CALIBRATION USING CYLINDRICAL ARTIFACTS FOR LASER 3D MEASUREMENT SYSTEM

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Abstract:
We are now developing inner shape measurement system for superconducting accelerator cavities. An acceleration cavity is shaped like bellows which have some cells. Inner shape of a cavity influences accelerating efficiency of particles. To improve and inspect accelerator cavities, we are now developing a system which can measure inner 3D shape. This system scan inner surface by inserting and rotating a laser displacement sensor unit attached to the end of the pole. This system is simple and useful not only for an accelerator cavity but also for a long pipe and a deep hole on an industrial part. We proposed calibration method for such a system. We simulated and analyzed the proposed calibration method and shows availability of cylindrical artifact calibration method.

Keywords: Measurement, Calibration, 3D Measurement

1. INTRODUCTION

2. LASER 3D MEASUREMENT SYSTEM

2.1 Measurement of axial symmetry object using Laser 3D system

Our main target is inner measurement of axial symmetrical object. Our target accuracy is 0.1mm.

CMM is generally used to measure the industrial parts and CMM has rectangular coordinate system. However, polar Coordinates is more useful for axial symmetrical object. We supposed a simple measuring system [1]. The system consists of distance sensor and 2-dof (1 linear and 1 rotation) system. We choose laser system to measure distance with no contact. Figure 1 shows laser 3d measurement system. Figure 2 shows target measuring area. Outer diameter is 200mm and inner diameter is 80mm.

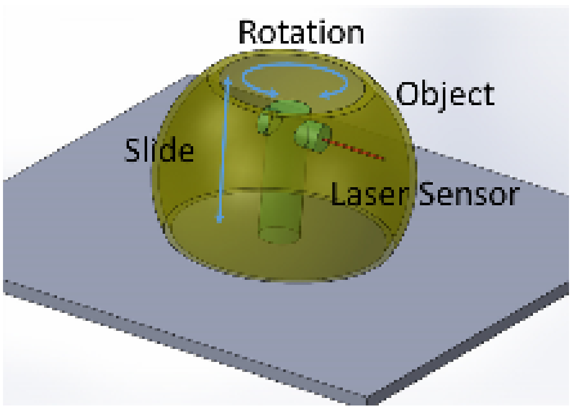

Fig. 1: Laser 3D measurement system

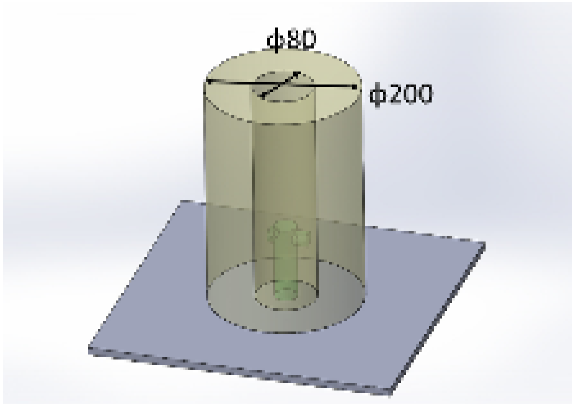

Fig. 2: measuring target area

3. CYLINDRICAL ARTIFACT CALIBRATION

For calibration of CMM, ring grid array and double ball bar are proposed [2]. We proposed a simple calibration method using a cylindrical artifact for rectangular coordinate measuring system. The proposed method has mainly 2 advantages. One is ease of producing artifacts. Since a cylindrical artifact has a simple and axisymmetric shape, it is easy to machine an artifact with lathe precisely. We do not need to turn up an artifact to designed diameter. The diameter can be caught by measuring it with CMM. The other is ease of performing calibration. The other is ease of performing calibration. We only place an artifact and measure it for calibration. It is not needed to align the artifact precisely.

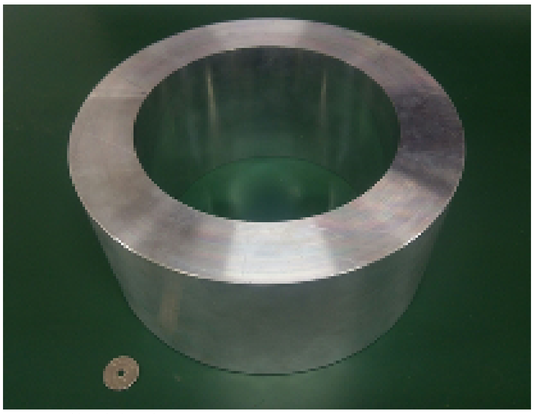

Fig. 3: Cylindrical artefact

4. 2D CALIBRATION

4.1 uncoaxial method

The 2D shape is given by rotating the distance measurement system. If the equipment is ideal, an accurate 3D position is easily obtained from the measured distance and setting angle. However, the original point of the measuring head differed from the axis of rotation. Therefore, to obtain an accurate point, a vector from the axis to the original position is necessary. Hence, the system was calibrated using a cylindrical artefact, which must be measured by CMM and have a known diameter. We solved the vector from the measurement results of the artefact without aligning the artefact.

Figure 4 shows the parameters to be considered [3]. The vector from the rotation axis to the original point of the measuring unit is (a_x, a_y,), while the vector from the center of the observed circle to the rotation axis is (s_x, s_y). Both vectors are unknown, but the radius of circle R and rotation angle θ are known. The observed distance is l. The relationship between the unknown parameters and observed values is:

$$\left| \begin{pmatrix} a_x \\ a_y \end{pmatrix} + \begin{pmatrix} s_x \\ s_y \end{pmatrix} \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} + l \begin{pmatrix} \cos\theta \\ \sin\theta \end{pmatrix} \right| = R \qquad (1)$$

We calculated the parameters by solving the following equation:

$$p = \mathrm{A}d. \qquad (2)$$

Parameter vector p, Jacobin matrix A, and observation vector d are defined below:

$$p = \begin{pmatrix} a_x \\ a_y \\ s_x \\ s_y \end{pmatrix}, \qquad (3)$$

$$A = \begin{pmatrix} -p_{x1}/r_1 & -p_{y1}/r_1 & (p_{x1}\cos\theta_1 + p_{y1}\sin\theta_1)/r_1 & -(p_{x1}\sin\theta_1 + p_{y1}\cos\theta_1)r_1 \\ \vdots & & & \vdots \\ -p_{xn}/r_n & -p_{yn}/r_n & (p_{xn}\cos\theta_n + p_{yn}\sin\theta_n)/r_n & -(p_{xn}\sin\theta_n + p_{yn}\cos\theta_n)r_n \end{pmatrix}, \qquad (4)$$

$$d = \begin{pmatrix} r_1 - R \\ r_n - R \end{pmatrix}, \qquad (5)$$

$$\begin{aligned} p_{xi} &= (a_x + s_x\cos\theta_i - s_y\sin\theta_i + l_i\cos\theta_i) \\ p_{yi} &= (a_y + s_x\sin\theta_i - s_y\cos\theta_i + l_i\sin\theta_i) \\ r_i &= \sqrt{p_{xi}^2 + p_{yi}^2} \end{aligned} \qquad (6)$$

The parameter vector was calculated by the nonlinear least square method using the Gauss-Newton method.

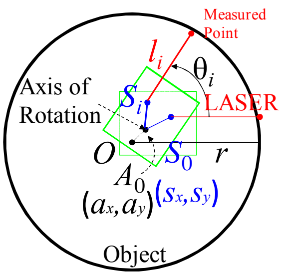

Fig. 4: Parameter to be solved

4.2 simulation of calibration

We carried out 2D simulation of measurement. Radius of cylindrical artefact is 75mm.

At first, we simulated using data without error. Figure 5 shows the raw data. The data is deformed by parameters

We solved parameters from data points and 32 points. At both condition, we could solved the parameters by only three loops of calculations (Table.1). Figure 6 and figure 7 shows the reconstructed data. The data reconstructed from the parameters had circular shape.

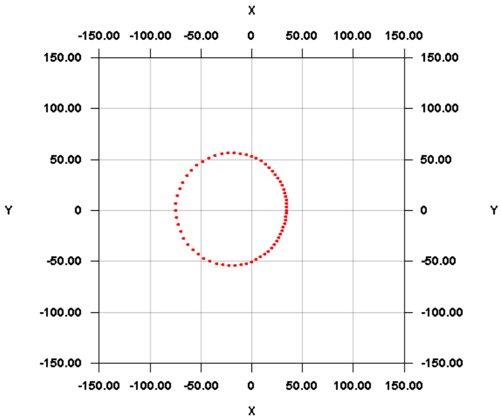

Fig.5: Raw data: ax=20, ay=0, sx=20, sy=5, R=75
The shape is deformed by parameters.

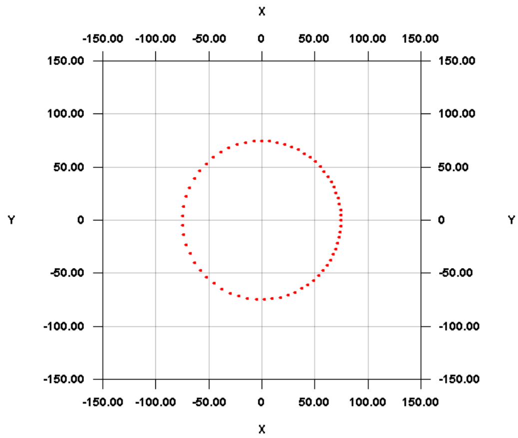

Fig.6: Reconstructed from 64 points
Circle shape is correctly restricted.

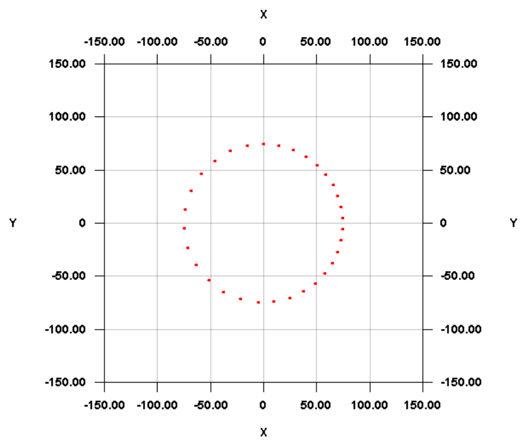

Fig.7: Reconstructed from 32 points
Circle shape is correctly restricted.

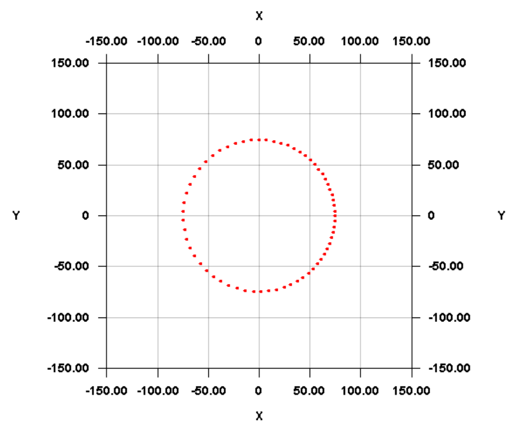

Fig.8: Reconstructed data from 64 points with errors

4.3 simulation with measurement error

Secondary, we simulated reconstructing using data with errors. We added ±0.1mm error to sample data.

Parameters are solved with errors. Figure 8 shows reconstructed data from 64 sample points. Parameters are solved with small errors and original shape is reconstructed. Table 1 shows simulation result. If sample points are not enough, parameters errors get larger. Figure 9 shows the result from 32 sample data. Figure 10 shows the enlarged view of original data and reconstructed data. Figure 11 shows coordinate error of reconstructed data using parameters from 32 points. The max coordinate position error is 0.38mm. These are caused by mainly parameter *sy*. The *sy* error appears as rotation error (squeezing error to be precise). Rotation angle is approximate following value

$$\arctan\,(\Delta sy\,/\,R) \tag{7}$$

R is radius of the artefact and Δsy is *sy* error.

Figure 12 shows rotating data. Coordinate error is smaller than 0.1mm in measurement area.

We can reduce sy error by making *ax* and *ay* larger if possible. It means that distance of rotation axis from axis of cylindrical artefact is larger. For example, if (*ax*,*ay*) is (40,0), error of sy is under 0.1mm. This value is acceptable.

Table 1 solved parameters

Error (mm)	0	0	±0.1	±0.1
Points	32	16	32	16
ax (20mm)	20	20	20.001	19.990
ay (0mm)	0	0	-0.023	-0.077
sx (20mm)	20	20	19.999	20.013
sy (5mm)	5	5	4.914	4.705
Max position Error (mm)	0	0	0.108	0.378

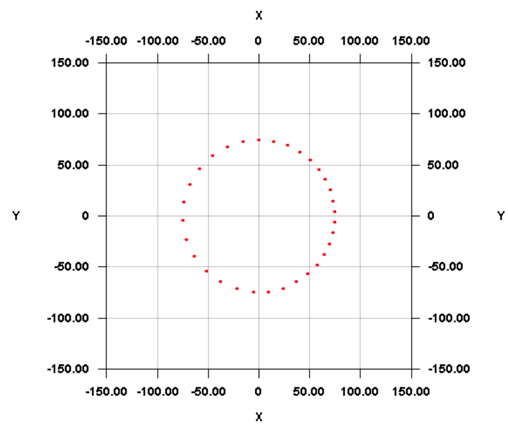

Fig.9: Reconstructed data from 32 points with errors

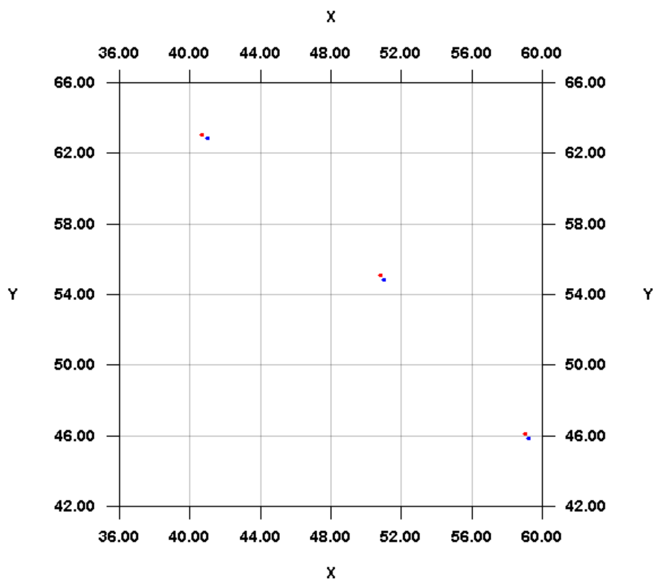

Fig.10: Original data (red) and reconstructed data (blue)

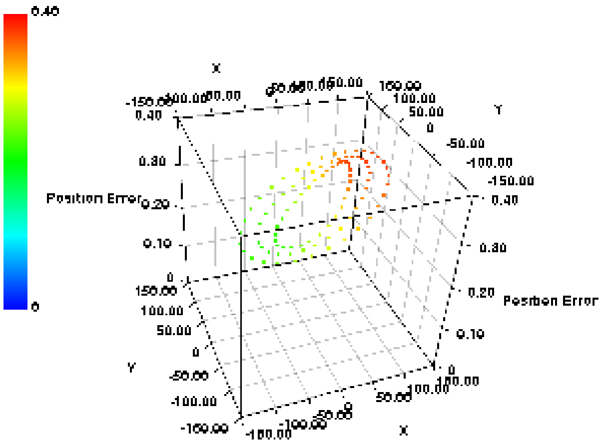

Fig.11: Position error at radius=50, 75, 100mm
Max error = 0.378

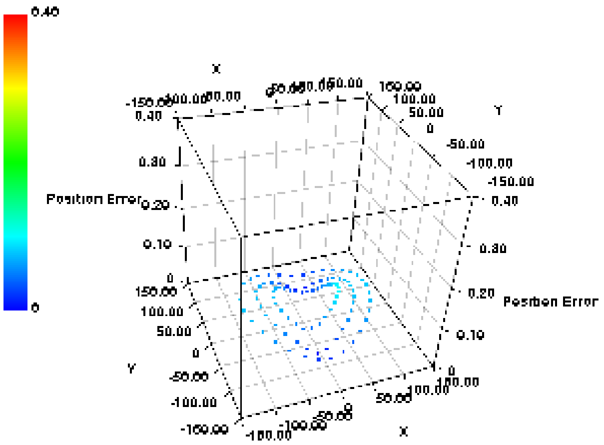

Fig.12: Position error after rotation
Max error =0.098

5. 3D CALIBRATION

5.1 Rotating point and 3d calibration

Figure 13 shows 2 rotating systems of 3D measuring system. Stem rotating type is rotating a root of stem. Unit rotating type is rotating only measuring unit at the end of stem.

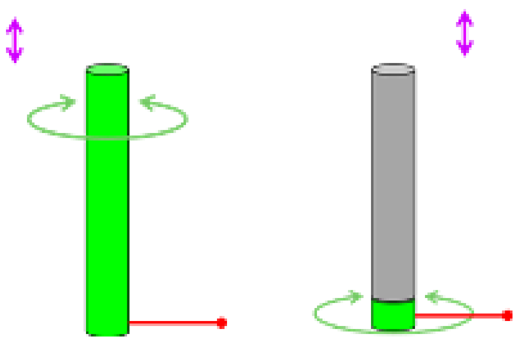

Fig.13: 2 rotating systems: left is stem rotation and right is unit rotation

5.2 3D calibration

Figure 13 shows the 3Dcalibration model. For 3d measurement, we get 2D parameters in some cross sections.

In 2D measurement, *sy* error is ignorable because it causes only rotation and the shape is constant. However, in 3D measurement, *sy* error causes serious influence if longitudinal position is important. All shapes of cross sections are correct. On the other hand, relative position of each section is disturbed by rotation error. To avoid this, we must measure enough sampling point or make distance of axes larger to get *sy* parameter correct enough. If the system is unit rotation, *sy* is same in each sections. Therefor we can avoid 3D rotation error by fixing *sy* in each sections.

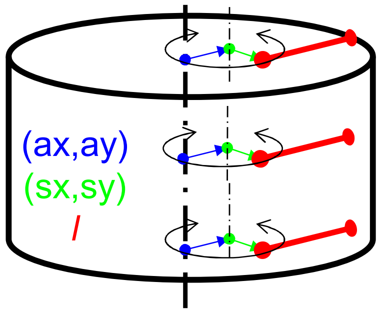

Fig.14 Model of 3D calibration: sy is variable at stem rotating

7. Conclusions

We suggested cylindrical artefact calibration for laser 3d measurement system.

We only place an artifact and measure it for calibration. It is not needed to align the artifact precisely. We carried out simulations. The result shows availability of cylindrical artifact calibration method.

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