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Research on the Effect of Reinforcing Plate on Thermal Deformation Field of Hydrostatic Bearing Worktable

***Abstract**. Firstly, carry on numerical simulations for thermal deformation field of studied worktable by using software ANSYS WORKBENCH; then take study of the reasons why it will produce such thermal deformation by analyzing simulation results; finally, bring forward the measure of adding circumferential reinforcing plates, which could improve the homogenization of temperature field, decrease thermal deformation and increase processing precision.*

***Streszczenie.** W artykule opisano badania dotyczące deformacji termicznej stołu roboczego. Symulacje przeprowadzono przy pomocy programu ANSYS WORKBENCH. Na podstawie analiz, wyznaczono rozwiązanie problemu, w postaci płytek wzmacniających, dzięki którym następuje ujednorodnienie rozkładu temperatury i zmniejszenie deformacji. (**Zastosowanie płytek wzmacniających do stołu roboczego do łożysk hydrostatycznych w przeciwdziałaniu deformacji termicznej**).*

Keywords: worktable, thermal deformation field, temperature field, reinforcing plate.
Słowa kluczowe: stół roboczy, deformacja termiczna, pole temperaturowe, płyta wzmacniająca.

Introduction

In recent years, thermal deformation of machining system has generated impact on machining accuracy and automation of mechanical equipment. So it has been paid more and more attentions. In actual processing, thermal deformation has become a key factor affecting the efficiency of processing. Khobragade.NL, and Deshmukh.KC obtained the deformation law of plate enduring axisymmetric thermal load[1]. Ma M. T and Taylor C M made an experiment investigation of thermal effects in circular and elliptical plain journal bearings[2]. Zhang Yanqin, Yu Xiaodong and other scholars conducted simulation and analysis of temperature field of oil film of hydrostatic bearing and obtained the temperature distribution, which provided theoretical basis for acquiring heat source of worktable[3,5]. Yang Xiaodong researched the impact of speed on thermal deformation with different speed. Besides, he also studied the impact of auxiliary-hole position on thermal deformation of worktable and provided theoretical guide for the design of structure[6,8]. Obviously, research on deformation of bearing play an important role in bearing study, and at present there is no feasible mean on how to improve the worktable deformation, so this paper is of practical significance in product manufacturing.

Geometric model and mathematical model

External oil supply way is applied to the studied worktable. In working process, worktable and workpieces are supported by pressure oil film. As the type of contact belongs to solid-liquid contact, the fiction will be greatly decreased and the thermal deformation that is caused by fiction will be also decreased. Because there are 24 oil chambers whose shape are same and the worktable rotates at a certain rotating speed, so temperature and thermal deformation field are symmetric. Therefore, the thermal deformation field can be obtained by simulating 1/24 of whole model. The simplified model is shown in Figure1.

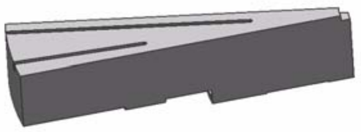

Fig.1. Simplified model of worktable

In cylindrical coordinate, various parameters in equilibrium equations, geometric equations and physical equations can be replaced each other, so many unneeded parameters can be eliminated. Then thermoelastic equations can be obtained, which is shown in the following equation:

$$\left.\begin{aligned}
&(\lambda+2G)\frac{\partial e}{\partial r}-2G\left(\frac{1}{r}\frac{\partial \omega_z}{\partial \theta}-\frac{\partial \omega_\theta}{\partial r}\right)-(3\lambda+2G)\alpha\frac{\partial T}{\partial r}=0\\
&(\lambda+2G)\frac{1}{r}\frac{\partial e}{\partial \theta}-2G\left(\frac{\partial \omega_{rz}}{\partial \theta}-\frac{\partial \omega_z}{\partial r}\right)-(3\lambda+2G)\alpha\frac{\partial T}{\partial \theta}=0\\
&(\lambda+2G)\frac{\partial e}{\partial r}-\frac{2G}{r}\left(\frac{1}{r}\frac{\partial (r\omega_\theta)}{\partial r}-\frac{\partial \omega_{rz}}{\partial \theta}\right)-(3\lambda+2G)\alpha\frac{\partial T}{\partial z}=0
\end{aligned}\right\}$$

$$\omega_r=\frac{1}{2}\left(\frac{1}{r}\cdot\frac{\partial u_z}{\partial \theta}-\frac{\partial u_\theta}{\partial z}\right),\ \omega_\theta=\frac{1}{2}\left(\frac{1}{r}\cdot\frac{\partial r_z}{\partial z}-\frac{\partial u_z}{\partial r}\right)$$

$$\omega_z=\frac{1}{2r}\left(\frac{\partial (ru_\theta)}{\partial r}-\frac{\partial u_r}{\partial \theta}\right),\ 2G=E/(1+\mu)$$

$$e=\varepsilon_r+\varepsilon_\theta+\varepsilon_z$$

Where: u_r , u_θ , u_z — radial, circumferential and axial displacement components, ε_r , ε_θ , ε_z — radial, circumferential and axial strain components, $\gamma_{r\theta}, \gamma_{\theta z}, \gamma_r$ — shearing strain; α—linear expansion coefficient. Based on analyzing above equations, as long as temperature distribution situation of worktable is obtained, required deformation can be gained by inserting that into above equations. Temperature distribution of worktable will be studied by the mean of coupling temperature of oil film to worktable.

Simulatin of thermal deformation field of original worktable without reinforcing plante

In software ANSYS WORKBENCH, convective heat transfer coefficients will be applied to the corresponding position of upper surface and side surface of worktable, and periodic condition is applied to both surfaces. Oil film temperature as heat source is coupled to fluid-solid contact surface, and temperature field of worktable will be obtained. After the result of temperature field is applied to worktable and fixed boundary is applied to internal cylinder, the thermal deformation field will be acquired. Because of limited space, only the result at 20r/min is listed as below. The profile of original worktable model without reinforcing plate is shown in figure 2 and its thermal deformation field is shown in figure 3.

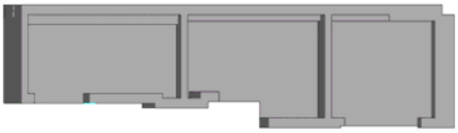

Fig.2. Section plan of worktable

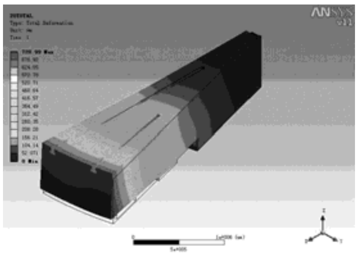

Fig.3. Total thermal deformation field of worktable at 20r/min

Based on the analysis of thermal deformation field, we can infer that the largest deformation occurs on outer edge where an upwarping phenomenon appears. The reason why deformation occurs lies in the temperature difference caused by inhomogenity of temperature field between upper and lower surface. The temperature difference will lead to inconsistency of radial expansion between the upper and lower surface, and worktable appears unwrapping due to a distortion movement being generated in side surface, which will decrease workpiece flatness, even lead to manufacture failure. Deformations of whole worktable as well as every surface can be divided into deformations in radial X and axial Z direction, the difference is that deformation in different directions of each side has a different impact on total deformation of worktable. The deformation of side surface in x direction and upper surface in z direction is key factors to be considered. In order to analyze the impact of rotating speed on deformation, relationship curves of deformation and rotating speed will be made regarding rotating speed and deformations as horizontal abscissa and vertical ordinate respectively shown in figure 4 and 5.

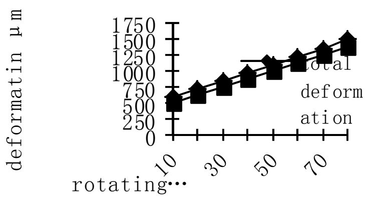

Fig.4. Relationship curve between deformation and rotating speed

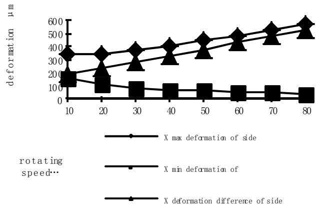

Fig.5. Relationship curve between deformation of side and rotating speed

Figure 4 shows total deformation and axial Z deformation of upper surface almost increase linearly with the increasing of rotating speed, and have basically same change law trend. And analysis of Figure 5 reveals that deformation difference between upper and lower portion of side surface also rises with the increasing of rotating speed. The reason is that the heat generated due to the rotating speed increase leads to heat expansion increase of the worktable, which is characterized by deformation increase.

Simulation of thermal deformation field of modified worktable with reinforcing plate

Based on upper analysis on worktable thermal deformation field, we can know upwarping deformation is caused by expansion difference between upper and lower portion of side surface in X direction, the temperature difference between upper and lower surface should be reduced as much as possible in order to decrease expansion difference of both surfaces. So we bring forward the measure of adding circumferential reinforcing plate to enhance heat transfer and improve the homogenization of temperature field to decrease expansion difference. We set 11 positions where add reinforcing plate. Because of limited space, only the result at 20/min is listed. The profile of modified model is shown in figure 6,7and the corresponding thermal deformation field is shown in figure8 and figure 9.

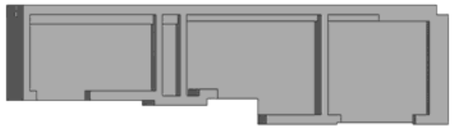

Fig.6. Modified worktable in position 1

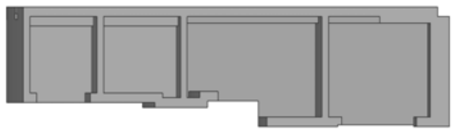

Fig.7. Modified worktable in position 10

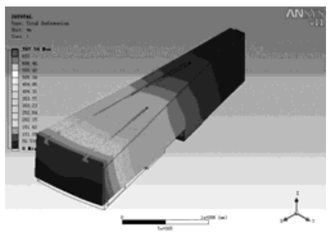

Fig.8. Thermal deformation field in position 1 at 20r/min

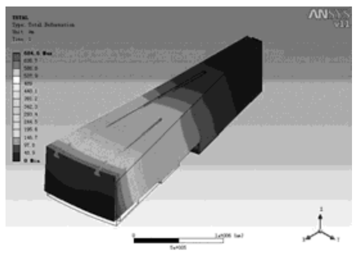

Fig.9. Thermal deformatin field in position 10 at 20r/min

Based on analysis of figure 8 and 9, deformation distribution of worktable with circumferential reinforcing plate is basically same as deformation distribution of original worktable without reinforcing plate, worktable deformation also gradually increases from the inside to the outside in radial direction. But deformation value changes with the addition of reinforcing plate and alteration of its location, obviously, worktable with circumferential reinforcing plate decreases thermal deformation.

In order to gain the best position where reinforcing plate is added, we choose 11 positions to add it in its adding ranges and their thermal deformation fields are analyzed. Based on simulations, we obtained relationship curve of deformation and position shown as figure10, where position

0 stands for the deformation of original worktable without circumferential reinforcing plate; then for studying the impact of reinforcing plate on thermal deformation field, the relationship curve before and after adding reinforcing plate is drawn as in figure11.

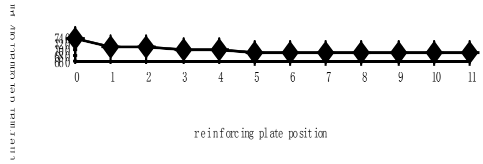

Fig.10. Relationship curve between total deformation and reinforcing plate positions at 20r/min

Figure10 shows that increasing reinforcing plate is positive to decrease deformation. As the radius increases, the deformation decreases accordingly. But when the radius exceeds certain value, the deformation will change slowly. So there must be a best position. Analyzing on the relationship curve in figure 10, it could be seen that position 10 is the best position where is added reinforcing plate.

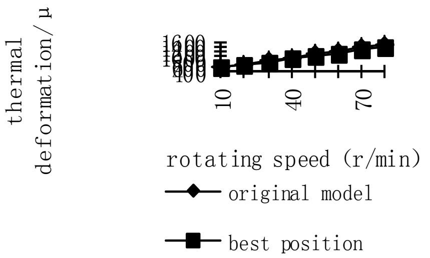

Fig.11. Relationship curve between thermal deformation and rotating speed

Figure11 shows that original model and modified model have the same trend basically, which both show linear increase. But the decreasing deformation value of modified model with best reinforcing plate position is 34.44 μm at 10r/min, and accounts for 5.7% of total deformation. When worktable speeds is up to 80r/min, the decreasing deformation value is 92.2 μm, accounting for 6.2%. As the rotating speed rises, the decreasing amount of deformation will increase. Since the requirement for machining accuracy is lower than 20μm generally, it is feasible for adding circumferential reinforcing plate to decrease thermal deformation.

Conclusions

Based on thermoelasticity theory, we built thermo-elastic equations used for analyzing thermal deformation field, exposed temperature field that has been gotten and initial conditions to worktable and carried on numerical simulations for thermal deformation field of original worktable without reinforcing plate, meanwhile we analyzed reasons for which thermal deformation occurred. For the measure how to decrease deformation, we took the method of adding circumferential reinforcing plate and simulated the deformation of modified model with circumferential reinforcing plate in different positions, furthermore, we found out the best position adding circumferential reinforcing plate, finally the relationship curve before and after adding reinforcing plate was drawn to reveal the role of circumferential reinforcing plate. The research results provided a valuable theoretical basis for improving deformation situation.

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