OPTIMIZATION DESIGN OF THE CROSSBEAM FOR THE VIADUCT TYPE FIVE-AXIS GANTRY BORING AND MILLING MACHINING CENTRE

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Abstract - In order to enhance the national research and development capability of large five-axis linkage machine tools, promote the improvement of performance and accuracy, promote industrialization, replace imports and meet the machining process requirements for large five-axis linkage machine tools in aviation and aerospace, this paper proposed a viaduct type five-axis gantry boring and milling machining centre. The centre's workbench is a floor standing platform, with the bed placed on both sides of the workbench. The two crossbeams are arranged back-to-back, and move longitudinally along the left and right guide rails (X-axis). The slide plate moves horizontally along the crossbeam guide rails (Y-axis), and the ram moves up and down along the slide plate (Z-axis). The double swing angle CNC universal milling head can achieve rotation around the Z-axis (C-axis) and X-axis (A-axis) to achieve five-axis simultaneous machining under the control of the CNC system. At the same time, the crossbeam of the machining centre has been structurally optimized to effectively reduce the weight of the moving parts, improve the dynamic performance of the machine tool and achieve a μ-level output of repeatable positioning accuracy for large strokes of the machine tool.

Keywords: Five-axis, Machining centre, Crossbeam, Finite element analysis, Optimization.

1. Introduction

China has made certain progress in the development of five-axis linkage CNC machine tools [1-5], but there is still a gap in the accuracy, reliability and key functional components of the machine tools compared with foreign advanced levels [6-10]. As a result, large-scale high-speed gantry five-axis machining centres with complex structures and shapes, such as large aluminium alloy, titanium alloy parts and automotive moulds, are almost completely dependent on imports in aviation, aerospace, high-speed trains and automobile industry projects involving major national economic interests and even national security [11-15].

Under the above situation, a number of China's domestic machine tool manufacturers are developing five-axis linkage CNC machine tools [16-20]. The viaduct type five-axis gantry boring and milling machining centre proposed in this paper will enhance the research and development capability of the national large-scale five-axis linkage machine tool, effectively promote the development process of the five-axis linkage gantry machining centre in the major project of high-end CNC machine tools and basic manufacturing equipment, promote the improvement of performance and accuracy, promote industrialization, replace imports, meet the processing requirements of large five-axis linkage machine tools in aviation, aerospace and other fields, break the technological monopoly of foreign manufacturers, meet the space station and other large aircraft cabin structure installation surface features integrated and efficient processing needs, meet the demand for machining equipment in key industries such as aerospace, automobile, and rail transit.

2. Structure and Principle of Machining Centre

The viaduct type five-axis gantry boring and milling machining centre is shown in Figure 1. The centre's workbench is a floor standing platform, with the bed placed on both sides of the workbench. The two crossbeams are arranged back-to-back, and move longitudinally along the left and right guide rails (X-axis). The slide plate moves horizontally along the crossbeam guide rails (Y-axis), and the ram moves up and down along the slide plate (Z-axis). The double swing angle CNC universal milling head can achieve rotation around the Z-axis (C-axis) and X-axis (A-axis) to achieve five-axis simultaneous machining under the control of the CNC system. The CNC system adopts the Huazhong HNC-848 CNC system.

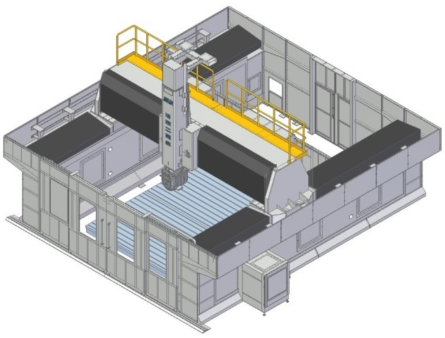

Figure 1: Viaduct type five-axis gantry boring and milling machining centre

The whole machine adopts the optimal combination of cast iron and steel plate welding parts. The workbench and bed are made of resin sand shaped, high-strength and high-quality cast iron parts, while the crossbeam, slide plate, and ram are made of steel plate welding parts.

The X/Y/Z three axes are all equipped with heavy-duty precision roller linear guides and full closed-loop position feedback.

X-axis is driven by a bilateral synchronous drive, each side adopts double motors and double gearbox electrical clearance elimination structure to realize the gantry frame movement. Y-axis is driven by rack and pinion, adopts double motors and double gearbox electrical clearance elimination structure. Z-axis adopts AC servo motor directly connected to the gearbox to reduce the speed, and then drive the ball screw nut pair to realize the linear motion of each axis.

3. Optimization of the Crossbeam

3.1 Structure Optimization of the Crossbeam

The crossbeam of the viaduct type five-axis gantry boring and milling machining centre is shown in Figure 2.

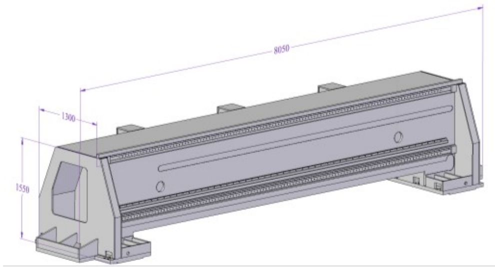

Figure 2: Crossbeam

Figure 3 shows the right angle crossbeam structure, while Figure 4 shows the diagonal crossbeam structure. The deformation of the crossbeams of these two structures under the action of load gravity is obtained by the finite element analysis method [21-25]. The deformation results are shown in Table 1, and the deformation diagram is shown in Figure 5 and Figure 6. A reasonable crossbeam structure is selected through deformation.

From the analysis results in Table 1, it can be seen that, compared with the right angle crossbeam structure, the X-direction deformation and Z-direction deformation of the diagonal crossbeam are smaller. Combined with the weight of the crossbeam, the diagonal crossbeam is relatively lighter, so the diagonal crossbeam structure is chosen.

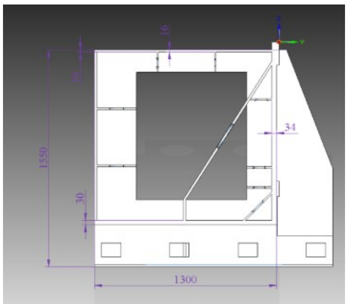

Figure 3: Right angle crossbeam structure

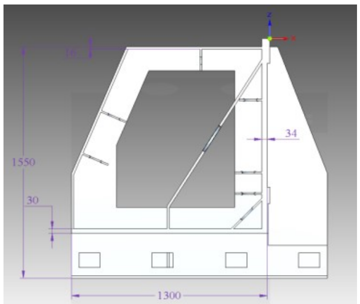

Figure 4: Diagonal crossbeam structure

Table 1. Deformation of crossbeam

Crossbeam structure	Working condition	X-direction /mm		Z-direction/mm		Weight of finite element model/kg
		Upper guide rail	Lower guide rail	Upper guide rail	Lower guide rail	
Right angle crossbeam	Intermediate load gravity	0.0269	-0.0030	-0.0371	-0.0371	
Diagonal crossbeam	Intermediate load gravity	0.0256	-0.0020	-0.0338	-0.0338	13653.68

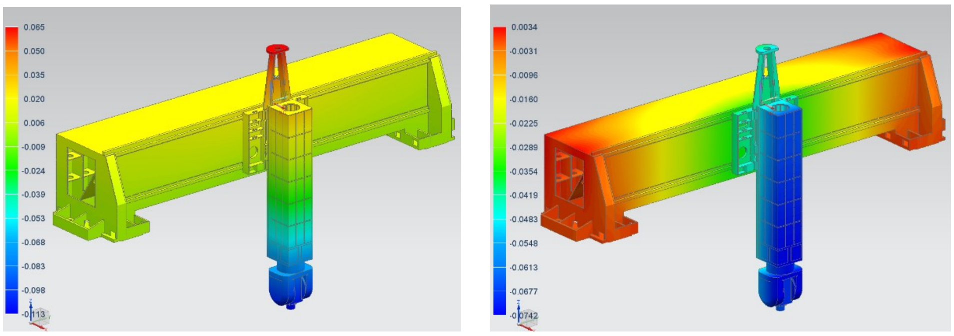

Figure 5: Schematic diagram of deformation of right angle crossbeam in X and Z directions

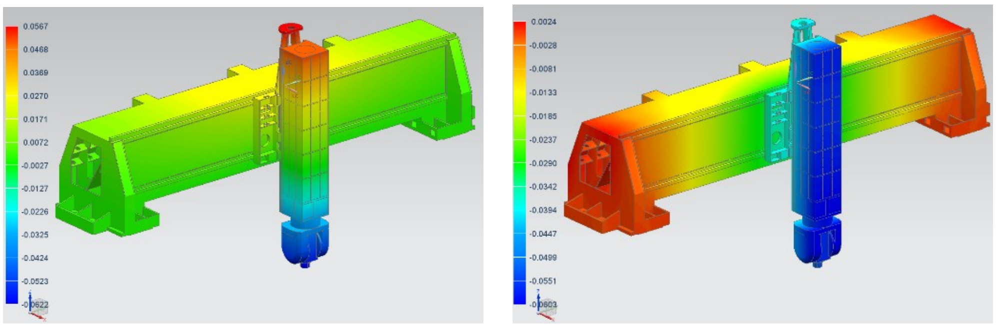

Figure 6: Schematic diagram of deformation of diagonal crossbeam in X and Z directions

3.2 Crossbeam Deflection Compensation

When processing the crossbeam, it is processed in a free state, so that the deformation caused by the crossbeam's own weight can be ignored. In the actual assembly structure, under the gravity of the sliding plate, milling head and Z-axis transmission gravity, the crossbeam will have an X-direction overturning deformation and Z-direction droop, which will directly affect the Y-axis straightness and Z-axis straightness of the machine tool. In order to ensure the straightness of the entire machine tool and eliminate the impact of crossbeam deformation on accuracy, the method of reverse deformation processing is adopted for deflection compensation [26-30].

Through the finite element analysis method, the deformation values in the X and Z directions at the upper and lower guide rail surfaces of the crossbeam are analyzed and calculated. Based on the difference in deformation of the crossbeam when the slide plate is located at the limit position and the middle position, the compensation amount for reverse deformation processing is determined to ensure the straightness of the Y-axis of the entire machine during the design stage.

The concave value of the upper guide rail joint surface should be the difference in deformation between the middle of the slide plate and the extreme position in the X-direction, and the lower guide rail should be flat or convex within 0.01mm. The convex value of the upper and lower guide rails in the middle of the table is equal, and the magnitude is the difference in Z-direction deformation between the extreme position and the middle position of the sliding plate.

The reading position of the deformation curve is taken according to the schematic position shown in Figure 7. Point 0 is the middle stroke. The boundary position of the guide rail, the left and right limit position of the sliding plate operation, the 1/4 stroke position and the 3/4 stroke position are taken for reading.

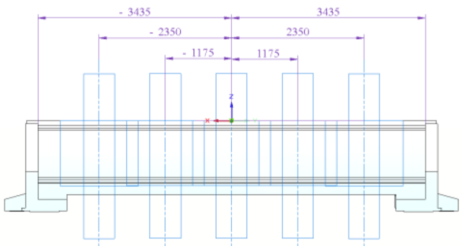

Figure 7: Stroke position of the slide plate (Middle position is 0 point, left is negative, right is positive)

3.2.1 X-direction Deflection Compensation of the Crossbeam

In the selection stage of the crossbeam structure, a three-dimensional model of the crossbeam is established and constrained according to the actual working state. The X-direction deformation of the upper and lower guide rails of the crossbeam under the main load gravity such as the slide plate, ram, and milling head from left to right at different positions (taking 7 slide plate stroke positions) is analyzed as shown in Table 2. The X-direction deformation curves of the upper guide rails of the crossbeam are obtained as shown in Figure 8, and the X-direction deformation of the crossbeam is corrected through reverse deformation processing to ensure the accuracy of the Y-direction operation of the slide, and the deformation diagram is shown in Figure 9.

According to the data in Table 2 and the deformation curve in Figure 6, the upper guide rail joint surface of the crossbeam should be concave in the middle by about 0.018mm, and the lower guide rail joint surface should be machined in a straight line.

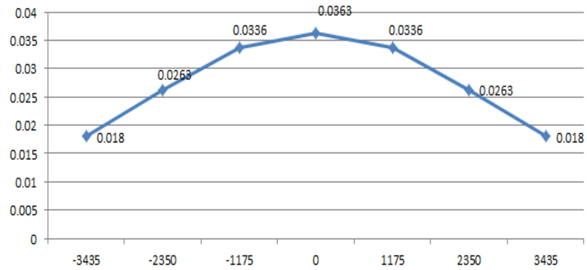

Figure 8: X-direction deformation curve of the upper guide rail joint surface

Table 2. X-direction deformation of the joint surface of the crossbeam guide rail under the action of load gravity (unit: mm, "-" represents direction)

Milling head position	-3435	-2350	-1175	0	1175	2350	3435
Deformation of the upper guide rail joint surface in the X-direction	0.018	0.0263	0.0336	0.0363	0.0336	0.0263	0.018
Deformation of the lower guide rail joint surface in the X-direction	0.0005	-0.0010	-0.0020	-0.0020	-0.0020	-0.0010	-0.0005

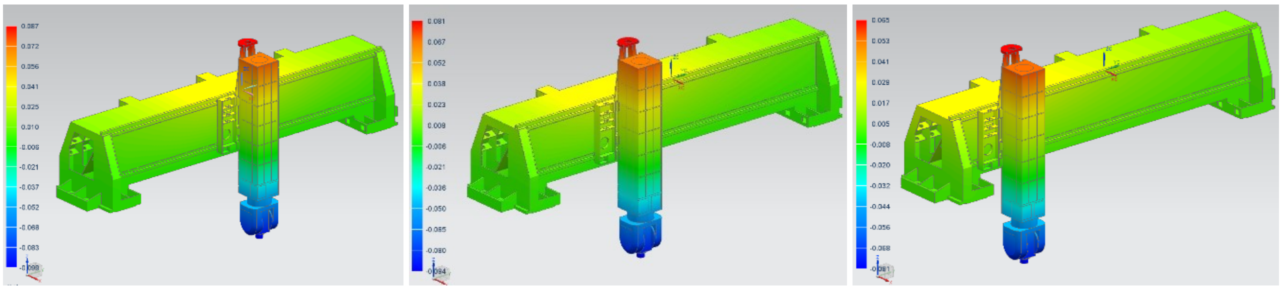

Figure 9: Schematic diagram of X-direction deformation of the crossbeam at different strokes of the slide plate

3.2.2 Z-direction Deflection Compensation of the Crossbeam

In the selection stage of the crossbeam structure, a three-dimensional model of the crossbeam is established and constrained according to the actual working state. The Z-direction deformation of the crossbeam guide rail under the main load gravity such as the slide plate, ram, and milling head from left to right at different positions (taking 7 slide plate stroke positions) is analyzed in Table 3.

The Z-direction deformation curve is obtained as shown in Figure 10. The Z-direction deformation of the crossbeam is processed and corrected through reverse deformation to ensure the deflection of the crossbeam, and the deformation diagram is shown in Figure 11.

Table 3. Z-direction deformation of the upper and lower guide rails of the crossbeam against the workbench surface under the action of load gravity (unit: mm, "-" represents direction)

Milling head position	-3435	-2350	-1175	0	1175	2350	3435
Z-direction deformation of the upper and lower guide rails against the workbench surface	-0.002	-0.0181	-0.0373	-0.0443	-0.0373	-0.0181	-0.002

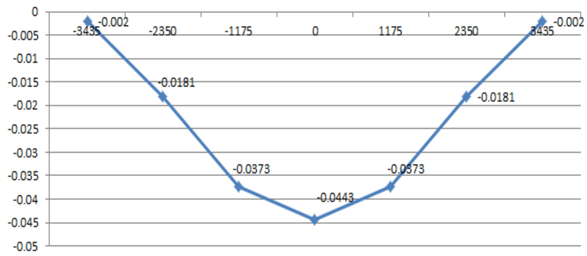

Figure 10: Z-direction deformation curve of the lower guide rail against the workbench surface

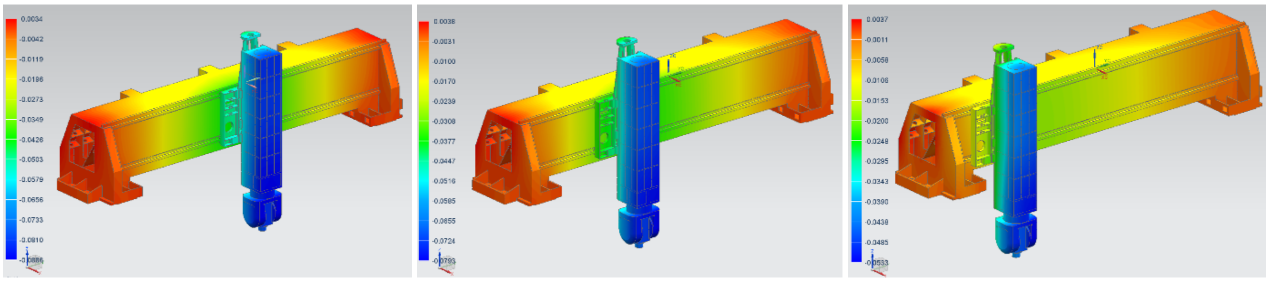

Figure 11: Schematic diagram of Z-direction deformation of the crossbeam at different strokes of the slide plate

According to the data in Table 3 and the deformation curve in Figure 8, the upper and lower guide rails of the crossbeam should protrude approximately 0.04mm upwards in the middle when machined against the workbench surface.

4. Results

After the optimization and selection of the above large components, the dynamic performance of the machine tool was improved through the processing deflection compensation, and the output of the repeated positioning accuracy of the machine tool with large stroke was μ level [31-35]. The specific accuracy values are shown in Table 4.

Table 4. Position accuracy of three axes and measured values

Position accuracy of three axes		Measured values/mm
X-axis (Stroke:5200)	Positioning accuracy	0.0062mm/m; 0.01mm/Whole stroke
	Repeated positioning accuracy	0.0027mm/m; 0.005mm/Whole stroke
Y-axis (Stroke:4700)	Positioning accuracy	0.0065mm/m; 0.008mm/Whole stroke
	Repeated positioning accuracy	0.0025mm/m; 0.005mm/Whole stroke
Z-axis (Stroke:1500)	Positioning accuracy	0.0052mm/m; 0.006mm/Whole stroke
	Repeated positioning accuracy	0.0022mm/m; 0.003mm/Whole stroke

5. Conclusions

The successful development of the viaduct type five-axis gantry boring and milling machining centre has achieved a breakthrough in this type of machine tools in Shandong province. At the same time, it can improve the design and manufacturing level of China's CNC machine tools, further promote the development of heavy CNC machine tool manufacturing industry, and enhance the comprehensive competitiveness of enterprises.

By optimizing the structure of the large components (crossbeam) of the machine tool, the weight of the moving parts has been effectively reduced, the dynamic performance of the machine tool has been improved, and the precision of repeated positioning with large stroke has been achieved μ level output.

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