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

Georgi Dukendjiev
Faculty of Mechanical Engineering
Technical University of Sofia
Sofia, Bulgaria
duken@tu-sofia.bg

Dimitar Diakov
Faculty of Mechanical Engineering
Technical University of Sofia
Sofia, Bulgaria
diakov@tu-sofia.bg

Hristiana Nikolova
Faculty of Mechanical Engineering
Technical University of Sofia
Sofia, Bulgaria
hnikolova@tu-sofia.bg

Velizar Vassilev
Faculty of Mechanical Engineering
Technical University of Sofia
Sofia, Bulgaria
vassilev_v@tu-sofia.bg

Rositsa Miteva
Faculty of Mechanical Engineering
Technical University of Sofia
Sofia, Bulgaria
rosimiteva@tu-sofia.bg

***Abstract* — The modern approach to ensuring the quality of measurements and control requires consideration of all factors influencing the measurement process. To assess the quality of measurement systems during operation, the analysis methods - Measurement System Analysis (MSA), which are standardized for the automotive industry, are used. These methods make it possible to assess the quality of the control and the suitability of the measuring instruments easily and quickly.**

This paper examines the application of MSA methods to stationary coordinate measuring machines (CMMs). Results of the evaluation of two types of CMMs are presented.

Keywords — coordinate measurements, performance evaluation, accuracy, MSA, coordinate measuring systems

I. INTRODUCTION

Coordinate-measuring systems are universal means for measuring the dimensions, form, location and orientation of the geometrical elements of the details. The principle of measurement is common to all coordinate-measurement systems. In them, by measuring the coordinates of individual oints on the surface of the part in the spatial (rectangular, spherical or cylindrical) coordinate system (Fig. 1) and by subsequent mathematical processing of the obtained measurement information, the parameters of a virtual (mathematical) model of the part are calculated.

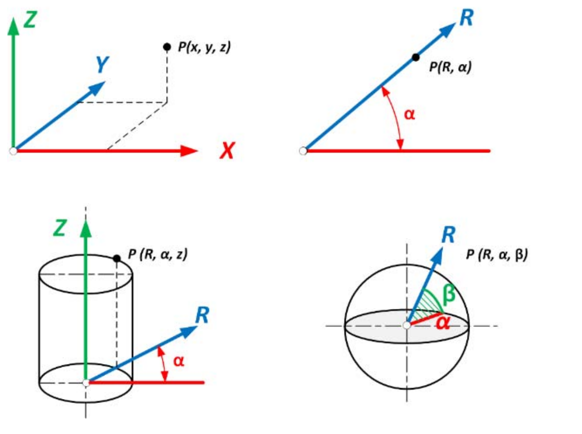

Fig. 1. Types of coordinate systems used in Coordinate Measurement Systems

A large number of modern high-precision measuring machines belong to this group: three-coordinate (stationary) measuring machines; coordinate measuring machines with parallel structure (hexapod, delta mechanism); hand-type mobile coordinate measuring machines; laser trackers; laser scanning devices; laser radars; iGPS systems; optical coordinate-measuring systems.

<u>*The Three-coordinate measuring machines*</u>

Three-coordinate measuring machines (or just CMMs) are universal measuring systems, making possible to determine almost all deviations of the form location and orientation of the surfaces and axes of the details. Depending on their configuration (Fig. 2) and purpose can measure details with a length of up to 16000 mm.

Each CMM materializes a spatial rectangular (Cartesian) coordinate system, analogous to the three mutually perpendicular directions of movement along the three axes of the machine, accounting for the spatial displacement of the center of the probe.

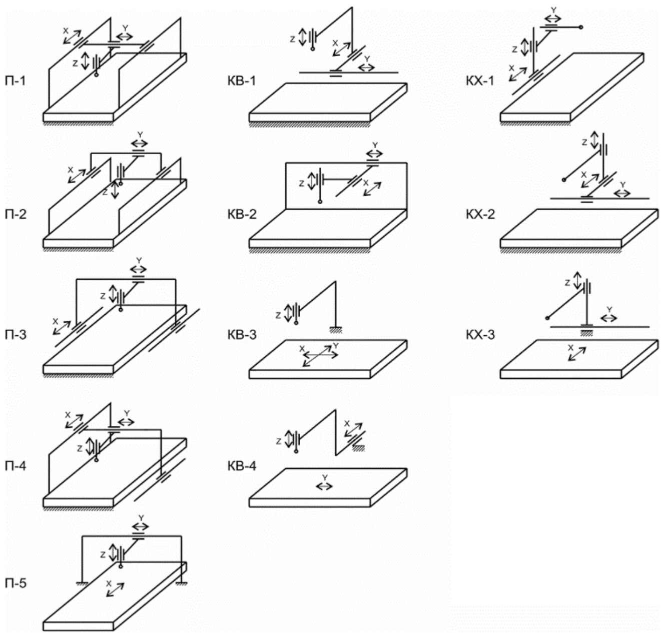

Fig. 2. Typical constructions of CMMs

It is characteristic of coordinate measurements that no prior physical orientation (exact basing) of the part relative to the coordinate axes of the measurement system is required.

Coordinate-measuring machines are used in the measurement and control of manufactured products, mainly at the end of the production cycle and in metrological laboratories. Flexible automated CMMs are an integral part of the production line in flexible automated manufacturing and serve to control the details and status of the technological process. The architecture of the mechanical structure must meet the following requirements: ensure measurement of all elements of the product from all possible sides in one establishment; to ensure maximum maneuverability of the operator and good visibility of the measured object; to ensure the greatest static and dynamic stability of the structure with minimal mass. With a view to maximum satisfaction of the above requirements, depending on the field of application, the following main options have become widespread:

- cantilever construction with a vertical quill;
- cantilever construction with a horizontal quill;
- portal construction.

II. Methods for MSA

The modern approach to ensuring the quality of measurements and control requires consideration of all factors influencing the measurement process. To assess the quality of measurement systems, the methods of analysis - MSA are used [1]. These methods make it possible to assess the quality of the control and the suitability of the measuring instruments easily and quickly.

The measurement process is considered as a production process processing measurement data. The measurement system that implements this process includes the operations, procedures, measuring instruments, standards and auxiliary equipment, software and operator, i.e. all factors on which the quality of control depends. The purpose of MSA is to statistically evaluate the capabilities of the measurement system, which means - the reliability of the control. A quantitative indicator of this assessment is the total variation (TV) of the measurement process. The other important indicator is stability, i.e., preservation of credibility over time and when control conditions change.

The analysis methods of MSA measuring systems are standardized for the automotive industry. The application of a separate method depends on the type of control - quantitative or qualitative (attributive), manual or automatic, as well as on the conditions under which it is carried out (static or dynamic mode, temperature, etc.).

The main components of the Total Variation (TV) of the measurement system are repeatability, reproducibility, stability, linearity. Deviation is the difference Δx between the average value of the measurements of a parameter on a single device with a single measuring instrument and the actual value of the parameter. This indicator characterizes the calibration of the measuring device at the corresponding point of the range. The repeatability (EV) is determined by the standard deviation of the measurements s_p and characterizes the variance of the measuring system. Reproducibility (AV) indicates the influence of the operator or other external factor on the measurement result.

The stability of the sustainability of the measuring system over time and/or when the control conditions change is determined by the shift of the mean value after a certain time. Linearity is a measure of the non-constancy of the deviation within the range of control (e.g., the tolerance zone).

Table 1 lists the MSA methods with their capabilities and applications [2].

TABLE I. Methods for MSA

Method	Capabilities and applications	Cons
ANOVA	Analysis and identification of EV, AV, PV components, the total variation TV and the interaction between them	Requires complex calculations or specialized software
AIAG	Through the arithmetic mean value and the range, the components of the TV and their % in the total variation are determined. It shows the direction of improvements in the measurement system.	It does not show interactions between components.
WIV	It identifies the influence of control conditions (e.g., when rotating the measured object) through an additional WIV component.	
Quick Method	For quick evaluation of measuring devices in workshop conditions.	It does not identify the EV and AV components
Automatic test	For evaluation of automatic control systems where there is no operator influence.	Estimation is by EV only

The ANOVA method applies a design of experiment in which the relative share of each factor in the total variation of the measurement process is determined.

The AIAG method uses the mean and the range to determine EV, AV and PV – a component accounting for the influence of the controlled object.

WIV is applied to amplitude measurements (e.g., runout). In addition to the already mentioned components, the WIV component in the full variation is also taken into account.

The quick method is used for express evaluation of measurement systems in workshop conditions, and in case of a bad result, one of the above methods is applied for detailed analysis.

The automatic test is applied to automated measuring systems and the evaluation is based on repeatability.

The results obtained from the individual assessments are plotted on control charts. In this way, the stability of the measurement systems over time is monitored and the time for subsequent evaluations is predicted.

When using the measuring system, the linearity in the measuring range is also evaluated.

III. Application Of MSA in Coordinate Measuring Machines.

In past years, CMMs have evolved from high-precision laboratory measuring devices into shop floor systems. This trend is observed in high-tech processes, a typical example being the automotive industry.

Standardized procedures for quality assurance in the automotive industry require proof of the quality of the control processes and of the measuring devices, for which the MSA methodology is applied.

The procedure for conducting MSA includes the following steps:

Sampling of the controlled parts (e.g., n=10).

Measurement of individual parts by several operators several times.

Processing the obtained results and determining the components of the total variation.

Comparison of the result with the permissible values and evaluation of the measurement system.

To obtain more information about the accuracy of the measurement with CMM, it is suggested to use certified standards when applying the 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 CMM, as well as for periodic inspections during operation.

Fig. 3. Aberlink Extol 370

The modified methodology was tested on two stationary CMMs:

1. CMM with parallel structure ABERLINK EXTOL 370 (Fig. 3) with the following characteristics:

2. CMM ABERLINK HORIZON 2000 (Fig. 4) with the following characteristics:

Fig. 4. Aberlink Horizon 2000

These CMMs 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).

TABLE II. Variable MSA - Gauge R&R Results

Aberlink Extol 370	
Repeatability Equipment Variation (EV)	0.3 µm
Reproducibility Appraiser Variation (AV)	0.8 µm
Repeatability & Reproducibility (GRR)	0.3 µm
Product Variation (PV)	0.5 µm
Total Variation (TV)	0.6 µm
AIAG Method	
% of Total Variation	***% of Tolerance***
EV = 54.2%	EV = 45.9%
AV = 13.6%	AV = 11.5%
GRR = 55.9%	GRR = 47.4%
PV = 82.9%	PV = 70.3%
Component Variance Method (*% of Total Variation*)	
EV = 29.3%	
AV = 1.9%	
GRR = 31.2%	
PV = 68.8%	

The study involves the use of certified length standards with the following characteristics:

In this study 10 measurements of the standards were made by three operators in the main coordinate directions and at an inclination of 120° and 240°.

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

The results were processed with the statistical software MINITAB. Table 2 presents the summarized results for Fig. 1. Aberlink Extol 370, and Table 3 gives the summarized results for Aberlink Horizon 2000.

TABLE III. VARIABLE MSA - GAUGE R&R RESULTS

Aberlink Horizon 2000	
Repeatability Equipment Variation (EV)	0.2 µm
Reproducibility Appraiser Variation (AV)	0.1 µm
Repeatability & Reproducibility (GRR)	0.2 µm
Product Variation (PV)	0.3 µm
Total Variation (TV)	0.3 µm
AIAG Method	
% of Total Variation	***% of Tolerance***
EV = 47.2%	EV = 50.4%
AV = 17.3%	AV = 18.4%
GRR = 50.3%	GRR = 53.7%
PV = 86.4%	PV = 92.3%
Component Variance Method (*% of Total Variation)*	
EV = 22.3%	
AV = 3.0%	
GRR = 25.3%	
PV = 74.7%	

Formal analysis of the results obtained by the Component Variance Method shows that both and Aberlink Extol 370 and Aberlink Horizon 2000 are suitable for use.

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.

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

Aberlink Extol 370:

GRR = (0.31/ 4) . 100 = 7.75%

Aberlink Horizon 2000:

GRR = (0.17 / 1.9) . 100 = 8.95%

CONCLUSION

The application of the standardized MSA methodology allows for the evaluation of the CMMs 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.

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