INNOVATION TESTING OF BENDING OF THE MACHINE-TOOL FRAMES

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The paper deals with the issue of geometric precision measuring at large parts (especially at castings having big dimensions) in their manufacturing stage. The large parts of machine-tool frames are required to have their geometric tolerances in thousandths of millimetres. The production or cooperation abilities of the particular company must be adapted to these demands and it is also necessary to adapt the company metrological equipment and measuring procedures to them. The standard measuring equipment cannot be used in most cases, because the particular parts are too large. For this reason, it is necessary to search such methods and procedures which enable to perform measuring with the relevant result. It could be considered to use e.g. 3D scanners. Unfortunately, their measuring precision has not reached the required tolerances up to now. For example, the HandyPROBE 3D scanner measures with the precision of 0.022 mm [CMM 2015].

KEY WORDS

geometric precision, guideways, FEM calculations, machine tools, machine-tool frame, rotating screw

1 INTRODUCTION

The size of geometric tolerances can be presented on the example of the vertical machining centre column, see Fig. 1. The straightness tolerance is 0.005 mm and the flatness tolerance is 0.01 mm, when the guideways are approx. 2500 mm long.

Figure 1. 3D model of the column [Ucen 2014]

To provide measuring of the column, the measuring methodology was elaborated by means of the available means and devices to enable the check of the ground guideways. The measuring jig was designed for measuring, this measuring jig has the basic carrying part which the holders are attached to. These holders are specified to fix the dial gauges. The carrying part has five tilting supports which are located in two rows and their spacing is 300 mm. When measuring is performed, the jig moves along the column and measuring is performed in steps by 300 mm. It is hard to describe the measuring device briefly. If you have any question, please do not hesitate to contact authors.

The jig slight turning in relation to the initial value is measured in the particular measuring positions by means of the laser and two water levels. The water levels and laser are located on the carrying part of the measuring jig. Using the values obtained in this way, it is possible to determine the shape of the column guideways which the tilting supports move along (Fig. 2).

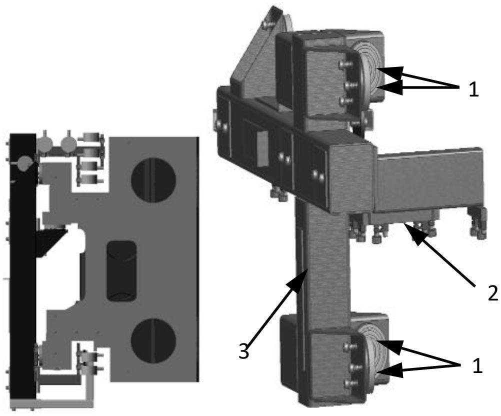

Figure 2. Gauges holders, cross rail measures [Ucen 2014]

Legend to Fig. 2:

1) Slideways,
2) Base for measuring points,
3) Frame of the measuring jig.

There are altogether 8 dial gauges located in the holders. These dial gauges are set to zero at the measuring beginning and they measure successively the profile of the column guideways, while the jig moves. The dial gauge zero setting is performed on the precise measuring plate so that perpendicularity and parallelity can be guaranteed in relation to the check plate. The values measured by means of the water levels and laser are added to the values measured by means of the dial gauges. The measured column can be also loaded statically and measuring can be performed at loading in the horizontal position as well as in the vertical position. The problems at these load tests consist in the fact that it is very difficult to deform the parts (to load them by force), when these parts are freely located on the floor, etc. (thus, if they are not assembled on the machine). On the contrary, when the parts are assembled in the machine frame, it is not possible to measure the deformations of the parts to the whole extent (one frame part always covers another frame part).

In the first stage, the FEM model arose for the needs of a machine-tool design – in order to design the machine-tool properties, especially its rigidity. The jig design arose parallelly with it. The FEM models presented hereinafter are determined to illustrate the behaviour of the actual machine-tool frame. The measured deformation values on the actual frame are in hundredths of millimetres and therefore, it is not possible to show them in the photo. The other purpose, why the FEM models arose, is the verification of the FEM model harmonization towards the actual machine-tool frame.

2 GEOMETRIC PRECISION OF THE MACHINE TOOL

Many different measurings of the machine-tool properties are performed not merely when the machine tool is built (Fig. 3 and Fig. 4). One of these measurings consists in the check of the machine-tool geometric precision. The final result depends on many phases preceding this measuring. These phases include especially the process of the machine design development, the quality of the manufacturing documentation for the particular machine parts, the manufacturing process accuracy, the precision and quality of the assembly process supported by metrological devices.

The main geometric precision tests include measuring of straightness (rectilinearity), of flatness, of parallelity (coincidence of distances and alignment) as well as measuring of perpendicularity and of rotation. The most often used appliances determined to measure these tests are the following ones: mechanical appliances (dial gauges, measuring plugs, measuring rules and angles, water levels, granite prisms, measuring jigs), optical appliances (laser interferometers) and electronic appliances (water levels).

Figure 3. Vertical turning machining centre [TOSHULIN 2014]

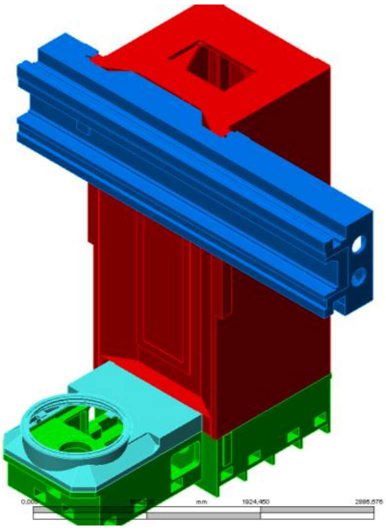

Figure 4. CAD model of the machine-tool frame [Ucen 2014]

When the machine is built, the first measuring which is performed by means of the water level is the machine setting and levelling in regard to the flatness. If the machine is not set well in the horizontal direction or if the horizontality is not kept at the motions of the linear axes within the whole stroke, it is useless to continue. The machine anchorage to the concrete foundation in the production object (hall) has also a great influence on the compliance with the flatness. In some cases the customer refuses to drill holes for anchor bolts in the floor. Then, it is necessary to convince the customer based on good arguments that the machine must be anchored on the foundation by means of anchor bolts for the reasons of its geometric precision as well as for the reasons of the machine stability at dynamic behaviour.

The perpendicularity of the guideways towards the bed is then measured by means of the angle and the dial gauge. Or, the check is performed by means of the dial gauge located on the stand on the spindle, whether the guideways are perpendicular to the spindle axis. When slight rotation by one half-revolution is made, the dial gauge must show the same value.

Required geometric tolerances of the column. The size of geometric tolerances can be presented on an example of the vertical machining centre column (Fig. 5 and Fig. 6). The straightness tolerance is 0.005 mm, the flatness tolerance is 0.01 mm at the length of the guideways approx. 2000 mm. The column weight is 4350 kg. The sizes of geometric tolerances are determined in the check sheet for the corresponding column position.

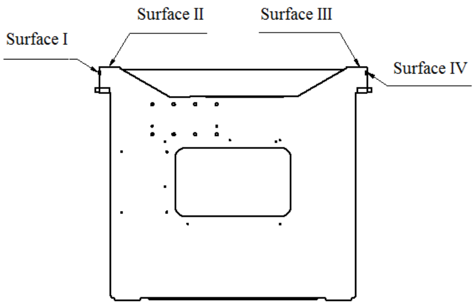

Figure 5. Measured faces [Ucen 2014]

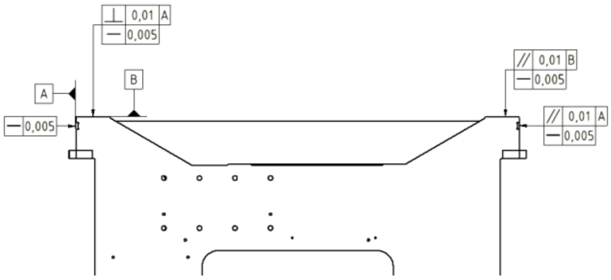

Figure 6. Examples of precision of ground faces [Ucen 2014]

3 MEASURING METHODOLOGY

The measuring methodology has been elaborated to measure the column by means of available tools and devices so that it can be possible to check the ground guideways on the column of the vertical machining centre. The measuring jig was designed for measuring. This measuring jig has the basic supporting part which is equipped with five tilting supports. The tilting supports were selected in order to copy better possible inaccuracies on the column guideways. The designed measuring jig has five supports which are able to provide setting of the measuring jig towards the column. Three tilting supports are located in one plane, two tilting supports are located in the other plane (which is perpendicular to the first one). The tilting supports are located on the measuring jig in two rows having the above-mentioned spacing (three tilting supports are in one row and two tilting supports are in the other row).

The surfaces for the attachment of the holders for dial gauges are located on the measuring jig body. The holders for dial gauges are screwed to the measuring jig and they enable the variable location of dial gauges. Ten dial gauges were selected to measure the column of the vertical machining centre. Two dial gauges were located on each guideway so that is can be possible to measure possible torsion of the measured guideway. One dial gauge was located on each hardened strip considering the hardened strip width.

After the jig with the dial gauges is installed on the measured column, the holders including the dial gauges will be screwed-off. Zero setting of the dial gauges will be performed on the precise measuring plate that the perpendicularity to the check plate and the parallelity with it can be guaranteed. Subsequently it is possible to read the deviations of the guideways from the absolute zero. The other elements which are located on the measuring jig body are two water levels and the laser measuring sensor.

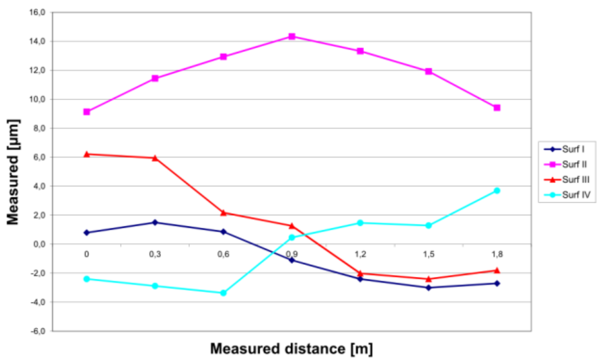

Figure 7. Measured precision values of the guideways on the column [Ucen 2014]

Before the measuring is performed, it is necessary to install the measuring jig on the measured column. It is necessary to perform zero setting of the dial gauges on the holders on the measuring plate. Moreover, it is necessary to perform zero setting of the water levels and to install the measuring laser so that it can be able to measure along the whole length of the guideways.

While the measuring is running, the measuring jig moves along the column and the measuring is performed in the steps by 300 mm. The jig slight rotation towards the initial value is measured in the particular measuring positions by means of the laser and two water levels.

All measured values are recorded (Fig. 7). From the values obtained in this way it is possible to determine the shape of the column guideways which the tilting supports move along.

The measured column can be also loaded statically to obtain the deformation characteristic features of the column. The measuring can be performed in the horizontal position as well as in the vertical position. If the measuring is performed in the vertical position, it is necessary to use the special jig gripping system which shall provide the fixed position of the measuring jig on the measured column and which does not deform the measuring jig itself and the measured column. Fig. 5 and Fig. 6 show the surfaces which the cross rail moves along. They are designated as Surface I up to Surface IV. The guideways having the designation Surface II and Surface III are ground and the material of the guideways is cast iron. The guideways having the designation Surface I and Surface IV are also ground and the material of the guideways is hardened steel. Fig. 7 shows the deformation curves as well as the manufacturing inaccuracies measured by the measuring jig as it has been described above. The column load is according to Var. No. 1 which is described in the following section.

The measuring jig is located freely on the measured part, i. e. on the cross rail in this case. The measuring jig is moved in selected measuring steps by 200 mm as standard. It is possible to change the value at own discretion. The measuring jig moves along the measured part (cross rail) in the selected direction and in the selected steps. The jig motion is provided by the measuring technician manually.

4 FEM ANALYSIS

The Autodesk Simulation Mechanical 2015 program and the ANSYS program, version 15 were used for calculation modelling of frame deformations at loading. When the FEM model was created, the details on CAD geometry were suppressed which would increase the mesh size and prolong the calculation length due to this.

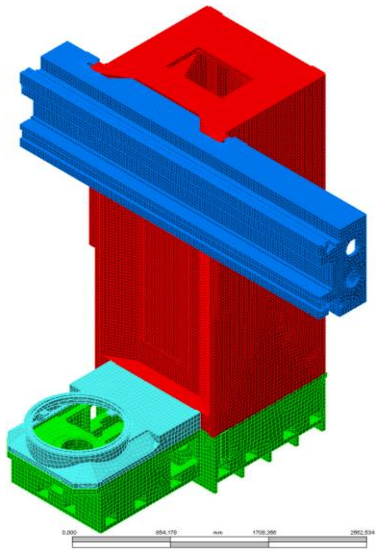

Figure 8. FEM Model (Autodesk Sim.) [TOSHULIN 2014]

Main technical data (parameters of the model):

- material of castings ČSN 42 2425,

Load:

- acceleration due to gravity acting on:
  - the castings of the column (Var. No. 1)
  - the castings of the bed, column, ram and of the slide (Var. No. 2),
- considered working temperature $20 \pm 10^{\circ}$

Frame conditions:

- Var. No. 1 – the column is lying on its back part. The machined surfaces are directed upwards. The column is supported on 3 points. The displacement in the direction of gravitation acting of the Earth is prevented in these points (Fig. 5 and Fig. 6).

Var. No. 2. – assembled frame. The frame is located on fixed support plates. The feeds and rotation of nodal points are limited in the places where the support plates are (see Fig. 8).

The FEM model in the above mentioned variants reflects the actual object – the machine tool shown in Figure 3. The bed is fixed on the floor, zero displacements are expected in relation to the foundation. Note: The foundation is a monolithic concrete block having the dimensions of approx. 3500 x 3000 x 1000mm for this machine. The contact type elements are located between the frame contact surfaces (bed – column). The cross rail is connected with the column along the whole length by the bonded type contact. The prestressed "bold" type elements are specified to transfer forces. The contact elements are located between the contact surfaces. The elements having the defined rigidity are also located between the contact surfaces. The defined rigidity represents the rigidity of bearing packs. The bearing packs (on the actual frame) are located on the machine-tool slide and the slide moves along the cross rail by means of these bearing packs. The volume elements, brick type (20 nodes) and tetrahedron type (10 nodes) have been used there. The difference between Fig. 9 and Fig. 1 is caused due to the fact, that FEM tasks were performed in different FEM programs in different machine-tool development stages.

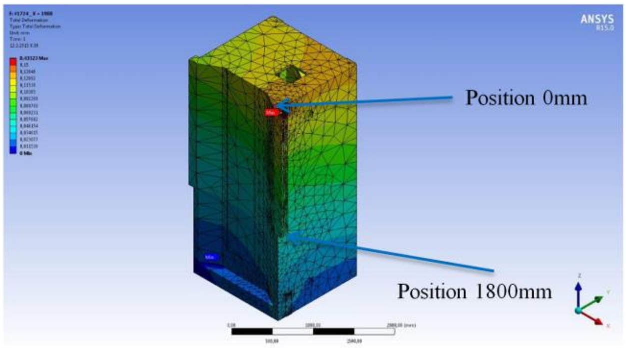

Figure 9. Measured positions –examples (ANSYS) [TOSHULIN 2014]

Fig. 10 shows the total deformation of the machine frame. Fig. 11 shows the situation when only the column has been skeletonized. The edges are marked in the figure where the deformations are drawn in the stated range (see Fig. 9).

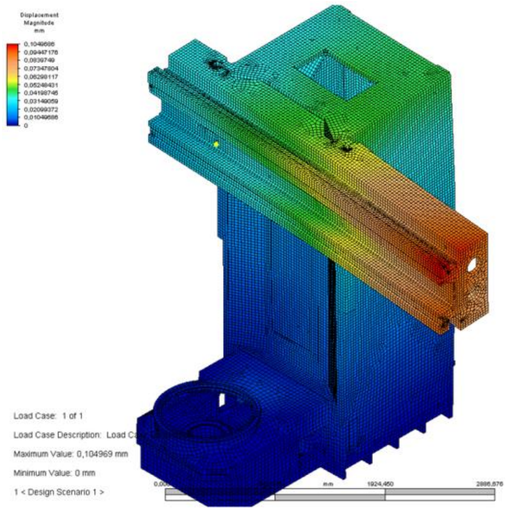

Figure 10. Deformation of the frame (Var. No. 2) [TOSHULIN 2014]

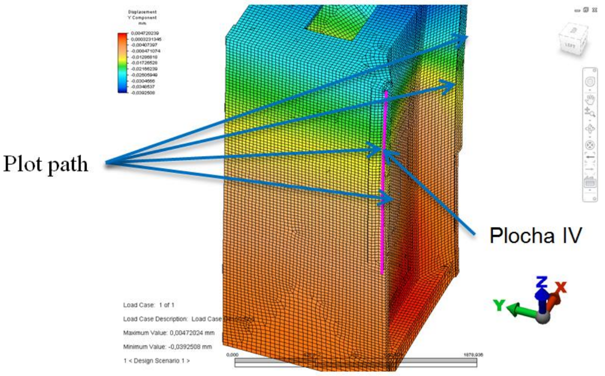

Figure 11. Plot path edges [TOSHULIN 2014]

Fig. 12 and Fig. 13 are the examples of the deformations at the column of the vertical machining centre found out using the numerical methods (calculation variant No. 2). The break can be seen in the curves which can be found in the connection place between the column and the cross rail. This loading condition has not been measured yet, because the machine had not been assembled at that time, when this paper originated. The first calculation variant can be compared with measuring only with difficulties, because gravitational loading in the model (calculation) conditions causes so big deformations as it could be expected.

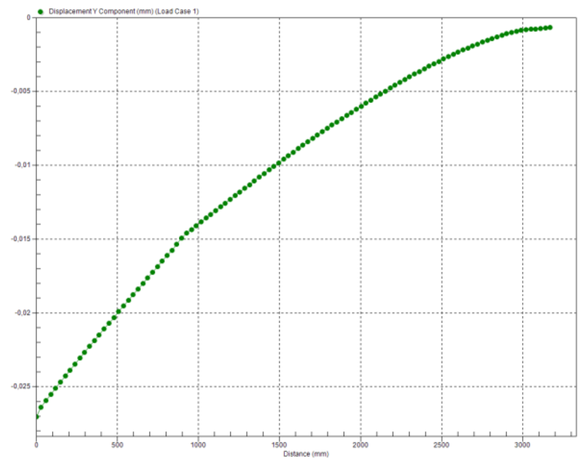

Figure 12. Example of the plot path – deformations (X-axis and Y-axis in mm units) [TOSHULIN 2014]

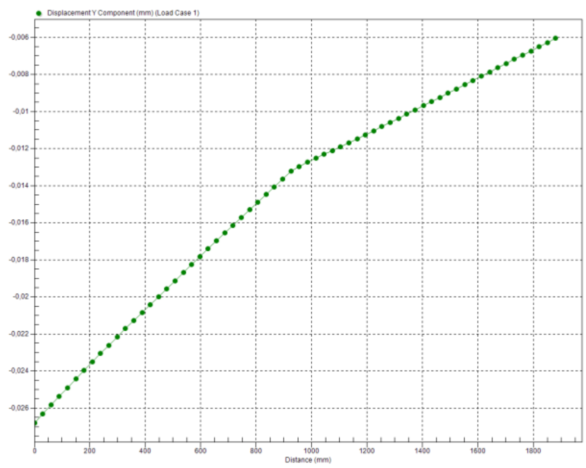

Figure 13. Plot path (Surface IV), deformations (X-axis and Y-axis in mm units) [TOSHULIN 2014]

Enclosed Fig. 10 up to 13 represent a very limited selection of the data packet obtained by measuring and FEM calculations. The particular deformation numerical values have not the declarative value – it is not possible to show the results in their coherences (this text is not a calculation report). Therefore, we ask possible readers of this text to stay on top of things especially at graphs and to consider the whole issue rather than the particular values. More detailed information can be found in the report [Ucen 2014].

5 CONCLUSIONS

Measuring of the external impacts (machining accuracy, geometric precision, etc.) of the internal force effects at the machine-tool motion axes (moving of big masses) was implemented in dependence on the design made by the paper authors within the prototype tests, research and development activities of TOSHULIN, a. s company. Measuring was performed at those machines, where the authors participated by the FEM calculations [2] and design work (design of the jig, etc.). E.g. at the machine with the rotating screw, the authors created the just measured horizontal motion axis (X-axis), the whole machine frame and other functional units. Moreover, this machine also enables to influence the dynamic properties of the machine frame by utilization of the materials damping vibrations and noise, which is also based on the knowledge obtained at the research activity performed by TOSHULIN, a. s. company and on the experiments designed by the authors of this paper. The numerical simulation of this experiment is performed in [3].

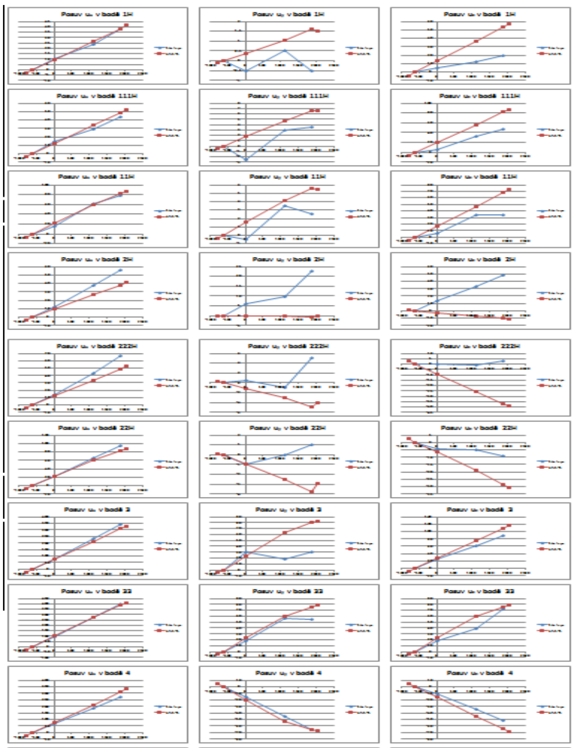

Figure 14. Plot paths on measured edges [TOSHULIN 2014]

The calculations and experimental measuring were performed. The verification of the measuring of the unloaded frame with the calculations is being prepared. It will be possible to perform the measuring on the column, after the machine is assembled. At that time, when this conference paper was written, it was impossible to perform the measuring, because the machine had not been prepared for the measuring (it had not been assembled yet). The measured data (by measuring device, see Fig. 2) serve not only for providing the column check according to the manufacturing drawing but also for comparing the calculated values by means of the FEM calculations. These calculations serve for the analysis of the machine behaviour as the whole unit as well as for the analysis of the particular parts of the future machine, which shall enable the precise and stable machining. The measured data serve for assessing correlation with calculations. The modifications at grinding are also performed in accordance with the measuring data so that the better results can be reached at the geometric tolerances.

Fig. 14 shows an extract from the comparison of measuring results of actual objects and FEM analyses. The conformity is 5 – 10 % in many cases. In those places, where such a good conformity of the results cannot be found, we attribute the differences to manufacturing inaccuracies. The CAD/FEM models are perfect in their geometric aspect, the actual objects are made precise with the particular accuracy; however, they are also made imprecise by intent.

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