The impact of support points during the measurement of machine tool bodies on Coordinate Measuring Machines

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Abstract. The article concern on the considerations regarding the influence of support points during measurement using coordinate measuring technique. The object of research, slide of the X axis of a five-axis numerically controlled machine CMX 70U from the portfolio of DMG MORI, produced at FAMOT Pleszew Sp. z o.o., set on the coordinate table of the measuring machine, using three- and four-point fixing. The aim of the research is to determine the optimal method of supporting the bodies, which in effect will reduce the measurement time and increase the efficiency of the process. The MES analysis available in the Creo software was used to calculate and graphically present the results.

1. Introduction

Coordinate measuring technology is currently one of the most universal measurement methods, used both in industrial conditions, for quality control of manufactured elements, as well as in highly specialized research and development centers. This is mainly due to the very high accuracy of coordinate measuring machines and the ability to measure objects with complex shapes, whose measurement is often impossible when using traditional workshop tools.

An important factor affecting the results of measurements performed with the use of coordinate technology are errors of measuring and their sources of origin. Figure 1 shows sources of errors, depending not only on the machine, which may have an adverse effect on the measurement result. The origin of error sources is divided into five groups. These include: measuring machine, environment, i.e. external factors, properties of the material under test, operator's skills and what is often omitted – measuring strategy, which component is the method of mounting the measured element [1].

The method of attaching the measuring part affects not only the quality of the results, but also its duration. In general, the fixing method should determine the task. In the case of unit measurements, standard clamping devices such as vices or prisms can be used. In the case of mass production or measurement of elements with very large freedom of shape, it is necessary to use special equipment to ensure quick and repeatable fastening [2].

In the article, the authors presented the results of measurements of selected geometrical features of the X-sledge body of the CMX 70U milling center (figure 2) using three different mountings to be measured on a coordinate measuring machine.
Figure 1. Sources of errors in coordinate measuring technique [1, 3].

Figure 2. 5-axis numerically controlled machine tool [4].

1.1. Types of fasteners
Attaching the measuring elements is very important in terms of the efficiency and accuracy of the measurement control process.

Figure 3. Types of fasteners [5]
The diagram (figure 3) shows the general systematics of the division of fasteners used in industry. In the case of CMM, modular fasteners (automotive, large-scale production) or general-purpose (low-volume and single-unit production) are most commonly used. The most rare are dedicated fasteners commonly found in In-line solutions in mass production. Modular fasteners increase their market share due to their flexibility and affordability. This solution is now offered by any manufacturer of coordinate machines [6].

The most commonly used modular solutions are: adaptive base plates, flat, semi-spherical and pressure retaining elements, universal elements, self-centering and self-centered matrix. The following are some examples of Spannfix's modular fasteners (figures 4 and 5).

![Figure 4. Adaptation plate with supporting elements [7].](image1)

![Figure 5. Matrix mounting [7].](image2)

2. Description of the test stand and subject of research

The research were carried out on a portal coordinate measuring machine Zeiss Accura II 10 aktiv located in the measurement laboratory of the company FAMOT Pleszew Sp. z o.o. shown in figure 6.

![Figure 6. Coordinate measuring machine Zeiss Accura.](image3)

It is a coordinate machine with a stationary table with measuring range X, Y, Z 1200 mm / 2400 mm / 1000 mm designed for measuring accurately made machine parts – measurements of dimensions and geometrical deviations. In each axis, an electronic drive control is used, and in the X and Z axes, the advancing force is additionally limited [1]. The machine is equipped with a VAST GOLD scanning head from Zeiss, Zeiss measurement scale glass ceramic with a resolution of 0.04 μm, an integrated vibration damping system and temperature correction of the measured part. The measuring machine has computer-
calculated corrections of all dynamic impacts on the machine. In this way, optimal precision is obtained during rapid scanning [8, 9].

The object of research, sleigh of the X axis of the universal machining center CMX 70U is shown in figure 7. The test sample was 30 pieces.

The body under test was placed on the CMM table with the use of a stable three-point (two variants) and a four-point attachment, which eliminated possible stresses (figure 8).

![Sleigh X CMX 70U on the CMM table](image)

**Figure 7.** Sleigh X CMX 70U on the CMM table

![Various types of fastening slide to research on CMM](image)

**Figure 8.** Various types of fastening slide to research on CMM.

2.1. **Measuring cycle**

The measurements were carried out using a modified program for measuring serial parts at FAMOT Pleszew Sp. z o.o. The measurement methodology and the stylus used were analogous to those in the case of serial measurement. 30 bodies were measured in three different mountings. In total, 90 measurements were made, during which 510 geometric features were measured. The program was prepared in the Zeiss Calypso 2017 environment [6], using the offline programming tool – Zeiss Calypso Planer (figure 9).

Each subsequent measurement cycle consisted of the following operations:

1. preparation parts for measurement,
2. qualification of styli,
3. fixing the body for measurement on the CMM table (variant 1, three-point),
4. manual orientation of parts,
5. starting CNC cycle,
6. analysis of the results obtained,
7. saving results in PDF format, and ASCI for further analysis,
8. dismantling the body from the CMM mount,
9. re-mounting the measuring part (variant 2, three-point),
10. manual orientation of parts,
11. starting CNC cycle,
12. saving results in PDF format, and ASCI for further analysis,
13. dismantling the body from the CMM mount,
14. re-mounting the measuring part (variant 3, four-point),
15. manual orientation of parts,
16. starting CNC cycle, etc.

**Figure 9.** Zeiss Calypso Offline Planner

During the measurements, the geometric features shown in table 1 were measured [10].

**Table 1.** Measured geometric features.

| No. | Deviation | Tolerance (mm) | Drawing position |
|-----|-----------|----------------|-----------------|
| 1   | c         | 0.01           | 1               |
| 2   | u         | 0.01           | 4               |
| 3   | c         | 0.01           | 7               |
| 4   | f         | 0.01           | 9               |
| 5   | u         | 0.01           | 11              |
| 6   | b         | 0.01           | 12              |
3. Measurement results
As a result of a series of measurements of the X-sledge body in various fasteners (variant 1, 2, 3), specific measurement results were obtained, on the basis of which statistical calculations were performed in the Statistica program. In tables 2–4, the results of statistical calculations are presented.

| Table 2. Statistical calculations for three-point support (variant 1). |
|---|---|---|---|---|---|---|---|---|---|---|
| Drawing position | Checked parameter | Tolerance [mm] | Cardinality | Average | Median | Mode | Cardinality mode | Min | Max | Variance | Standard deviation | Slant |
| 1 | c | 0.01 | 30 | 0.004270 | 0.004300 | Wielokr. | 3 | 0.002800 | 0.006200 | 0.000000 | 0.000672 | 0.362037 |
| 4 | u | 0.01 | 30 | 0.002447 | 0.002400 | Wielokr. | 3 | 0.001200 | 0.003700 | 0.000000 | 0.000674 | 0.084810 |
| 7 | e | 0.01 | 30 | 0.005293 | 0.005150 | Wielokr. | 3 | 0.003200 | 0.006500 | 0.000000 | 0.001392 | 0.074440 |
| 9 | f | 0.01 | 30 | 0.008050 | 0.008600 | Wielokr. | 3 | 0.004200 | 0.013000 | 0.000000 | 0.002194 | 0.229107 |
| 11 | u | 0.01 | 30 | 0.002537 | 0.002550 | .002700 | 4 | 0.001700 | 0.003400 | 0.000000 | 0.000433 | -0.049862 |
| 12 | b | 0.01 | 30 | 0.009367 | 0.007100 | .002800 | 3 | 0.002500 | 0.030200 | 0.000000 | 0.007298 | 1.444936 |

| Table 3. Statistical calculations for three-point support (variant 3). |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drawing position | Checked parameter | Tolerance [mm] | Cardinality | Average | Median | Mode | Cardinality mode | Min | Max | Variance | Standard deviation | Slant |
| 1 | c | 0.01 | 30 | 0.004417 | 0.004500 | Wielokr. | 3 | 0.002600 | 0.006100 | 0.000000 | 0.000830 | -0.395655 |
| 4 | u | 0.01 | 30 | 0.002363 | 0.002300 | Wielokr. | 3 | 0.001000 | 0.003900 | 0.000000 | 0.000704 | 0.104788 |
| 7 | e | 0.01 | 30 | 0.005687 | 0.005600 | .005800 | 4 | 0.003100 | 0.008800 | 0.000000 | 0.001401 | 0.831296 |
| 9 | f | 0.01 | 30 | 0.008953 | 0.009000 | .010600 | 3 | 0.004100 | 0.015100 | 0.000000 | 0.002424 | 0.569357 |
| 11 | u | 0.01 | 30 | 0.002507 | 0.002550 | .002600 | 6 | 0.001800 | 0.003300 | 0.000000 | 0.000418 | 0.421322 |
| 12 | b | 0.01 | 30 | 0.009140 | 0.007350 | Wielokr. | 2 | 0.002100 | 0.029000 | 0.000000 | 0.007061 | 1.567851 |

| Table 4. Statistical calculations for a four-point support (variant 2). |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drawing position | Checked parameter | Tolerance [mm] | Cardinality | Average | Median | Mode | Cardinality mode | Min | Max | Variance | Standard deviation | Slant |
| 1 | c | 0.01 | 30 | 0.004260 | 0.004100 | .004100 | 5 | 0.002900 | 0.007000 | 0.000000 | 0.001033 | 1.308233 |
| 4 | u | 0.01 | 30 | 0.002800 | 0.002550 | .003000 | 3 | 0.001100 | 0.013500 | 0.000000 | 0.002143 | 4.527567 |
| 7 | e | 0.01 | 30 | 0.005487 | 0.005450 | .004900 | 3 | 0.003700 | 0.008400 | 0.000000 | 0.001156 | 1.200030 |
| 9 | f | 0.01 | 30 | 0.008890 | 0.008600 | Wielokr. | 2 | 0.004100 | 0.016800 | 0.000000 | 0.002813 | 0.851390 |
| 11 | u | 0.01 | 30 | 0.002560 | 0.002600 | .002600 | 7 | 0.001800 | 0.003200 | 0.000000 | 0.000361 | -0.171255 |
| 12 | b | 0.01 | 30 | 0.009230 | 0.007550 | .007800 | 2 | 0.001900 | 0.028100 | 0.000047 | 0.006887 | 1.543857 |

3.1. FEA analysis
Research on the influence of support points on the results of the X sledge body of the CMX70U measurement carried out on CMM Zeiss Accura (figure 10).

Measured geometric parameters:
1. item 1 – flatness (0.01) for fasteners for linear guide carriages (area A); marked in the table as "1",
2. item 4 – straightness (0.01) of the bearing surface of linear guides (area B); marked in the table as "2",
3. item 7 – flatness (0.01) for fasteners for linear guide carriages (area C); marked in the table as "3",
4. item 9 – parallelism (0.01) of four surfaces of the linear guide carriages (area C) to the base A; marked in the table as "4",
5. item 11 – straightness (0.01) of the guide surface of linear guides (area D); marked in the table as "5"
6. item 12 – perpendicularity (0.01) area D to base B; marked in the table as "6".
Figure 10. Sleigh body X – measured geometric features.

Theoretical analysis of the bending of the body under the influence of gravity achieved by the FEM method in the CREO Simulate program (figures 11–13).

Boundary conditions for tests:
1. material EN-GJL 300,
2. points of restraint – according to the draft,
3. loads – gravity.

The program simulates the theoretical deflection of the cast body under the influence of gravity, when attaching the measuring body to specific support points.

After analyzing the results, the following conclusions can be made:
1. for the three-point support currently in use, the maximum linear displacement for the body is 0.006600 mm in the area of the fastening surface of the drive motor. The value of the linear displacement in the area of the remaining areas covered by the measurement ranges from 0.000045 to 0.006600 mm
2. for the three-point modified support, the maximum linear displacement for the body is 0.004800 mm in the area of the surface C. The value of linear displacements in the remaining areas covered by the measurement ranges from 0.000029 to 0.004800 mm.
3. for a four-point support, the maximum linear displacement for the body is 0.001200 mm in the center area (deviation irrelevant from the point of view of the static geometry of the body) and the mounting surface of the drive motor. The value of the linear displacement in the area of the area covered by the measurement ranges from 0.000024 to 0.001200 mm.
Figure 1. FEM analysis for three-point support (variant 1).

Figure 2. FEM analysis for three-point support (variant 3).

Figure 3. FEM analysis for a four-point support (option 2).
4. Conclusions
As a result of the research and FEM analysis it is possible to hypothesize that the previously used fasteners is the worst variant and causes the largest deformation of the body. Support four-point causes a deflection of 0.001mm and it is more evenly distributed. Support of this type is an alternative to the currently used solution. The modified three-point support is rejected due to uneven deflections in areas particularly important for the geometry of the measured body.

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