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Deformation and thermal analysis of the Guideways of a Large Scale Aspheric Machine Tool

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Abstract

Large scale aspheric lens are very important in both national defense and civil industries. For the fabrication of such lens, a large scale aspheric machine tool is developed. In this paper, we focus on the analysis of the temperature distribution and the deformation of the guideways of this machine tool. Thermal and strain deformation of three guideways are analyzed when the thickness of the oil film is different, and the relationship between the thickness of the oil film and the deformation is built up.

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Keywords: Machine tool, guideways, deformation, thermal analysis.

1. Introduction

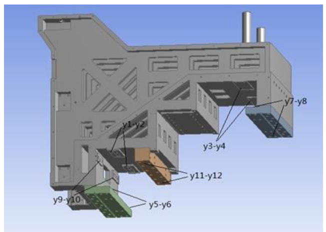
A precision machine tool developed by Xi'an Jiaotong University has three linear axes, named X, Y and Z. The guideways of three axes are placed oil pockets. However, when the temperature of hydrostatic oil in the guideways is changed, deformation is produced.The thickness of the hydrostatic oil film affects the flow in each pocket, the temperature of pockets and the guideways[1,3].

2. Modeling and simulation

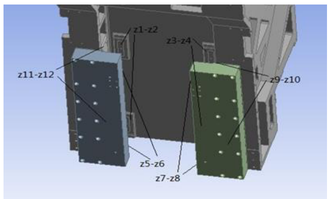
2.1. The distribution of each pocket in Y-axis andz-axis together with their press calculation

There are twelve pockets in Y-axis system, named y1 -y12 as shown in Fig.1(a) We can classify them into two types, y1 to y4 as the lifting pockets and y5 to y12 as the side pockets. The size of each pocket differs from others, but their shapes are all rectangle [2,4,5].

Similarly, there are twelve pockets in Z-axis system named z1 to z12 as shown in Fig.1(b). We also classify them into two types, z1 to z8 as the lifting pockets and z9 to z12 as the side pockets. Their size and shape are similar to the pockets of Y-axis.



(a)



(b)

Fig.1 the distribution of pockets in Y-axis and Z-axis

Loads on Y-axis consist of the own gravity and the counterweight. It is assumed that the size and presses of y1 to

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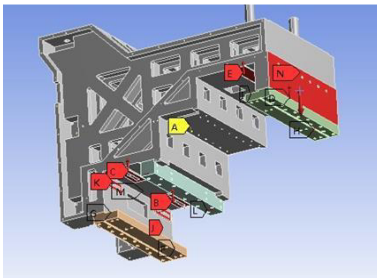
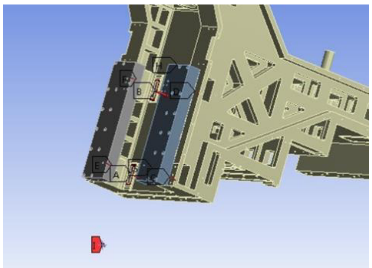
y4 pockets are the same and others are also the same. Considering that the external load on Z-axis comprises only the cutting force, we assume that presses of z1 to z8 are all the same and z9 to z12 are equal to them correspondingly[7,9]. We name the presses of each pockets ranging from y1 to y12(z1 to z12) as F_1 to F_{12}.The presses of Y-axis pockets are shown in Fig.2(a), the presses of Z-axis in Fig.2(b), and the results are listed in tables 1 and 2.

In Fig.2(a) and Fig.2(b), A~N represent these presses referred above(F_1~F_{12}).



(a)



(b)

Fig.1 the distribution of loads and supports in Y-axis and Z-axis

Table1 the supports of Y-axis

supports	F_1=F_2	F_3=F_4	F_5=F_6	F_7=F_8	F_9=F_{10}=F_{11}=F_{12}
N	3104	6896	310	689	100

Table2 the supports of Z-axis

supports	F_1=F_3	F_2=F_4=F_6=F_8	F_5=F_7	F_9=F_{11}	F_{10}=F_{12}
N	250	150	250	500.	300

All linear axis use oil VG46 with pump pressure 32 bar at oil temperature able to work at 18℃ to 25℃. For highest precision the room temperature should be 20℃+/-1℃ same as oil enter temperature to machine tool.

2.2. Calculation of the heat

All the pockets of the guideways are rectangles[8]. L is the length and B is the width, whereas l and b represent the length and width of the smaller rectangle in it. The burden size of each pocket is named as A.

As the hydrostatic guideways are in the work process, power consumption consists of two parts: the first part is the power consumption in the oil transportation process (P_P)[10]; the other part is the consumption of the oil cutting (P_f)[12]. Both of them make up the total power consumption of hydrostatic guideways. However the flow of each pocket is depended on the P_s , B, b, L and l[13,15,16].

Area separated by the oil A=BL

Heat power of the film cutting $P_f=\eta v^2(A/h)$

Power of the oil pumping $P_P=QP_s/\eta_p$

Total heat $P_t=P_f+P_p$

Flow of the pockets $Q=P_s h^3[b/(B-b)+l/(L-l)]/6\eta$

Heat flow of the area $q=P_t/A$

P_s —— the pressure in the entry of the pocket

h —— the thickness of the oil film（ranging from 20 um to 40um）

η_p —— the efficiency of pumping

η —— the dynamic viscosity of the oil

v —— the kinematic viscosity of the oil

2.3. The temperature field and strain field of the machine tool with a oil film thickness of 30um

Each pocket size and oil pressure in the guides of X-, axis, Y- axis and Z-axis are known, so we can obtain all their flow and heat power in the table3, that is the situation of the thickness of oil film being 30um[6,11].

Table3 the flow and heat power of pockets for 30um oil film

pockets	P_f (W)	Q ($10^{-6}m^3/s$)	P_P (W)	P_t (W)	A (m^2)	q(W/m^2)
x1-x8	0.14	0.576	1.90	2.04	0.026	78.46
x9-x16	0.09	0.597	1.97	2.06	0.0162	127.16
x17-x20	0.07	0.710	2.34	2.41	0.0128	188.28
y1-y4	0.12	0.641	2.12	2.24	0.02	112
y5-y12	0.07	0.690	2.28	2.35	0.012	195.83
z1-z8	0.05	0.639	2.11	2.16	0.0084	257.14
z9-z12	0.07	0.736	2.43	2.50	0.0112	223.21

Firstly we should mesh the whole machine tool to process the thermal analysis without considering small structures in view of their tiny effect on the analysis. The mesh is shown in Fig.3 and the mesh quality is shown in Fig.4.As we can see, average of the metric is 0.69(bigger than 0.5) and standard deviation is merely 0.21, so we can conclude that the mesh is quite acceptable. After that we can apply all the heat loads referred above on the machine tool as is shown in Fig.5.And then we can get the thermal solution in the situation of oil film thickness being 30um.