Calibration of Parallelism Error About Rotating Shafts Based on the Three-coordinate Measuring Machine

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Abstract: The three-coordinate measuring machine is widely used in advanced manufacturing technology and scientific research. Optimized design is extremely essential for improving accuracy of measuring machine. According to the applied coordinate measuring machine's structure, a method is proposed to realize the calibration of parallelism error about rotating shafts. A large number of experiment and data have proved that the proposed theory can quickly and efficiently complete the calibration work of parallelism error about two rotating shafts. It posses some advantages such as easy operation, high flexibility and low cost. The efficiency of calibration is also greatly enhanced.

1 INTRODUCTION

Accuracy is an important index to measure the quality of measurement system. The accuracy of modern industrial processing and detection precision demand is higher and higher in the measurement system. It is very important to reduce the error and improve the measurement accuracy in practical application[1-3]. There are many factors affecting the mechanism error, and the structural parameter error is one of the most important factors affecting the measurement accuracy. At present, the commonly used error calibration method is divided into external calibration and self-calibration[4-5]. Theoretically, the external calibration adopts precision measuring machine to obtain higher calibration results, but the calibration cost is expensive[6-7]. In response to these problems, based on the actual structure of the measuring machine, a method is proposed to realize the calibration of parallelism error about rotating shafts based on the applied coordinate measuring machine's structure, and completes the error calibration work.

2 THE STRUCTURE OF THE MEASURING MACHINE

The measuring machine consists of five kinematic pairs, namely two prismatic pairs and three revolute pairs which move linearly along the X and the Z direction. In the rotating shaft, the -axis and the B-axis are theoretically parallel, and the axis of the A axis is perpendicular to the B axis. The length of the measuring rod is 250 mm and the length of the cantilever is 500 mm, as shown in Figure 1. Due to the installation error of the mechanism, the rotating shafts the -axis and the B-axis are not completely parallel. It can be seen from the reference that the error caused by the rotation axis has the greatest influence on the measurement accuracy, and with the length of the link is gradually enlarged[8-9]. Therefore, it is particularly important to solve the problem of parallelism error between two rotating axes.

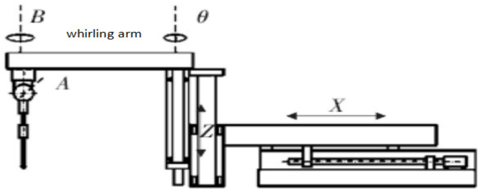

Figure 1: The structure of measuring machine.

3 PRINCIPLE OF PARALLELISM ERROR CALIBRATION

There are many factors affecting the mechanism error, and the structural parameter error is one of the most important factors affecting the measurement accuracy. At present, the commonly used error calibration method is divided into external calibration and self calibration. The external calibration method is similar to the calibration method of the traditional tandem mechanism. The accurate external 3D measurement device is used to estimate and calibrate the kinematic parameters of the parallel robot. General use of laser interferometer, theodolite and so on. The self-calibration method is used to obtain redundancy information about the position by the redundant joint sensor of the parallel system. Theoretically, the external calibration requires the use of highly accurate precision measuring instruments or sensors, fine adjustment and measurement results in higher calibration results. However, the calibration cost is high, and the actual accuracy is usually difficult to achieve the expect effect in the worse calibration environment. For the above reasons, aiming at the parallelism error of rotating shaft, a calibration method with low cost, high efficiency and low environmental requirements is proposed in this paper, which solves the existing problems of external calibration.

In order to obtain the parallelism error between the rotation axesθand B in the measuring machine, it is necessary to obtain the perpendicularity relationship between the two rotation axes and the plane based on the same reference plane. It is important to note that the accuracy of the plane is higher than the accuracy of the measuring machine. Therefore, using a high-precision plate as a standard reference plane, the data detected by the probe on the plate is obtained by rotating the two rotating shaftsθand B respectively. By the least square method, the perpendicularity relationship between each axis and the reference plane, the plate can be calculated. Finally, the parallelism error between the two axes can be calculated.

3.1 The Perpendicularity Between the Axis ofθand the Plate

In the measurement system, the rotation angle range of the axisθis -120º～120º, the rotation angle range of the axis B is 0º～360º, and the rotation angle range of the axis A is 0º～120º. In order to measure the relationship between the axis of the whirling arm and the plate, the measure machine sends the probe above the plate, as shown in Figure 2. Let the probe be properly rearward, rotate 180ºabout the B axis and 70ºabout the A axis. In this way, the whirling arm can be shorten and the scanning range of the probe can be increase; otherwise, a larger plate is needed, and the cost is expensive.

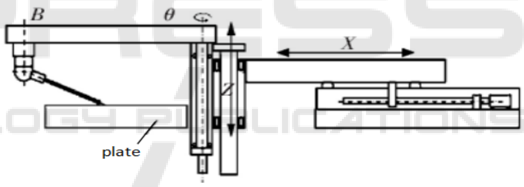

Figure 2: Axis of whirling arm and the parallelism of Z - axis.

The measuring rod is vertically falling down along Z direction to the point where the measuring ball is in contact with the plate, Rotating the rotating shaft θ, record the coordinates of the probe on the panel every 20° . Using the least square method fit to find the normal direction of the forming plane, and it represents the axial direction of the rotating shaft θ. The two measurements date are shown in Table 1.

Table 1: The measurement data of whirling arm.

First measurement data			Second measurement data		
X/mm	Y/mm	Z/mm	X/mm	Y/mm	Z/mm
652.8527	-519.2574	-103.6222	651.3632	519.9587	-99. 80469
738.4846	-459.1523	-103.4558	737.1935	460.1162	-100.0824
812.3357	-385.1113	-103.2305	811.3597	386.3012	-100.4047
872.1877	-299.3770	-102.9571	871.5892	300.7864	-100.7593
916.2238	-204.5483	-102.6344	916.0750	206.1492	-101.1384
943.1135	-103.5361	-102.2890	943.4800	105.2317	-101.5287
952.0455	0.5895	-101.9144	952.9548	1.1398	-101.9164
942.76967	104.6915	-101.5305	944.2203	-103.0000	-102.2908
915.5651	205.6187	-101.1400	917.5271	-204.0426	-102.6439
871.2652	300.3030	-100.7604	873.6930	-298.8837	-102.9623
811.2077	385.8848	-100.4026	814.0226	-384.6790	-103.2378
737.2077	459.7684	-100.0828	740.3389	-458.7936	-103.4626
652.1034	519.3504	-99.8066	655.4735	-518.6305	-103.6302

The plane normal vector value and the axis direction of the rotate shaft and the corresponding angle of the normal vector by fitting based on the measured data, as shown in Table 2.

Table 2: The axis normal vector of rotation shaft θ.

Serial number	The plane normal vector value			Normal angle/(°)		
	I	J	K	α	β	γ
1	-0.000675	0.003667	-1.000000	90.038693	89.789861	179.786328
2	-0.000669	0.003675	-1.000000	90.038372	89.789396	179.785929
average value	-0.000672	0.003671	-1.000000	90.038533	89.789629	179.786123

3.2 The Perpendicularity Between the Axis of Rotating Shafts B and the Plate

The perpendicularity relationship between the axis B of the rotating shaft and the plate is shown in Figure 3. Based on the above calibration principle and the range of the B-axis rotation, the measuring rod is rotated about 80°around the A-axis. The coordinate of each point of that probe on the plate are recorded every 10ºof rotation of the B axis, and the data of two measurement are shown in Table 3 and Table 4.

The normal direction data of the circular section is shown in Table 5.

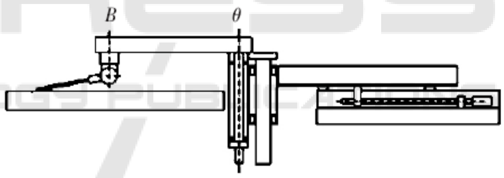

Figure 3: The relationship of perpendicularity between axis B of rotating shaft and the plate.

Table 3: The first measurement data of axis B rotation.

Rotation angle of B axis/(°)	X/mm	Y/mm	Z/mm	Rotation angle of B axis/(°)	X/mm	Y/mm	Z/mm
0	556.6987	-44.1303	-103.9333	180	557.5235	404.9366	-101.0477
10	595.6403	-40.7952	-104.0142	190	518.5317	401.597	-100.9706
20	633.4609	-30.73622	-104.0426	200	480.7112	391.53569	-100.9395
30	668.9628	-14.2660	-104.0287	210	445.2132	375.06477	-100.9546
40	701.0622	8.1159	-103.9667	220	413.1104	352.6746	-101.01543
50	728.7859	35.73773	-103.8583	230	385.3833	325.0547	-101.1226
60	751.2850	67.7524	-103.7090	240	362.8753	293.0388	-101.2697
70	767.8961	103.1967	-103.5213	250	346.2632	257.5931	-101.4546
80	778.0986	140.9822	-103.3026	260	336.0622	219.8093	-101.6714
90	781.5782	179.9707	-103.0591	270	332.5765	180.8229	-101.9106
100	778.2532	218.9581	-102.8012	280	335.9122	141.8263	-102.1708
110	768.1982	256.7931	-102.5307	290	345.9676	104.0013	-102.4404
120	751.7292	292.2963	-102.2615	300	362.4361	68.4918	-102.7105
130	729.3521	324.3988	-101.9995	310	384.8170	36.3995	-102.9744
140	701.7347	352.1311	-101.7513	320	412.4334	8.6734	-103.2249
150	669.7192	374.6452	-101.5259	330	444.4498	-13.8370	-103.4527
160	634.2845	391.2501	-101.3286	340	479.8898	-30.4407	-103.6496
170	596.5041	401.4512	-101.1682	350	517.6703	-40.6397	-103.8132

Table 4: The second measurement data of axis B rotation.

Rotation angle of B axis/(°)	X/mm	Y/mm	Z/mm	Rotation angle of B axis/(°)	X/mm	Y/mm	Z/mm
0	556.7003	-44.1307	-103.9356	180	557.5227	404.9366	-101.0470
10	595.6425	-40.7956	-104.0144	190	518.5330	401.5989	-100.9687
20	633.4599	-30.7400	-104.0452	200	480.7122	391.5391	-100.9380
30	668.9620	-14.2663	-104.0291	210	445.2156	375.0635	-100.9538
40	701.0631	8.1152	-103.9656	220	413.1110	352.6766	-101.0144
50	728.7844	35.7353	-103.8578	230	385.3840	325.0540	-101.1223
60	751.2892	67.7515	-103.7075	240	362.8752	293.0391	-101.2691
70	767.8984	103.1950	-103.5197	250	346.2628	257.5919	-101.4540
80	778.0968	140.9814	-103.3015	260	336.0630	219.8103	-101.6707
90	781.5806	179.9695	-103.0589	270	332.5788	180.8237	-101.9096
100	778.2512	218.9577	-102.7994	280	335.9113	141.8265	-102.1704
110	768.1989	256.7924	-102.5302	290	345.9649	104.0005	-102.4392
120	751.7310	292.2954	-102.2609	300	362.4351	68.4941	-102.7092
130	729.3484	324.3981	-101.9998	310	384.8170	36.3996	-102.9740
140	701.7326	352.1296	-101.7506	320	412.4319	8.6730	-103.2238
150	669.7200	374.6467	-101.5237	330	444.4517	-13.8363	-103.4516
160	634.2838	391.2508	-101.3288	340	479.8888	-30.4404	-103.6489
170	596.5043	401.4519	-101.1686	350	517.6717	-40.6387	-103.8132

Table 5: The normal vector of circular plane.

Serial number	The plane normal vector value			Normal angle/(°)		
	I	J	K	α	β	γ
1	-0.002429	0.006443	-1.000000	90.139143	89.630848	179.605494
2	-0.002429	0.006446	-1.000000	90.139149	89.630673	179.605329
average value	-0.002429	0.006445	-1.000000	90.139146	89.630761	179.605412

Since the calibration of parallelism needs to calibrate the deviations in two directions relative to the reference plane, that is the X and Y directions, this is different from the calibration of perpendicularity error. Therefore, the deviation angles of the axes of the two shafts relative to the plate in the X and Y directions are given, as shown in Table 6.

Table 6: The result of parallelism calibration.

	Plate X-direction	Plate Y-direction
axisθ/(″)	-134.400	734.200
axis B/(″)	-485.800	-1 289.000

The axis of rotating shaft B produce an error value is - 485.800 " in the X direction relative to the plate and the error value is 1289.000" in the Y direction. The deviation of the parallelism of the rotating shaftθwith respect to the plate in the X direction is - 134.400" and the deviation of the parallelism in the Y direction is 734.200". Thus, the parallelism error between the rotating shaftθand B is 362.099 " and - 572.488 2". The results show that with the increase of the joint number and the gravity of the mechanism itself, the parallelism error will be amplified.

4 CONCLUSIONS

Through the above calibration method, the calibration of parallelism error of rotating shafts can be realized by using a high-precision plate.

Compared with the external calibration laser interferometer, theodolite, etc. it is simple, easy to operate, low requirements for environment, just ensure the stability of the plate during measurement, and the calibration cost is greatly reduced.

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