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STATIC STIFFNESS CALCULATION OF A LATHE HEADSTOCK

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Abstract: *Checking and calculation of the headstock static stiffness for every machine tool is important because it directly influences the machine accuracy, which is one of the most important factors. This paper describes the calculation and results of the static stiffness of a bearing housing in different areas of the headstock of a universal centre lathe. To determine the stiffness, we performed a calculation using the finite element method (FEM). The computational model was loaded by maximum forces that were calculated via analytic calculations. Displacement of several important areas of the headstock was found by using this FEM calculation. Stiffness was calculated from displacements and loading forces by using well known formula.*

Keywords: Stiffness, Machine tool, Finite element method, Universal centre lathe, Headstock.

1. Introduction

Modern machining processes require machine tools to work accurately and dynamically. This leads to the necessity for a method which can analyse the stiffness of machine tools. (Lianqing and Liping, 2009) The aim of this calculation is to examine the static stiffness of the spindle bearing housing in the headstock (Fig. 1) of a universal centre lathe via calculation by finite element method (FEM). The headstock stiffness is one of several values of stiffness that are necessary for calculation of the overall static stiffness of a spindle bearing. This stiffness has a crucial influence on the machining accuracy of the lathe. Decisive criteria of machine tools quality are the productivity and working accuracy. (Šooš, 2008) In addition to these structural parameters the accuracy of the machining process is also influenced by the diameter and the geometry of the workpiece. (Chen, Wei and Tsai, 1999)

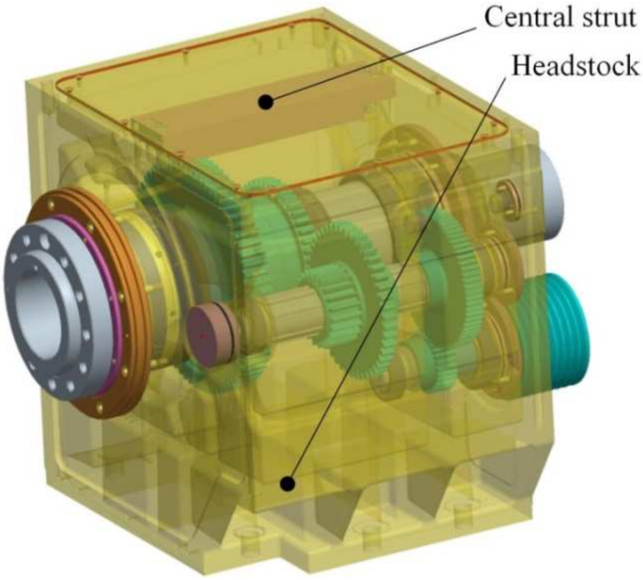

Fig. 1: Headstock of the universal centre lathe.

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Only the headstock and pliable central strut was modelled volumetrically, other parts were simplified for this calculation (Fig. 1). Stiffness was examined in three mutually orthogonal directions by loading of places where spindle bearings are in the real machine. The calculations were made in the FEM system MSC Marc 2011. Only small deformations were considered in this calculation.

2. Calculation settings

Pliable parts of the model – the headstock and the central strut were meshed using linear volume elements with 8 (hex8) or 6 (penta6) nodes. The bed of the lathe was discretized as a non-deformable surface. The spindle bearings were considered as absolutely rigid – contact surfaces between every bearing and the headstock were linked with an imaginary point on the axis of the bearing by using absolutely rigid links (Rigid Link in MSC Marc). Contact surfaces of the bolt heads with the headstock were also replaced with absolutely rigid links. Bolts were replaced by links with a possibility of preload (Overclosure link in MSC Marc). One end of the preloaded link was placed on the rigid links that connect the contact surface of the bolt head, and the second end of the preloaded link was connected to one internal node of the non-deformable surface, where there is actually a thread in the bed of the lathe (threaded holes have not been simulated). Overclosure ties were loaded with the recommended preloading force specified by the bolt manufacturer.

The validity of Hook's law (i.e. linear stress distribution on deformation) was considered for all the materials used. Their parameters are listed in Tab. 1. The headstock is made of cast iron (EN-GJL-300) and the central strut is made of steel (S235JRG2).

Tab. 1: Mechanical properties of used materials.

Material	Density [kg·m^{-3}]	Young's modulus [GPa]	Poisson's ratio [-]	Compressive strength [MPa]	Tensile strength [MPa]	Yield strength [MPa]
EN-GJL-300	7350	130	0.26	860	300	-
S235JRG2	7800	210	0.3	340		235

The contact with friction was defined between parts of the model (between the headstock and the central strut and between the headstock and the bed of the lathe). This contact does not allow transfer of tensile normal forces, but it transfers all other forces (contact touching in MSC Marc). The coefficient of friction between all contact surfaces was specified as 0.15. The size of the transmitted tangential forces was derived from this coefficient.

The computational model was used to investigate the stiffness, and for this task it was necessary to set the geometric and static boundary conditions.

Forbidding all displacements and rotations has been prescribed for the solid surface that represents the bed. All displacements and rotations were also forbidden for the selected nodes of the headstock and the central strut, but only in the first calculation step in which the model has not been loaded with any static boundary conditions. In the second and next calculation steps these geometric boundary conditions have been released.

For this calculation, a static load of the model was considered and the model was loaded with forces transmitted through the bearings and bolted connections. Forces transmitted through the bearings were always prescribed in one central node for each bearing. (See Fig. 2) The position of this central node was tied to nodes corresponding with their position to the position of the contact points between the headstock with the bearings. Similarly, the preloading force of the bolt connections was always applied to the node located on the axis of the screw, while the relative position of the central node was linked with nodes that correspond with their position to the points of contact between the headstock and the bolt head. Other possibilities of numerical modelling of preloaded bolted joints are described in Lašová & Kosnar (2006).

Loading was done in three basic steps:

- Geometric boundary conditions were activated - positions of all elements of the model were defined.
- Bolt connections were preloaded.
- Loading forces to the bearings points were applied.

During investigation of the stiffness, the last basic step of the calculation (loading forces to the bearing points) was conducted with five different settings. For each of these five different calculations always only one bearing was loaded with a simple force in one coordinate direction (see Tab. 2). For all five calculations always the maximum value of the loading force in particular bearings was chosen. The value of the loading forces was calculated via analytical calculations from the load spectrum of the lathe.

Tab. 2: Individual loading forces.

Calculation - *n*	**1**	**2**	**3**	**4**	**5**
Bearing designation	**NN 3936**	**NN 3936**	**NN 3932**	**NN 3932**	**180 TAC**
Type of bearing	**radial**	**radial**	**radial**	**radial**	**axial**
Force in the X direction [N]-$F_{X,n}$	-30 000	0	30 000	0	0
Force in the Y direction [N]-$F_{Y,n}$	0	30 000	0	-30 000	0
Force in the Z direction [N]-$F_{Z,n}$	0	0	0	0	30 000

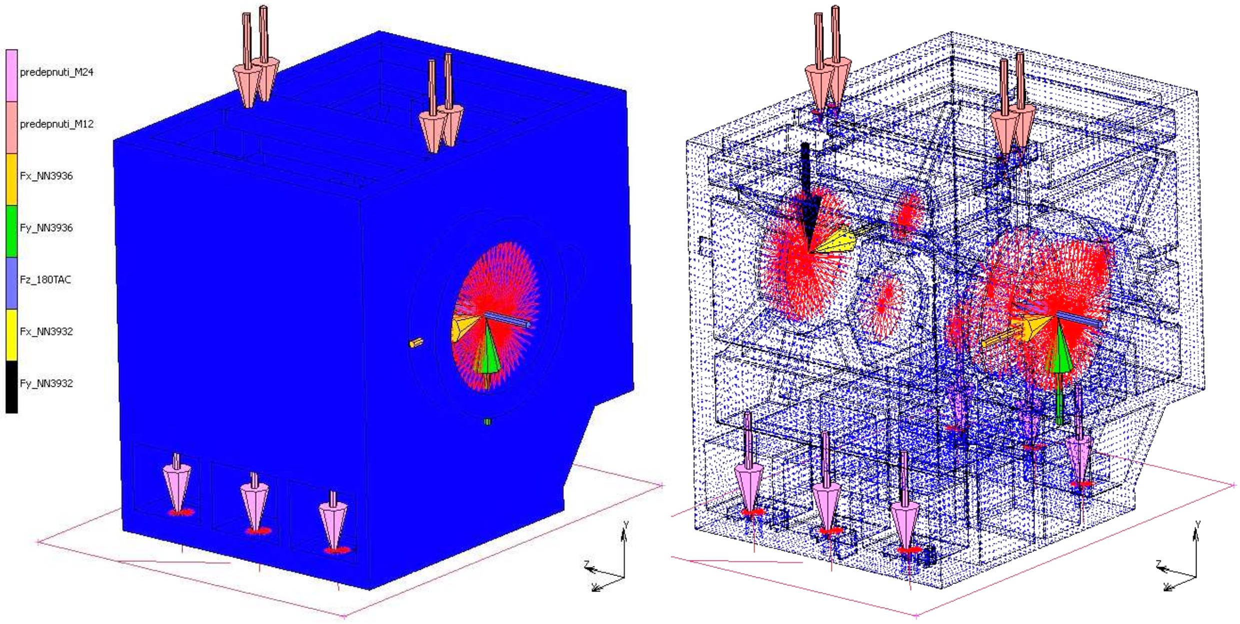

Fig. 2: Static boundary conditions.

3. Stiffness evaluation

The stiffness was examined in the directions of the coordinate axes on the basis of the specified static boundary conditions and the discovered displacements of the nodes where the loading forces was placed (node in the middle of bearings), according to the equation:

$$k_{i,n} = \frac{F_{i,n}}{u_{i,n}} \tag{1}$$

while $F_{i,n}$ is loading force from Tab. 2, where the index i is coordinate X, Y or Z and the index n is the number of calculation (1-5) from the same table.

The discovered values of the displacement of the centre points of bearings $u_{i,n}$ are given in Tab. 3 and values of stiffness calculated according to equation (1) are stated in Tab. 4. In Fig. 3 you can see an example of the calculated displacement of all nodes in the direction of the loading force (loading force $u_{x,1}$).

Tab. 3: Displacement of centre points of bearings.

Calculation - *n*	**1**	**2**	**3**	**4**	**5**
Bearing designation	**NN 3936**	**NN 3936**	**NN 3932**	**NN 3932**	**180 TAC**
Type of bearing	**radial**	**radial**	**radial**	**radial**	**axial**
Displacem. in the X direction [mm]-$u_{X,n}$	-0.016	0	0.018	0	0
Displacem. in the Y direction [mm]-$u_{Y,n}$	0	0.011	0	-0.005	0
Displacem. in the Z direction [mm]-$u_{Z,n}$	0	0	0	0	0.021

Tab. 4: Calculated stiffness of the headstock in coordinate directions.

Calculation - *n*	**1**	**2**	**3**	**4**	**5**
Bearing designation	**NN 3936**	**NN 3936**	**NN 3932**	**NN 3932**	**180 TAC**
Type of bearing	**radial**	**radial**	**radial**	**radial**	**axial**
Stiffness in the X direction [kN/mm]-$k_{X,n}$	1875	0	1667	0	0
Stiffness in the Y direction [kN/mm]-$k_{Y,n}$	0	2727	0	6000	0
Stiffness in the Z direction [kN/mm]-$k_{Z,n}$	0	0	0	0	1429

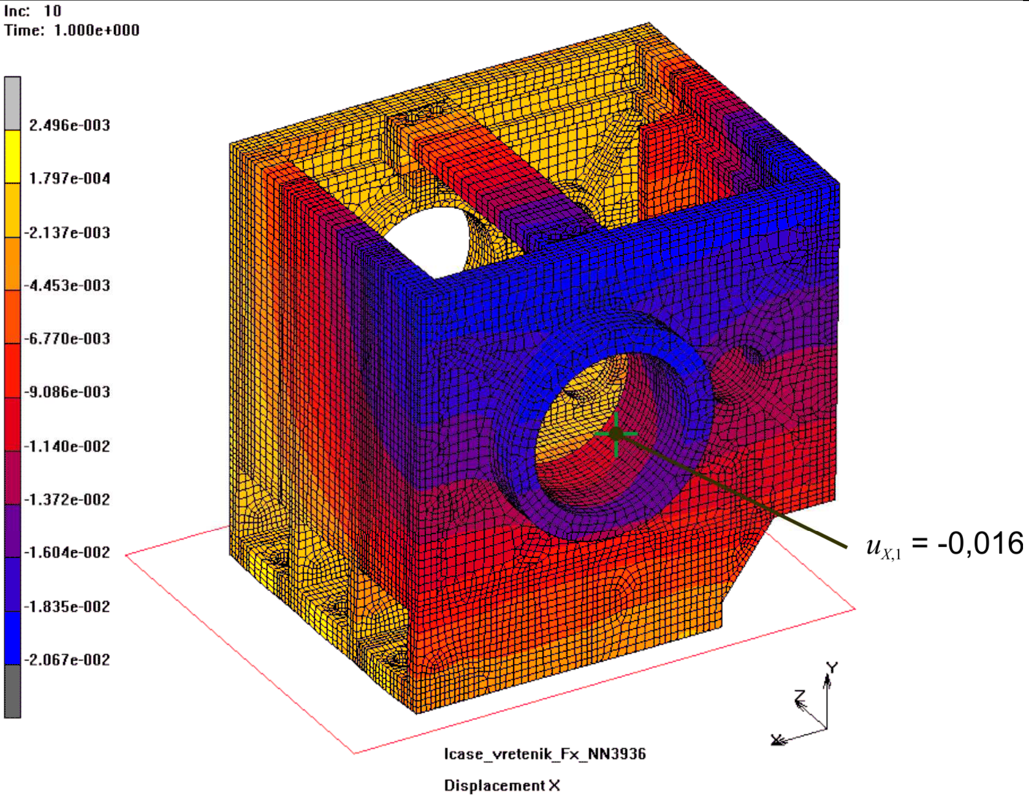

Fig. 3: Displacement in the direction of loading force [mm], calculation n=1.

4. Conclusions

The goal of this calculation was to discover the static stiffness of bearing housing areas in the headstock of a universal centre lathe via calculation by FEM. The stiffness was examined in three orthogonal directions by loading the spindle bearings. From the values gained from this calculation, it is possible to calculate the overall stiffness of the spindle bearing, which is very important for the accuracy of the designed machine. The calculated values show that the lowest stiffness of the headstock was observed in the spindle axis direction.

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