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MODELLING OF THE INFLUENCE OF WEARING OF SAW UNIT ELEMENTS OF A WOOD SHAPER ON ITS VIBRATIONS

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ABSTRACT

Mechanic - mathematical model of the saw unit of the wood shapers developed by the authors is presented in the paper. This model is designed for studying the influence of wearing and change of parameters of saw unit elements on the accuracy and quality of the production. Wearing and changes of elastic and damping parameters of a belt drive are the first factors analysed and accounted in the model. A variable torsional moment of an electric motor formed by inevitable deviation from correct stator shape and rotor imbalance is the second considered factor. The third factor taken into account is a variable torsional moment of a cutting tool of a wood shaper. These three factors affect machine torsional vibrations and its precise work directly. The mechanic - mathematical model developed by the authors allows numerical investigation of free and forced torsional vibrations of a saw mechanism in this type of machines. The conclusions based on the numerical investigations are confirmed by the examinations of a machine in real conditions. The results of the investigation can be applied in specific well-founded recommendations concerning the operation of the machines. The recommendations are important to increase the accuracy and quality of wood shaper production.

Key words: wood shapers, modelling, torsional vibrations.

INTRODUCTION

Wearing and change of parameters of cutting mechanism elements are one of the main reasons for the impaired accuracy and quality of the production of the wood shapers. The belt drive that is included in this mechanism is its most vulnerable part and often leads to problems (WITTENBURG 1977). The faults of the electric motor, resulting from the inevitable deviation from the correct stator shape and rotor imbalance, are another problem in practice (STEVENS 2007). Intense torsional vibrations are formed as a result of wearing and change of parameters of cutting mechanism elements. A variable load from a cutting tool of a wood shaper has a significant impact on characteristics of torsional vibrations (BARCÍK *et al*. 2011, BELJO *et al*. 2001, GENCHEV, OBRESHKOV 1998, GRIGOROV 1985).

Principally, the investigation of the causes for origin and increasing torsional vibration of wood shapers requires understanding the essence of dynamic processes in them when the machine works (COUTINHO 2001, KMINIAK *et al*. 2016). It is necessary to conduct purposeful studies in which the machine can be considered a mechanical vibrating system with known characteristics of its individual elements (AMIROUCHE 2006, ORLOWSKI 2007). For this purpose, firstly, it is necessary to have mechanic-mathematical modelling and composing the equations describing the vibration of the elements of the wood shaper. Well-targeted research can be carried out by solving these equations in different conditions. It leads to some recommendations for the construction's design and the work regimes of the machine.(Dzurenda *et al*. 2015, Shabana 2013).

The types of wood shapers that are commonly used in practice in the forest industry (Filipov 1977) are examined in the proposed study. Fig. 1 shows the general view, and Fig. 2 – scheme of this type of wood shapers (Obreshkov 1997). A machine body is marked with *1*, *2* is an electric motor, *3* – a belt drive, *4* – a spindle with bearings, *5* –spindle bearings, *6* – wood shaper saw.

Fig. 1 Wood shaper – general view.

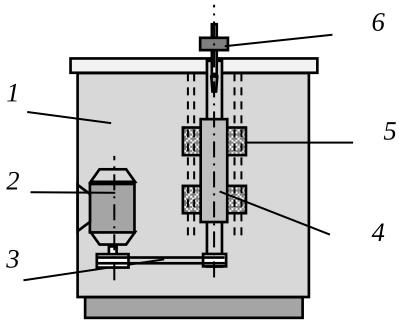

Fig. 2 Scheme of the wood shaper.

Next figures show components of a wood shaper saw unit that is a subject of this study. Fig. 3 shows an electric motor with a pulley, attached to its shaft, and Fig. 4 – a spindle and its bearings. Fig. 5 shows a cutter.

Fig. 3 Electric motor with a pulley.

Fig. 4 Spindle and its bearings.

Fig. 5 Cutter.

Some special features in the modelling of the woodworking machines are examined in the previous papers of the authors (Vukov e*t al.* 2016).

The aim of this study is to develop an adequate mechanic - mathematical model of a cutting mechanism of wood shapers to study torsional vibrations. The model is designed to investigate the influence of wearing and changes in parameters of elements of this mechanism on the accuracy and quality of the machine production. This aim requires studying the effect of the wearing of each element on the forming the torsional vibrations in this mechanism. The model renders an account features in construction of a kind of wood shapers with lower spindle.

MATERIAL AND METHODS

A mechanic-mathematical model for investigation of dynamical processes and vibrations in a wood shaper saw unit is built by the authors. The model is shown in Fig. 6. This model includes four discrete mass connected with three massless elastic elements. φ_i, $i = 1, 2, 3, 4$, are angles of a rotation of the corresponding rotor. Elasticity coefficients of the electric motor shaft, the belt and the spindle are taken into account. Elasticity angular coefficient of the electric motor shaft is marked with c_1, and this one of the spindle – with c_3 (*N.m/rad*). Elasticity linear coefficients of the two parts of the belt between the belt puller are c_{23} and c_{32} (*N/m*). Damping coefficients are marked with b and respective indices. The applied moments M_i on disks are shown, too.

The necessary reduced mass inertia moments ($kg{\cdot}m^2$) are rendered an account (Fig. 6): They are J_1 – the mass inertia moment of the electric motor's rotor; J_2 – the mass inertia moment of the belt puller on the electric motor's shaft; J_3 – the mass inertia moment of the belt puller on the spindle; J_4 – the mass inertia moment of the wood shaper saw with cutter arbor.

Some other symbols in Fig. 3 are: d_1, d_3 – diameters of the electric motor shaft and spindle (m); l_1, l_3 – computing length of the electric motor shaft and spindle (m); r_2, r_3 – radius of the belt pullers on the electric motor shaft and spindle (m); G – modulus of shearing.

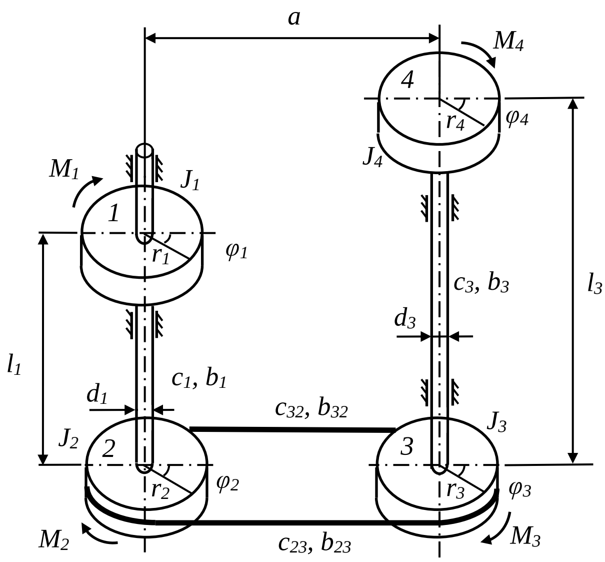

Fig. 6 Mechanic-mathematical model.

The investigation of the torsional vibrations of the wood shaper saw unit requires formulation and solution of the differential equations describing these processes. The Lagrange's method is used combined with the priority of the matrix mechanics (ANGELOV, SLAVOV 2010). This method supposes receiving a system of parametric linear differential equations which describe the small forced torsional vibrations of the saw unit. They are

$$\mathrm{M}.\ddot{q} + \mathrm{B}.\dot{q} + C.q = Q \quad , \tag{1}$$

where $\mathbf{q}$ is the vector of the generalized coordinates, $\mathbf{q} = [\varphi_1 \quad \varphi_2 \quad \varphi_3 \quad \varphi_4]^T$;

$\mathbf{Q} = [M_1 \quad -M_2 \quad -M_3 \quad -M_4]^T$ – the vector of the generalized loads includes all torsional moments, applied to the rotors;

M, **B**, **C** are the matrix, which characterizes the mass-inertial properties of the mechanical system, the damping properties and the elastic properties

$$\mathbf{M} = [a_{ij}], \quad a_{ij} = \frac{\partial^2 \mathrm{E_K}}{\partial \dot{q}_i . \partial \dot{q}_j}, \quad \mathbf{M} = \begin{bmatrix} J_1 & 0 & 0 & 0 \\ 0 & J_2 & 0 & 0 \\ 0 & 0 & J_3 & 0 \\ 0 & 0 & 0 & J_4 \end{bmatrix} \tag{2}$$

$$\mathbf{B} = [b_{ij}], \quad b_{ij} = \frac{\partial^2 F}{\partial \dot{q}_i . \partial \dot{q}_j}, \quad \mathbf{B} = \begin{bmatrix} b_1 & -b_1 & 0 & 0 \\ -b_1 & b_1 + b_{23}.r_2^2 + b_{32}.r_2^2 & -b_{23}.r_2.r_3 - b_{32}.r_2.r_3 & 0 \\ 0 & -b_{23}.r_2.r_3 - b_{32}.r_2.r_3 & b_3 + b_{23}.r_3^2 + b_{32}.r_3^2 & -b_3 \\ 0 & 0 & -b_3 & b_3 \end{bmatrix} \tag{3}$$

$$\mathbf{C} = [c_{ij}], \quad c_{ij} = \frac{\partial^2 E_p}{\partial \dot{q}_i . \partial \dot{q}_j}, \quad \mathbf{C} = \begin{bmatrix} c_1 & -c_1 & 0 & 0 \\ -c_1 & c_1 + c_{23}.r_2^2 + c_{32}.r_2^2 & -c_{23}.r_2.r_3 - c_{32}.r_2.r_3 & 0 \\ 0 & -c_{23}.r_2.r_3 - c_{32}.r_2.r_3 & c_3 + c_{23}.r_3^2 + c_{32}.r_3^2 & -c_3 \\ 0 & 0 & -c_3 & c_3 \end{bmatrix} \tag{4}$$

where E_K и E_P are the kinetic energy and the potential energy of the mechanical system, F is the dissipative function.

The general solutions of the system of differential equations (1) in the harmonious appearance of disturbing forces and initial conditions $t = 0$, $q(0) = q_0$, $\dot{q}(0) = \dot{q}_0$, written in matrix form, are

$$\begin{aligned} q(t) = & \sum_{r=1}^{4} \frac{2}{g_r^2 + h_r^2} \left[\boldsymbol{G}_r \boldsymbol{M}_{\dot{q}}(0) + (-a_r \boldsymbol{G}_r \boldsymbol{M} + \beta_r \boldsymbol{H}_r \boldsymbol{M} + \boldsymbol{G}_r \boldsymbol{B}) q(0) \right] . e^{-a_r t} . \cos\beta_r t + \\ & + \sum_{r=1}^{4} \frac{2}{g_r^2 + h_r^2} [\boldsymbol{H}_r . \boldsymbol{M} . \dot{q}(0) + (-a_r \boldsymbol{H}_r \boldsymbol{M} - \beta_r \boldsymbol{G}_r \boldsymbol{M} + \boldsymbol{H}_r \boldsymbol{B}) q(0)] . e^{-a_r t} . \sin\beta_r t + \\ & + \mathrm{Re} \left\{ \sum_{k=0}^{n} \sum_{r=1}^{4} \frac{2}{g_r^2 + h_r^2} \frac{a_r . \boldsymbol{G}_r + \beta_r . \boldsymbol{H}_r + i.k.\Omega.\boldsymbol{G}_r}{\omega_r^2 - k^2.\Omega^2 + i.2.k.\sigma_r.\omega_r.\Omega} \boldsymbol{Q} . e^{ik\Omega t} \right\} \end{aligned} \tag{5}$$

where:

$$g_r = -2\alpha_r \left(\mathbf{V}_r^T . \mathbf{M} . \mathbf{V}_r - \mathbf{W}_r^T . \mathbf{M} . \mathbf{W}_r \right) - 4\beta_r \mathbf{V}_r^T . \mathbf{M} . \mathbf{W}_r + \mathbf{V}_r^T . \mathbf{B} . \mathbf{V}_r - \mathbf{W}_r^T . \mathbf{B} . \mathbf{W}_r ;$$

$$h_r = 2\beta_r \left(\mathbf{V}_r^T . \mathbf{M} . \mathbf{V}_r - \mathbf{W}_r^T . \mathbf{M} . \mathbf{W}_r \right) - 4\alpha_r \mathbf{V}_r^T . \mathbf{M} . \mathbf{W}_r + 2\mathbf{V}_r^T . \mathbf{B} . \mathbf{W}_r ;$$

$$\mathbf{G}_r = g_r \mathbf{L}_r + h_r \mathbf{R}_r ; \quad \mathbf{L}_r = \mathbf{V}_r . \mathbf{V}_r^T - \mathbf{W}_r . \mathbf{W}_r^T ;$$

$$\mathbf{H}_r = h_r \mathbf{L}_r - g_r \mathbf{R}_r ; \quad \mathbf{R}_r = \mathbf{V}_r . \mathbf{W}_r^T + \mathbf{W}_r . \mathbf{V}_r^T .$$

V is the modal matrix; W – the matrix of the imaginary part of the natural vectors of the damping system; $p_r = -\alpha_r \pm i\beta_r$ – natural values; $u_r = v_r \pm i w_r$ – natural vectors; σ_r – relative damping coefficient; α_r – damping coefficient; β_r – frequency of free damping vibration; $\alpha_r = \sigma_r . \omega_r$; $\beta_r = \omega_r \sqrt{1 - \sigma_r^2}$; w_r – the imaginary part of the natural vector caused by dampening system; v_r , ω_r – natural modes and natural frequencies of the non damping system.

RESULTS AND DISCUSSION

The developed mechanical – mathematical model allows conducting number of studies of the torsional vibrations in the saw unit of the wood shapers with lower spindle. The vibration behaviour of the mechanism, when the belt drive and the drive motor are worn and their parameters are changed, is investigated in this study. The variable moments on the cutting tool also are taken into account in this study. The wearing of the belt drive results in a change in its elastic and damping parameters. It means that the matrix of the damping properties (3) and the elastic properties (4) are changed. The unavoidable deviation of the correct shape of the stator and the unbalance of the rotor lead to the occurrence of a variable torsional moment on the electric motor. This moment is modelled as to its constant part M_1 are added two components that have the type $M_{11} \sin \omega_1 t$ and $M_{12} \sin 2\omega_1 t$

$$M_1^I = M_1 + M_{11} \sin \omega_1 t + M_{12} \sin 2\omega_1 t, \tag{6}$$

where :ω_1 is the frequency of the rotor rotation;
M_{11} and M_{12} are the amplitudes of the two components

A variable moment of the cutter tool is introduced in order to model the real operating conditions. The variable moment of the wood shaper cutter tool with six blades (Fig. 5) is modelled as to the concentrated saw moment M_4 is added a variable component M_{4P}. This component has the type $M_{4P} = M_P \sin 6\omega_4 t$

$$M_4^I = M_4 + M_{4P} = M_4 + M_P \sin 6\omega_4 t, \tag{7}$$

where ω_4 is the frequency of rotation of the wood shaper saw;
M_P – the amplitude of this variable component).

Some numerical investigations are carried out using the presented model and modern engineering software. The data of the universal wood shaper with the lower position of the spindle model FD-3, manufactured in the ZMM - Plovdiv, is used. The numerical investigations are conducted for two different work regimes of the mechanism. The saw mechanism which is at the beginning of its operation is modelled in the first investigation. The belt drive has a new belt and belt pulleys and all the components are in good condition. A cutting mechanism, which has passed a significant part of its exploitation resource but is still in serviceability, is modelled in the second investigation. It is assumed that the belt drive has elastic and damping parameters which are degraded by continuous, but not beyond the permissible work. This leads to a change in the respective coefficients of the elasticity and damping. The results, obtained from the numerical studies, will be presented in the next part of the paper because of the limited volume. The results of the conducted experiments in real conditions will be also presented in the next part of the paper.

CONCLUSIONS

An original mechanic - mathematical model of the saw unit of the wood shapers is presented in this study. This model is elaborated by the authors. The model is designed to study the influence of wearing and change of the parameters of the saw unit elements on the accuracy and quality of the production. The wearing and the changes of the elastic and damping parameters of the belt drive are the first factor, which is analyzed and accounted in this model. The variable torsional moment of the electric motor, which is formed by the inevitable deviation from the correct stator shape and the rotor imbalance, is the second considered factor. The third factor to be taken into account is the variable torsional moment of the cutting tool of the wood shaper. These three factors directly affect the machine's torsional vibrations. These vibrations affect the machine's work accuracy. The mechanic - mathematical model developed by the authors allows various numerical investigations of the torsional vibrations of the saw mechanism of this type of machines. The main features in the construction and the manner of work of the wood shapers are rendered an account in the presented model. The obtained and considered results of the whole investigation are applicable to formulate some specific well-founded recommendations concerning the operation of the machines. The accuracy and quality wood shaper production may increase on the base of these recommendations. The obtained results of this research are useful also for technical diagnostics (in particular for vibro-diagnostics) of the wood shapers.

REFERENCES

AMIROUCHE F. 2006. Fundamentals of Multibody Dynamics – Theory and Applications. Birkhäuser. Boston. 683 pp. ISBN 978-0-8176-4236-5.

ANGELOV I., V. SLAVOV 2010. Book of problems. Matrix mechanics – Dynamics. Sofia : Avangard Prima, 2010. 214 pp. ISBN 978-954-323-749-7.

BARCÍK Š., M. KVIETKOVÁ, P. ALÁČ 2011. Effect of the chosen parameters on deflection angle between cutting sides during the cutiing of aglomerated materials by water jet. Wood Research, 56(4): 577–588.

BELJO-LUČIĆ R., V. Goglia 2001. Some possibilities for reducing circular saw idling noise. Journal of Wood Science, 47(5): 389–393

COUTINHO M. 2001. Dynamic Simulations of Multibody Systems. New-York : Springer-Verlag. 375 pp. ISBN 978-1-4419-2902-0.

DZURENDA L., J. LADOMERSKÝ, E. HRONCOVÁ 2015. Conversion factor of fuel-bound nitrogen to oxides in the process of spruce wood combustion in boiler grate furnaces. Pol. J. Environ. Stud. 24(2): 505–509.

FILIPOV G. 1977. Woodworking machines. Technics. Sofia. 1977. (in Bulgarian)

GENCHEV, G., P. OBRESHKOV 1998. Design and examine of woodworking machines. Sofia. 1998. 226 pp. ISBN 954-8563-14-2. (in Bulgarian)

GRIGOROV, P. 1985. Cutting of wood. Sofia : Technics., 1985. 365 pp. (in Bulgarian)

KMINIAK R., M. SIKLIENKA, J. ŠUSTEK 2016. Impact of tool wear on the quality of the surface in routing of MDF boards by milling machines with reversible blades. Acta Facultatis Xylologiae Zvolen, 58(2): 89−100.

OBRESHKOV P. 1997. Woodworking machines. Sofia, 1997. 182 pp. ISBN 954-8563-11-8. (in Bulgarian)

ORLOWSKI K., J. SANDAK, C. TANAKA 2007. The critical rotational speed of circular saw: simple measurement method and its practical implementations. Journal of Wood Science, 53(5): 388–393.

SHABANA A. 2013. Dynamics of Multibody Systems. New York. Cambridge University Press. 380 pp. ISBN 981-1-107-04265-0.

STEVENS D. 2007. Machinery Vibration Diagnostics. http://www.vibanalysis.co.uk/.

VUKOV G., ZH. GOCHEV, V. SLAVOV 2012. Torsional Vibrations in the Saw Unit of a Kind of Circular Saws. Numerical Investigations of the Natural Frequencies and Mode Shapes. Proceedings of Papers, 8th International Science Conference "Chip and Chipless Woodworking Processes". Zvolen. 2012. pp. 371–378.

VUKOV G. Y. 2008. Torsional Vibrations of the Driving Mechanism of a Carved Veneer Machine. Amplitude-Frequency Spectrum. Mechanics of machines 3 (75). Varna, 2008, pp. 13–16.

VUKOV G., ZH. GOCHEV, V. SLAVOV, P. VICHEV, V. ATANASOV 2016. Mechanic-Mathematical Model for Investigations of the Natural Frequencies and Mode Shapes of the Free Spatial Vibrations of Wood Shaper and its Spindle. Proceedings of the 10th International Science Conference „Chip and Chipless Woodworking Processes". Slovakia. Technical University in Zvolen. 10(1). 2016. pp. 203–209.

VUKOV G., ZH. GOCHEV, V. SLAVOV, P. VICHEV, V. ATANASOV 2016. Numerical Investigations of the Natural Frequencies and Mode Shapes of the Free Spatial Vibrations of Wood Shaper and its Spindle. Proceedings of the 10th International Science Conference „Chip and Chipless Woodworking Processes”. Slovakia. Technical University in Zvolen. 10(1). 2016. pp. 211–216.

VUKOV G., ZH. GOCHEV, V. SLAVOV 2016. Mechanic-Mathematical Model for Investigations of the Free Damped Spatial Vibrations of Wood Shaper and its Spindle. Proceedings of the IInd International Furniture Congress. Mugla. Turkey. October 13th–15th. 2016. pp. 216–219.

VUKOV G., ZH. GOCHEV, V. SLAVOV 2016. Numerical Investigations of the Free Damped Spatial Vibrations of Wood Shaper and its Spindle. Proceedings of the IInd International Furniture Congress. Mugla. Turkey. October 13th–15th. 2016. pp. 220–224.

WITTENBURG J. 1977. Dynamics of Systems of Rigid Bodies. Stuttgard : B.G. Teubner. 223 pp. ISBN 978-3-322-90943-5.

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