mechanical properties of the high-speed rotary fixture, which determines the working life of the fixture [8].

In this paper, ANSYS finite element software was used to analyze the stress and strain characteristics of the disc body of the K55 series high-speed rotary fixture. Under the condition of centrifugal force, the influence of different inner and outer diameters, materials and rotation speeds of the clamp disc on the stress and strain of the disc body was explored. The weak links of the strength of the fixture disc and the large deformation position are found, which lays a foundation for the determination of the physical property parameters and working condition parameters of the fixture and the subsequent research work.

2. High-speed Rotary Fixture

Fig. 1 is an explosion view of the K55 series high-speed rotary fixture [9], which is mainly composed of a push-pull ring, a push-pull sleeve, a wedge sleeve, a disc body, a slide, a T-block, a flap and a soft jaw. The authors will conduct finite element analysis on the high-speed rotary fixture to study the influence of different sizes, materials and speeds of the clamp disc structure on its stress and strain characteristics.

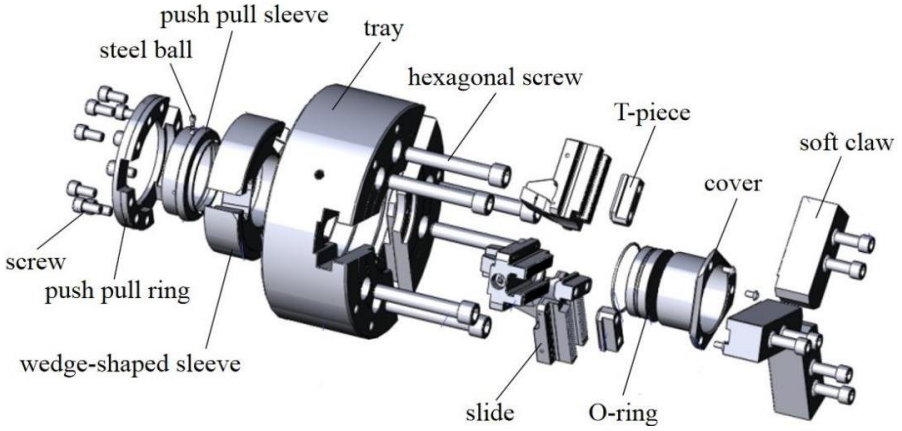

Figure 1. Exploded view of high-speed rotary fixture.

3. Model Handling and Boundary Conditions

3.1. Simplify the geometry

It can be seen from Figure 1 that the structure of this high-speed rotary fixture is complex, and there are more parts and assembly features therein. However, the existence of features such as fillets, chamfers, threaded holes, positioning holes, and oiling grooves has no great impact on the overall mechanical properties of the fixture [10], and it will occupy more resources when performing finite element analysis, making the meshing more complex [11]. In order to facilitate finite element analysis, the fixture screws, caps, sealing rings, springs and other parts that have little influence on the analysis results are omitted and modeled in Solidworks, and the simplified fixture model is shown in Figure 2.

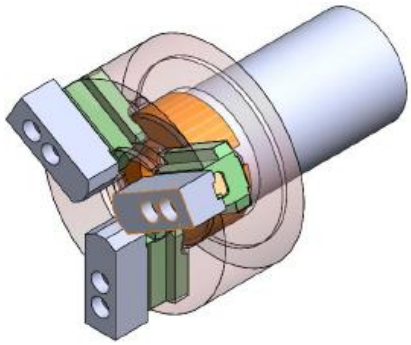

Figure 2. Simplified fixture model.

(1) Import the 3D model into the Static Structural-Mechanical module in ANSYS software to complete the relevant settings for geometric pre-processing. The specific settings are as follows:

(2) Complete the material settings for each part of the geometric model. The material of the clamp disc body and each part of the parts is initially set to 42CrMo.

(3) Connection settings. Soft jaws and bolts, bolts and T-blocks, soft jaws and base jaws, base jaws and T-blocks, tie rods and wedge sleeves are all set up as fixed connections [12], limiting the degree of freedom of their relative movements. The upper and lower end faces of the two wings of the base jaw, the upper and lower end faces of the chuck base jaw groove, and the outer wedge surface of the base jaw wedge block and the outer wedge surface of the wedge groove of the wedge sleeve (working stress surface) are set up as frictional connections [13].

(4) Meshing. Because the clamp body is an irregular geometric model, Solid92 mesh elements from ANSYS are selected for meshing. Solid92 can mesh irregular models well [14], and the final mesh model is shown in Figure 3.

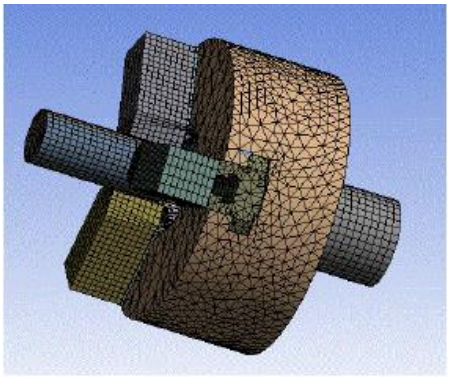

Figure 3. Finite element model.

Fig. 4 is the structural diagram of high-speed rotary fixture disc body, and fixture disc body is connected with machine tool spindle by transition flange.

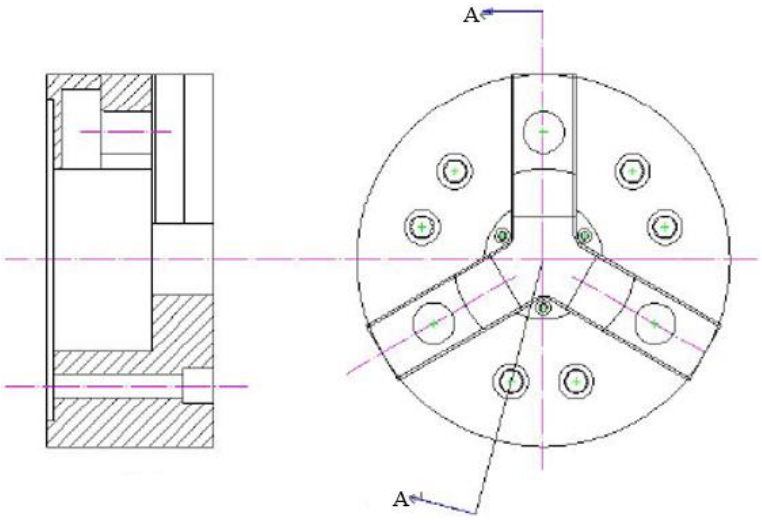

Figure 4. Schematic diagram of fixture disc body.

When the high-speed rotary fixture is working, the clamp disc body will be subjected to the force of the lever, and because the lever is evenly distributed in the disc body, the reasonable amount of the disc body being subjected to the lever is zero. Therefore, when studying the influence of the inner and outer diameters of the disc on the stress and strain characteristics of the disc body, it is only necessary to analyze the disc body in the idling state, when the disc body is only subjected to centrifugal force at high speed, and the magnitude of centrifugal force depends on the rotation speed under different working conditions [15]. When adding constraints, since the fixture disc body is connected to the machine spindle by a transition flange, it is sufficient to limit its Z direction to a fixed constraint. Due to the limitation of the size of the sliding shaft, the inner diameter of the disc is in the range of 100~140 mm, and the outer diameter is in the range of 230~260 mm.

4. Analysis and Discussion of Results

The established geometry was imported into ANSYS for finite element analysis of the fixture disc, and the initial parameters of the fixture disc were 250 mm outer diameter, 120 mm inner diameter, and 42 CrMo material. The working speed is set to 8000 r/min. Under this condition, the stress and strain distribution of the clamp disc body are shown in Fig. 5 and Fig. 6 respectively.

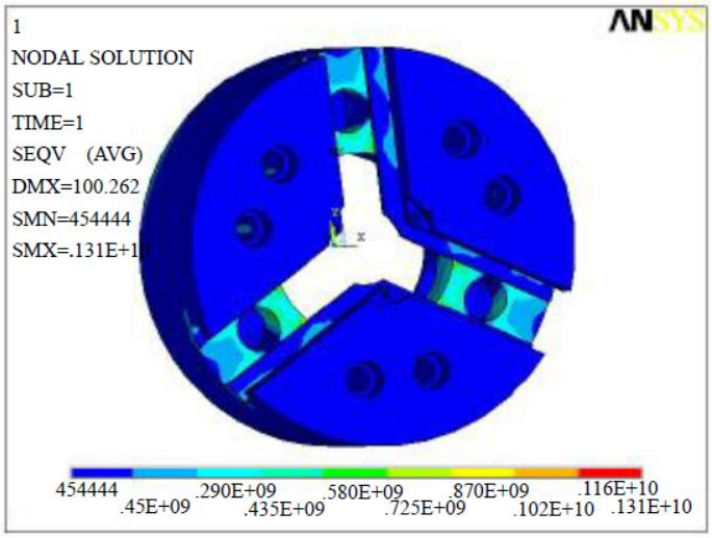

Figure 5. Stress distribution of fixture disc.

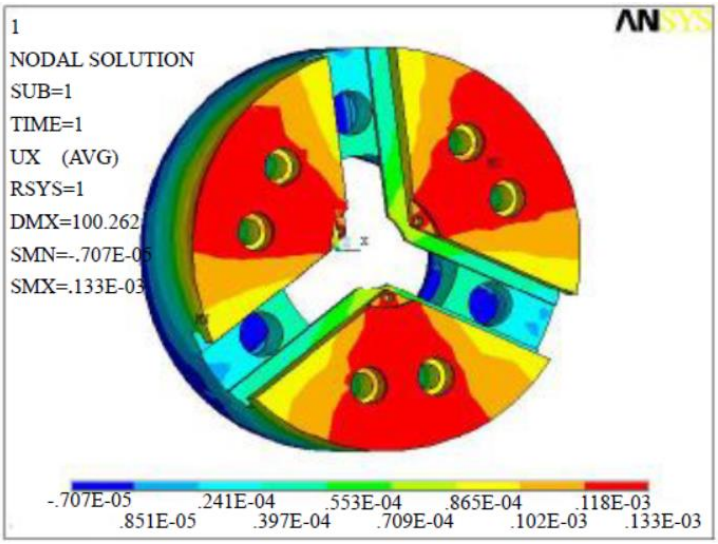

Figure 6. Strain distribution of fixture disc.

It can be seen from Fig. 5 that under the condition of this parameter, the maximum stress of the clamp disc appears in a small area at the junction of the slide and the lever, and this area is close to the center of the clamp disc body; The maximum stress value of the disc is 1310 MPa, which exceeds the yield limit of the material [16], and the disc body undergoes plastic deformation. Fig. 6 is the strain diagram of the clamp disc body, and it can be seen from the figure that the maximum deformation of the disc body occurs at the front end face position of the fixture disc body, and the maximum deformation amount is 0.133 mm, which will have an impact on the positioning accuracy of the fixture. Therefore, under the condition of 8000 r/min, the centrifugal force of the clamp disc body is large, which exceeds the stress and strain limit of the fixture disc body, and the fixture fails.

It is worth noting that the stress and strain characteristics of the clamp disc body are not only affected by the working speed, but also the inner and outer diameter dimensions of the disc body and the material also affect its stress and strain characteristics.

4.1. Effect of the inner diameter of the disc

Based on the above analysis process, the inner diameter of the clamp disc body is analyzed by changing the inner diameter size of the disc body at different speeds. According to the analysis results, the variation curve of the maximum stress value of the disc body with the inner diameter of the disc

at different speeds can be plotted, as shown in Fig. 7, and the variation curve of the maximum strain value with the inner diameter of the disc at different speeds is shown in Fig. 8.

As can be seen from Fig. 7, the change of rotation speed has a great influence on the maximum stress value of the clamp disc body, when the rotation speed reaches 8000 r/min, the clamp disc body has exceeded or approached the allowable stress value of 42CrMo of the disc material, and the disc body fails. It shows that centrifugal force plays an important role in the safety performance of the fixture when the fixture rotates at high speed, so how to compensate the centrifugal force is an important issue to be considered in the later stage when the fixture is designed. In addition, under different speeds, the maximum stress value of the clamp disc body rises with the increase of the inner diameter size, so the reasonable inner diameter size also has an important influence on the force of the clamp disc body.

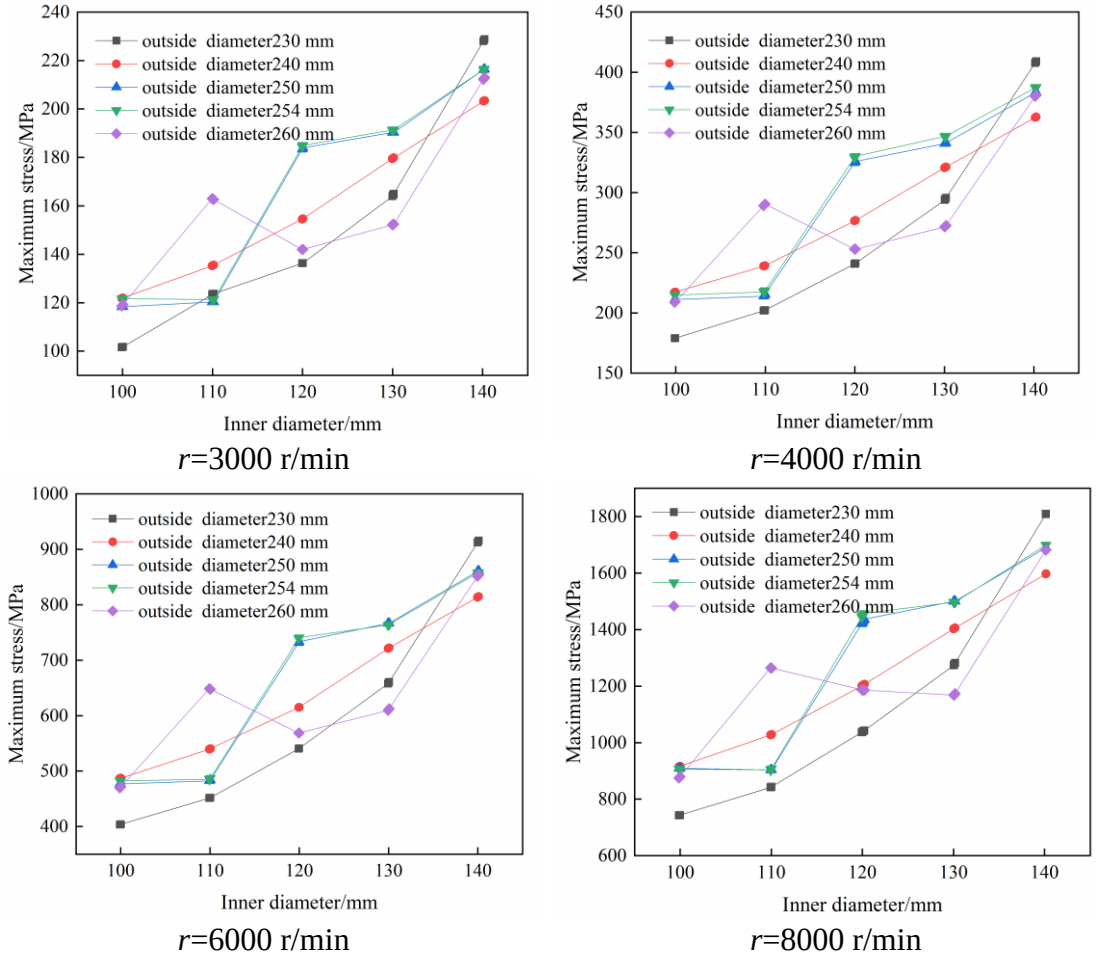

Figure 7. The maximum stress of the clamp disc body changes with the size of the inner diameter at different speeds.

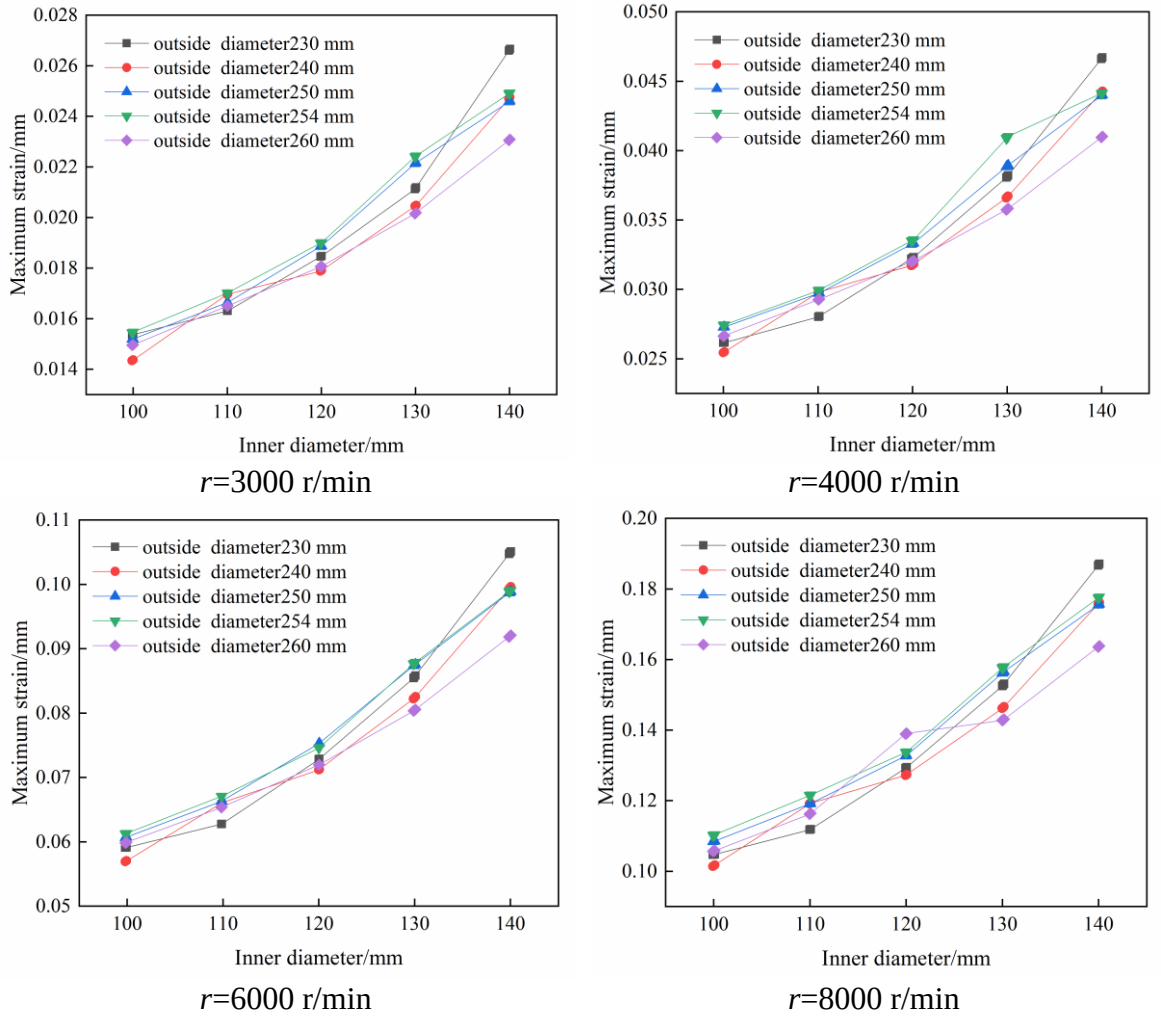

Figure 8. The maximum strain of the clamp disc body changes with the inner diameter size at different speeds.

It can be found from Fig. 8 that under the condition that the outer diameter of the disc is the same, the maximum strain of the disc gradually increases with the increase of the inner diameter size, and the greater the change of the inner diameter, the greater the trend of the maximum strain. When the outer diameter of the disc is 250 mm and the outer diameter is 254 mm, the maximum strain under the same inner diameter is basically the same. When the rotation speed reaches 8000 r/min, the maximum strain of the clamp disc body is also higher than 0.1 mm, which has an impact on the working accuracy of the fixture.

4.2. Influence of the outer diameter of the disk

As mentioned above, the outer diameter of the clamp disc body is analyzed by changing the outer diameter size of the disc body at different speeds. According to the analysis results, the variation curve of the maximum stress value of the disc with the outer diameter of the disc at different speeds can be plotted as shown in Fig. 9, and the variation curve of the maximum strain value with the outer diameter of the disc at different speeds is shown in Fig. 10.

It can be seen from Fig. 9 that when the inner diameter of the clamp disc is 140 mm, the maximum stress value of the clamp disc has a downward trend under the condition that the outer diameter size changes in the range of 230~240 mm. When the outer diameter changes in the range of 240~260 mm, the maximum stress of the disc body increases. This phenomenon is due to the fact that the wall thickness of the lever hole wall of the disc body is small in the range of 230~240 mm, and the wall thickness of the lever hole wall of the disc body increases gradually in the range of 240~260 mm, so

the maximum stress changes slowly. It can be seen that the wall thickness of the lever hole wall of the disc body also has an important influence on the force of the disc body.

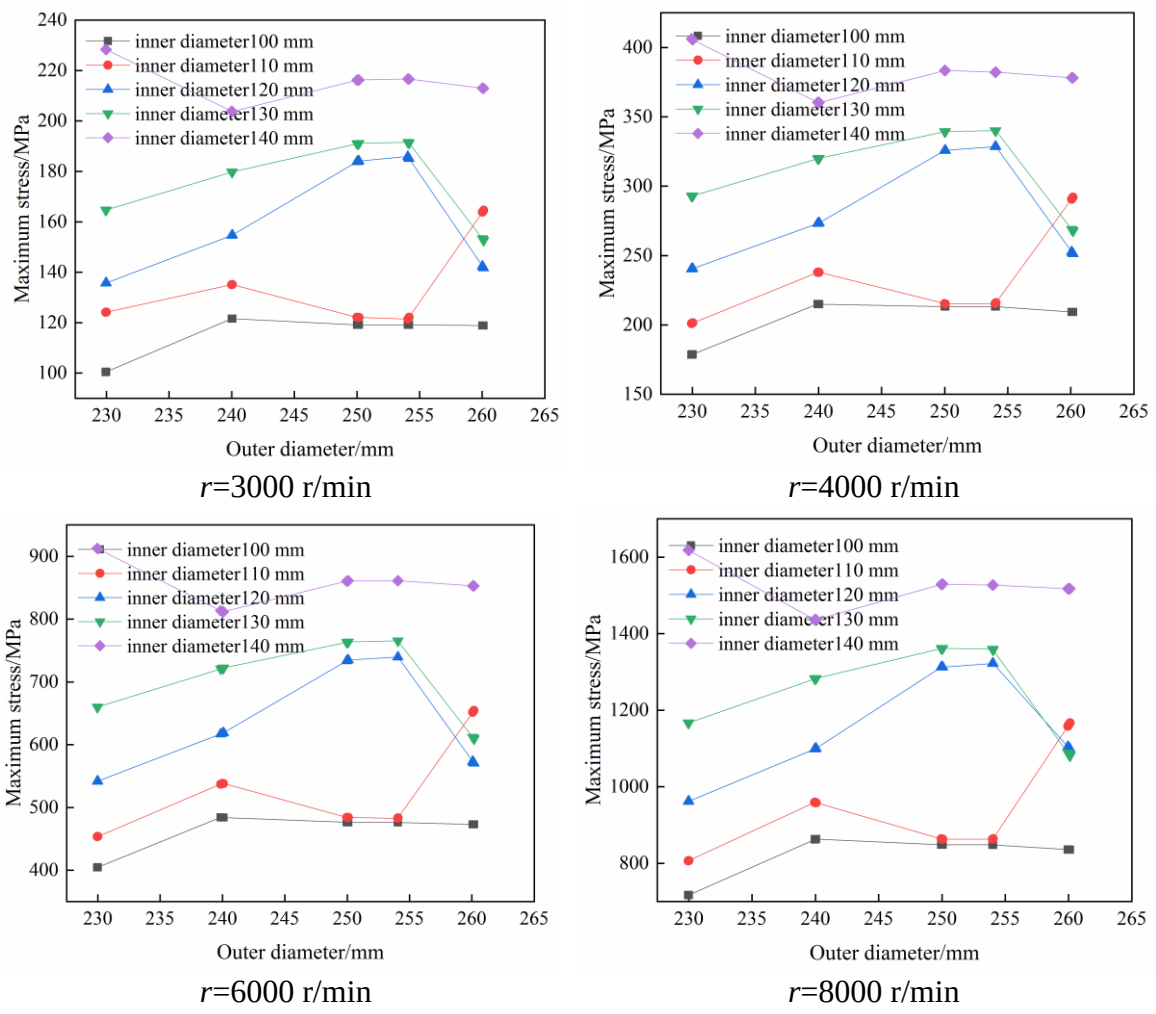

Figure 9. The maximum stress of the clamp disc body changes with the size of the outer diameter at different speeds.

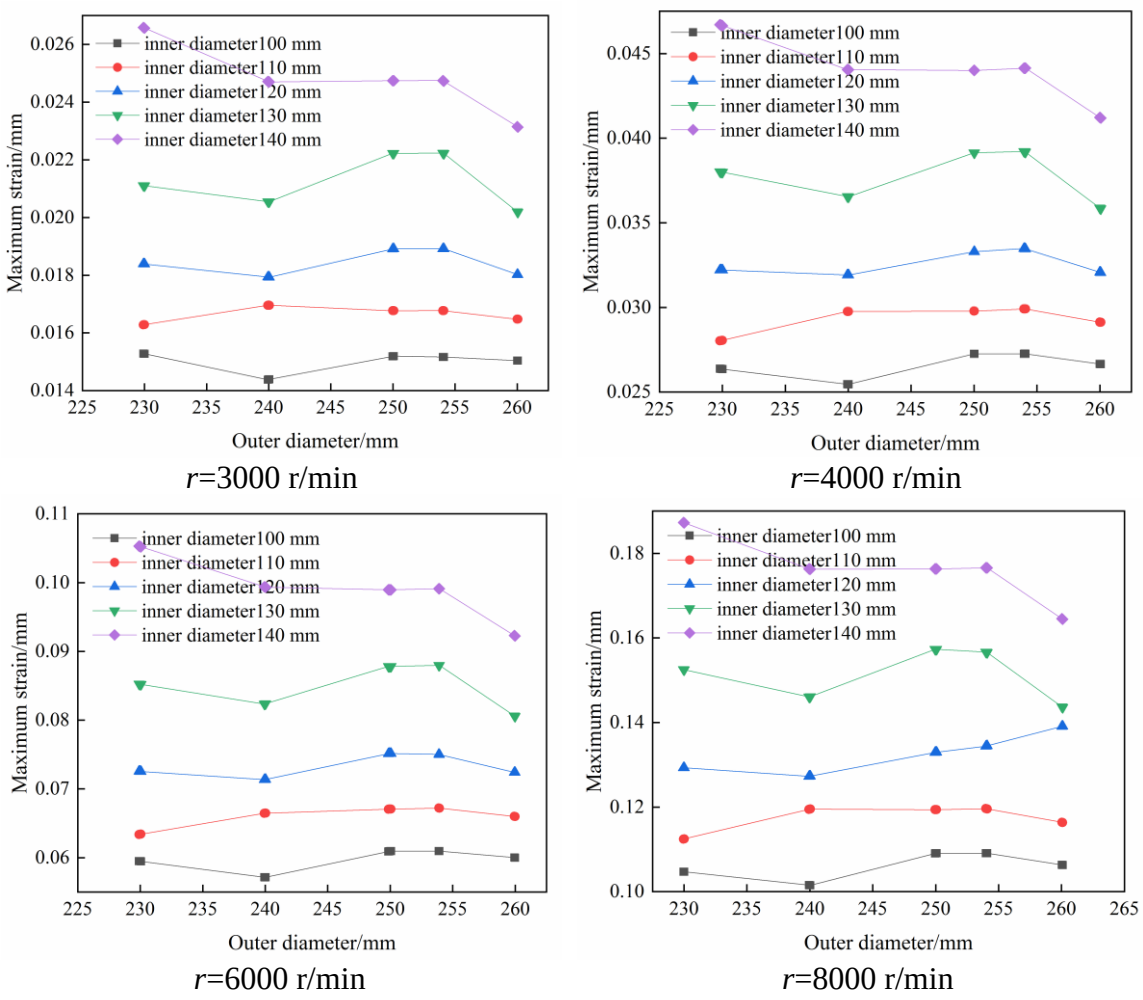

Figure 10. The maximum stress of the clamp disc body changes with the size of the outer diameter at different speeds.

As can be seen from Fig. 10, when the inner diameter of the clamp disc is 110 mm and the outer diameter changes in the range of 230~240 mm, the maximum strain of the disc increases slowly. When the outer diameter changes in the range of 240~260 mm, the maximum strain of the clamp disc decreases. The trend is basically the same for the other inner diameter sizes.

5. Conclusion

In this paper, ANSYS finite element software was used to analyze the high-speed rotary fixture. The main work is as follows: under the condition of centrifugal force, the influence of the inner and outer diameter size, material and rotation speed of the clamp disc on the stress and strain characteristics of the disc body are studied. The following conclusions can be drawn:

(1) The deformation of the end face of the clamp disc body is large, the local stress at the interface between the lever and the slide is large, and the stress distribution is uneven, which reduces the accuracy and working quality of the fixture, and provides a reference for the later structural optimization design and failure analysis.

(2) The stress and strain characteristics of the fixture disc body will also have an important impact on the positioning error of the fixture, which needs to be further studied in the later stage.

References

[1] QI Q, JIANG B H, SHAO R Y. Research on Mechanical Performance of Hydraulic Power Chuck Based on ANSYS Analysis[J]. Machine Tool and Hydraulics, 2019, 47 (07): 72 - 75.

[2] SHEN J. The structure and performance analysis of hydraulic power chuck [J]. Modular Machine Tool and Automatic Processing Technology, 2004 (12): 106 - 107.

[3] WANG J, ZHANG J F, FENG P F, et al. Study on the static clamping force characteristics of wedge power chuck [J]. Journal of Sichuan University (Engineering Science Edition), 2015, 47 (01): 207 - 214.

[4] XU X H. Development of a comprehensive testing machine for hydraulic power chucks[J]. Machine Tool & Hydraulics, 2018, 46 (14): 31 - 35.

[5] YANG H Y, ZHOU C. Research summary of self-centering hydraulic power chucks [J]. China Mechanical Engineering, 2007 (02): 244 - 251.

[6] LI Q. Failure analysis and optimization of hydraulic power chucks [D]. Shanghai Jiaotong University, 2014.

[7] XUAN L H. Design of a new type of power chuck [J]. Mechanical Engineer, 2012 (05): 139 - 140.

[8] XU X R. Structural analysis of hydraulic power chuck [J]. Modern Manufacturing Technology and Equipment, 2018 (12): 157 - 158.

[9] ZHANG W T. Research on the hydraulic chuck clamping control system of CNC lathes [J]. Industrial Instrumentation and Automation, 2014 (02): 74 - 76+86.

[10] WANG J X, ZHAO C J. The design of a new type of hydraulic chuck [J]. Inner Mongolia Coal Economy, 2013 (10): 145.

[11] WANG J J, FENG P F, ZHANG J F, et al. Finite element calculation method for dynamic clamping force of high-speed rotating power chuck [J]. Journal of Huazhong University of Science and Technology (Natural Science Edition), 2015, 43 (03): 7 - 11+27.

[12] TANG X, XIE L M. Control and realization of hydraulic circuit of power chuck of CNC lathe[J]. Hydraulics and Pneumatics, 2010 (10): 41 - 43.

[13] HU Z D, JIANG J H, DAI D J, et al. The influence of power chuck on the machining accuracy of CNC machine tools [J]. Modern Manufacturing Engineering, 2009 (08): 4 - 9.

[14] WANG J F, ZHANG W H, LIU Z J. Development and calculation of three-jaw self-centering hydraulic power chuck [J]. First Technology, 2003 (01): 19 - 20.

[15] LUO Y Y. Research on hydraulic power chuck force control system of direct-drive CNC machine tools [D]. Xi'an University of Technology, 2018.

[16] CHEN H J. Research on centering accuracy and clamping force characteristics of wedge power chuck [D]. Yantai University, 2016.