ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering

Tome XII [2014] – Fascicule 4 [November]
ISSN: 1584-2673 [CD-Rom, online]

a free-access multidisciplinary publication
of the Faculty of Engineering Hunedoara

[1.] Nelly NIKOLOVA STANEVA, [2.] Vasil Vlasev VASILEV

FINITE ELEMENT ANALYSIS OF THE STRESS AND STRAIN DISTRIBUTION IN A MILLING WOODWORKING MACHINE SPINDLE

[1.] Faculty of Forest Industry, University of Forestry, Sofia, BULGARIA

Abstract: A finite element analysis of stresses and strain distribution in a milling spindle with two bearing supports from five-operating woodworking machine KP400 with lower position and console V-belt pulley is carried out with CAD/CAE system Autodesk Inventor Professional®. The milling spindle 3D model is generated with the modulus "Shaft Generator" of the program Autodesk Inventor® section by section with all elements of the real spindle – key-slot, grooves for clip ring, tread for fixing of the cutter, segments, chamfers, filets, etc. A static analysis of the spindle 3D model is performed with Autodesk Inventor Professional®. 1-st principal, 3-rd principal and Von Mises stresses, equivalent strains, resultant displacements and factor of safety distribution in the 3D spindle model are obtained and visualized. The maximum values of these parameters are localized near to the bearing support "A" on the side of the cutter fixture. In these places the minimum safety factor is received. The maximum resultant displacement is localized in the upper end of the spindle where the cutter is fixed. The finite element analysis results must be taken into account in designing of new machines.
Keywords: spindle, milling woodworking machine, static analysis, FEM, CAD

1. 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. The working shafts of the milling woodworking machines operate with high revolutions and in bad-case conditions, which induce different dynamics processes and their operation is getting more complicated. Because of that of especially importance is not only the proper calculations 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 by finite element method (FEM) of the operating woodworking cutting mechanisms are applied (Chaitanya and Kaladhar, 2013; Droba et al, 2013; Ioros et al, 2002; Gok et al, 2013; Marta and Corduta, 2010; Michna and Svoren, 2007; Staneva, 2012; Staneva and Vlasev, 2010; Staneva and Belberov, 2009). As it is known engineering FEM is a procedure for determining the deformation and/or stress field in a structural system. It is also established that finite element method (FEM) is the most frequent method applied in calculating and in predicting the stress and strain in solid bodies (Horman et al 2010). *The object of this study* is caring out of a finite element analysis (FEA) of static strength (stresses and strains) of a milling woodworking machine spindle with CAD/CAE system Autodesk Inventor Professional®.

2. METHODS

2.1. 3D MODELLING 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.

ISSN: 1584-2673 [CD-Rom, online]

The 3D model of the cutting spindle is created with the modulus “Shaft Generator” of the program Autodesk Inventor® section by section. For every section “Shaft Generator” gives opportunities for creation of all elements of the real spindle – key slot, tread for fixing of the cutter, grooves for clip ring, wrench, chamfers, filets, center holes in both ends, etc. The sequence of creation of the 3D geometrical model and the 3D model of the cutting spindle are shown on Figure 1.

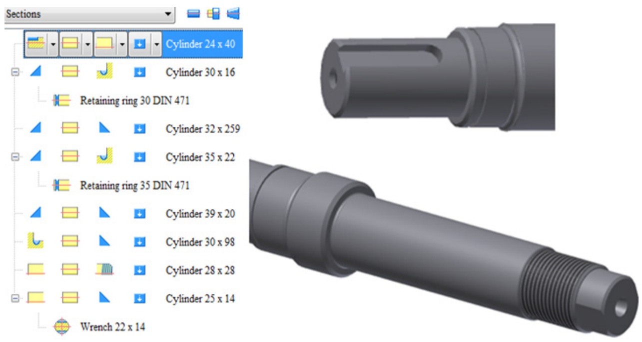

Figure 1. Sequence of creation of the cutting spindle 3D model

2.2. 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, 1979 as pointed on the scheme of loading (Fig. 2). The meaning of the variables on Figure 2 are given below in 2.3.

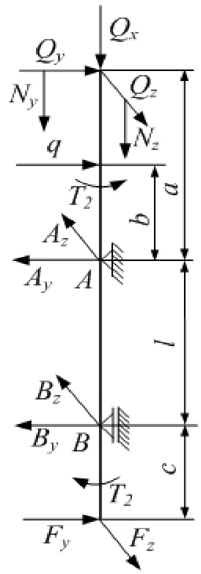

Figure 2. Scheme of loading of the cutting spindle

2.3. STATIC ANALYSIS

The static analysis of the cutting spindle 3D model is performed by the method of finite elements (FEM) with the CAD/CAE system Autodesk Inventor Professional®.

First, from the Inventor® library, the material “Carbon Steel” is chosen with the following characteristics: yield strength 350·10^{6} N·m^{-2}; ultimate tensile strength 420·10^{6} N·m^{-2}; elastic modulus 2.0·10^{11} N·m^{-2}, shear modulus 7.75·10^{10} N·m^{-2}; Poisson’s ratio 0.29; density 7870 kg·m^{-3}. 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 (Figure 2): fixed, without translations.

The following loads according to the scheme of loads (Figure 2) are set for the simulation:

- *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;

Figure 3. Loading of the spindle

- *force, with which the gauge is clamped to the guide roller:* q = 616.82 N, radial force directed along the y-axis (c=50.0 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 = 38.0 mm).

Specified forces and torque are shown on Figure 3 in such a way as they are visualized by the system Autodesk Inventor Professional®.

The following characteristics of the finite elements mesh are set: average element size 0.1; minimum element size 0.2; grading factor 1.5; maximum turn angle 60 deg; curved mesh elements; The created mesh for the model has 33067 numbers of nodes and 21499 numbers of finite elements. For the solver the following are set: maximum number of h refinements 3; stop criteria 10%; h refinements threshold 0.75.

3 REZULTS AND DISCUSION

Some of the results from the static analysis of the cutting spindle are represented on Figure 4 to Figure 9. In order to understand where deformation is occurring an exaggeration effect is provided with "Adjust Displacement Display" – Adjusted x 2 (Autodesk Inventor Professional® 2012, Online User's Guide & Help Files).

The distribution of equivalent Von Mises stresses in the cutting spindle 3D model is represented on Figure 4. The maximum value of $68.42{\cdot}10^6$ $N{\cdot}m^{-2}$ is received and localized in the spindle shoulder with maximum diameter, near to the bearing shoulder "*A*" on the side of the cutter. In the same place the maximum of the 1-st principal stress 67. $42{\cdot}10^6$ $N{\cdot}m^{-2}$ is received (Figure 5).

On Figure 6 the distribution of equivalent strains is represented. Maximum strain $3.14{\cdot}10^{-4}$ is received in the same places where the stresses are maximal – in the spindle shoulder with maximum diameter, near to the bearing shoulder "*A*" (Figure 2 and Figure 6).

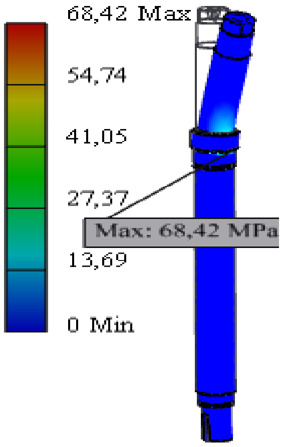

Figure 4. Distribution of the Von Mises stresses

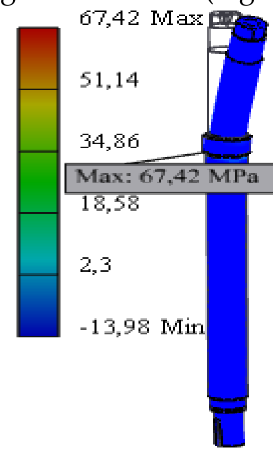

Figure 5. Distribution of the 1-st principle stresses

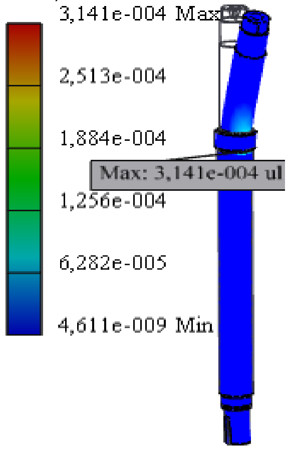

Figure 6. Distribution of equivalent strain

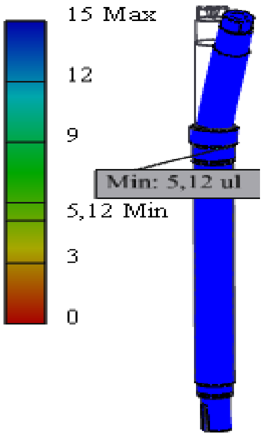

Figure 7. Distribution of factor of safety

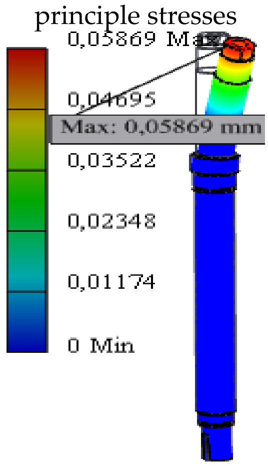

Figure 8. Distribution of resultant displacement

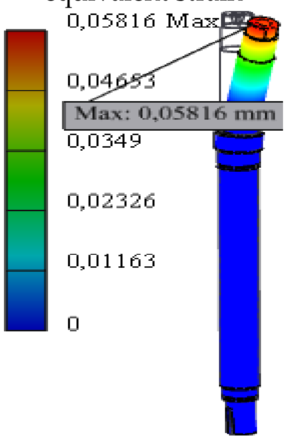

Figure 9. Distribution of *Z*-displacement

A strength control for spindle failure was carried out. The program calculates the factor of safety as the ratio of the maximum allowable stress to the maximum von-Mises stress when using Yield Strength as a Yield Limit. The distribution of Safety Factor is shown on Figure 7. A minimum Safety Factor of 5.12 is received localized to the bearing support "*A*" (Figure 2). The factor of safety is not under the 1 for no one finite element, i.e. there is no danger of spindle failure. The distribution of resultant displacements in the spindle 3D models is shown on Figure 8. Maximum resultant displacement 0.05869 mm is received in the upper end of the spindle where the cutter will be fixed.

The distribution of *Z*-displacement is shown on Figure 9 – the maximum *Z*-displacement is 0.0902 mm and is received in the upper end of the cutting spindle. The values of stresses and strains according to 3rd Principal and in the different planes *XX*, *XY*, *XZ*, *YY*, *YZ* and *ZZ* of 3D spindle model are calculated. The obtained maximal values of these parameters are shown in Table 1.

Table 1. Values of the maximum stresses and strains

Name	Max. Stress, $\cdot 10^{-6}$ N·m^{-2}	Max. Strain, $\cdot 10^{4}$
3rd Principal	9.769	0.016827
XX	63.478	2.73
XY	11.438	0.7377
XZ	28.923	1.8655
YY	20.967	0.7457
YZ	8.214	0.5298
ZZ	22.584	1.1437

CONCLUSIONS

3D results of von Misses stresses, 1-st principal stresses and equivalent strains distribution in the 3D model of a cutting spindle with two bearing supports from a 5-operating aggregate woodworking machine with lower spindle position and console pulley are received by FEM.

The maximum values of these parameters: $68.42\cdot10^{6}$ N·m^{-2} for von Misses stresses, 67. $42\cdot10^{6}$ N·m^{-2} for 1-st principal stresses and $3.14\cdot10^{-4}$ for equivalent strains are localized near to the bearing support "*A*" on the side of the cutter. In this place the minimum factor of safety 5.12 is received. The maximum resultant displacement of 0.05869 mm is localized in the upper end of the spindle where the cutter is fixed.

A strength control for spindle failure was carried out - the received factor of safety is not lower than 1.0 for no one node that shows no danger of spindle failure exists, i.e. the spindle is correctly dimensioned and will stand the setting loading.

The static analysis results must be taken into account in designing of new machines.

ACKNOWLEDGMENTS

This document was supported by the grant No BG051PO001-3.3.06-0056, financed by the Human Resources Development Operational Programme (2007 – 2013) and co-financed jointly by the European Social Fund of the European Union and the Bulgarian Ministry of Education and Science. The author thanks for a financial support to deal with the project.

REFERENCES

[1] Autodesk Inventor Professional®, Online User's Guide & Help Files, 2012.
[2] Chaitanya, K.; Kaladhar, M.: Design and analysis special shaped milling cutter using FEA, Int. J. of Modern Engineering Research (IJMER), 3 (6), 3716-3722, 2013.
[3] Filipov, G.: Machines for furniture production, Sofia, Technika, 1979. (in Bulgarian)
[4] Droba, A.; Pauliny, D., Svoren, J.: Comparison of theoretical and Experimental values of natural frequencies of circular saw blade, Acta Facultaties Technical, XVIII (1) 39-46, 2013. (in Slovak)
[5] Ioros, H.; Nicholls, T., Perkins, M., Munz, U., Larmann, A.: A review for cutting forces and stresses in circular saws, Holz als Roh- und Werkstoff, 60 (1), 55-59, 2002. http://dx.doi.org/ 10.1007/ s001070100220.
[6] Gok, K.; Turkes, E., Neseli, S., Kisiouglu, Ya.: Failure analysis of support during profile cutting process using horizontal milling machine, Int. J. Adv. Manuf. Technol., 70 (5-8), 1169-1179, 2013. http://dxdoi.org/10.1007/s00170-013-5356-4.
[7] Horman, I.; Hajdarevic, S., Martinivic, S., Vukas, N.: Numerical Analysis of Stress and Strain in a wooden chair, Drvna Industria, 61 (3, 151-158, 2010.
[8] Marta, L.; Corduta, L.: Concerning about the computer simulation and modeling in FEM the HSMCNC woodworking machine spindle, Analele Universitatii din Oradea, Fascicula, Protectia Mediului, XV, 469-476, 2010.
[9] Michna S.; Svoren, J.: Application of CAD/CAE with FEM for estimation ranges of values of critical rotational speed of circular saw blades, Acta Facultaties Technical, 9 (1), 201-206, 2007. (in Slovak)
[10] Staneva, N.: Fatigue study of a circular saw shaft with CosmosWorks®, Innovations in Woodworking Industry and Engineering Design, 1 (1), 99-106, 2012.
[11] Staneva, N., Vlasev, V.: Accelerated modeling of circular shaft in CAD environment, International J. of Engineering, VIII (3), 21-23, 2010. http://annals.fih.upt.ro/ANNALS-2010-3.html
[12] Staneva, N., Belberov, M.: Analysis of stressed and strained state of circular saw shaft with Cosmos Works®, Woodworking and Furniture Production, 1, 31-36, 2009. (in Bulgarian)