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DEVELOPMENT OF A NEW ARTIFACT TO CALIBRATE A BALL PLATE

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Abstract: In this paper, we propose a new design artifact to calibrate a ballplate. Ballplates are usually used to calibrate CMMs (Coordinate Measuring Machines). At present, for the calibration of ballplates, gauge blocks are being used. Gauge blocks are not appropriate as length transfer gauges because of their shape. Therefore, we developed a new artifact, which we call a one-dimensional ballplate. It consists of a steel bar that is designed as an ***H*** *section and balls. It has two advantages, namely, it can be calibrated by a laser interferometer and the positions of balls do not change in the event of elastic and thermal deformation.*
Keywords: CMM, Calibration artifact, Interferometer

1 INTRODUCTION

CMMs (Coordinate Measuring Machines) have numerous geometrical errors and scale errors. Some artifacts such as ballplates, holeplates, ballbars, stepgauges, ballcubes and gauge blocks are usually used to calibrate CMMs. Currently, ballpates are the most popular artifacts to calibrate CMMs. Ballplates, however, cannot to be calibrated by laser interferometers. When we calibrate the ballplate, we use a highly accurate CMM using swing-round technique with two gauge blocks (X direction, Y direction) for transfer length standard. Therefore, the ballplate cannot be calibrated more accurately than the performance of the CMM. Additionally, gauge block measurement has a problem of probing error. In effect, five probing points are used to calculate the center position of each ball for measuring the ballplates. Only two points, however, are probed to measure the length of a gauge block, therefore the probing error cannot be canceled. We propose a new artifact to calibrate ballplates. The artifact consists of a steel bar having an **H** section design and ceramic balls. This design is very simple and has two advantages, it can be calibrated by a laser interferometer and the positions of the balls do not shift in the event of elastic and thermal deformation. In this paper, we describe the concept of the new artifact, its features and how to calibrate it by the laser interferometer.

2 NEW ARTIFACT DESIGN

Figure 1 shows the new artifact and Table 1 shows its specifications. The body is made of steel with an **H** section design and the size is 68 mm × 68 mm × 560 mm. The ball is ceramic and its size is 7/8 inch. The ceramic ball is free from rust. The **H** section design enables the arrangement of all balls in the neutral bending plane. Thus, the balls do not shift in the event of elastic and thermal deformation (bimetal effect). The distance between adjacent balls is 83 mm. This is the same as in commercial ballplates. The artifact has an advantage of transferring the length standard to the CMM scale. Also the distance from ball to ball is measured by the laser interferometer (4-path interferometer). Figure 2 shows the instrument that enables calibration of the new artifact interferometrically. It is constrained kinematically (6-points constraint). The instrument sits on two balls. One ball constrains three DOF (degree of freedom) using a three-balls seat. Another ball constrains two DOF (yawing, pitching) using two cylinders. Additionally, one DOF (rolling) is constrained on the shoulder of the **H** design base.

Table 1. Specifications of new artifact

Material	Thermal expansion coefficient	Number of balls	Diameter of ball	Sphericity	Distance from ball to ball
Steel	11.386×10^{-6} /K	7	7/8 inch	0.54 µm	83 mm

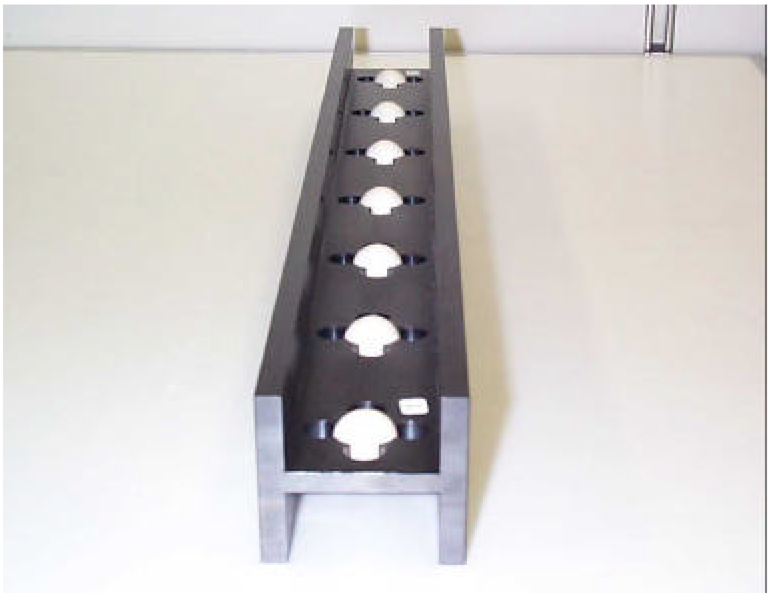

Figure 1. Appearance of the new artifact

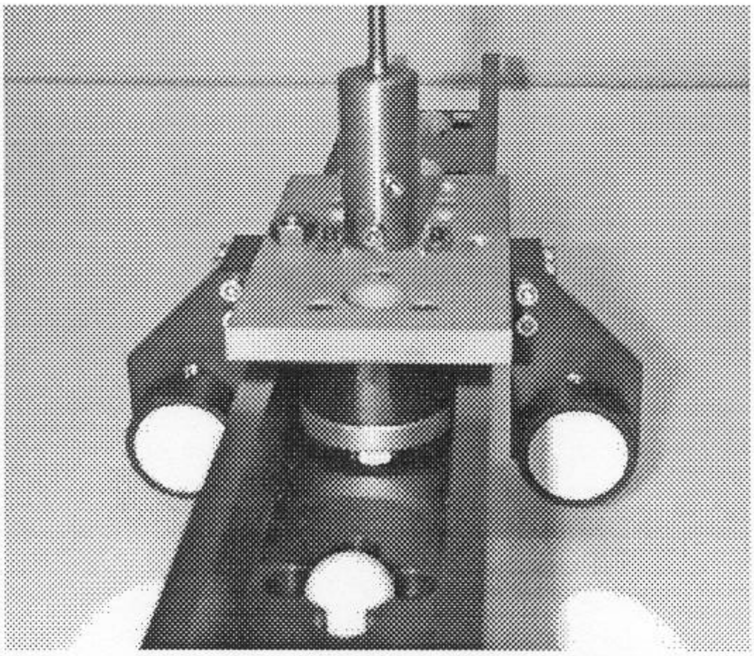

Figure 2. 4-path interferometer system with kinematic constraint

3 MEASUREMENT OF THE NEW ARTIFACT BY THE CMM

At first, we measured the new artifact using the CMM (Leitz PMM866). The swing-round technique was used in this measurement. During the measurement, object and the room temperatures were approximately 20 degrees. The measurement results are shown in Table 2.

Table 2. The measurement results at the center positions of the new artifact by CMM [mm]

No.	1	2	3	4	5	6	7
X	0	83.0048	166.0032	248.9952	331.9919	415.0137	498.0070
Y	0	0.0075	0.0208	0.0351	0.0298	0.0125	0
Z	0	0.0937	0.0546	0.0440	0.0324	0.0113	0

4 MEASUREMENT OF THE NEW ARTIFACT BY THE FOUR-PATH INTERFEROMETER

4.1 Four-path interferometer system

The four-path interferometer method has been often used for stepgauge measuring systems [1][2]. We used the method for the measurement of the new artifact. In this measurement, it is of atmost importance that the mirror is located at the same position repeatedly after the movement. Our system has a feature for enabling this. Our system is a six points constraint system as shown in figure 3. The instrument with two mirrors, which we call an "interference stepper", is constrained kinematically. It sits on two balls. One ball constrains three DOF (degree of freedom) using a three-balls seat. Another ball constrains two DOF (yawing, pitching) using two cylinders. Additionally one DOF (rolling) is constrained on the shoulder of the **H** design base. The stepper was lifted by the Z spindle of the CMM which acts like a crane and the artifact on the X table of the CMM moved above the balls and then the stepper was set on the balls. Figure 4 shows the four-path interferometer system. This system can cancel the "Abbe error".

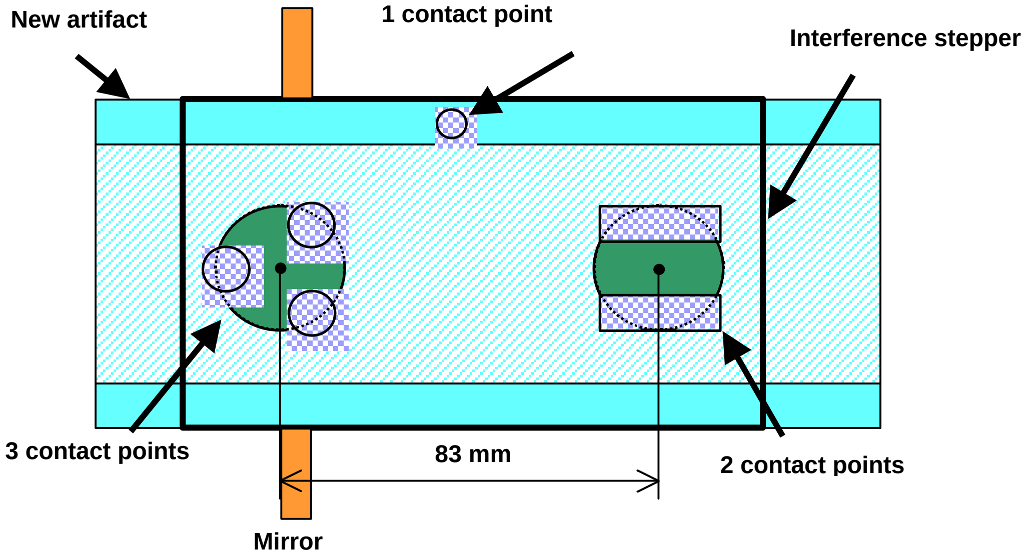

Figure 3. 6-points constraint system

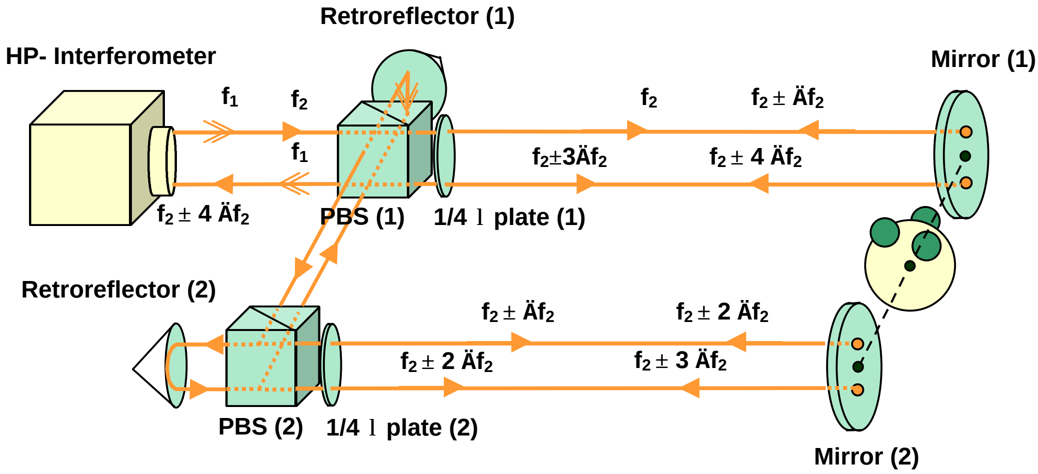

Figure 4. 4-path interferometer system

4.2 Examination of positioning accuracy of 6-points constraint system

First, we examined the positioning accuracy of this kinematic constraint system. It is very important for calibration of the artifact. We moved the stepper up and down fifty times and measured its position using four-path interferometer system. Figure 5 shows the result of this repeatability. The deviation of the positioning error is about 4 µm. The most likely reason for this is the friction between two balls or between the ball and the cylinder. Therefore, we improved the stepper. We used the vibration system using the eccentricity of a DC motor. This vibration system was effective for solving the friction problem. Figure 6 shows the result of using the vibration system. The deviation of the positioning error is about 50 nm. This means the stepper is able to measure the positions of the balls which are mounted on the new artifact.

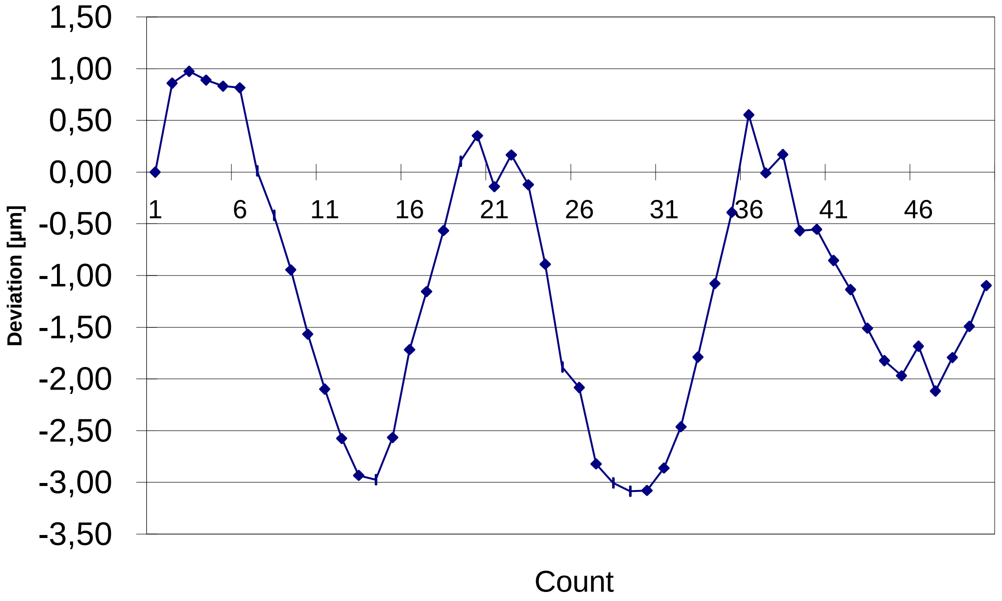

Figure 5. Repeatability of the positioning (50 times)

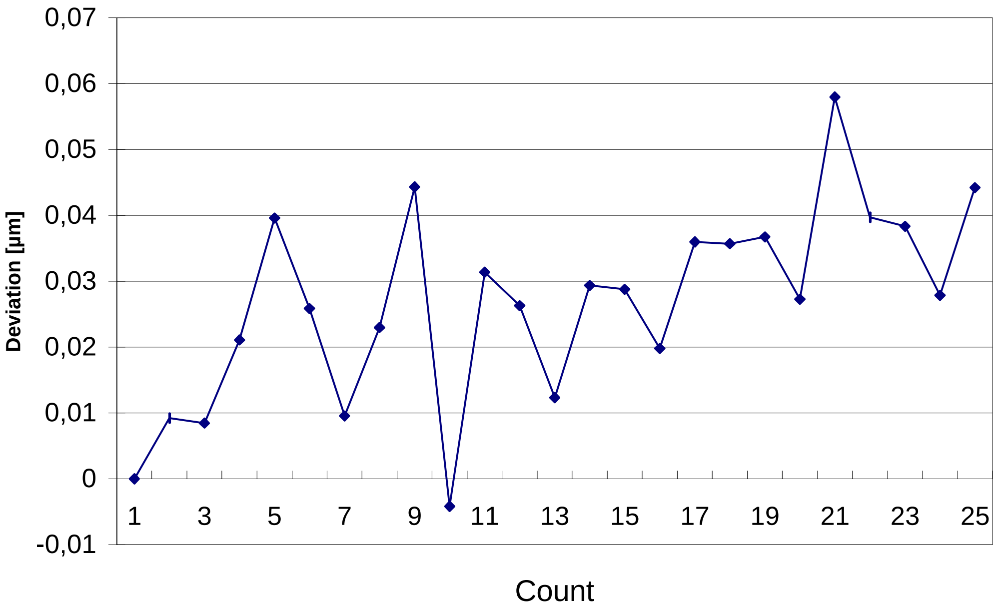

Figure 6. Repeatability of the positioning with vibration (25 times)

4.3 Measurement by 4-path interferometer system

In order to obtain good positioning repeatability, we ensured that the artifact was calibrated with at least 0.2 µm accuracy. It is important that the alignment of the artifact corresponds to the alignment of the CMM table motion. Therefore, we examined the alignment using a dial gauge. Figure 7 shows the setup of this system. We measured the distance between balls. We started this measurement from back to front (from ball No.6 to No.1). The measurement was repeated five times. Table 3 shows the results of this measurement. Figure 8 shows the deviation from the CMM results. The deviation is less than 0.4 µm except for balls 3~4. These results show that the interferometer system is able to calibrate the new artifact. The result for balls 3~4, however, is 1 µm different from the CMM result. The deformation of the ball or the rolling of stepper is probably the cause of this result.

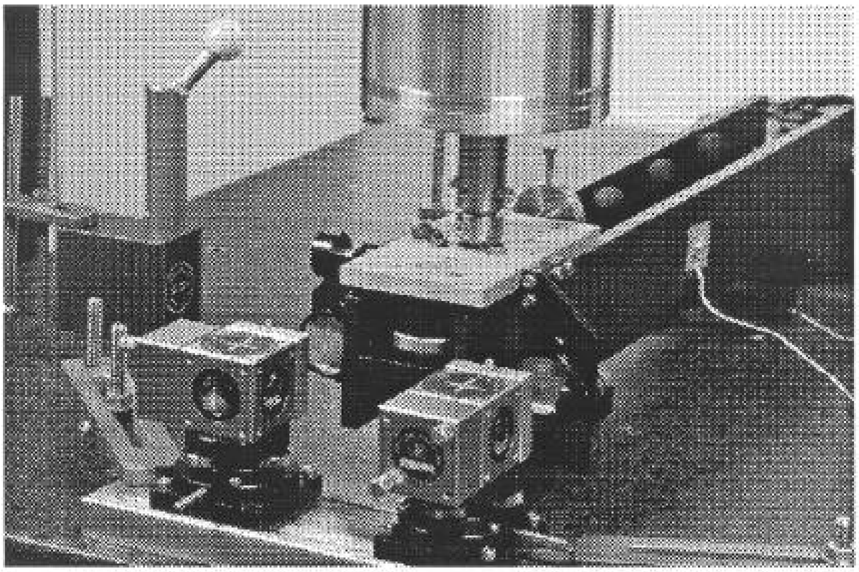

Figure 7. The system setup

Table 3. The result of the measurement by a 4-path interferometer system [mm]

	1	2	3	4	5	Standard Deviation	Average
No.1~No.2	83.005	83.005052	83.00503	83.005	83.00499	0.00002	83.00501
No.2~No.3	82.99836	82.998342	82.99835	82.99834	82.99836	0.00001	82.99835
No.3~No.4	82.9909	82.990919	82.99092	82.99093	82.99093	0.00001	82.99092
No.4~No.5	82.99638	82.996342	82.99636	82.99635	82.99637	0.00002	82.99636
No.5~No.6	83.02145	83.021429	83.02146	83.02145	83.02141	0.00002	83.02144

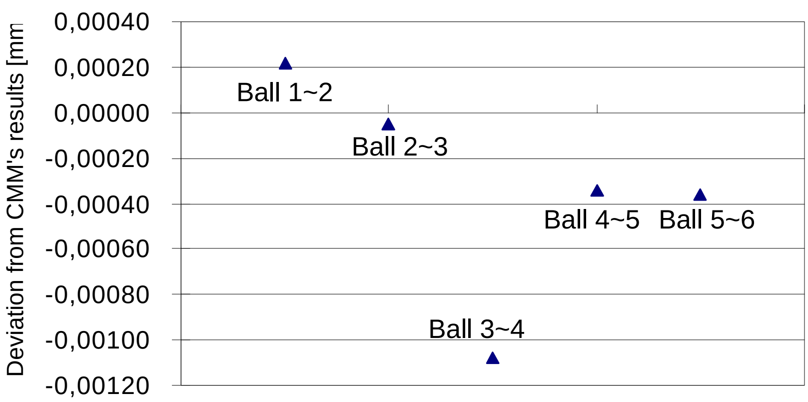

Figure 8. The deviation from the measurement result by CMM

5 SUMMARY

In this paper, we described the new artifact developed by us. The features of this artifact are as follows.

1. The new artifact can be used to calibrate ballplates.
2. The artifact can be calibrated by a laser interferometer.
3. The design of the new artifact prevents changes in the ball position that may result from elastic and thermal deformation.

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