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Working Precision of the Machining Centre

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Abstract: The aim of the article is to analyse the precision of the machining centre using numerical and experimental quantification. The identification of the effects of the machining process itself as well as the impact of machine design features will allow it to predict and subsequently optimize its construction in terms of its working accuracy. Measurement of dynamic forces and geometric tolerances was also carried out. The practical importance of virtual machining is primarily the reduction of financial costs and acceleration of machine design without the need to produce a physical prototype. Using simulation models, it is possible to repeatedly analyse the weaknesses of the machine design, to determine the effects of each machine component on its properties and to optimize them, but also to take account of ergonomic and other requirements.

Keywords: *Virtual reality, FEM, parallel milling, opposed milling.*

1. Introduction

The current situation on world markets can be briefly characterized by terms such as globalization of markets, great competitive pressures and innovation. Innovation is key to maintaining competitiveness. Innovations can relate to different areas such as product, technology, and organization. The key factors of competitiveness are time, cost and quality. If they want to achieve and maintain their competitiveness, they must focus on all these factors. There are various methodologies, tools and procedures that are geared to improving these factors. One of the activities that affect all factors at the same time is virtual designing. Over the past few years, we have seen a great development and trend in CAD / CAM. CAD and individual modules are currently commonly used to speed up work from production visualization to simulation of the factory. They include all tools for modelling and visualization with a simple manageable graphical user interface. The program provides a direct link between visual design and production. It enables quick product design, instant presentation of ideas, it saves time and reduces the cost of producing models and prototypes. Today, we will make a sketch of the product, visualize it, make the necessary changes and complete the details, define the materials and colours and create a photorealistic image of the product including real shadows and mirror reflections. The use of 3D models to simulate real-world situations is now practiced in all industries. One of them is also manufacturing technology. Intelligent machining is a modern method used in the manufacturing process of engineering and related companies or companies in connection with the latest development of CNC machine tools. A modular system is built on the multi-level structure to implement an integrated monitoring, diagnosis and control procedure. The built-in PC hardware uses a basic software structure to work with multiple machining parameters in performing on-line scanning of variable machining parameters through sampling and digital signal processing. The simplified scheme for intelligent machining is shown in fig. 1.

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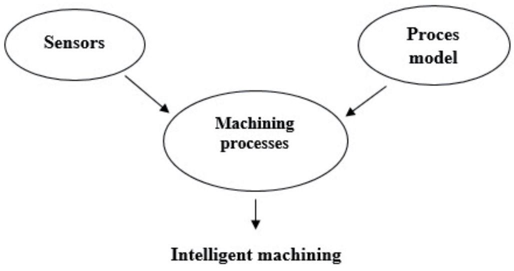


Fig. 1: *Simplified smart machining scheme.*

2. Virtual modelling

Modelling and 3D visualization is irreplaceable in designing, manufacturing systems, implementing changes in production processes, and introducing new technologies and products. Using virtual reality tools, it is possible to create 3D realistic scenes in a 3D environment, usable for practical purposes to further develop and test the product, or even train workers and maintenance workers who will produce and operate the product in the future. The virtual 3D model of the workspace represents a virtual computer environment in which the user can move through his senses. The 3D workspace model can detect collisions at the primary stage of the solution to overcome the overall solution to optimize detected deviations from the original state after implementation of the selected solution. Thanks to 3D modelling, you can get an idea of real machine layout in the production process as well as the ability to explore objects from different perspectives and interactions. In addition to graphical outputs, it is possible to create animated video sequences from the series of images and simulate the functional relationships of the mechanisms. Similarly, the animation of production or assembly operations helps students illustrate and better understand many technological processes. Simulation is defined as the method of experimenting with a 3D product model, computer system. The first step in computer simulation is to build a virtual model of any object. By simulating a parameterised virtual prototype, it is checked whether the specified values and properties of the components are achieved, Fig. Second. We can define it as a modelling of a particular object, such as a machining centre and its components, using state-of-the-art software tools. Nowadays, the accessibility of these software environments is unlimited and we can choose from a wide range. An example could be a few software tools used for pedagogical purposes and later for practical purposes:

- SolidWorks
- Catia
- ProEngineer / Creo
- Siemens NXSiemens

Software - SIEMENS NX 10.0 - was chosen to solve the problem. The reason was mainly access to the department, fast and easy manipulation of the program, relatively simple modelling of the 3D components and also the creation of FEM analysis, which was subsequently made according to the studied object, fig. 2.

FEM (Finite Elements Methods) - also called the Finite Element Method. It is a numerical method designed to solve technical problems such as power solutions for machines and machine components.

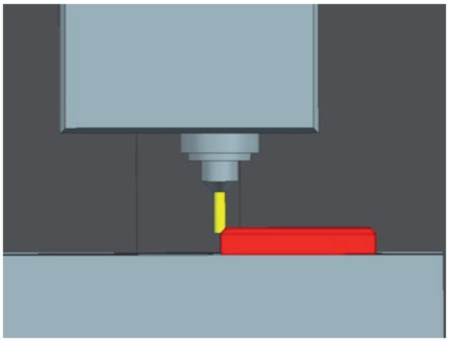


Fig. 2: *Virtual Machining Model - Outline.*

3. Machining of the test piece and experimental analysis of its accuracy

The milled and measured work piece is made of material ČSN 11 523 or according to new standards F355, fig. 3. This type of steel is classified in the construction class. It is used for bridge welded constructions, welded water turbine cabinets, machine structures, cars and motorcycles that are statically and dynamically loaded.

On the clamped and machined work piece, the following measured work piece tolerances were compared with parallel and counter milling:

- ***Parallel milling*** *- chip machining where the tool rotation is the same as the feed direction.*
- ***Opposed milling*** *- spindle machining where the tool is rotated counter-clockwise.*

After machining the work piece, the dimensions of which are shown in fig. 2, the geometric tolerances were judged by the five points of the machined area on the 3D scale, fig. 4 and fig. 5.

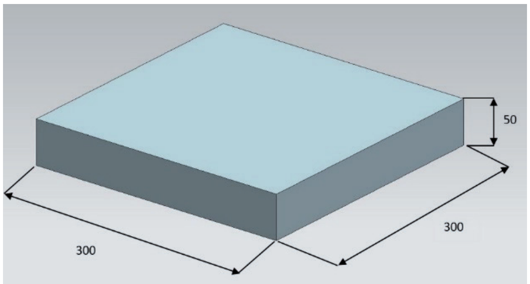


Fig. 3: *Dimensions of the test piece.*

Fig. 4: *3D measure.*

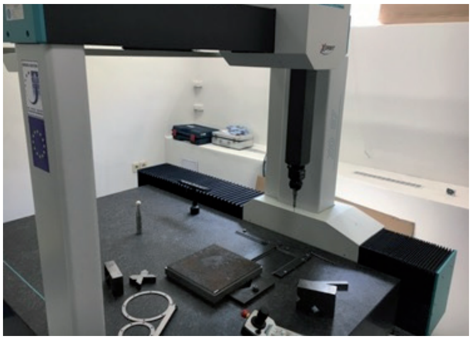


Fig. 5: *Practical measurement of machined surfaces.*

4. Measurement Protocols of counter current and parallel milling and their variations

The subsequent step was to compare the measured values in parallel and counter-milling, fig. 6 and fig. 7. Geometric tolerances according to the measurement protocols were measured by the following deviations and recorded in tab. 1 and tab. 2:

1. Distance of parallel machined surfaces 1/290 - comparison of first and third machined surfaces.

Opposed milling *- deviation is -0.070 mm.*

Parallel milling *- deviation is 0.160 mm.*

2. Distance of parallel machined surfaces 2/290 - Comparison of second and fourth machined surfaces.

Opposed milling *- deviation is – 0,093 mm.*

Parallel milling *- deviation is 0.176 mm.*

3. Parallelism 1/3 - comparison of parallelism tolerances of the first and third machined surfaces.

4. Parallelism 2/4 - Comparison of the parallelism tolerance of the second and fourth machined surfaces.

5. Perpendicularity 1/2 - Comparison of perpendicular tolerance of the first and second machined surfaces.

6. Perpendicularity 3/4 - Comparison of the perpendicular tolerance of the third and fourth machined surfaces.

7. Angle 90° 1/2 - adherence to tolerance of 90° angles of the first machined side against the other.

8. Angle 90° 3/4 - adherence to tolerance of 90° angle of third machined side versus fourth.

9. Straightness 1 - adherence to the roughness tolerance of the first machined surface.

10. Straightness 2 - adherence to the margin tolerance of the second machined surface.

11. Straightness 3 - adherence to the tolerance of the line of the third machined surface.

12. Straightness 4 - adherence to the roughness tolerance of the fourth machined surface.

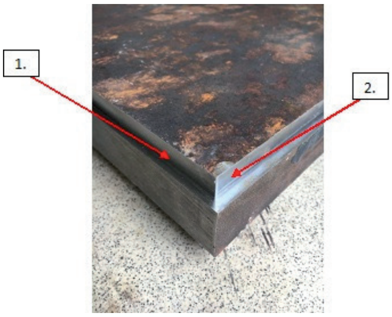


Fig. 6: *Machined and measured areas.*

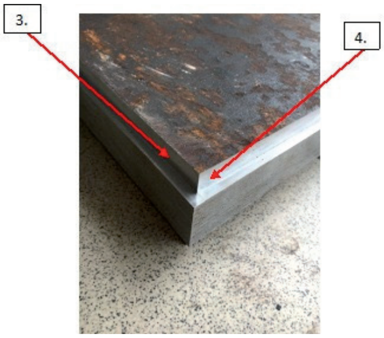


Fig. 7: *Machined and measured areas.*

Tab. 1: *Measured geometrical tolerances for opposed milling.*

Nr.	Property name	Nominal value	Upper tolerance	Lower tolerance	Measured values	Variation	Graph
1	distance 1/290	r 290.000	0.500	-0.500	r 289.930	r -0.070	-14% ----*.-----
2	distance 2/290	r 290.000	0.500	-0.500	r 289.907	r -0.093	-19% ----*.-----
3	parallelism 1/3	0.000	t= 0.050		0.000	0.000	0% *----------
4	parallelism 2/4	0.000	t= 0.050		0.000	0.000	0% *----------
5	upright 1/2	0.000	t= 0.050		0.024	0.024	48% .----*-----
6	upright 3/4	0.000	t= 0.050		0.024	0.024	49% .----*-----
7	corner 90° 1/2	0.000	t= 0.100		0.024	0.024	24% .--*-------
8	corner 90° 3/4	0.000	t= 0.100		0.024	0.024	24% .--*-------
9	straight 1	0.000	t= 0.050		0.011	0.011	23% .--*-------
10	straight 2	0.000	t= 0.050		0.012	0.012	24% .--*-------
11	straight 3	0.000	t= 0.050		0.006	0.006	13% .-*--------
12	straight 4	0.000	t= 0.050		0.005	0.005	10% .-*--------

Tab. 2: *Measured geometric tolerances for parallel milling.*

Nr.	Property name	Nominal value	Upper tolerance	Lower tolerance	Measured values	Variation	Graph
1	distance 1/290	r 290.000	0.500	-0.500	r 290.160	r 0.160	32% -----.*---
2	distance 2/290	r 290.000	0.500	-0.500	r 290.176	r 0.176	35% -----.-*---
3	parallelism 1/3	0.000	t= 0.050		0.000	0.000	0% *----------
4	parallelism 2/4	0.000	t= 0.050		0.000	0.000	0% *----------
5	upright 1/2	0.000	t= 0.050		0.030	0.030	59% .-----*----
6	upright 3/4	0.000	t= 0.050		0.016	0.016	32% .---*------
7	corner 90° 1/2	0.000	t= 0.100		0.030	0.030	30% .--*-------
8	corner 90° 3/4	0.000	t= 0.100		0.016	0.016	16% .-*--------
9	straight 1	0.000	t= 0.050		0.004	0.004	7% .*---------
10	straight 2	0.000	t= 0.050		0.011	0.011	22% .--*-------
11	straight 3	0.000	t= 0.050		0.006	0.006	13% .-*--------
12	straight 4	0.000	t= 0.050		0.004	0.004	8% .*---------

5. Dynamic force measurement and analysis of measured values

The dynamic forces in the materials were measured on a three-component dynamometer, fig. 8. Axis designation for the dynamometer was as follows: X axis (Ff), Y axis (Fp), Z axis (Fc).

A. In the first step, the dynamometer had to be calibrated to 5 kg by weight, the value of which had to be known in advance. Calibration took place in all directions.

B. Next, the work piece was machined according to fig. 2 and according to predetermined cutting conditions.

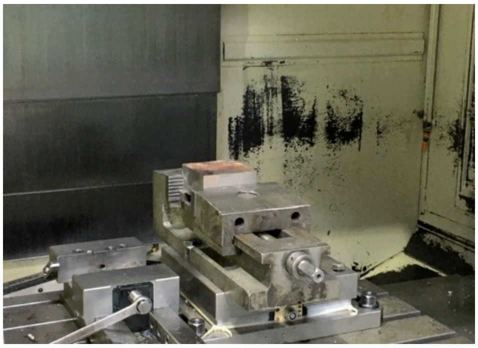


Fig. 8: *Clamped work piece with dynamometer.*

C. The after-treatment values that were measured were subsequently imported through DAISYLAB software into Microsoft Excel, fig. 9 and fig. 10.

Fig. 9: *DAISYLAB and import the measured values.*

Fig. 10: *Dashboard control panel.*

D. The measured data was 300 data per second, with the lowest, middle and highest values being determined in each direction. The measured values were recorded in table 3 and shown in graph 1.

E. After determining the appropriate values, the mean values were used in the FEM analysis in the SIEMENS environment in the NX 10 program. This program allows us to divide the body itself into several parts, which we also call the finite elements. Even before we start creating such an analysis, we need to identify the material, define in detail the bonds or the load of the particular object being investigated.

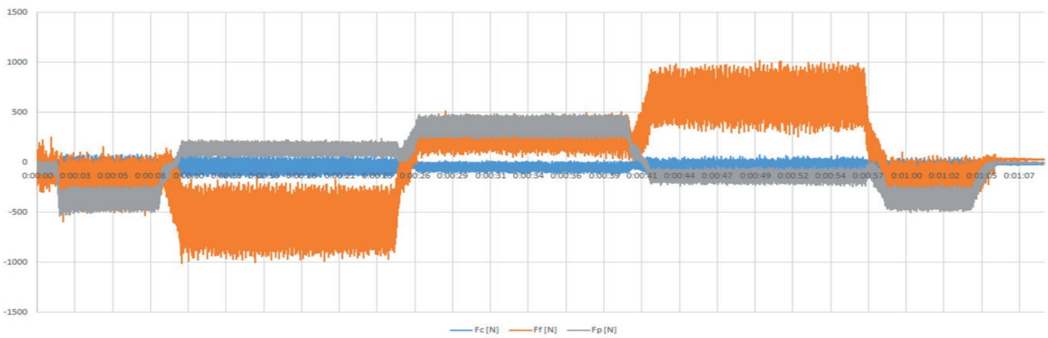
In our case, we loaded the machining stand in three components:

1. The X-axis component was loaded with a force of Ff = -71,093N. The resulting analysis determined a maximum displacement of 1.5-5 mm, fig. 11.
2. The component operating in the Y-axis direction was loaded with the force Fp = -49,218N. The maximum displacement in this direction is 1,835-5mm, fig. 12.
3. The Z-axis component was loaded with the force of Fc = 3.417N. The maximum displacement in this direction is 1,255-6 mm, fig. 13.

Measuring geometric accuracy tolerance has shown that parallel milling of the material is more appropriate from a technological point of view, but also in terms of gear savings. It is an operation that is used more often in practice than counter-machining. Opposed-milling causes larger forces on the tool and therefore the tool is pushed away and consequently larger deviations occur as we could see when comparing two parallel faces. From the point of view of the dynamics of the measured values under our cutting conditions, they were stable and therefore we can evaluate the milling machining center according to the FEM analysis as stable and strength-compliant.

Tab. 2: *Measured geometric tolerances for parallel milling.*

Fc [N] - Z			Ff [N] - X			Fp [N] - Y		
Min.	Med.	Max.	Min.	Med.	Max.	Min.	Med.	Max.
-95,7031	3,417969	63,23242	-295,313	-71,0938	225,5859	-123,438	-49,2188	8,59375



Graph 1: *Graph of the measured values.*

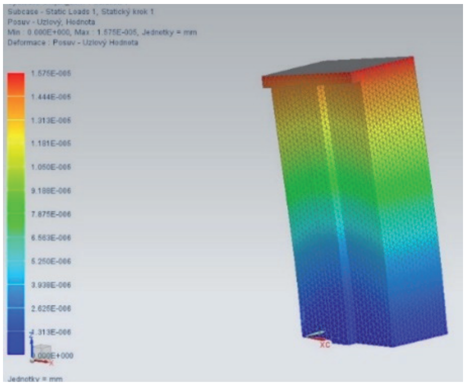


Fig. 11: *FEM analysis in the X axis direction.*

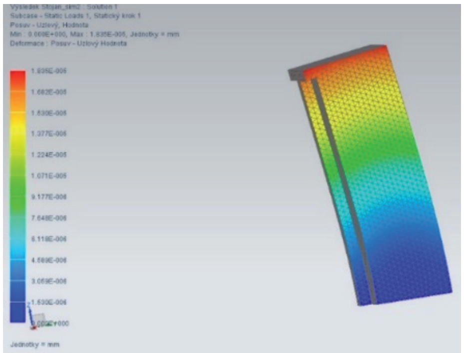


Fig. 12: *FEM analysis in the Y axis direction.*

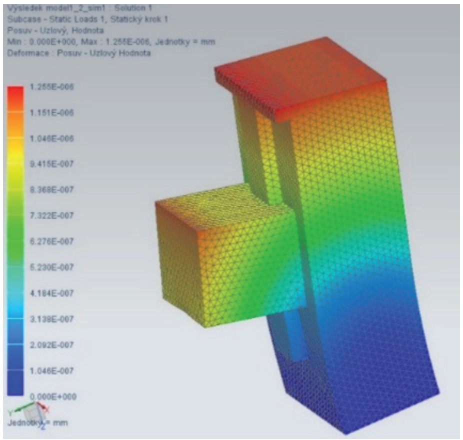


Fig. 13: *FEM analysis in the Z axis direction.*

5. Conclusion

In the article, we worked on machining the work piece and then measuring the machined surfaces on a 3D scale. There were comparison geometric tolerances of distance, parallelism, perpendicularity and linearity. However, we can evaluate that the selected machining centre works in hundreds, sometimes up to thousands of millimetres. That is to say, it is not necessary to reinforce or reconstruct a particular machining centre. The next step was to dynamically force the workloads of the machine after the work piece has been machined and imported into Microsoft Excel. Subsequent FEM analysis shows the stiffness and accuracy of the machine that is used every day in operation. When comparing the results of virtual machining and after the practical machining and measuring of specific values, it is possible to note the fact that the machining centre does not have to be rebuilt or strengthen its components, because of the accuracy of its machining.

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