Műszaki Tudományos Közlemények vol. 17. (2022) 42–45.
DOI: Hungarian: https://doi.org/10.33895/mtk-2022.17.09
English: https://doi.org/10.33894/mtk-2022.17.09

MODERN MEASUREMENT METHODS INTRODUCED IN I4.0 MANUFACTURING SYSTEMS

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Abstract

The main target of this research, as with other I4.0 related research, is to create a system by which a quantitatively lower human resources workload is achieved in manufacturing processes, thereby allowing efforts to be better focused on creating development activities. The focus of the research work is the creation of an I4.0 compatible data processing system and algorithm which can store and forward data obtained from various machine tool and measurement equipment. To establish and appropriately use these measurement values, it is important to process the data in the most optimum way. The first step is to introduce and evaluate the measurement equipment available for our system and its capabilities in the proper transfer of data. This study intends to introduce these systems, focusing on theoretical and practical attainable accuracy.

Keywords*: I4.0, CMM, CNC, measurement accuracy.*

1. Introduction

The manufacture of highly complex technical components with a large number of specifications requires companies to have rapid inspection tools to carry out conformity assessment. In this context metrology is an important resource for supporting innovation and development processes, as well as manufacturing processes, threreby allowing the monitoring of technological improvement in line with the principles of Industry 4.0. In order to guarantee the reliability of the manufacturing process and to ensure the dimensional and geometrical conformity of technical parts, companies are demanding increasingly complex metrology tools capable of ensuring the correct performance of measurement functions. The extraordinary need to ensure the dimensional and geometrical compliance of technical parts can be fulfilled by checking with coordinate measuring machines. This technology supports rapid inspection and can produce large amounts of data, improving the interaction with the manufacturing process in order to guarantee compliance. **[1]**

The coordinate measuring machine is a multi-axis measuring machine developed for universal application. In terms of structural design, the three-axis construction is common but there are also five-axis designs. Each axis of this machine is equipped with a position sensor and can record any desired points and the position vectors associated with the points in the coordinate system of a machine, based on the position of the measuring probe. In most cases measuring machines are of the portal design but there are also some versions with a moving table, moving column or moving bridge. The most common type of guideway is the air-bearing type which has the great advantage of low resistance due to friction, but there are also roller types. Since the measuring system of a coordinate measuring machine requires accurate positioning resolution, it is not sufficient to use the rotary encoder method commonly used on CNC machine tools. However, glass gauge positioning is necessary. The continuous supply of remote control is essential because of the air bearings. Most often the plant's air supply is also used but in this case particular attention must be paid to air quality. [2]

The probe is in direct contact with the work piece. There are several types, the most common being the perfect spherical shape, but for special measurements there are special shaped probes (e.g. star. L-shaped. etc.) made of ruby.

This paper is concerned with the functioning and adaptability of the methods used for the advanced opportunities offered by Industry 4.0. The main aim is to assess accuracy under real-world conditions of the various I4.0 compliant measurement systems available at the Savaria Institute of Technology. Using the measurement results, a comparison is made about the accuracy of the systems based on and using these data.

2. Measuring methods

For measuring machines and machine tools, accuracy is a key performance requirement. Verification of the accuracy of measuring and inspection equipment is an important prerequisite for the quality departments in industry as production quality is based on the objective of "zero defects". Hence, it is essential to have a good knowledge of the condition of the equipment. For CMMs the DIN EN ISO 10360-2:2009 standard specifies calibration to be carried out regularly and at defined intervals. In addition, repeatability accuracy tests must be carried out.

Measurements were taken both inside the CNC machine and on the coordinate measuring machine using a block gauge and calibration ring of accuracy class 2 according to DIN EN ISO 3650 with a manufacturer's tolerance of −0.32 μm at 20°C. The uncertainty of measurement can be defined by the following standard relation given by the manufacturer:

$$U = 1,5 \cdot 10^{-6} \cdot L \qquad (1)$$

which in our case is:

$$U = 1,5 \cdot 10^{-6} \cdot 20\ mm = 0.03\ \mu m.$$

The linear coefficient of thermal expansion of the etalon material as specified by the manufacturer is $11.5 \cdot 10^{-6}\ K^{-1}$. The respective measurement types were carried out with 30 replicates and the results obtained and the differences between the different measurement methods were investigated using different statistical analyses.

Before starting the evaluation, it is of key importance to be aware of the positioning accuracy of the equipment. This is available from measurements carried out by the manufacturer or other accredited organisations. In the case of a CNC machine the linear positioning accuracy can be determined by calibration with a laser interferometer. [3–6]

For the measurements a Renishaw OMP40-2 probe unit was used. Prior to starting the measurements, it is necessary to adjust the radial runout of the probe head. Since the software can bridge a maximum of ±2.5 μm beat, which in the current case was ±0.02 μm. The achieved value was adjusted using screws on the adapter.

3. Results of measurement processes

The work piece to be measured was placed and fixed on CNC machine initially, then pre-positioned by approaching the work piece at a specified speed by touching the coordinates and moving away to a safe distance. In current work, the parallel surfaces of the gauge were touched from 1 to 1 and the distance between the points was recorded using the software by subtracting the coordinate values. Accurate clamping was ensured by the vertical compass on the vice and the parallel sides of the slit leg.

Next, measurements were taken with ring gauges. The etalon was used in this study. The bore diameter of 63.0021 mm was specified by the supplier. Before starting the operation, the position of the ring had to be determined and then the position taken as the centre was used as a starting point. During the measurement 4 points were touched by the feeler and the diameter was calculated from these points based on a theoretical circle. The results are presented in **table 1**.

For further measurements, a coordinate measuring machine located in the metrology laboratory of the Savaria Institute of Technology was used, equipped with Renishaw touch trigger probes and TouchDMIS software whose accuracy

Table 1. *Measurement results (CNC)*

	x direction	y direction	Circle
Average [mm]	20.0018	20.0000	63.0024
Average deviation [mm]	0.0021	0.0005	0.0003
Variation [mm]	0.0003	0.0006	0.0003
Minimum [mm]	20.0008	19.9991	63.0019
Maximum [mm]	20.0027	20.0013	63.0030
+2 σ variation [mm]	20.0024	20.0012	63.0030
-2 σ variation [mm]	20.0011	19.9989	63.0018

can be calculated for the given lengths from the calibration certificate issued according to DIN EN ISO 10360-2 [4]:

$$MPE = \pm(15\ \mu m + L/333), \qquad (2)$$

which in our case is:

$$MPE = \pm(1.5\ \mu m + 20\ mm/333) = 1.56\ \mu m.$$

Before starting the measurements, it was checked that the error of the probe did not exceed the permissible range using the calibration sphere. This check should be carried out at prescribed intervals. depending on the use, but usually once a week.

After the calibration measurements were taken on both the gauge block and the ring gauge. Before starting the process, it was necessary to ensure a constant laboratory temperature. The measurement software has in-built temperature compensation **[4]**.

The measurements were made on the CMM using different methods, two point and two plane measurements in the case of a block gauge, and nine point and scanned measurements in the case of a ring gauges. So that not only the measuring instruments but also the measurement methods were comparable. The point-to-point measurements were made in exactly the same way as was done on the CNC machining centre. During the plane-to-plane measurement, the coordinate measuring machine software fits a theoretical plane to the points and then gives the distance between the two resulting planes.

In the case of the nine-point measurements the first 5 probes belong to the frontal surface of the calibration ring. The reason being to compensate for inaccuracies due to positioning errors of the object to be measured. During the planar probing, care must be taken to ensure that the points are not recorded on the matrices or other markings on the planar surface. By touching the additional 4 points the software defines a theoretical circle.

When determining the diameter of a circle with points, the software acts exactly as it would when measuring on a CNC machine. In the case of the scanned surface a value is obtained from the profile drawn from the 2400 points taken over the entire surface.

The results in **table 2** conclude that there are no systematic errors between our measurement systems. The variances of the observed variables are within an acceptable range for all measurement scenarios. Since the measurement uncertainty of the used measurement results is an order of magnitude lower than the accuracy of our measurement systems, it can be concluded that the two measurement systems are equivalent to each other for the current given application.

Table 2. *Measurement results (CMM)*

	Between points	Between planes	Circle (9 point)	Circle (scanned)
Average [mm]	20.0004	19.9994	63.0023	63.0024
Average deviation [mm]	0.0008	0.0002	0.0002	0.0003
Variation [mm]	0.0002	0.0001	0.0001	0.0001
Minimum [mm]	20.0003	19.9993	63.0021	63.0023
Maximum [mm]	20.0006	19.9995	63.0026	63.0026
+2 σ variation [mm]	20.0007	19.9996	63.0026	63.0026
-2 σ variation [mm]	20.0002	19.9993	63.0020	63.0022

4. Conclusion

The accuracy of the measuring system integrated in the newly calibrated milling machine easily matches the tolerance fields specified by the manufacturer. Based on experience the measurement is typically fast, and the resulting data can be easily transmitted and stored using the MES system.

Post-production measurement of work pieces is one of the most common, yet most debated areas in terms of quality assurance and product conformity. The simplest example is the application of many different sizes and tolerances and then the real need for these which is often modified only during the assembly of the product or based on the data obtained from use. An unnecessarily tight tolerance often multiplies the cost of a given machining, not to mention the unnecessary environmental impact. The integrated workpiece measuring system of the CNC milling machine used in the research is able to perform measurements with a significantly tighter tolerance as specified by the manufacturer. The CMM measuring machine is an excellent monitoring tool of the CNC machine as the measurement process can be almost the same. Based on this it can be easily integrated and process data into the production system. The institute has meanwhile integrated a 3D scan probe, a new generation of measurements. It could be a perfect, fast prefilter for classic contact measurements as it is faster, and if an error is found, the program can move on to more accurate but slower tactile measurements without human intervention. With this, an advanced and precise quality system can be set up at our institute.

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