XVII IMEKO World Congress
Metrology in the 3rd Millennium
June 22–27, 2003, Dubrovnik, Croatia

THE ESTIMATION METHOD OF UNCERTIANTY OF ARTICULATED COORDINATE MEASURING MACHINE

*Ken Shimojima , Ryoshu Furutani ,*Kiyoshi Takamasu and**Kenji Araki*

Department of Precision Engineering, Faculty of Eng,
Tokyo Denki University
Kanda-Nishiki-Cho 2-2,Chiyoda-Ward,101-8457 TOKYO JAPAN
* Department of Precision Engineering, Faculty of Eng,
University of Tokyo
Hongo 7-3-1,Bunkyo-ward, 113-8656, TOKYO JAPAN
** Instruments Div,Technical Section,
Kosaka Laboratory LTD
63-3Takano,Misato,341-0035 , SAITAMA JAPAN

Abstract - Articulated Coordinate Measuring Machines (A-CMM) are commercial products. However, it is difficult to keep the traceablity of it, because the calibration of A-CMM is performed by the manufacturer's own method. We planed to use 3D artifact, which had 9 balls for calibration, and test it. The kinematical model of A-CMM was described in D-H notation. In A-CMM measurement, a cone-shaped stylus was used. We measured the artifact in five different locations and orientations. Because the artifact has nine balls, 45 points in total ware measured. the parameters were determined in each location and orientation. Each set of kinematical parameters is applied to the measured points in five different locations and orientations. Then the root mean squares are calculated in 25 kinds of combinations. As a result, the calibration result is better than the specified accuracy of Vectron.

Keyword: Articulated Coordinate Measuring Machine, Estimate uncertainty, Calibration

1. INTRODUCTION

Recently, the coordinate measuring machines (CMMs) are used widely for a large measuring volume and its precision in the industry. A lot of Conventional coordinate measuring machines (C-CMMs) that has a orthogonal X, Y, and Z axis are used in the industrial. Figure 1 shows C-CMM. C-CMM is a mature measuring machine in various respects. The accuracy of the C-CMM is high, and the accuracy improvement more than present accuracy is difficult. Moreover, there is a measuring machine of different type from CMM. It is

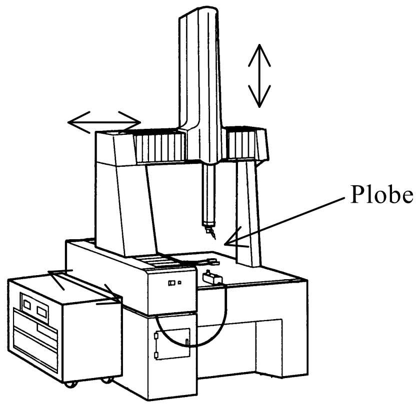


Fig.1 Conventional coordinate measuring machine(C-CMM)

Fig. 2 Articulated Coordinate Measuring Machine(A-CMM)

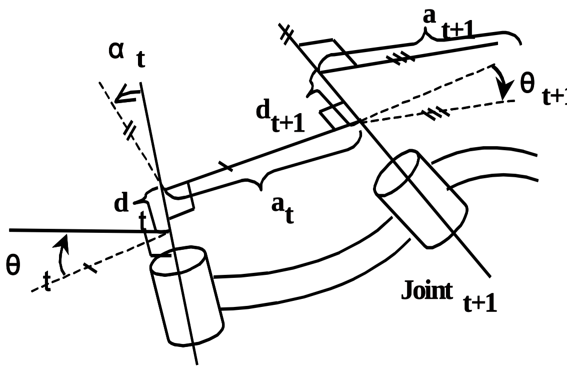


Fig.3 D-H-Kinematical Parameters between Two Joints

Articulated Coordinate Measuring Machine (A-CMM) shown in Figure 2. The A-CMM is more useful than Cartesian type CMM (C-CMM), because it has more degree of freedom and compact than C-CMM. Nowadays, A-CMMs are commercial products. However, it is difficult to keep the taraceablity of it because the calibration of A-CMM is performed by the manufacturer's own method. Then, we presume the uncertainty of A-CMM. We assumed the establishment of the guarantee method of the accuracy of the A-CMM to be a purpose of this research. We use The A-CMM that it is "Vectron" made of the Kosaka laboratory. "Vectron" of which the precision is 0.15mm in the range of 400mm, is handled in this report. This A-CMM has six joints that has 1 degree. The encoder is attached in each joints. Position coordinate of the end of A-CMM is calculated from the each joint degree and length of the arms. At first, the kinematical model and its parameters are described. Secondly, the artifacts calibrate the kinematical parameters. And we estimate uncertainty of measurement of A-CMM

2. KINEMATICAL PARAMETER

To estimate the uncertainty of A-CMM, we decided the kinematical model and parameters of it. We described the kinematical model of A-CMM in D-H notation to avoid the redundant parameters. The four parameters are necessary describe the relationship between two joints [1].

Four kinematical parameters consist of two parameters of angle and two parameters of length.

Each joint of Vectron is expressible by the movement coordinates in each link of A-CMM by the use of four parameters (ai,αi,di,θi) .

$$T_{i-1}^{i} = \begin{pmatrix} \cos(\theta_i) & -\sin(\theta_i) & 0 & a_{i-1} \\ \sin(\theta_i)\cos(\alpha_{i-1}) & \cos(\theta_i)\cos(\alpha_{i-1}) & -\sin(\alpha_{i-1}) & -\sin(\alpha_{i-1})d_i \\ \sin(\theta_i)\sin(\alpha_{i-1}) & \cos(\theta_i)\sin(\alpha_{i-1}) & \cos(\alpha_{i-1}) & \cos(\alpha_{i-1})d_i \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad (1)$$

The kinematical parameter of the A-CMM is expressible as (ai',αi',di',θi'), and added to the D-H

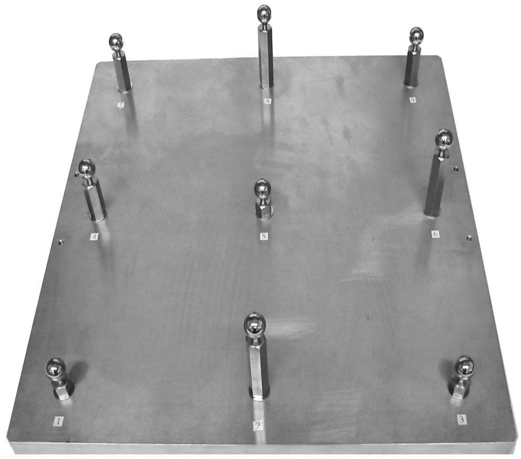


Fig.4 3D Ball Plate(3DBP)

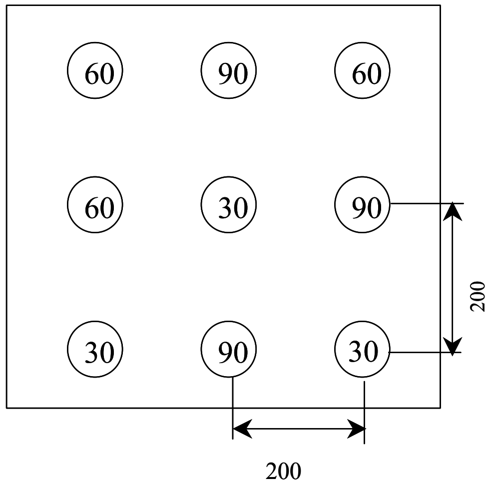


Fig .5 Height of center of spheres

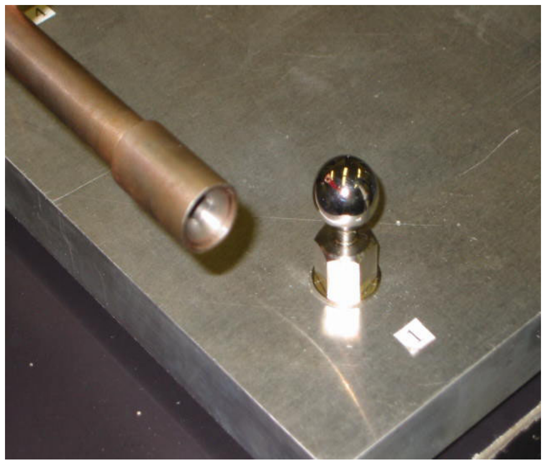


Fig.6 The cone-shaped stylus is approaching the ball

parameter of each joint. This is called a Kinematical parameter. As "Vectron" has 6 rotational joints, but it is five joints are described each joints in D-H notations. The number of the kinematical parameters becomes 20 in total. The coordinates of the end effecter (stylus top) can be described by three parameters (Px',Py',Pz')of translation, two parameters can be reduced because the origin could be freely chosen. As the coordinate system of A-CMM is different from the that of the artifact, six parameters(truncation(Tx,Ty,Tz)rotation (Rx',Ry',Rz') are necessary to convert from the coordinate system of A-CMM to that of the artifact. We call an ordinate translation parameter. Therefore, it is provide that 27(=20+3-2+6) kinematical parameters should be determined.

3. MEASURING METHOD OF ARTIFACT

The photograph of artifact is shown in the Fig.4. The balls are fixed on 3 kinds of different heights (30, 60, 90mm) on the flat plate and it is called 3D Ball Plate (3DBP). Figure 5 shows the height of center of spheres from the plane. The spheres are mounted on the flat plane with the screw of the bar. They were arranged not on the same plane. We used High precision C-CMM (Mitutoyo:FALCIO/APEX707) as the reference CMM to measure the center coordinates of the balls.

In A-CMM measurement, the cone-shaped stylus, shown in Fig.6, was used. The center of the ball always exists on a conic axial line of the cone-shaped stylus. Each ball was measured five times in five different angular postures of A-CMM. The kinematical parameter of each joint is determined as a result by the least squares method.

4. PROCEDURE OF CALIBRATION

As the numbers of kinematical parameters are 27, at least 9 balls should be measure, and determined the parameters. In this paper, we estimate more precisely kinematical parameters. every nine spheres are measured 5 times.

We measure the artifact in five different locations and orientations as shown in Fig.7. 45 points of the each position of the artifact are measured and the parameters are determined in each location and orientation.

5. CONCLUSION OF CALIBRATION

It is confirmed to have settled to a value close to the calculated initial value. Each set of kinematical parameters is applied to the measured points in five different locations and orientations. Then the root mean squares are calculated in 25 kinds of combinations. 25 kinds of results are shown in Table 2. In Table 2, the i-th row means the i-th set of parameters were applied. The j-th column means the measured data in the j-th location and orientation were used.

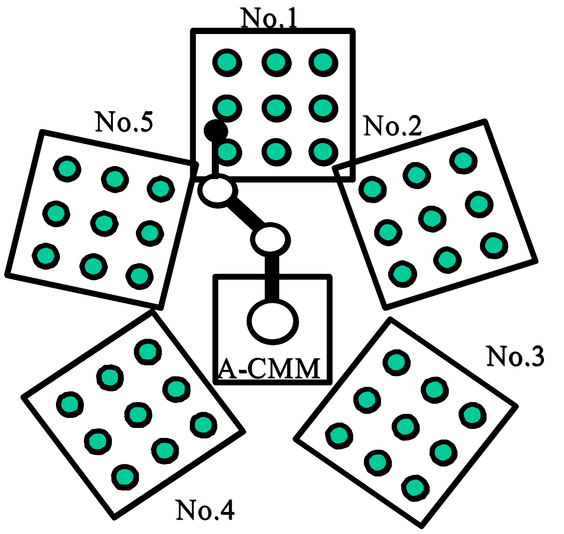


Fig.7 The artifact is put in some different locations and orientations

TABLE 2 Root Mean Squares using corn-shape stylus (mm)

	Group of Kinematical Parameters				
	No.1	No.2	No.3	No.4	No.5
No.1	0.050	0.085	0.099	0.104	0.099
No.2	0.080	0.061	0.125	0.116	0.117
No.3	0.083	0.109	0.062	0.094	0.085
No.4	0.080	0.096	0.079	0.078	0.079
No.5	0.087	0.115	0.078	0.104	0.068

TABLE3 Estimation of Uncertainty of Measurement(mm)

	Group of Kinematical Parameters				
	No.1	No.2	No.3	No.4	No.5
No.1	0.072	0.096	0.112	0.162	0.116
No.2	0.094	0.068	0.07	0.132	0.115
No.3	0.118	0.072	0.067	0.109	0.106
No.4	0.151	0.112	0.092	0.071	0.075
No.5	0.121	0.118	0.105	0.075	0.069

$$\{ Tx,Ty,Tz,Rx,Ry,Rz \} =\{106.315,-342.319,397.325,0.155,2.828,0.125\} \quad (2)$$

As a result, the calibration result is better than the specified accuracy of Vectron.

6. ESTIMATION OF THE UNCERTAINTY

6.1 Estimate of measurement of A-CMM

Position of Vector(x) including error is defined by equation(3) . Error factor of parameter is p, Error factor of angle in encoder is θ , Error of contact with cone-shape-stylus and ball of 3DBP is c. The uncertainty of A-CMM could be estimates according to ISO 14253-2[2]. It is defend as equation (4).

$$\chi = f(p,\theta) + c \cdots (3)$$

$$u_x = \sqrt{\left(\frac{\partial f}{\partial p}\right)^2 u_p{}^2 + \left(\frac{\partial f}{\partial \theta}\right)^2 u_\theta{}^2 + u_c{}^2} \cdots (4)$$

We determine the uncertainty that the cone-shaped stylus and the spheres of artifact come in contact(u_c) is 3 μ m . The uncertainty of rotary encoder (u_θ) is 3pulses.the estimated uncertainty is shown table 3. The factor of other uncertainties (temperature, measurer, and artifact) was not taken into consideration. The column shows the group of kinematical parameters and the row is measured result . And, a typical factor in A-CMM is influence of balancer and exchange stylus . We investigate those two factors.

6.1 Influence of balancer

The actuator is not installed in each joint of Vectron, and it measured workpiece being supported by person's hand. This balancer is necessary for the A-CMM. This balancer makes collaboration joint2 a fulcrum, and always lifts collaboration joint4 for above as shown in Fig.8. The bend and the distortion influence the causing accuracy for this balancer, but this is indispensable from respect of convenience. If there is no balancer, it falls by gravitation, the floor comes in contact, and the plobe is damaged. Then, we investigated how the balancer exerted the influence on the result of estimate uncertainty. Clause 6.1 is a result of estimate uncertainty when the balancer is operated. And, the same estimate of measurement is done by not operating it. Table 4 shows the result. It concluded that the influence of the balancer is small as it is possible to disregard it by comparing this result with Table 3 compared with the accuracy of the measuring instrument.

6.2 Influence of stylus

The shape of the measuring object of Vectron extends to many topics, and has the parabola antenna, the door of car etc. as the example. It has some attached stylus. It touches to the thing usually measured with a needle shape stylus, and the position of stylus is measured by pushing the trigger installed in link 6. There are various shapes in stylus, and the measuring object uses it. Figure 9 shows the picture of the stylus. Whenever stylus is exchanged, it is necessary to calibration. However, it takes time and labor hour when calibration every time. We investigated how to influence the method of estimate of uncertainty by exchanging the stylus. We prepare

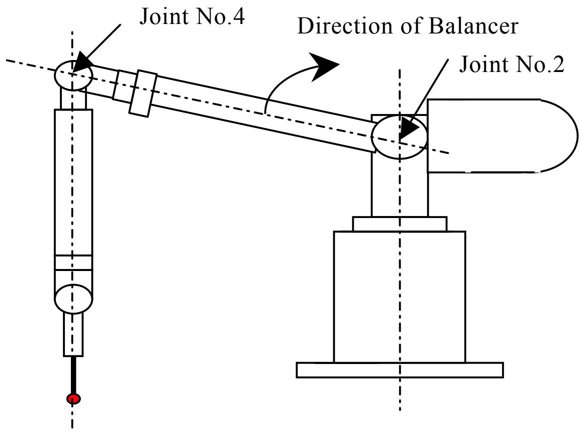
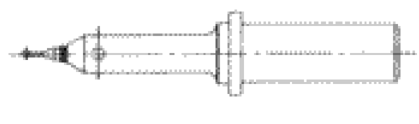


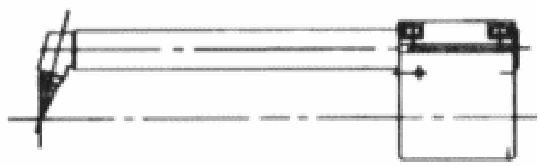
Fig.8 Picture of Balancer of A-CMM

TABLE4 Estimation of Uncertainty of Measurement(mm)
(Influence of balancer)

	Group of Kinematical Parameters				
	No.1	No.2	No.3	No.4	No.5
No.1	0.087	0.173	0.121	0.112	0.168
No.2	0.120	0.092	0.109	0.149	0.127
No.3	0.152	0.133	0.075	0.126	0.143
No.4	0.093	0.168	0.137	0.083	0.132
No.5	0.147	0.152	0.092	0.124	0.090



Standard stylus



Extension stylus

Fig.9 shape of stylus of Vectron

the cone-shaped stylus A and B, and 3DBP was set up in surroundings of Vectron by five places as well as Chapter 4. Installation location No1 was measured with stylus A, and it changed to stylus B afterwards, it measured it again. The measure is repeated five times. And estimate uncertainty of measurement. The result is shown in Table 5. It concluded that the influence of the change stylus is small as it is possible to disregard it.

7. IMPROVEMENT OF STYLUS

We paid attention to the factor of Error of contact with cone-shape-stylus and ball of 3DBP to enlarge the uncertainty. When 3DBP is measured, the posture of the measuring instrument is changed with the stylus touched. The resistance of the contact forth in measurement and friction of changing posture of A-CMM when coming in contact is large. Because it is a line contact in the contact of a conic stylus and the ball. We mannifacture the stylus with three balls. We call three-sphere stylus. It shows Figure 10. Three balls (10mm in the diameter) are bonding fixed to the edge side of the stylus. The distance between the balls is 15mm. Contact with the ball of three sphere stylus and 3DBP became point contact.

The measurement results with each stylus were compared. The measuring method is the same as Chapter 4 and 5. The table 6 shows the result of using three spheres. It can be said that accuracy improved compared with the result in Table 2, because the value with the three-sphere stylus is more than the values with the cone-shape stylus good values. It can be said that accuracy improved.

8. CONCLUSION

To propose the method of guaranteeing the accuracy of A-CMM, the mechanism parameter was decided.

We proposed new artifact and stylus for the calibration of the A-CMM. The kinematical parameters were determined using 3DBP.

The parameter assessment was performed. The result is better than the original accuracy.

It proposed the method of estimate uncertainty of measurement of A-CMM The uncertainty budget of balancer of A-CMM and exchanging the stylus are investigated.

We mannifacture the stylus with three balls,and the accuracy improved.

REFERENCES

[1] J.J.Craig : “Introduction to Robotics”, *Addison - Wesley*,1989

[2] ISO TS14253-2: “Geometrical product specifications(GPS)-Inspection by measurement of workpieces and measuring equipment-“

Authors: Ken Shimojima, Department of Precision Engineering, Faculty of Eng,Tokyo Denki University, Kanda-Nishiki-Cho 2-2,Chiyoda-Ward,101-8457 TOKYO JAPAN
Tel:+81-3-5280-3455,Fax:+81-3-5280-3571,
e-mail: k_shimo@mes.p.dendai.ac.jp

TABLE5 Estimation of Uncertainty of Measurement (mm)(Influence of Stylus)

	Group of Kinematical Paramertars(stylus A)				
	No.1	No.2	No.3	No.4	No.5
No.1	0.068	0.121	0.079	0.114	0.083
No.2	0.146	0.073	0.119	0.142	0.120
No.3	0.124	0.092	0.081	0.098	0.094
No.4	0.094	0.074	0.089	0.075	0.121
No.5	0.121	0.110	0.101	0.083	0.069
	Group of Kinematical Paramertars(stylus B)				
	No.1	No.2	No.3	No.4	No.5
No.1	0.074	0.132	0.125	0.132	0.124
No.2	0.121	0.091	0.146	0.105	0.132
No.3	0.142	0.135	0.075	0.124	0.143
No.4	0.151	0.182	0.102	0.087	0.172
No.5	0.106	0.165	0.134	0.168	0.082

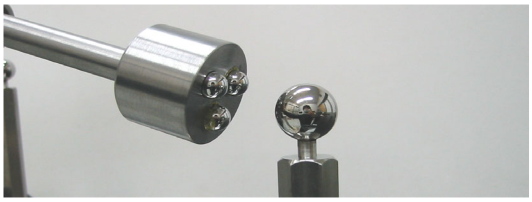


Fig.10 Three-sphere stylus

TABLE 6 Root Mean Squares using three-sphere stylus (mm)

	Root Mean Squares				
	No.1	No.2	No.3	No.4	No.5
No.1	0.055	0.073	0.101	0.098	0.078
No.2	0.078	0.042	0.069	0.073	0.084
No.3	0.065	0.061	0.057	0.094	0.103
No.4	0.067	0.068	0.085	0.065	0.064
No.5	0.073	0.078	0.059	0.106	0.054