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FREE SURFACE SCANNING WITH CMM AND ITS REPRODUCTION IN CAD SYSTEM

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Summary: *common usage of Coordinate Measuring Machines in industry means that they are applied not only for the measurement of the details, but also for the digitalization of the geometrical elements. Nowadays, the development of scanning methods enables the easy measurement of free surfaces. Digitalization of such surfaces with scanning probe heads is much faster than touch trigger probing, while the uncertainty level remains almost the same. However, the accuracy of points localization is dependent upon the scanning speed.*

Keywords:
- Coordinate Measuring Machine (CMM)
- scanning speed
- free surface
- CAD

1. INTRODUCTION

With the development of engineering and market demands, tools such as Coordinate Measuring Machines (CMM) become standard equipment in the measurement laboratory of almost every industrial enterprise. The CMM is mainly applied in the inspection of the details and their dimensions. However, because of the widespread presence of CMMs in industry, they often serve as a tool for object digitalization e.g. in the Reverse Engineering Process.

Continuous development of the technical sciences leads to new construction design in measuring heads, with new possibilities. Nowadays, in Coordinate Measurement, scanning measuring heads are often applied in addition to the touch trigger probe heads (Fig. 1). In touch trigger probing, measuring points are identified when the probe ball tip comes in contact with the measured surface, and the measuring head generates an electrical impulse. This signal causes the recording of the *x, y,* and *z* coordinates of the touch point from the measuring system of the CMM. Some measuring heads will measure the deflection of the probe with the measuring device located in the measuring head itself. In this type of measurement, the probe stays in touch with the measured surface while the measuring points are identified with the required resolution [3, 5].

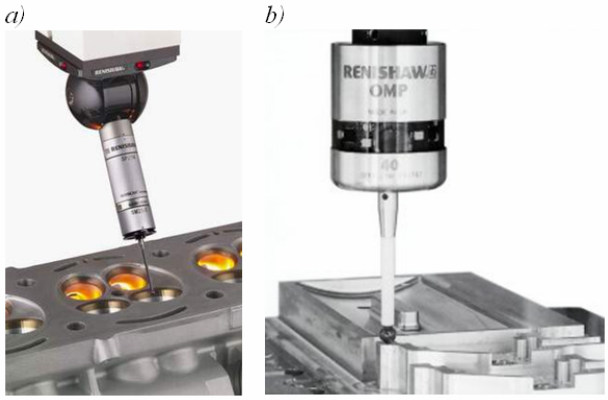

Figure 1. CMM probes made by Renishaw: scanning (a) and touch (b) [8]

This method of measuring points registration enables the registration of a greater number of measuring points in a much shorter time than in touch trigger probing.

According to manufacturer data, the uncertainty of measurement in both methods is comparable.
For example, the collection of 1,000 points in a length of 100 mm (0.1 pt/mm) with the touch trigger probing head would take more than 30 minutes, i.e. ca. 2 seconds per point. The same measurement with a scanning head would take no more than 20 seconds if the scanning speed is 5 mm/s.

The ability of scanning heads to collect a large number of measuring points in a short time enables them to be applied in the digitalization of free surface elements. However, it is important to determine the dependence of measurement accuracy upon scanning speed. A series of research experiments have been performed, in an attempt to correlate the accuracy of the surface reproduction with scanning speed in the CAD system.

2. INVESTIGATION APPARATUS

The main purpose of the experimental research was to find out the correlation between the scanning speed and reproduction accuracy in the process of digitalization of a free surface with the Coordinate Measuring Machine. Figure 2 presents the scheme of the performed experiment.

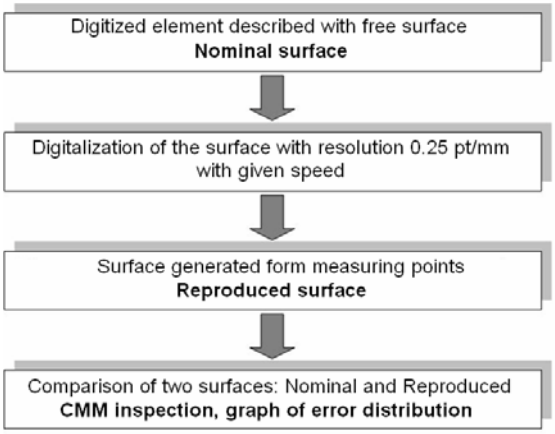

Figure 2. Block diagram of performed experiments

In the experimental research, the starting element was a detail with an unknown free surface, made out of the alloy AlZn 5MgCu. The examined detail is shown in Figure 3.

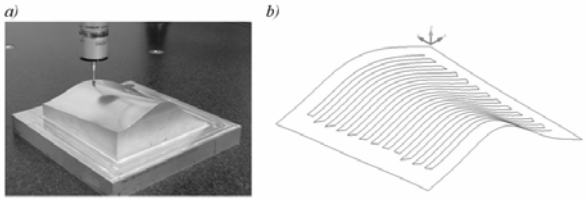

Figure 3. Digitalization of the free surface with CMM (a) and digitalization paths (b)

The surface of the detail (nominal surface) underwent digitalization with a grid of measuring points with a density of 0.25 pt/mm in the directions of the X and Y axes. The digitized area was a square 95×95 mm, which gave ca. 600 measuring points. Digitalization was performed with 8 different scanning speeds, presented in Table 1.

Table 1. Values of scanning speed used in experimental research

No.	1	2	3	4	5	6	7	8
Scanning speed [mm/s]	1	3	5	10	20	30	40	50

Each measurement was repeated three times. The digitalization was performed with a CNC CMM Dea Global Image equipped with a passive measuring head with a probe plunger of 21 mm length and a ball tip diameter of 3 mm. The Machine and probe head are shown in the Figure 4.
The main parameters of the Coordinate Measuring Machine used in the research are as following:

- maximum permissible error of indication of a CMM: $MPE_E = \pm (1.5 + L/333)\mu m$
- maximum permissible probing error: $MPE_P = 1.7\ \mu m$
- maximum permissible scanning probing error: $MPE_{THP} = 3.4/120\ \mu m/s$.
- measuring area XYZ: 700×700×500mm.

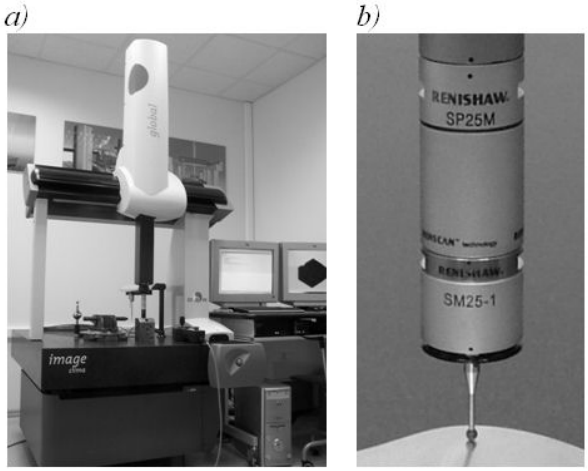

Figure 4. Coordinate Measuring machine (a) and passive measuring head (b)

The main parameters of the measuring head used in the research are as following:

- maximal force: 0.36 N
- low force: 0.06 N
- upper force: 0.18 N
- trigger force: 0.2 N
- return data: 7
- return speed: 1 mm/s
- positioning accuracy: 0.1 mm
- probing accuracy: 0.1 mm
- probing mode: DFL
- point density: 0.25 pkt/mm
- offset force: 0.24 N
- acceleration: 5 mm/s^2.

The measurements were performed under conditions of reproducibility, in an air-conditioned laboratory. The results of measurement were imported into the CAD system, where the NURBS surface (*Non-Uniform Rational B-Spline*) was generated with the algorithms of the system. In this way the reproduced surface was achieved. In the next step (Fig. 2), using the inspection possibilities of the CMM, the reproduced surface was compared with the nominal one. The CMM generated the distribution of the deviations between the nominal and reproduced surfaces [6]. The results were used to build a histogram and graphs of maximal dispersion.

3. EXPERIMENTAL RESULTS

The research was performed according the block diagram shown in Figure 1. After digitalization, the measuring points were imported into the CAD system which generated the NURBS surface. Next, the reproduced surface underwent comparison with the surface of the real element (nominal surface). The comparison process took place in the same CMM and with the same parameters of the scanning (speed of 5 mm/s). In this way the two values of coordinates for each point were gained: the nominal and the reproduced values. In the analysis of deviations, the measuring program function of surface tolerances was used. The examples of the analysis results are presented in Figure 5.

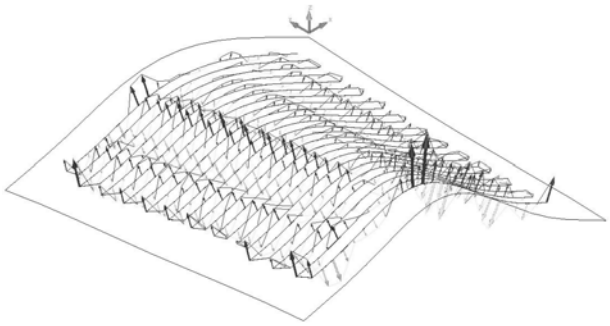

Figure 5. Graph of the measured surface tolerances

The achieved values of deviations were also used in the analysis of the following characteristics: maximal and mean deviations, standard deviation and percentage of deviations. A sample of the achieved results is shown in Table 2, and the histogram is presented in Figure 6.

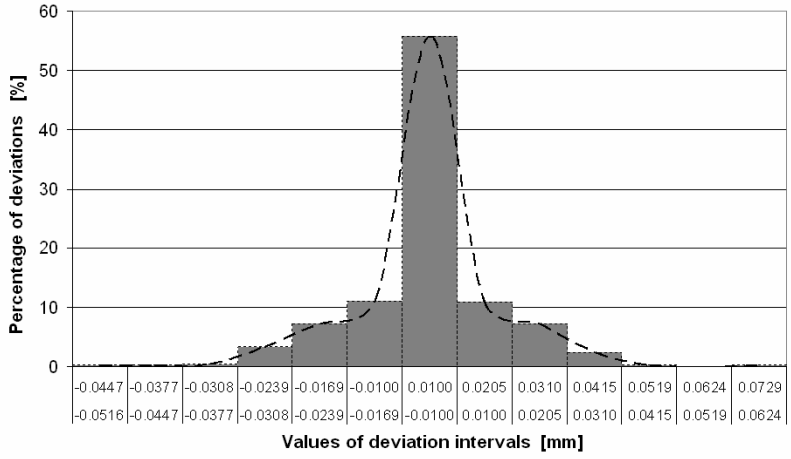

Figure 6. Histogram

Table 2. Examples of the nominal and reproduced surface comparison

DEVIATION	VALUE [mm]
Maximal in plus	**0.0728**
Maximal in minus	**-0.0515**
Mean in plus	**0.0119**
Mean in minus	**-0.0110**
Standard	**0.0152**

In order to determine the influence of scanning speed on the reproduction of a free surface in the CAD system, the range of dispersion was calculated as the difference between maximal and minimal values of deviation for each scanning speed used in the experiment. It may be assumed that this will be the value of the examined surface tolerance. The calculated deviations are shown in Table 3, and are presented in the graph (Fig. 7). Table 3 and Figure 7 present scanning time as well.

Table 3. Examples of nominal and reproduced surface comparison

Scanning speed [mm/s]							
1	3	5	10	20	30	40	50
Range [mm]							
0,123 0	0,124 1	0,124 2	0,123 6	0,159 9	0,159 9	0,158 0	0,159 1
Scanning time [s]							
2400	1063	627	394	372	360	360	360

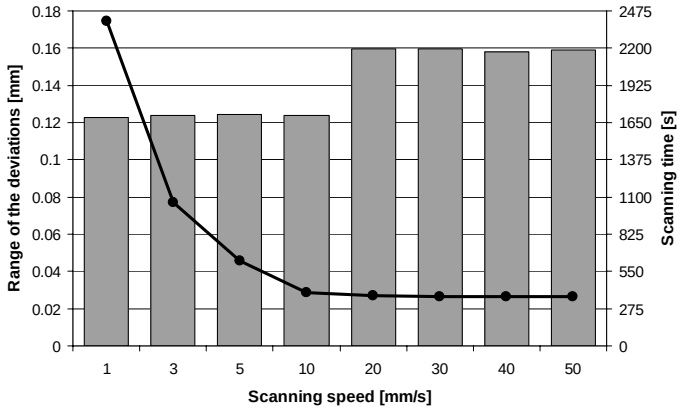

Figure 7. Experimental results

4. CONCLUSION

A series of experimental research was conducted in order to determine the correlation between the scanning speed and the accuracy of digitalization and further reproduction of a free surface in the CAD system. The achieved results confirmed that a higher scanning speed always affects the accuracy of the reproduced surface. In Figure 6 there is a graph of deviations versus scanning speed, combined with the graph of scanning time versus scanning speed. When the speed exceeds 20 mm/s, the measurement time does not change and stays on the level of ca. 360 seconds. Theoretically, we would expect that an increase in scanning speed would shorten the scanning time, but this does not take place when the speed is over 20 mm/s. In fact, when too high of a scanning speed is given for the digitalization of a free surface with various curvatures, the control unit tries to keep the probe in touch with measured surface and reduces the speed. This is seen during the measurement process.

Investigations into the correlation between the scanning speed and accuracy of reproduction of free surfaces in the CAD system were conducted and developed within the framework of research activity conducted at the Division of Metrology and Measurement Systems on Reverse Engineering (Poznan University of Technology).

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Original scientific paper

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