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STATIC STIFFNESS RESEARCH OF LARGE-SIZE MACHINE TOOLS BASED ON THE EXAMPLE OF TV 240 CNC MACHINE TOOL

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ABSTRACT
Experimental research of static qualities of machine tool carrying framework and shears systems prove maladjustment of the results provided by contact mechanics research serving as input data for determining parameters of models' structures of finished elements. Such association leads to significant discrepancies in assessing stiffness of various constructions. One way to prevent it is to identify parameters as based on experimental research of real objects. The objective of the aforementioned research was measuring the stiffness properties of a CNC large-size machine tool TV 240. We tried to present problems referring to research of that type, ways of conducting measurements and sample results followed by their interpretation.
Keywords: stiffness properties, large-size machine tool

1. INTRODUCTION
Heavy machine tools pose the greatest problems for researchers dealing with stiffness properties. The greatest technical issue that appears during the static stiffness research is the necessity to conduct measurements of strains of the order of µm at the body whose size may be of several meters. In practice, scaffolding of lattice construction is being built around the machine tool to carry dislocation sensors. In order to isolate the scaffolding from vibrations separate scaffolding or moving landing are being constructed so as to enable sensor operation. Conducting measurements of heavy machine tool stiffness requires disabling not only the machine tool but also the whole shop floor, where the devise is located, from the production process for at least a couple of days. The disabling is necessary to eliminate possible influence of vibrations produced by the nearby machine tools or overhead traveling cranes.

2. LARGE-SIZE TV 240 CNC MACHINE TOOL
The object of the research was a large-size, numerically controlled machine tool identified with a symbol TV 240 CNC (figure 1.). Machine tools of the TV series are being manufactured as turning units meant for machining processes allowing both manual replacement of the tool and automatic gauging of tools and the machined element. Machine tools of that sort enable performance of machining, drilling and milling activities

3. STATIC STIFFNESS RESEARCH PLAN
Static stiffness research involved load application with the force equal to 30 kN in two directions (Y and Z axles). The point of load-force application and the location of measuring points were diversified during the research. Dislocation of only certain selected machine tool elements was recorded.
Firstly, (scenario I) the servo-motor was placed between a tool post located at the slide and the tailstock pinol (figure 2.). The following measuring points were selected for this arrangement:

- C_1 tailstock pinol distortion against the tool post,
- C_2, C_4 tailstock body distortion against turning slide,
- C_3 tailstock pinol distortion against tailstock body.

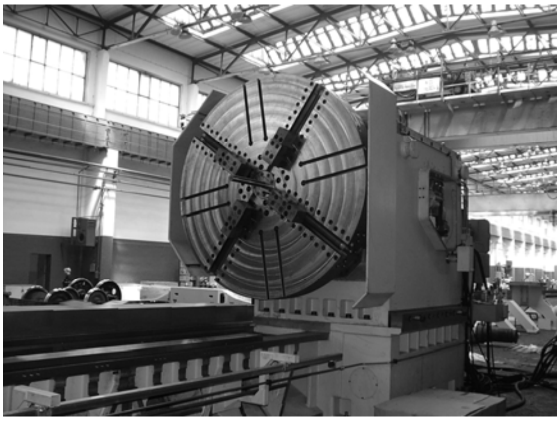
a)  b) 

Figure 1. TV 240 CNC machine tool view (a – general view; b – turning holder)

Secondly, the servo-motor was placed between the tool post and one of four jaws of the turning holder and the load being applied onto the machine tool along the Y axle. For this arrangement, the following measuring points were selected:
- C_5 loaded jaw distortion against the turning slide,
- C_6 distortion of the turning holder's shield against the tool post.

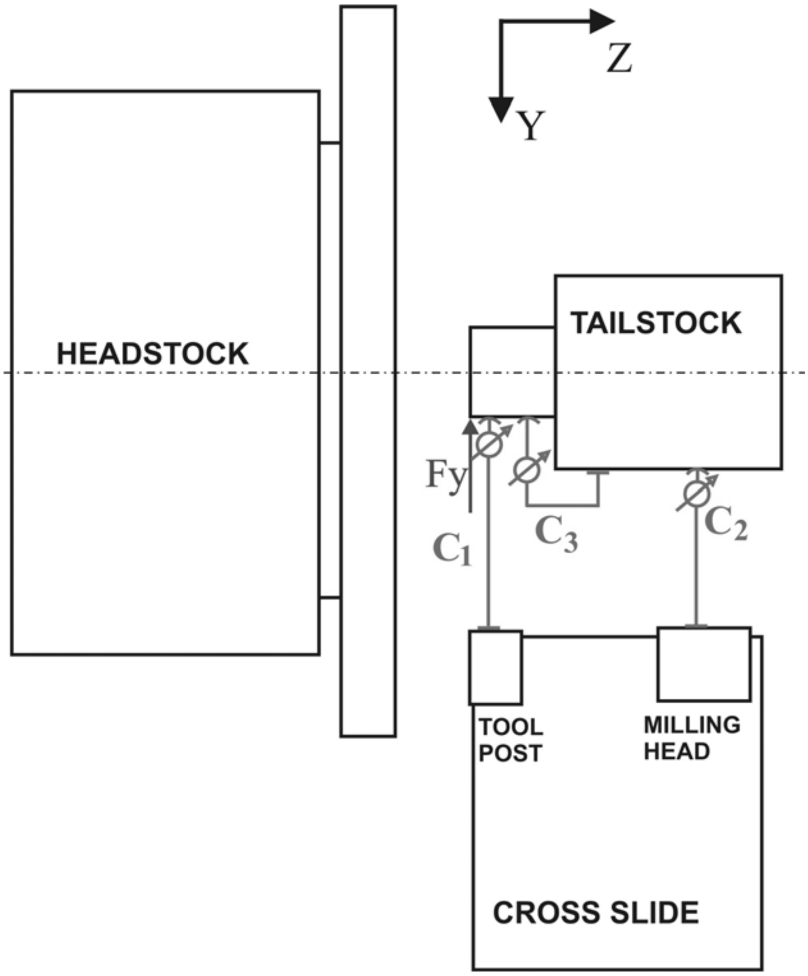


Figure 2. Location of measuring points during the static stiffness research of TV 240 CNC machine tool (scenario I)

Next, the direction of the load applied to the machine tool was changed from the axle Y to Z. Consequently; the load force was applied to the shield of turning holder. The following measurements were conducted:
- C_7 distortion of the turning holder's shield against the tool post,
- C_8 distortion of the turning holder's shield against the fixed headstock body.
In the last case (scenario III) the servo-motor was placed between milling machine slide and the tailstock body. The machine tool was loaded at Y axle. The following readings were recorded for this arrangement:
- C_9 tailstock body distortion against milling slide,
- C_{10} tailstock body distortion against milling slide,
- C_{11} milling slide distortion against its ways milling slide distortion against its bed.

4. SAMPLE READOUTS

The static stiffness research conducted by the use of a traditional method provided a diagram in force – dislocation system, which served as the basis to determine the value of static stiffness indicator. Figure 3. presents sample diagrams in force-dislocation system which were used for: determining the value of static stiffness indicators and measuring relative dislocation of pinol and tailstock body against the slide positioned in the Y axle, with the machine tool being loaded with the extortion force equal to 30 kN.

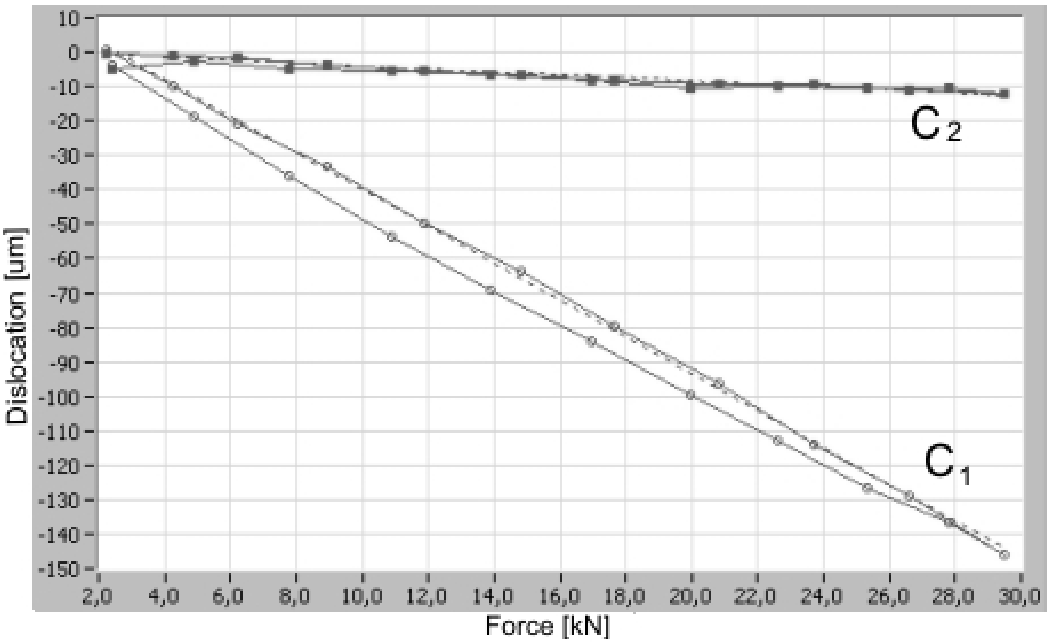


Figure 3. Diagram of the force-dislocation system (scenario I)

The diagrams of force-dislocation system served as the basis for determining the value of stiffness indicators characteristic for particular subassemblies of the tested machine tool. In each case, two values of stiffness indicator were included. The values were determined as: ratio of maximum force and maximum dislocation, or using linear regression.

5. RESEARCH FINDINGS

5.1. Conclusions referring to stiffness of TV 240 CNC machine tool

1. It is possible to conclude, that precision of the machining process is greatly influenced by the stiffness of the tool post and the turning slide (the relative stiffness of the tool post against tailstock pinol approximately 200 kN/mm; stiffness against the holder shield in Y axle approximately 200 kN/mm, in Z axle approximately 76 kN/mm).

2. The stiffness of both tailstock body against the turning slide (approximately 2000 kN/mm) and tailstock pinol against the body (approximately 3500 kN/mm) is quite satisfactory.
3. The stiffness of holder shield perceived as the element enabling the fixation of a unit to be machined was found to be satisfactory with its value exceeding 600 kN/mm (measuring point C_8).
4. The precision of the milling process is influenced by the stiffness of the milling slide, which oscillates from approximately 150 to 250 kN/mm for Y axle (relative stiffness against tailstock body). The extortion in Y axle entails slight raising of the slide's base in X axle at the ways (measuring point C_{12}, stiffness in X axle approximately 550÷750 kN/mm).

Table 1. Values of static stiffness indicators

Force [kN]	Values of static stiffness indicators [kN/mm]							
	Regr.	F_{max}/X_{max}	Regr.	F_{max}/X_{max}	Regr.	F_{max}/X_{max}	Regr.	F_{max}/X_{max}
Scenario I	C_1		C_2		C_3		xxx	
30	186,84	201,35	2309,18	2462,43	3841,21	3571,1	xxx	xxx
Scenario II	C_5		C_6		C_7		C_8	
30	171,49	192,26	199,12	221,89	76,03	76,66	612,95	658,17
Scenario III	C_9		C_{10}		C_{11}		C_{12}	
10	148,82	198,98	184,45	245,45	10739,20	4723,01	552,70	748,15

5.2. Conclusions on static stiffness determination of large-size machine tools

The main goal of static stiffness research is to determine stiffness characteristics and static stiffness coefficients. Due to limited range of measurements, the stiffness of the entire carrying framework is not being analyzed. The studies focus only on certain, selected machine tool elements that affect the precision of the machining process. The choice of elements that are to be subjected to testing (measuring points) is one of the most crucial decisions made before the research commences.

Generally, a simplified methodology of static stiffness research is limited only to determining the dislocation of the cutting edge tip against the base surface of the machined object including both various directions of load application and location of machine's working units (configuration). The results of such research are extremely interesting for the machine tool users since they provide information on possible machine precision that can be achieved. However, machine tool designers are interested in more detailed analyses. One of them is detection of weak links in carrying framework.

In case of heavy machine tools, slide blocks (either turning or milling) are of the highest susceptibility, moreover the susceptibility increases significantly as the slide block slides out to its outward position. When the slide block is slid out in a short distance, the resultant stiffness is being determined by contact stiffness and the stiffness characteristic is strongly nonlinear. It is the formal stiffness of the slide block itself that influences stiffness when the slide block is slid out insignificantly, and the stiffness characteristics is similar to linear one. Comparing static properties of machine tools of similar or identical construction may been extremely useful tool for assessing the assembly of those machines. For instance, if the two machine tool of the same construction differ greatly e.g. in stiffness, it may indicate certain faults that appeared during the assembly or manufacturing process [2].

6. REFERENCES

[1] Sliwka J., Kosmol J.: A dynamic method of determining the static rigidity of heavy machine tool, Proceedining of the 10th International DAAAM Symposium, Vienna, Austria, 1999

[2] Kosmol J., Śliwka J.: The repeatability of the static features of heavy machine tools. Prace Naukowe Instytutu Technologii Maszyn i Automatyzacji Politechniki Wrocławskiej Nr 84, seria: Konferencje Nr 41, t. I, Referaty plenarne i sesyjne, Wrocław 2003, s. 533-540.(in Polish)

[3] Grant no 6 ZR8 2005 C/06647 suported by the Polish Scientific Research Committee: Sterowana numerycznie tokarka kłowa typu TV 240 CNC x 30m, Katedra Budowy Maszyn, Politechnika Śląska, Gliwice 2005 (in Polish)