STUDY OF STATIC STRENGTH OF A MILLING WOODWORKING MACHINE SPINDLE BY FEM

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ABSTRACT

A static analysis of a milling spindle with two bearing supports from five-operating woodworking machine KP400 with lower position and console V-belt pulley is carried out by the method of finite elements (FEM) with program Cosmos Works®. The milling spindle 3D model is generated with Solid Works® with all elements of the real spindle – key-slot, grooves for clip ring, tread for fixing of the cutter, segments, chamfers, filets, etc. Von Mises stresses, equivalent strains, resultant displacements, stress intensities (P1 – P3) and factor of safety distribution is obtained and visualized. A decrease of the spindle inter-support distance is offered which brings about to reduction of stresses, strains, displacements, as well as to increase of the minimum factor of safety and will give opportunity to increase the vertical motion at spindle adjustment for this type of construction of the cutting mechanism.

Key words: spindle, milling woodworking machine, static analysis, FEM, Cosmos Works®

INTRODUCTION

Milling woodworking machines have large application in different productions – of furniture, doors, windows and another construction products, sport devices and consumer goods, as well as in the carriage-building and ship-building [1]. The working shafts of the milling woodworking machines operates with high revolutions and in bad-case conditions, which induce different dynamics processes and their operation is getting more complicated [1-3]. Because of that of especially importance is not only the proper calculation of the cutter spindle but the improvement and optimization of these calculations. This is coming true with the development of CAD/CAE software in the last years. More and more the modern CAD/CAE systems for 3D modeling and engineering calculations and analyses of the operating shafts of woodworking cutting mechanisms are applied [5-8].

The object of this study is caring out of a static analysis of a milling woodworking machine spindle by the method of finite elements (FEM) with CAE program Cosmos Works® and optimization of the spindle inter-support distance.

METHODS

1. 3D MODEL OF A CUTTING SPINDLE

A cutting spindle with two bearing supports from a 5-operating aggregate woodworking machine K5-400 with lower spindle position and console pulley is 3D modeled.

The 3D model of the cutting spindle is created with the program Solid Works® with all elements of the real spindle – key-slot, grooves for clip ring, tread for fixing of the cutter, segments, chamfers, filets, etc. Initially a base 3D model of the spindle is generated according to his sketch – Fig. 1. After, the base 3D spindle model is upgraded with the corresponding elements, some shown on Fig. 2.

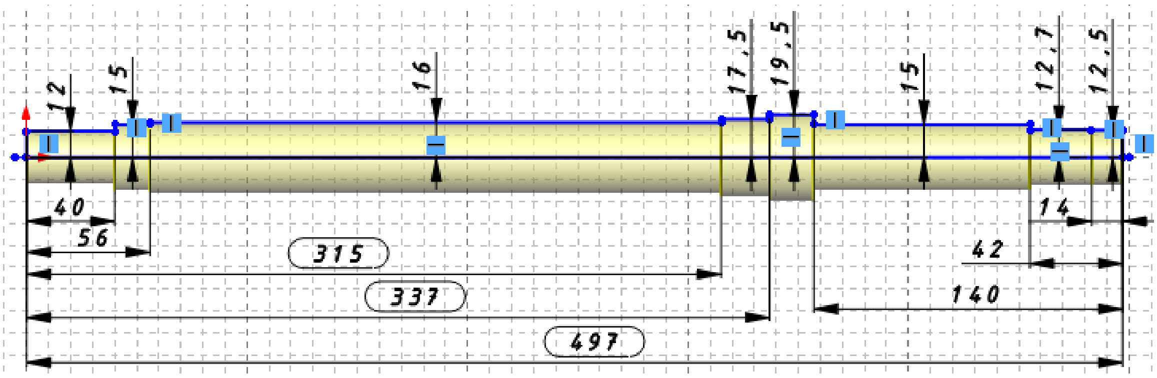

Figure 1: Sketch of the cutting spindle

After that *a second 3D model of the cutting spindle* is created for which the inter-support distance is decreased from l = 264 mm to l = 200 mm, as only enclosed distances on Fig. 1 are changed. For differentiation of the two 3D models, they are indicated as follow: model „264“ (with distances as on the Fig.1) and model „200“, for which the pointed on Fig.1 distances became 256 mm, 278 mm and 438 mm respectively.

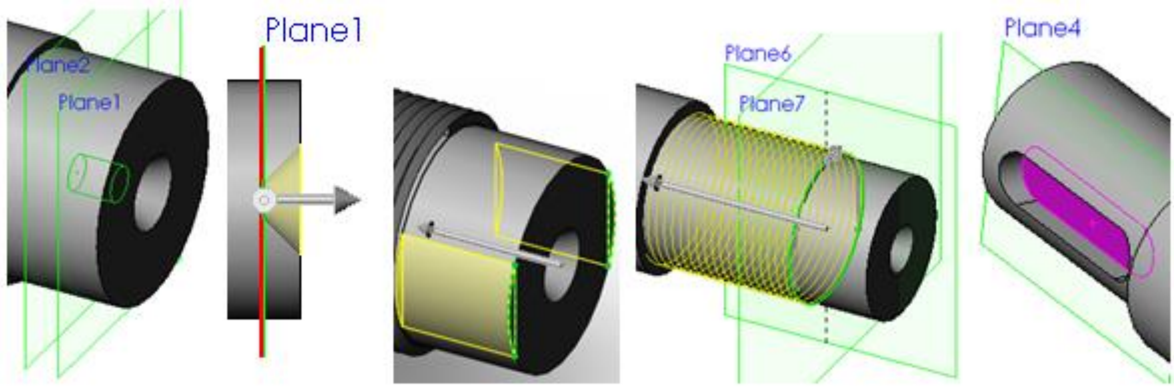

Figure 2: Creation of the cutting spindle elements

2. CALCULATION SHEME OF THE CUTTING SPINDLE

The milling aggregate from 5 operating woodworking machine processes longitudinal and conventional milling of different profiles. The spindle is driven by an asynchronous motor with 3 kW power and revolutions of 2860 min^{-1} by a high-speed belt gear with gear ratio i = 0,5. The cutting spindle is loaded with a torque and forces according to Filipov [1] as pointed on Fig. 3 – the axes y and z are oriented as they are in the program Solid Works®.

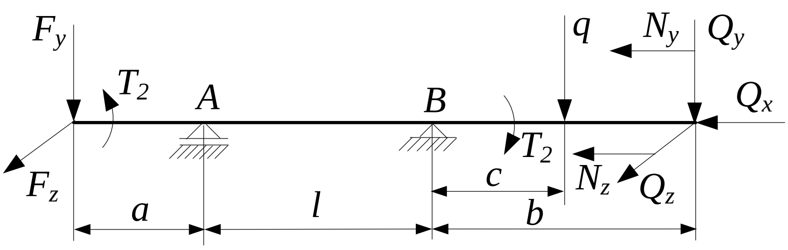

Figure 3: Scheme of loading

3. STATIC ANALYSIS

The static analysis of the cutting spindle 3D models is performed by the method of finite elements (FEM) with the CAE system Cosmos Works®, integrated with Solid Works® [4].

First, from the Cosmos Works® library „AISI 1035 Steel" is chosen with the following characteristics: tensile strength $585{,}0.10^{6}$ $N.m^{-2}$; yield strength $282{,}7.10^{6}$ $N.m^{-2}$; elastic modulus $2{,}04.10^{11}$ $N.m^{-2}$, shear modulus $8{,}0.10^{10}$ $N.m^{-2}$; Poisson's ratio 0,29. These characteristics are closest to the Bulgarian carbon steel brand 45 according BDS 2592:1971 usually used for production of cutting spindles.

The fixing of the spindle in the 3D model is set according to the loading scheme (Fig. 3): fixed, without translations – Fig. 4 and Fig. 5. The following loads according to the scheme of loads (Fig. 3) are set:

- *torque,* T_2=5,01 N.m;
- *forces, initiating at cutting process,* determined [1] from maximum moment force of one cutter P_{max}=684 N (for milling cutter with 160 mm diameter and two cutters) and the maximum radial cutting force R_{max}=684 N: Q_x = 997,82 N – axial force along x-axis, sum of the components P_x, R_x and the mass of spindle and assembled parts; Q_y = 324,02 N – radial force directed along y-axis, sum of the components P_y, R_y and the centrifugal force from unbalanced moving masses; Q_z = 610,53 N - radial force directed along z-axis, sum of the components P_z and R_z (b=73,5 mm); N_y = 171,2 N and N_z = 466,10 N – axial remote forces, received from the decomposition of forces P_x and R_x along the axes y and z and summation of corresponding components;
- *force, with which the gauge is clamped to the guide roller* – q = 616,82 N**,** radial force directed along the y-axis (c=50 mm);
- *stretching forces from belt gear:* F_y = 31,5 N – radial force directed along y-axis, which includes the centrifugal force from belt pulley unbalance because of fit inaccuracy; F_z = 469,69 N – radial force directed along z-axis (a=38 mm).

Specified forces and torque are shown on Fig.4 and Fig.5 in such a way as they are visualized by the program Cosmos Works®.

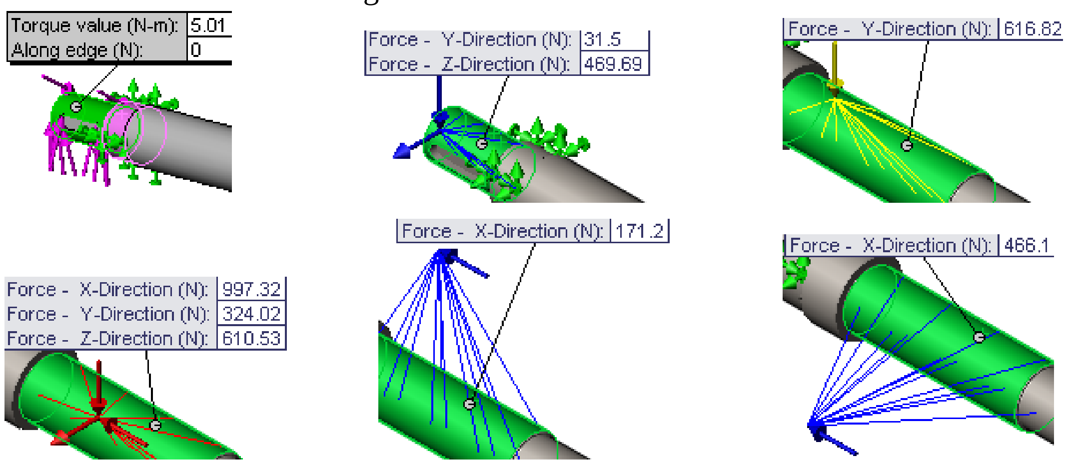

Figure 4: Load

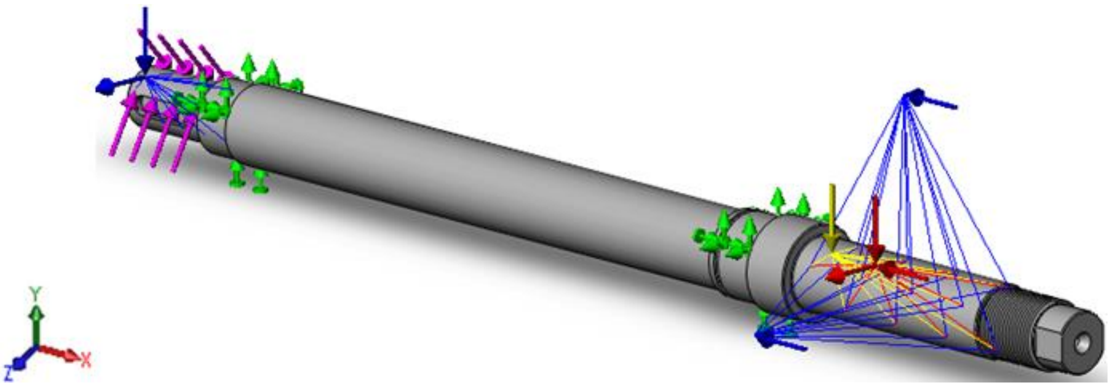

Figure 5: 3D model of cutting spindle, fixtures and load

The following characteristics of the finite elements mesh are set: type – standard; quality – high (every element has 10 nodes); kind of generation of the mesh – on smoth surface; number of iteration points for checking the level of tetrahedron elements twisting – 4. FFEPlus iteration method and „h“ adaptive method are used [4]. The created mesh for the model “264” has 30619 numbers of nodes and 19211 numbers of finite elements, for model „200“ – 29372 numbers of nodes and 18455 numbers of finite elements. The static analysis is carried out with recommended from the program finite element size – 7,19 mm for both models.

REZULTS AND DISCUSION

Some of the results from the static analysis are represented on Fig. 6 to Fig. 10 for model „264“ and for model „200“ respectively. The deformed shape of the spindle is depicted with coefficient 675 for both models.

The distribution of equivalent von Mises stresses in the spindle 3D models is represented on Fig. 6. The maximum value of $131,9.10^{6}$ $N.m^{-2}$ is received in node 4752 for model „264“ and $126,38.10^{6}$ $N.m^{-2}$ in node 10794 for model „200“. The both nodes are localized in the spindle shoulder with maximum diameter, near to the bearing shoulder “*B*” on the side of the cutter – Fig. 3 and Fig. 6.

The distribution of resultant displacements in the spindle 3D models is represented in Fig. 7. Maximum resultant displacement 0,06798 mm is received in node 751 for model „264“ и 0,0659 mm in node 766 for model ”200” in the end of the spindle to the cutter.

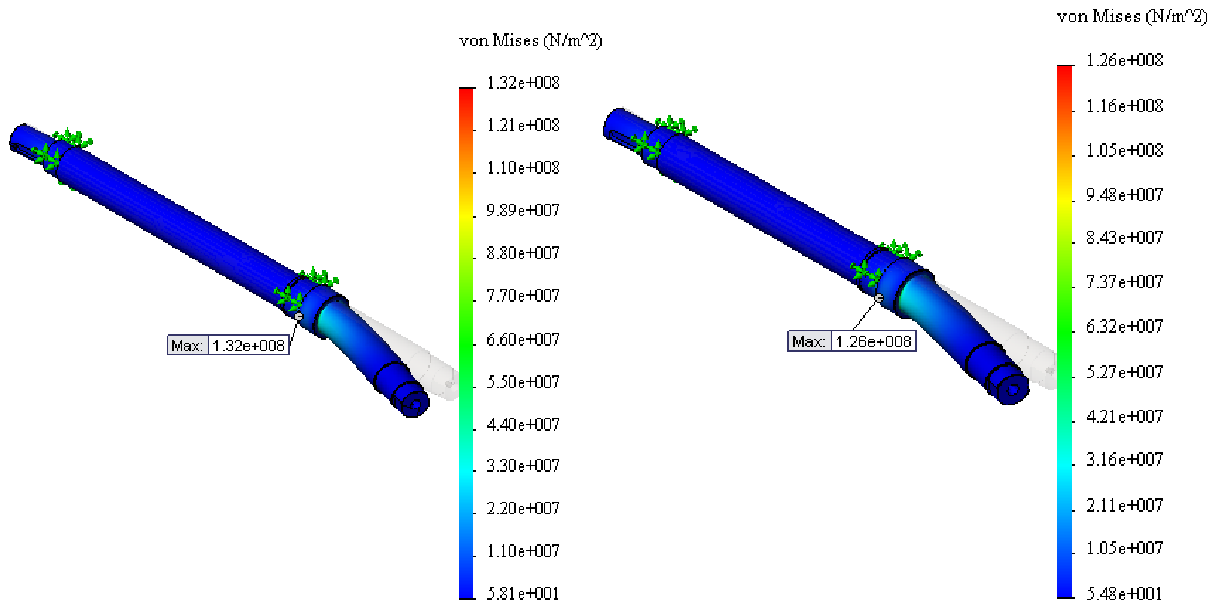

Figure 6: Distribution of von Mises stresses for model "264" and model "200"

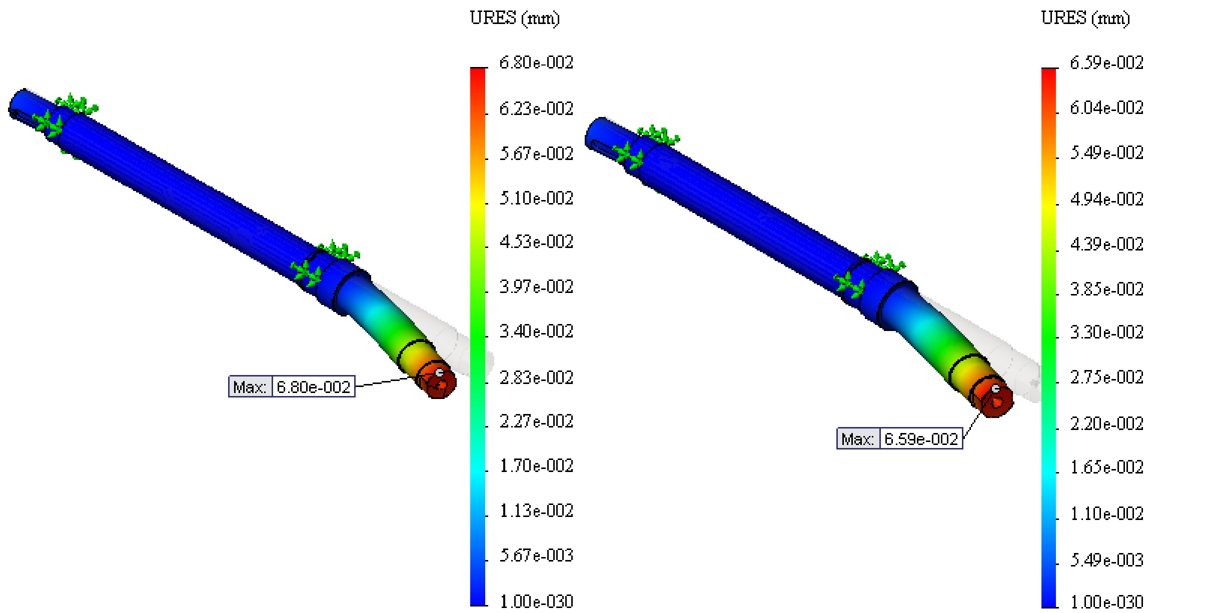

Figure 7: Distribution of resultant displacement for model "264" and model "200"

On the Fig. 8 the distribution of equivalent strains is represented. Maximum strain 0,00055 for model „264“ and 0,00053 for model „200“ is received in the nodes where the stresses are maximum – in the spindle shoulder with maximum diameter, near to the bearing shoulder "*B*" – Fig. 8.Strength verification for failure is carried out. The program calculates the factor of safety (FOS) by the maximum von Mises stress criterion by the following formula:

$$FOS = \frac{\sigma_{Limit}}{\sigma_{vonMises}} \succ 1$$

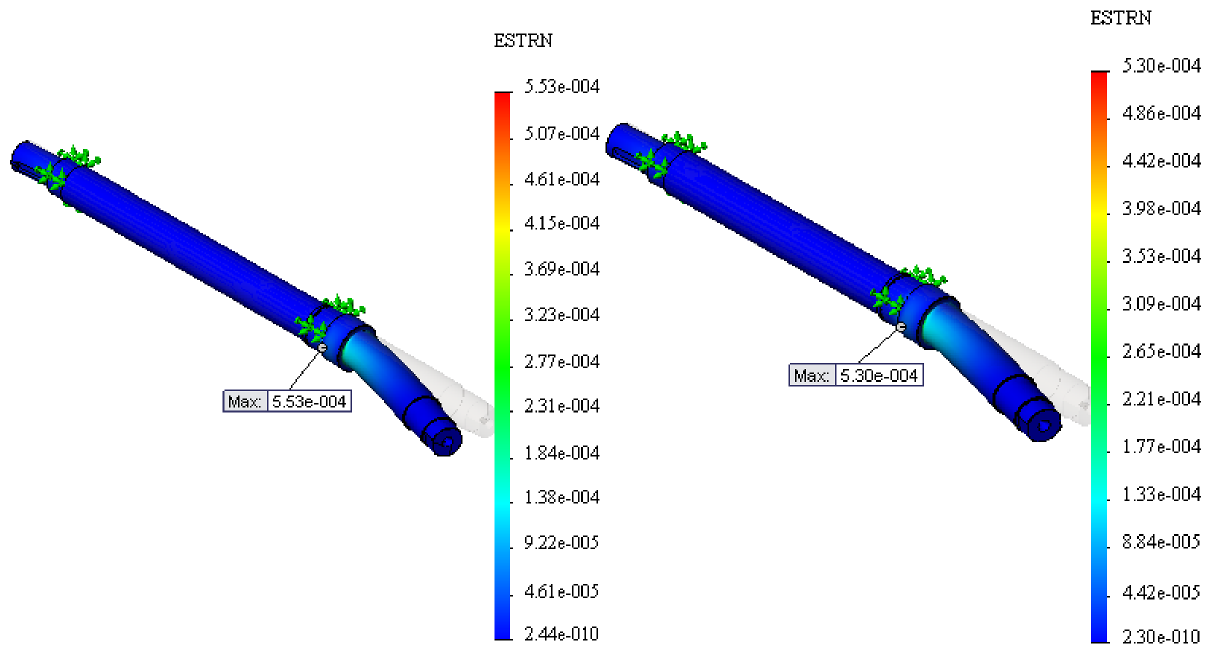

Figure 8: Distribution of equivalent strain for model "264" and model "200"

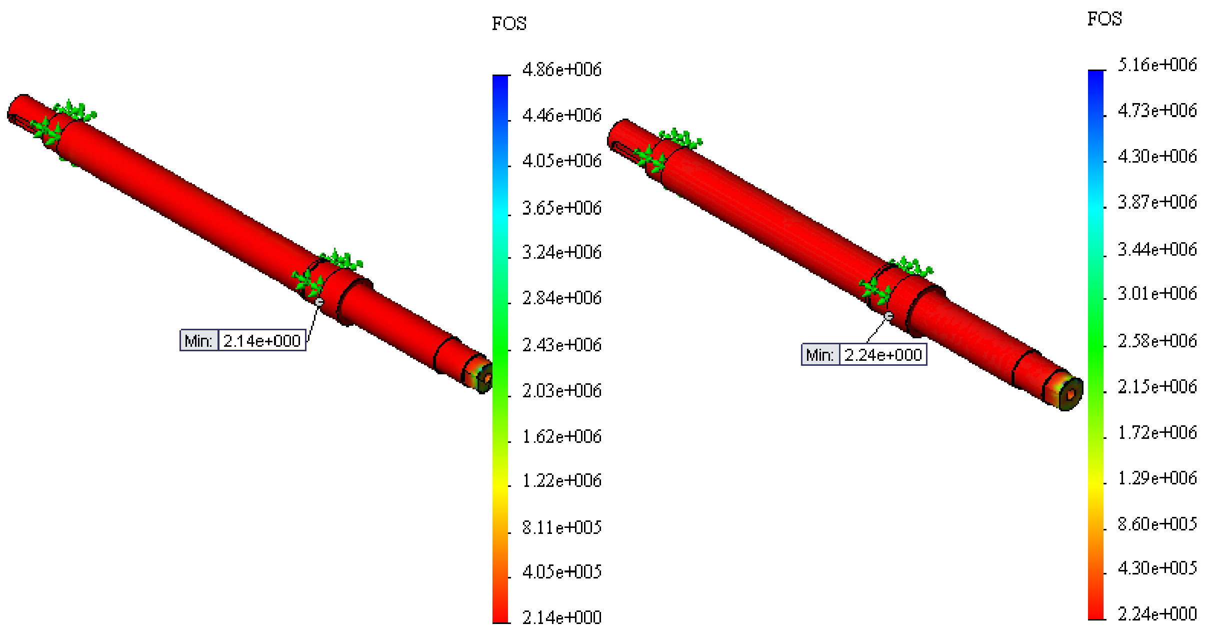

Figure 9: Distribution of factor of safety (FOS) for model "264" and model "200"

According this criterion a ductile material starts creeping in the places where von Mises stress reach to the stress Limit. As a stress Limit the yield strength is set. A minimum Factor of Safety 2,14 is received in node 4752 for model „264“ and 2,24 in node 10794 for model "200", localized to the bearing support "*B*" – Fig. 9. The factor of safety is not under the 1 for no one finite element, i.e. there is no danger of spindle failure in both cases.

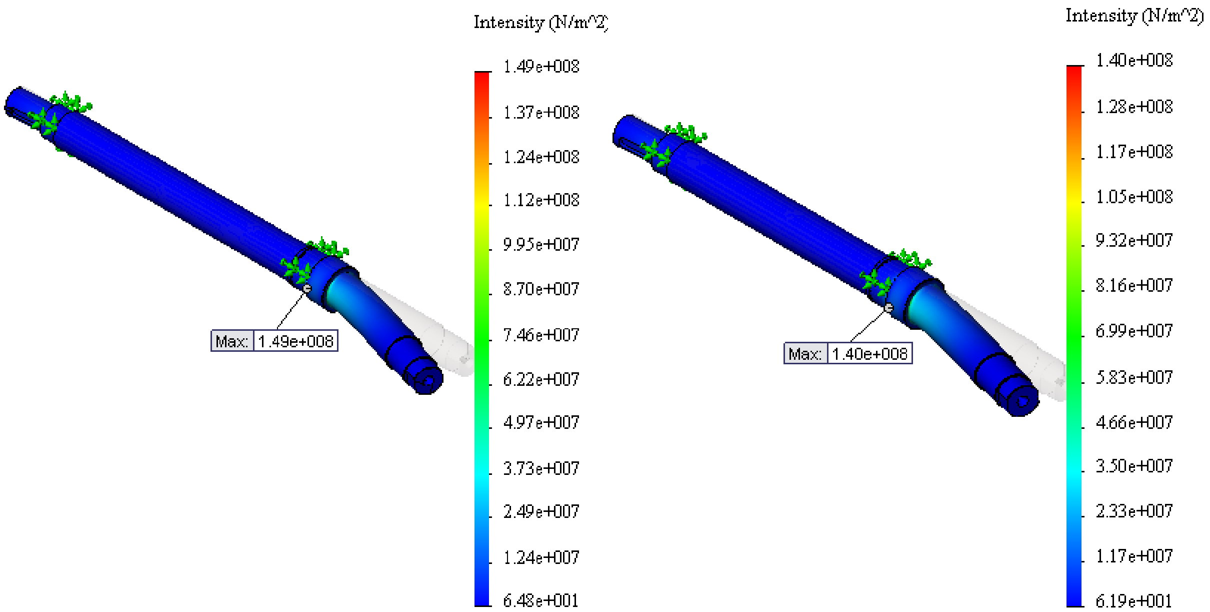

Figure 10: Distribution of stress intensity for model "264" and model "200"

The distribution of stress intensity (*P1 – P3*) for both models is represented on Fig.10. The maximum values of stress intensity are received in the nodes with maximum von Mises stresses: $149{,}2.10^6$ N.m^{-2} in node 4752 for model „264" and $139{,}8.10^6$ N.m^{-2} in node 10794 for model „200".

The maximum values of von Mises stresses, resultant displacements, equivalent strains and stress intensities (*P1 – P3*) and minimum values of the factors of safety for both models are given in Table 1.

Table 1: Rezults of static study

Parameter	Model "264"	Model "200"
Maximum stress von Mises, [N.m^{-2}]	$131{,}9.10^6$ node 4752	$126{,}3.10^6$ node 10794
Maximum resultant displacement, [mm]	0,0679 node 751	0,0659 node 766
Maximum equivalent strain	0,00055 node 4752	0,00053 node 10794
Minimum factor of safety (FOS)	2,14 node 4752	2,24 node 10794
Maximum stress intensity (*P1-P3*), [N.m^{-2}]	149.10^6 node 4752	$139{,}8.10^6$ node 10794

From the figures (Fig. 6 to Fig. 10) and Table 1 it is obviously that the maximum and minimum parameters values are smaller for model „200" than for model „264", i.e. for spindle with smaller support distance.

CONCLUSIONS

3D results of stresses, strains and displacements distribution in the cutting spindle 3D models with different inter-support distance are received by FEM. The nodes and elements in which these parameters have maximum values are localized. For both 3D cutting spindle models they are located near to the assembly point of the milling cutter. In these nodes the minimum factor of safety is received. The maximum resultant displacements are in the nodes localized in the end of the spindle from the cutter assembly point.

The static analysis results show that the maximum values of von Mises stress, strain and resultant displacement and minimum factor of safety are received for model with smaller inter-support distance (model „200"). Because of that a reduction of inter-support distance is recommended in the future construction of woodworking milling machines. This will give an opportunity to increase the vertical motion at spindle adjustment for construction of the cutting mechanism with lower spindle position.

The received factor of safety is not lower than 1 for no one node or element for both cutter spindle 3D models that shows no danger of spindle failure exists, i.e. the spindles are correctly calculated and will stand the setting loading.

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