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THE IMPACT OF CHANGING THE SENSING SYSTEM ON MEASUREMENT ACCURACY

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Abstract

The work includes an experiment aimed at determining whether repeated replacement of a contact probe with a non-contact probe affects the measurement accuracy of form or geometric characteristics. Each tool qualification typically takes several hours. For this reason, an experiment was conducted to establish whether it is necessary to qualify the probes after every probe change, or how frequently this should be done. The experiment was carried out on a gauge block.
It was demonstrated that probe qualification is not required after every probe change, resulting in time and cost savings. When operating the machine, it is essential to consider the required measurement accuracy. If only the maximum and minimum permissible measurement error of the gauge are considered, contact measurement requires more frequent calibration than non-contact measurement, as shown by the experiment. “The test results will be used to make the measurement plans for measurements in the Metrology Laboratory of the University of West Bohemia in Pilsen more effective [1]."

Keywords: CMM; Coordinate Measuring Machine; repeated probe head replacement; contact and non-contact probe; qualification

1. Introduction

Metrology is a scientific and technical discipline that deals with the analysis and measurement of shapes and geometric characteristics of objects. In industry and industrial production, metrology is a key element for manufacturing and quality control. Measurement on Coordinate Measuring Machines (CMM) was developed primarily for use in the automotive and later the aerospace industries. This was driven by the increasing need for fast and precise measurement of more complex parts. The development of CMM measurement took place in the second half of the 20th century, with the first CMM being developed in 1950 [2]. CMM belongs to the most productive and highly accurate methods for measuring geometric features. Today, manufacturing—especially in the industrial sector—faces continuously increasing demands for precision in production and subsequent inspection. At the same time, due to high competition and ongoing efforts to maximize profit, there is a need to reduce production and inspection times. Therefore, fast and accurate machines are required, which CMMs fulfill [3].

CMMs allow for the measurement and scanning of 3D objects. Scanning is conducted either by a tactile or non-contact probe. The scanned results are processed by software, providing very precise and repeatable measurements. Because they can record a 3D model, they are also used for reverse engineering. Reverse engineering enables scanning a product and creating a 3D model from the scanned data, usable in CAD software for further use or processing. This is applied for parts without existing documentation or for rare historical artefacts. Another significant advantage of CMMs is their ability to be integrated into automated operations. Due to these properties, they are an integral part of many industries, such as the automotive industry, aerospace, and healthcare [4].

Measurement is always subject to error. For this reason, each repeated measurement varies to some extent. Therefore, the deviation of the measuring instrument, machine, or tolerance on the measured part must always be specified and adhered to. Achieving an exact dimension is almost impossible, and the goal is to get as close as possible [5]. Tolerances and deviations are calculated relative to the theoretically exact dimension or ideal model. This deviation can be caused by various factors, such as the non-transferability of the measuring system, failure to maintain consistent conditions like ambient temperature, machine temperature and varying humidity, as well as the influence of the machine operator and the program [a reference to an article discussing measurement errors would be useful here]. Measurement uncertainty needs to be minimized or, at best, quantified precisely because it influences decision-making regarding whether the measured part meets specifications or not [6].

1.1. Aim of the Study

The aim of this study is to determine whether repeated replacement of tactile and non-contact probes affects the measurement accuracy of shape or geometric characteristics. This article addresses the deviation caused by this replacement on the linear dimension. Each sensor qualification is very costly in terms of time and finances, typically lasting several hours; in the case of more complex scanning systems with multiple positions, it can take up to six hours unless an accelerated qualification method is used [7]. For this reason, an experiment was conducted to investigate whether repeated probe replacement influences measurement accuracy. If sensor qualification on the calibration sphere would not be necessary after each probe replacement, it would save machine time, operator time, and ultimately reduce costs associated with non-productive machine operation. The results of this study could be useful for metrology laboratories using the Carl Zeiss Prismo 7 Navigator machine together with the Zeiss probes and sensors employed.

1.2. Used Machine:

CMM Carl Zeiss Prismo 7 Navigator The machine used for the experiment is from Carl Zeiss. It is the Prismo 7 Navigator model, shown in Figure 1. Its advantage lies in high-speed scanning while maintaining high accuracy. It is suitable for measuring precise and complex components. The machine can be equipped with both tactile probes for contact measurement and probes for non-contact measurement. This machine represents a key piece of equipment in the workshop metrology laboratory of the Regional Technology Institute, which is part of the Faculty of Mechanical Engineering at the University of West Bohemia in Pilsen.

Fig. 1. Carl Zeiss Prismo 7 Navigator [11]

Maximum Permissible Error	0,9 + L / 350 µm
Temperature	19–22ºC

Table 1. Prismo 7 Navigator properties [8]

1.3. Sensor Used in the Experiment

The sensor used during the experiment is shown in Figure 4. It is a direct sensor equipped with a ruby sphere with a diameter of 3 mm, the shaft material is carbon fibre, and the overall sensor length is 50 mm.

Fig. 2. Sensor Used in the Experiment [11]

1.4. The Zeiss LineScan sensor head

The Zeiss LineScan sensor head was used during the experiment and can be seen in Figure 3.

Fig. 3. ZEISS LineScan [11]

Scanning speed	250000 [points per sec]
Scanning accuracy	± 0,025 mm

Table 2. ZEISS LineScan properties [9]

2. Experiment Description

The experiment was carried out to evaluate the influence of changing the sensor head between individual measurements.

Experiment Procedure:

1. Creation of a 3D model of the gauge block and preparation of the measurement plan in the Calypso software.
2. Cleaning of the gauge block and its placement into the measuring area of the machine.
3. Measurement of the gauge block using discrete points with the previous probe qualification from February 9, 2024. (Repeated 3 times)
4. Replacement of the contact sensor head with a non-contact sensor head, followed by scanning of the gauge block using the qualification from October 16, 2023. (Repeated 5 times)
5. Replacement of the non-contact sensor head with the contact sensor head and subsequent probe qualification.
6. Measurement of the gauge block using discrete points with the new qualification from March 1, 2024.
7. (Repeated 3 times)
8. Replacement of the contact sensor head with the non-contact one and subsequent qualification of the LineScan sensor on the corresponding qualification sphere.
9. Scanning of the gauge block using the new qualification from March 1, 2024. (Repeated 5 times)
10. Replacement of the non-contact sensor head with the contact one again, followed by contact measurement of the gauge block (repeated 3 times) after the replacement, with the March 1, 2024 qualification.
11. Finally, the contact sensor head was replaced by the non-contact sensor head once more, and the gauge block was scanned (repeated 3 times) after the replacement with the March 1, 2024 qualification.
12. Data processing and subsequent evaluation.

2.1. Experimental Procedure

A 3D model of the gauge block (100 mm gauge) was created in a CAD program. In the Calypso software, which is used to control the coordinate measuring machine (CMM), planes were defined first, followed by the coordinate system, ensuring alignment with the machine's coordinate system. Contact measurement of the working surfaces of the gauge block was performed using a five-point discrete measurement strategy, with points arranged in a pattern resembling the five-dot side of a dice (see Figure 4).

As part of the experiment, two dimensional characteristics were evaluated:

- **Distance with caliper-like evaluation**, determined using two points located along a straight line,
- **Simple distance characteristic** along the gauge block's main axis.

For non-contact measurement, the **wbScan** software was used for scanning and storing the measured points acquired from the functional surfaces of the gauge block. The scanned data was then processed in the specialized software **Geomagic Control X**. The measured point cloud was polygonised and then it was aligned to the pre-created CAD model using the **best-fit** alignment function, and deviations from the CAD model were subsequently evaluated.

Figure 4 shows the CAD model of the gauge block with numbered points marked on it. These points are used for determining dimensions at specific locations. The functional surfaces are also indicated.

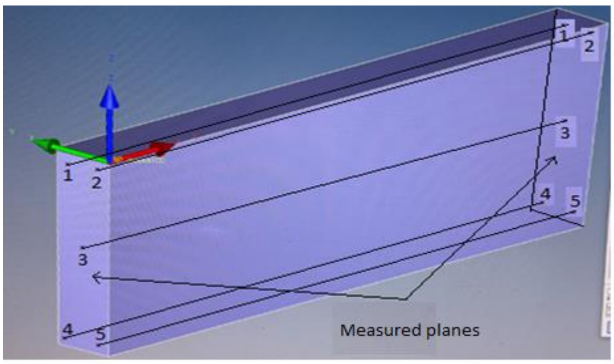

Fig. 4. End gauge model with predefined points [11]

2.2. Laser Sensor Qualification Procedure

The qualification is performed on a qualification sphere specifically designed for laser sensor calibration. This qualification sphere has a matte, grey surface to ensure the qualification process can be completed successfully. A standard ceramic qualification sphere is unsuitable for laser sensors due to its colour and glossy surface, which could lead to undesirable reflections of the laser beam.

Before starting the qualification, the qualification sphere is fixed to a plate within the machine's working area using screws in pre-drilled threaded holes. Figure 5 illustrates the threaded hole used. The sphere is then aligned with a reference sensor, and the laser sensor qualification can proceed.

Fig. 5. Laser sensor qualification [11]

2.3. Procedure for Qualification of the Contact Sensor

The qualification is performed on a sphere fixed to the machine table. The qualification sphere is secured with a screw in pre-drilled threads, as shown in Figure 6. The qualification sphere for contact qualification is made of ceramic material. The qualification process follows a predefined procedure [10], in which the sphere is scanned by contact. The scanning occurs twice during the qualification, with different applied forces, in order to determine the compliance/stiffness, especially in the case of long sensor shafts.

Fig. 6. Contact sensor qualification [11]

3. Results discussion

In the experiment, several data sets were obtained, including measurements with the contact sensor using both the previous qualification (performed some time ago) and the new qualification. The same two sets of data were also collected for the non-contact laser sensor.

The data were processed into graphs and tables to facilitate evaluation and improve clarity in the measured values. The measured values in the table are color-coded for better clarity. In the graphs, the MPE (Maximum Permissible Error) is indicated, which represents the maximum allowable error of the machine and is shown with an error bar. MPE applies to specific measured values. The diagrams display averaged values from the respective measurements. The value of 100 mm in the graphs represents the size of the measured part, which is the gauge block.

In this evaluation, the mean values of the plane distances in graphs 7 and 9 are compared. In graphs 8 and 10, the distances between points "2" and "2", which are marked on the end gauge model in Figure 4, are compared. The planes for the evaluation are calculated from the measured points using the Gauss method. In the case of contact measurement, the calculation is based on 270 measured points (measured by contact scanning method). For non-contact measurement using the scanner, the plane is calculated from 55,000 points.

For contact measurement, all average measured values with the new/fresh qualification from March 1, 2024, have about a 50% smaller deviation compared to the average measured values with the old/original qualification from February 9, 2024, as shown in Figure 7 and 8. The mean measured values can distort the results of the measured distances between individual points. However, as seen in graphs 7 and 8, the mean average values and the distance between points "2" and "2" behave similarly. It has also been shown that it is not necessary to re-qualify after every exchange. The values after the first exchange were still within the tolerance of ±0.0016 mm, with no significant changes, or only minimal changes, as seen in graphs 7 and 8. For this reason, further experiments would be advisable to determine the exact time/number of exchanges after which requalification is necessary.

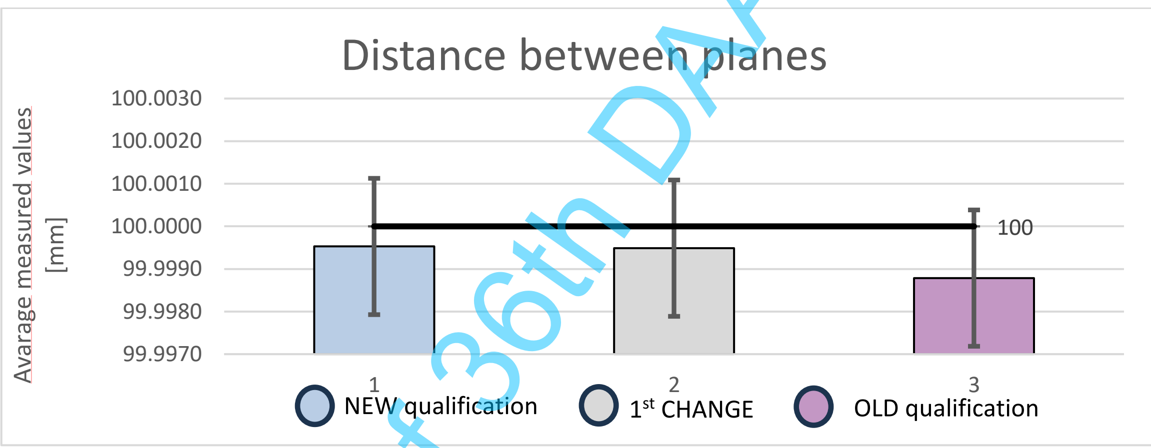

Fig. 7. Contact measurement – distance between planes

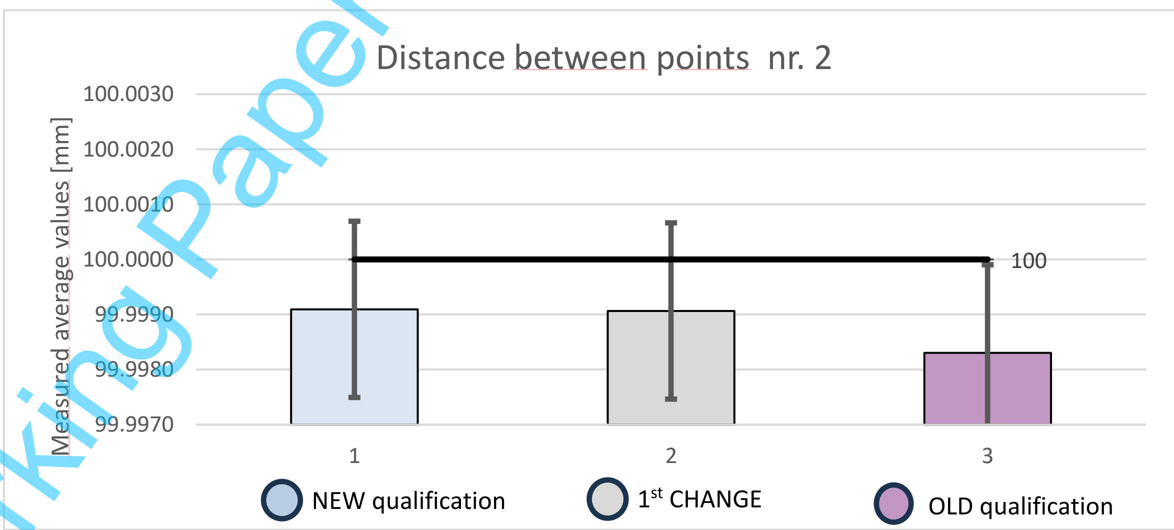

Fig. 8. Contact measurement – distance between points

In the case of non-contact measurement, the progression of the average measured value and the distance between points "2" and "2" appears differently, as shown in graphs 9 and 10. The average measured values may slightly distort the results due to extremes or measurement errors. The measured values remain within tolerance, as seen in graphs 9 and 10. The distances between points behave similarly, and it is noticeable that the measured values increased after the first exchange compared to the values immediately after calibration. It has also been shown that the measured values with the original/old qualification increased compared to the new calibration and even compared to the values after the first exchange, as seen in graph 10. For this reason, further experiments would be advisable to determine the exact time/number of exchanges after which requalification is necessary.

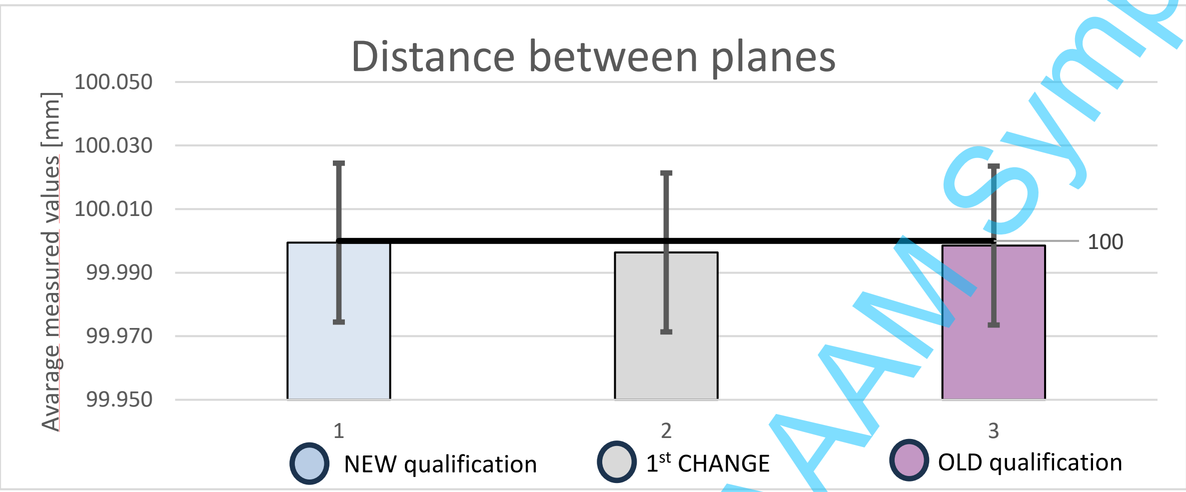

Fig. 9. Non–Contact measurement - distance between planes

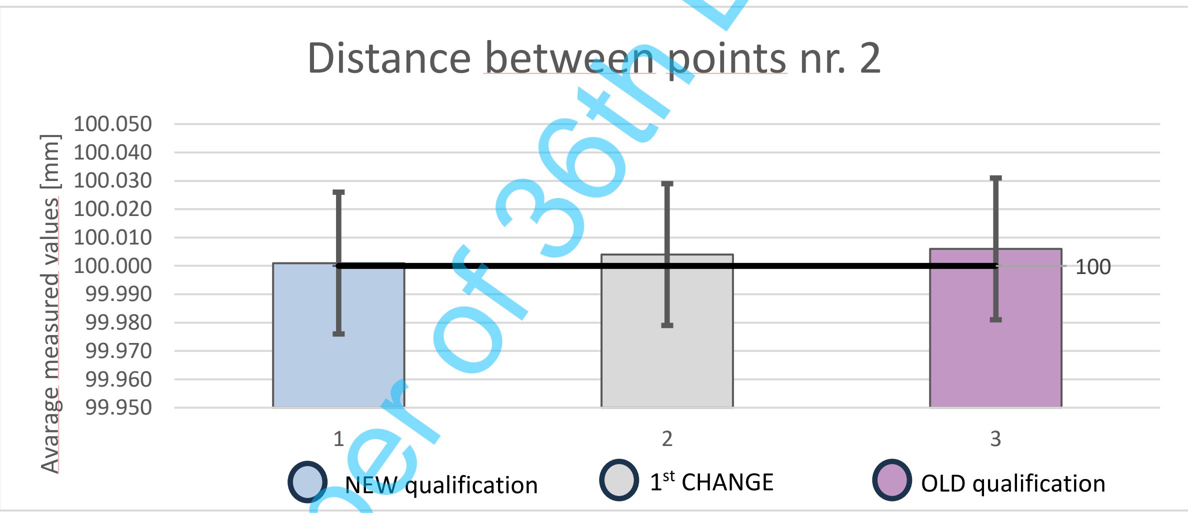

Fig. 10. Non-Contact measurement – distance between points

4. Conclusion

Each tool qualification costs 75 Eur per hour and in case of complex styluses with lot of qualified positions can take up to 6 hours. For this reason, an experiment was conducted to determine whether requalification is necessary after each measurement or how often it should be performed. **The results demonstrated that requalification is not required after every probe exchange.** This leads to significant time and cost savings. In machine operation, it is crucial to consider the required accuracy. When considering only the maximum and minimum permissible errors of the measuring instrument, contact measurements require more frequent qualification than non-contact measurements, as shown by the experiment. For future work, it would be beneficial to determine the exact time frame or number of exchanges after which requalification becomes necessary. This would allow for more efficient machine time usage and further cost savings. The ideal scenario would be if no additional qualifications were needed; however, this experiment has already disproven that. Therefore, it would be advantageous to create a table that links the number of exchanges and the time since qualification to measurement accuracy. Such a table could be used as a guide in future machine operations.

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