Evaluation the Performance of Portable Coordinate-Measuring Systems with MSA Methodology

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***Abstract*— To solve a wide range of metrological tasks, portable coordinate measuring machines (PCMMs) are used. They are also called "measuring arms" because of the analogy with the human arm. Unlike stationary CMMs, they are compact, portable, and easily applicable in almost all production conditions.**

For an assessment of the quality of measurement systems during measurement process, a methodology standardized for the automotive industry is used - Measurement System Analysis (MSA).

This paper deals with the application of MSA methods in the portable coordinate measuring machines (PCMMs). Results of the evaluation of two types of PCMMs are presented.

Keywords*— *MSA, portable coordinate measuring machines, measuring arms

I. Portable Coordinate Measuring Machines

An enduring trend in the world of metrology in past years has been the growing demand for measurements that take place ever further away from the controlled environment of measurement laboratories. Measurement in a production environment is becoming the industry standard in many large sectors, whether it is the presses in the car shop or the forges of the foundry. To solve a wide range of metrological tasks, portable coordinate measuring machines (PCMMs) are used, also called "measuring arms" because of the analogy with the human arm. Unlike stationary CMMs, they are compact, portable, and easily applicable in almost all production conditions. The main metrological issue is about the accuracy of measurement with portable CMMs – their accuracy is still inferior to stationary ones by an order of magnitude.

The ISO 10360 series of standards is applied to ensure the accuracy of the measurement with PCMMs [1]. This series of standards is defined for acceptance tests and re-verification of portable coordinate measuring machines. In October 2016, ISO 10360-12 was published. This document is dedicated to the certification of the accuracy of portable articulated measuring arms when measuring with a touch probe. The certification specifies four accuracy values known as E_{UNI}, P_{SIZE}, P_{FORM} and L_{DIA} (Fig. 1).

Each of these values represents a different aspect of the tactile measurement accuracy of a portable measuring arm.

The E_{UNI} value is the maximum permissible error (MPE) for unidirectional length measurements. Therefore, it most accurately reflects most measurement needs.

The P_{SIZE} value is the maximum permissible error (MPE) for measuring the diameter of a sphere. Therefore, it reflects the accuracy of the feature measurements.

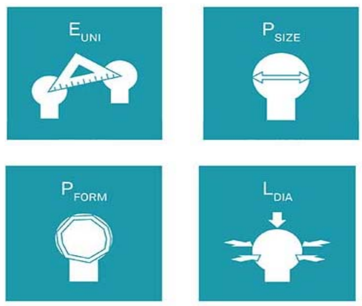

Fig. 1. Accuracy indicators of PCMMs according to ISO 10360-12

The value of P_{FORM} is the maximum permissible error (MPE) for the shape of a sphere. This is a value that determines the accuracy of the shoulder variance.

The L_{DIA} value is the maximum permissible error (MPE) for the articulation location. Therefore, it represents the repeatability of PCMM.

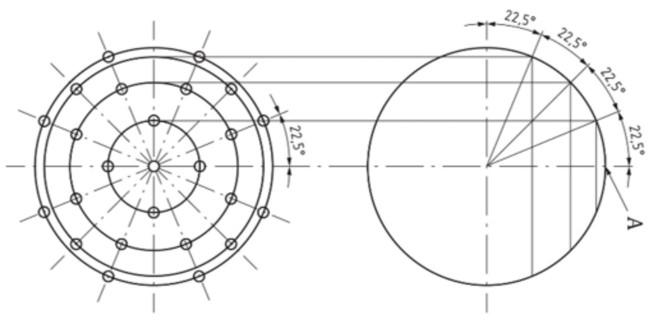

Fig. 2. Location of probing points according ISO 10360-12

According to the requirements of ISO 10360 first of should be determined the points of measurement (Fig.2) over the test sphere surface (at least 25 points) for examining the P form and P size errors. It should be used a material standard of size (test sphere) with diameter with size in range of 10 to 51 mm. It should be noted that if the test sphere is too small it

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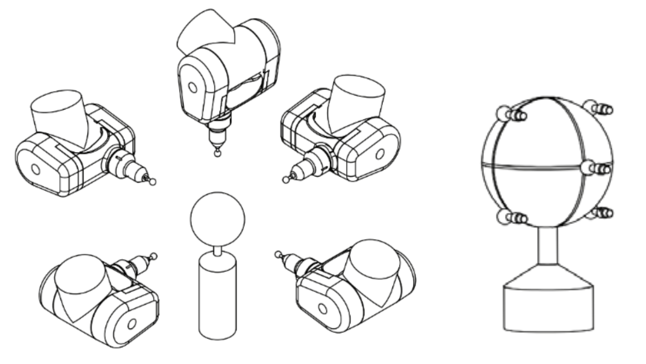
will be difficult to probe and normally this leads to significant errors. The procedure require to choose two different positions of test sphere in the working volume of the articulated arm. Normally one of this directions is placed near to the vertical axis of the arm, and the other is close to the maximum radii of working volume. When start measuring with the arm it is necessary to to probe without rotating the stylus or changing it direction, trying to distribute the measured point equally over the three different section of the test sphere by taking over hemisphere of it.



(*a*) (*b*)

Fig. 3. *Pole ponts according ISO 10360-12: a) five stylus direction; b) five points with common stylus direction*

To estimate the length measurement errors is used to stated the maximum permissible errors of length measuring with the arm. The assessment consist of measurement of five different calibrated standards of length in seven measurement lines. The length standards is possible to be single artefacts of to be a specified calibrated construction, known as ball bar. The longest length should be less than 66 % of the working volume of the arm. Each five calibrated test artefactsshould be measured in three different elbow positions of the arm (Fig.3).

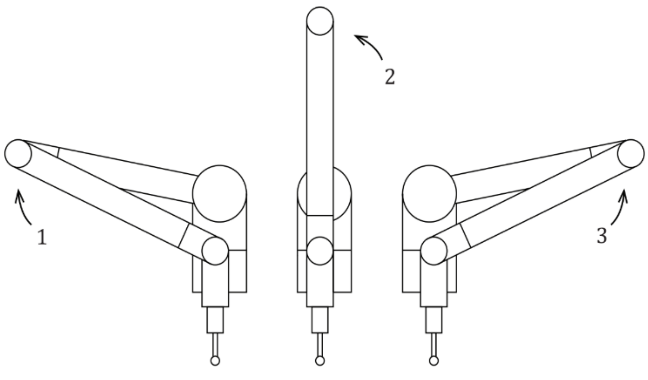


Fig. 4. *Elbow positions during length errors assessment*

According to the requirements of the ISO standard 105 points are measured as a combinateion between elbow position, different test lengths and three repeated measurements.

Certification to this ISO standard has clear benefits for the user – it is now possible to assess which arm more accurately is better for a particular application by first determining what is the most important aspect of the measurement for that application.

II. Application of MSA for PCMMs.

The ISO 10360-12 certificate provides only an initial information about the accuracy of the PCMM. In the operation of these measuring devices in several branches, in particular in the automotive industry, a periodic inspection is required to ensure the quality of the control. It is standardized as the MSA methodology [2], according to which a small sample of manufactured products is measured by different operators with several repetitions. The results thus obtained are statistically processed according to standard methodology and indicators are determined that assess the suitability of the measuring system.

This methodology does not provide complete information about the state of the measuring instruments in terms of their calibration and accuracy.

For the convenience of PCMMs users, some manufacturers offer machines with the ability to carry out inspection procedures themselves and thus carry out a type of self-certification. An example is the HEXAGON ROMER Absolute Arm, which offers a NIST metrologically traceable length reference element that can be used for a quick check to see if the machine meets the specifications. While self-certification is worthwhile as an interim check to ensure that the machine continues to meet the specifications, most companies' quality plans require third-party certification at specified intervals (often 1 year). If an interim or annual inspection shows that the machine is not operating within the claimed specifications, it cannot be certified. Adjustments must be made to the arm for its certification, in other words calibration is done.

To obtain more information about the accuracy of the measurement with the PCMM, it is suggested certified standards to be used when applying the MSA procedure. In this way, the calibration of the measuring system and the accuracy declared by the manufacturer are verified. This approach is suitable for the initial start-up of the PCMM, as well as for periodic checks during operation.

The modified methodology was tested on two PCMMs of the HEXAGON company with the following main characteristics [4]:

TABLE I. Main Characteristics of HEXAGON Arms

Characteristics	*Absolute Arm mod.8525*	*Absolute Arm mod.8512*
Max Range	2.98 m	1.49 m
E_{UNI}	0.031 mm	0.019 mm
P_{SIZE}	0.012 mm	0.006 mm
P_{FORM}	0.048 mm	0.016 mm
L_{DIA}	0.012 mm	0.012 mm

These PCMMs are part of the equipment of the newly built laboratory "Metrological assurance, intelligent systems for measurement and quality control" in Technical University of Sofia as part of the Center for Competence in Mechatronics and Clean Technologies MIRACle (Mechatronics, Innovation, Robotics, Automation, Clean technologies).

The study involves using the certified length standards provided by the manufacturer. 10 measurements of the standards were made by three operators in the horizontal coordinate directions and at an inclination of 120° and 240° (Fig. 5).

The results were processed with the statistical software MINITAB. Table 2 presents the summarized results for model 8525, and Table 3 gives the summarized results for model 8512.

The differences with different positioning of the standards are within 0.002 – 0.004 mm.

Fig. 5. Measurement with PCMM with certified standards

TABLE II. VARIABLE MSA - GAUGE R&R RESULTS

Absolute Arm mod.8525	
RepeatabilityEquipment Variation (EV)	2.2 µm
Reproducibility Appraiser Variation (AV)	1.8 µm
Repeatability & Reproducibility (GRR)	2.9 µm
Product Variation (PV)	0.7 µm
Total Variation (TV)	2.9 µm
AIAG Method	
% of Total Variation	***% of Tolerance***
EV = 75.0%	EV = 42.8%
AV = 61.5%	AV = 35.1%
GRR = 97.0%	GRR = 55.3%
PV = 24.5%	PV = 14.0%
Component Variance Method (*% of Total Variation)*	
EV = 56.2%	
AV = 37.8%	
GRR = 94.0%	
PV = 6.0%	

Formal analysis of the results obtained by the Component Variance Method shows that model 8512 is suitable for use, and model 8525 is not.

If we apply the AIAG criterion, both models are far from the acceptable 10%. This is because of the 6x increase in GRR in the calculation.

TABLE III. VARIABLE MSA - GAUGE R&R RESULTS

Absolute Arm mod.8512	
Repeatability Equipment Variation (EV)	1.3 µm
Reproducibility Appraiser Variation (AV)	2.2 µm
Repeatability & Reproducibility (GRR)	2.6 µm
Product Variation (PV)	3.7 µm
Total Variation (TV)	4.5 µm
AIAG Method	
% of Total Variation	***% of Tolerance***
EV = 29.3%	EV = 41.8%
AV = 49.0%	AV = 70.0%
GRR = 57.0%	GRR = 81.5%
PV = 82.1%	PV = 117.3%
Component Variance Method (*% of Total Variation)*	
EV = 8.6%	
AV = 24.0%	
GRR = 32.5%	
PV = 67.5%	

Another approach to evaluation is the ratio of GRR to the MPE for the relevant CMM. Applying this approach to the investigated PCMMs, the following results are obtained:

Absolute Arm mod.8525:

GRR = (2.86 / 31) . 100 = 9.2%

Absolute Arm mod.8512:

GRR = (2.58 / 19) . 100 = 13,6%

III. CONCLUSION

The application of the standardized MSA methodology allows for the evaluation of the PCMMs regarding their suitability for operation. The use of standards to apply the methodology allows assessment of calibration and actual measurement accuracy. The analysis of the results of the processing of the research data must be presented when declaring the reference datum.

Acknowledgment

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