Standardization of noncontact 3D measurement

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ABSTRACT

As the global R&D competition is intensified, more speedy measurement instruments are required both in laboratories and production process. In machinery areas, while contact type coordinate measuring machines (CMM) have been widely used, noncontact type CMMs are growing its market share which are capable of measuring enormous number of points at once. Nevertheless, since no industrial standard concerning an accuracy test of noncontact CMMs exists, each manufacturer writes the accuracy of their product according to their own rules, and this situation gives confusion to customers. The working group ISO/TC 213/WG 10 is trying to make a new ISO standard which stipulates an accuracy test of noncontact CMMs. The concept and the situation of discussion of this new standard will be explained. In National Metrology Institute of Japan (NMIJ), we are collecting measurement data which serves as a technical background of the standards together with a consortium formed by users and manufactures. This activity will also be presented.

Keywords: Coordinate measuring machine, noncontact measurement, standard, traceability, ISO

1. INTRODUCTION

Since there are a lot of measurement principles of non-contact coordinate measuring machines (CMMs), a unified method to assess overall performance of all types of non-contact CMMs does not exist. Assessment methods which cover many types of non-contact CMMs can assess limited part of various functions of the instruments. On the contrary, methods which can assess the measurement performance in detail covers limited types of instruments. Compromise of this contradiction is the research on the evaluation of measurement accuracy and standardization.

A unified assessment method is convenient for user. When the users are considering of purchasing instruments and if measurement results of different instruments under the same condition are written in their catalogues, the measurement results can be an indicator to judge the performance of the instruments. Actually each manufacturer is using a different assessment condition and procedure, and sometimes nothing is described concerning accuracy in the catalog. As a result, disadvantageous situation for the users often occur, for example it is made clear after purchasing the instrument that it does not meet the specification, or an argument between the manufacturer and the customer arises.

Not only users but also manufacturers suffer from the demerits that assessment methods have not been standardized. Since users are likely to buy products made by preceding or well-known manufacturers, it is not easy for new manufacturers to go into the market. For the product which has similar performance as a rival product under the same condition, establishing impartial assessment criteria will be effective. Additionally even some manufacturers do not know how to assess the performance of their products, and therefore they cannot improve their products. In this case, a theoretically-secured traceable assessment method will be useful.

In this paper, assessment methods of non-contact CMMs will be described as well as the significance, applications, and situation of standardization.

2. ASSESSMENT METHODS OF NON-CONTACT CMMS

No matter which the instrument is contact type or non-contact type, objects to be measured have wide variety. Characteristics needed for the CMM is different for measuring objects, and therefore it is impossible to assess the overall performance of the instrument by a single assessment method.

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Nevertheless a lot of efforts have been devoted for the standardization of assessment method of contact CMMs in ISO or other standardization bodies in each country. The term ‘standardization’ in this context means documentation of industrial standards such as ISO, ASME, VDI/VDE, JIS, and so on.

There are several standards for the assessment methods of CMMs; ISO 10360 series, ASME B.89 series in USA, and VDI/VDE 2617 series in Germany. In Japan there is a JIS B 7440 series which is a word-for-word translation of ISO 10360 series.

Concerning ISO 10360 series from Part 1 to Part 6 have already been published. Part 2 is the most important and frequently used, which stipulates the assessment method of measuring linear dimensions. Five gauge blocks of different sizes are measured seven times with changing their positions and orientations in the measurement volume.

All of these standards do not define the measurement principle, specifications, or structure of CMMs. It only defines the impartial measurement condition when the manufacturers and users jointly check the measurement performance, and procedures to judge whether the measurement result qualifies a certain criteria. The criteria mean in most cases the guaranteed accuracy (i.e. specification) on the catalogues and sometimes the contract made between the manufacturer and the user. The assessment methods which manufactures are thinking and that users are thinking should be the same, but actually slightly different. By compromising this difference, an industrial standard is made. The standard should be neutral between the two parties. Therefore all standards are compiled by committees which consist of manufacturers, users, and third parties (in most cases from academia). The numbers of the committee members of the three parties should be the same.

For contact CMMs, the simplest way to assess the measurement performance is to measure gauge blocks. By measuring the gauge blocks, only a limited part of the diverse functions and characteristics of the CMMs is assessed. It is, however, the practically attainable best compromise and better than nothing. Although the method is limited to the length measurement, it is capable of assessing fairly large parts of the performance which most users want to see.

3. MEASUREMENT STANDARD AND TRACEABILITY

‘Standardization’ in this paper is equivalent to ‘industrial standard’, but the term ‘standard’ can also have a different meaning ‘measurement standard.’ In addition, in the field of measurement standard, the word ‘traceability’ is often used. Roughly speaking the traceability is an unbroken chain system where an instrument is calibrated by a higher instrument, the higher instrument is calibrated by a much higher instrument, and eventually the chain reaches to the national or international standard.

Establishing measurement standards is the duty of government. In every country, a national metrology institute (NMI) develops, maintains, and disseminates measurement standards. In Japan, National Metrology Institute of Japan (NMIJ) and a few designated institutes are responsible for this task. Concerning the length, Meter Convention defines the length as the speed of light, and Japanese measurement law defines it as the wavelength of the stabilized He-Ne laser owned by NMIJ. All length gauges and instruments should be traceably calibrated to the national standard.

Length gauges such as gauge blocks are needed to perform the tests defined in ISO 10360-2. If the gauges are not calibrated or the calibration is incorrect, the credibility of the assessment result could be doubtful. All gauges must be traceably calibrated.

On the other hand, industrial standards are sometimes referred in the technical guidelines for the accreditation of calibration laboratories. Industrial standards and measurement standard are complementary and indispensable to each other.

In this paper the assessment methods particularly industrial standards are explained. In their practical execution, it is a prerequisite that measurement standards and traceability systems have been established properly.

4. STANDARD FOR ASSESSING MEASUREMENT PERFORMANCE OF NON-CONTACT CMMS

4.1 ISO standard

Contact CMMs measure ‘points’ on the surface of the specimen with contact probes, and calculate geometrical parameters from multiple measurement points. As far as non-contact CMMs measures ‘points’, conventional standards for contact CMMs can also be applied. However, because most non-contact CMMs are not capable of measuring reflective metal surfaces, commercial gauge blocks are not best suited as test gauges and an appropriate surface treatment should be given according to the characteristics of the instrument.

The most common non-contact CMM is the one with a video probe, and the standard for the video CMM has been discussed as ISO 10360 Part 7 in ISO/TC 213/WG 10 working group. Similar to Part 2, instead of the gauge blocks, glass plates on which lines or circles are printed with Chromium are used. Although general procedures are the same as those of Part 2, the most controversial point which differs from Part 2 is about bi-directional and uni-directional measurements. In bi-directional measurement, probing is carried out from two opposite directions like gauge block measurement, i.e. a synonym for size measurement. While in uni-directional measurement, a distance between the same patterns such as the engraved lines of a standard scale is measured. In order to regard the similarity with Part 2 as the most importance thing bi-directional measurement is desirable. However, measurement standard of the line width has not been established in most countries, therefore both measurements are allowed to use by clearly stating which is used in the product catalogues.

4.2 VDI guidelines

Only a few standards for the assessment of non-contact CMMs have been published so far. The most famous one is German standard VDI/VDE 2617 Part 6.2. Although strictly speaking VDI is not a standard but a guideline, in this paper we call VDI as standard. In this standard, by measuring a double ball bar measurement performance of the instrument is assessed. Gauge blocks in ISO 10360 Part 2 are replaced with the double ball bars and the measurement procedures are the same. For actually applying this standard a special consideration on the surface finish of the balls is needed. Nevertheless it is not defined in the standard, and to be decided between the manufacturer and the user.

Similar to ISO 10360 series, VDI/VDE 2617 series is supposed to apply for Cartesian CMMs. For non-Cartesian CMMs, VDI/VDE 2634 series is prepared. For non-contact CMMs, those having Cartesian translation stages are not common, therefore most instruments will be assessed by VDI/VDE 2634 series.

VDI/VDE 2634 series also uses a double ball bar, but the diameters of the balls are defined as 10 to 20 % of the measurement volume of the instrument; it does not look a double ball bar rather a pair of dumbbells. For example for the instrument having measurement volume of 1 m, balls of 10 to 20 cm diameter are needed. Because precise, lightweight, and inexpensive balls of this size are not easily available, this standard is not commonly used. Geometrical parameters to be measured in this standard are the distance between the balls and the deviation from the Gaussian associate (least square fitting) ball. Because most non-contact CMM users want to evaluate not only the distance but also the forms, the evaluation of the deviation is essential. In addition to the ball, a flat gauge is measured in this standard; hence the performance of the form measurement can also be evaluated also. Similar to VDI/VDE 2617 Part 2, no description on the surface condition of the gauges is in this standard, problems can happen in the evaluation of form measurement.

4.3 Standards for anthropometry

Non-contact CMMs have been used not only in production process but for anthropometry (human body measurement.) In anthropometry required measurement accuracy is at most 0.1 mm and most error sources arise from the human body itself. Therefore in most cases accurate and expensive instruments are not required. However, the degree of accuracy and the traceability are different things. Accuracy evaluation and traceability is needed even if the measurement accuracy is low.

4.4 Activities of the consortium

NMIJ had been asked by both manufacturers and users to make both industrial standard and measurement standard of non-contact CMMs. In response to this voice, NMIJ/AIST organized an assessment experiment in which both the manufacturers and the users participated. A ball plate and a ceramic cylindrical square gauge were used; both of them are often used for checking contact CMMs. Measurement results by each participant were compared with the specification stated in the corresponding catalogue. The amount of the errors is not important, while the conformity to the specification in the catalogue was checked.

Fig. 1 shows the scene of the experiment. A cylindrical square gauge made of ceramic is being measured by a non-contact CMM and a fringe on the surface of the gauge projected by the instrument can be seen. Many balls around the cylinder are markers which facilitate the stitching of images captured from different orientations. Unfortunately the results of the experiment are not confidential among the participants. The feasibility of making gauges and procedures to reveal the measurement performance of the instruments was assured.

In the next year 2006, a consortium was established in NMIJ to which 17 companies and about 40 private members currently belong. Three big Japanese motor companies Toyota, Nissan, and Honda are members and the other company members are non-contact CMM manufacturers or agencies of overseas manufacturers. The consortium members are trying to make impartial standard both for manufacturers and the users.

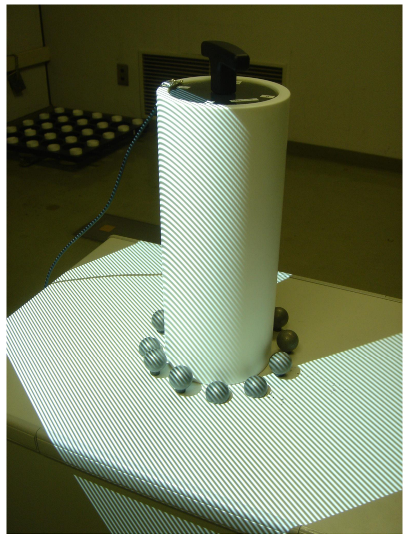

Fig. 1. The scene of the experiment. A cylindrical square gauge made of ceramic is being measured by a non-contact CMM and a fringe on the surface of the gauge projected by the instrument can be seen.

5. CONSIDERATION FOR THE GAUGES

5.1 Surface finish of the gauges

The first topic in the consortium is the surface treatment of the gauges. Most users want to measure highly reflective surface such as the surface of cars, while the manufacturer want to use diffusely reflective gauges for the performance assessment. We concluded that diffuse gauges should be used for checking the scale of the instrument. We made many balls having different surface finish and selected five of them which may reflect lights diffusely and uniformly. The balls are commercial bearing balls and the diameter is 25.4 mm. The upper low images of Fig. 2 shows the images of the balls; the surface treatments are dispersed plating (B-MOS), Cr plating after sandblasting, TiN coating after sandblasting, and chemical etching by $FeCl_2$ for 1 minutes and for 3 minutes. The bottom low images are examples of measurement results. For some balls specular reflection can be observed.

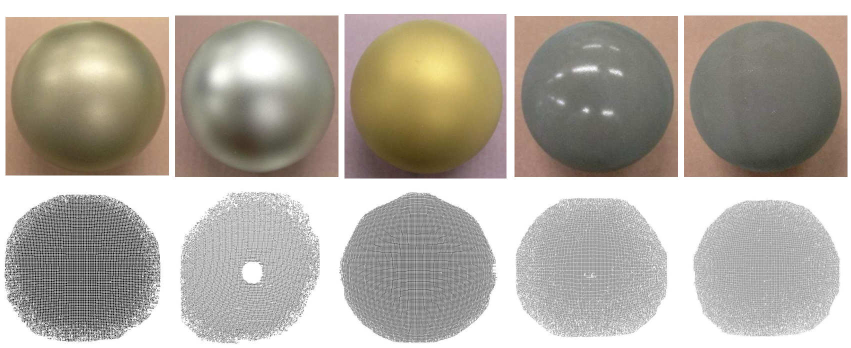

Fig. 2. The images of the balls; The surface treatments are (from left) are dispersed plating (B-MOS), Cr plating after sandblasting, TiN coating after sandblasting, and chemical etching by $FeCl_2$ for 1 minutes and 3 minutes.

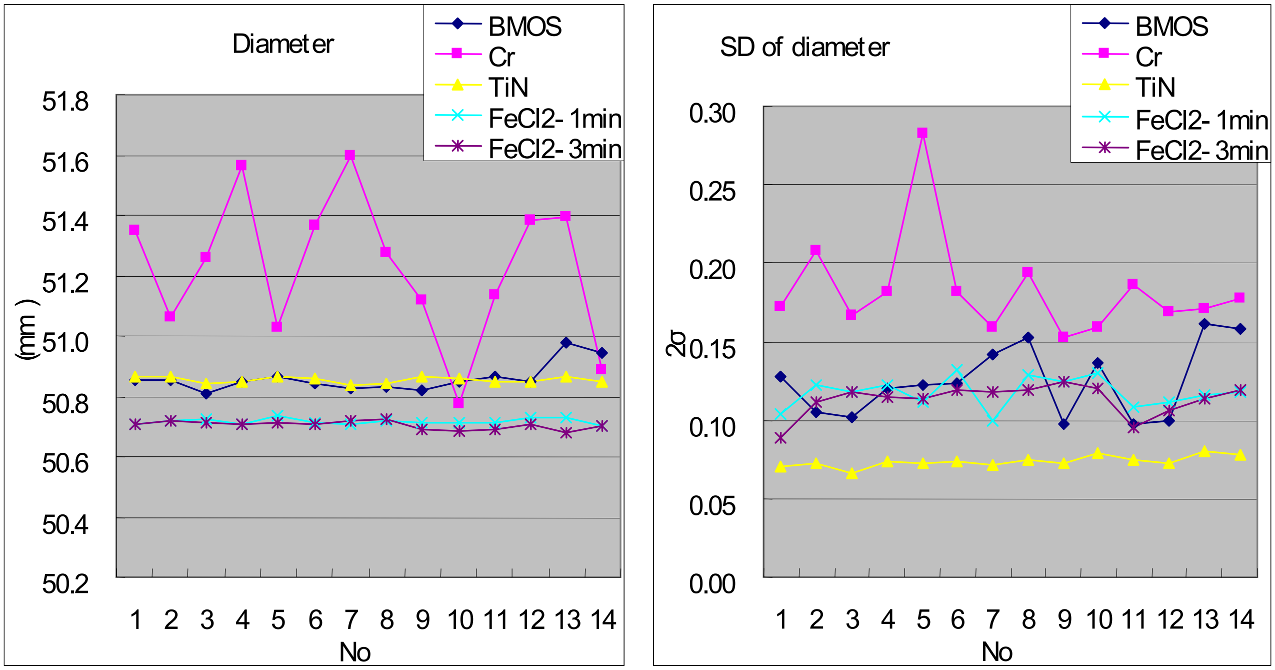

Fig. 3. The measurement results of the balls by 14 different non-contact CMMs. The averaged diameter (left figure) and the the standard deviation (right figure) of multiple measurements.

Not only the reflectivity but the hardness is very important characteristics for the gauges, because the gauges are calibrated using a contact type CMM. Finally the TiN coating ball was chosen because (1) the measurement result is stable, (2) the surface is hard, and (3) it is free from rust. However we do not intend to define TiN balls as the only one surface treatment. The TiN coating will be introduced in the informative annex of the standards.

Although the sandblasting is done by a skilled technician, the quality is not always constant and changes for grain size, grain material, and the pressure of spraying. Also too much sandblasting can deteriorate the sphericity of the balls. Fig. 4 is an example of the experiment to determine the process condition of the sandblasting.

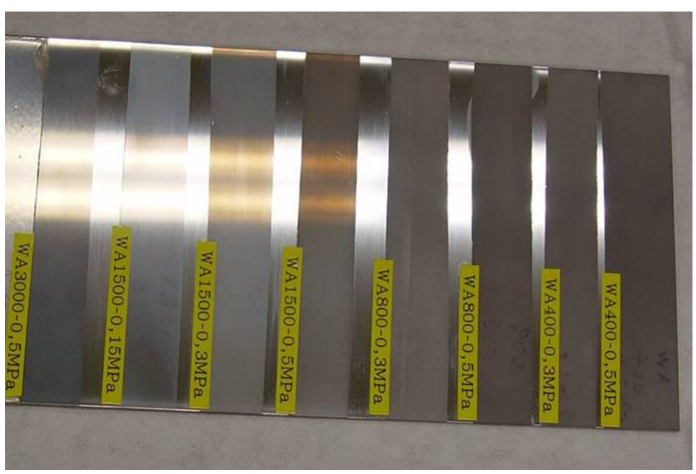

Fig. 4. An example of the experiment to determine the process condition of the sandblasting. Fluorescent lights reflecting on the surface can be observed.

5.2 Gauges for the probing error test

Figure 5 shows a steel ball with a diffusely reflecting TiN coating surface whose diameter is 120 mm and whose sphericity measured by a contact CMM is 20 µm. The ball is hollow and therefore very light-weight. It is used to assess the probing error of non-contact CMMs.

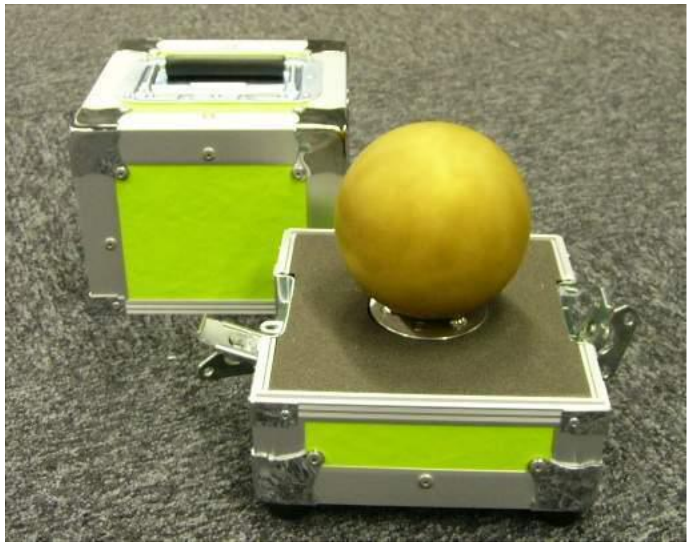

Fig. 5. A steel ball with a diffusely reflecting TiN coating surface whose diameter is 120 mm.

5.3 Gauges for the length measurement error test

Figure 6 shows a ball array made by the consortium for assessing the error of indication for length measurement. It was designed in conformity with VDI/VDE 2617 Part 6.2. Six matte steel balls coated with TiN are fixed at intervals of 200 mm on the gauge's flame made from carbon fiber. The diameter of each ball is 45 mm and their sphericity is 4 µm. The distance between the centers of the ball are calibrated with CMM in NMIJ.

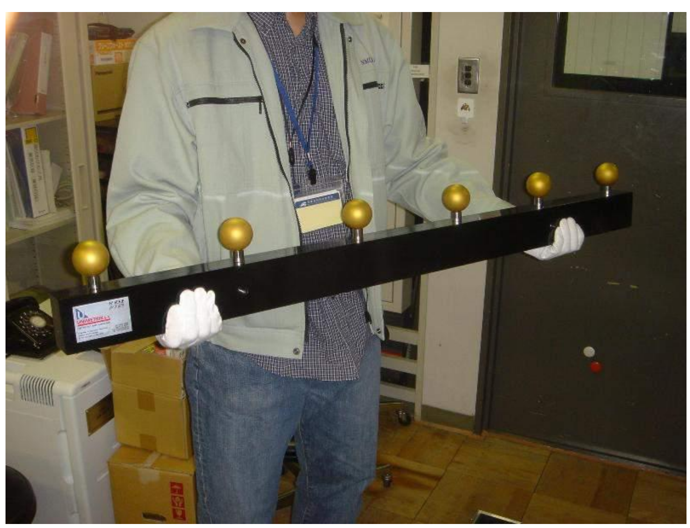

Fig. 6. A ball array made by the consortium for assessing the error of indication for length measurement.

5.4 Other gauges

Because of the existence of other error sources in the complex shape measurement, the combination of the probing error test and the length measurement error test cannot evaluate the performance of non-contact CMMs enough. We also made some gauges for the performance test through the discussion in the consortium. The designs of them are selected not only from the point of view of the similarity to actual products, but from those of the ease of manufacturing and calibration. All of them are designed whose geometrical parameters are easy to compute from the results of measurement with CMM.

Figure 7 shows the checking gauges for checking the practical performance of non-contact CMMs. The top-left one is a cylindrical gauge, which is used to check the diameter and cylindricity calculated from measurement data in large volume. The top-centre one is an attenuation curve gauge, which is used to assess the performance of fitting complex form. The top-right one is a concentric truncated cone gauge, which is used to check the concentricity of each cone and cone angle from the measurement data. The bottom-left one is a gauge with cylindrical steps and hexagonal column, which can check the step height measurement, angular measurement and other associated parameters. The bottom-right one is a cylindrical step with round corner, which is used to check the corner radius fitted to the measurement data. The surfaces of those gauges are also coated with TiN. They are under trial use among the members of the consortium.

Fig. 7. Gauges for checking the practical performance of non-contact CMMs.

Those gauges having complex forms are capable of evaluating practical performance, but generally speaking such gauges are difficult to calibrate. To perform accurate calibration the reversal or swing-round techniques are used, and from the point of view of calibration the gauges are desired to be simple and symmetrical. Standards which make use of such simple gauges together with appropriate evaluation procedure and are capable of various parameters are good standards.

6. FUTURE PROSPECT

Standardization processes in ISO committees are generally slow and the consortium members cannot wait so long. A new draft of JIS (Japan Industrial Standard) has already been compiled in the consortium and submitted to the government. It will be published in the near future. This standard is comprehensive and its scope covers all types of non-contact CMMs.

On the other hand, Japan proposed a new ISO standard (tentative number is ISO 10360 Part 8) to ISO/TC 213/WG 10 jointly with Germany. This standard was made based on VDI/VDE 2617 Part 6.2; therefore it covers only Cartesian type CMMs. After this standard is approved, above mentioned comprehensive standard will be proposed to the ISO committee.

Industrial standards are not compulsory law. Manufactures do not have to abide by them. They, however, can decrease current confusion and arguments between the manufactures and the users. Since the principles of non-contact CMMs widely vary, it is impossible to make an almighty standard, but a simple standard may apply for wide variety of CMMs. Development of assessment methods and standardization are at the beginning stage. The manufactures and the users should collaborate to pursue this task.