

# *Influence of end woodcutters design on the vibration level and surface roughness*

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**Abstract**— Wide application of processing multiaxes numerically controlled centres at machine-building enterprises with blank production necessitate the use of new effective milling tools constructions. The purpose of our work was to investigate the influence of the end woodcutting tools at numerically controlled lathes on the vibration degree and surface roughness. Cutting edge inclination  $\omega$ , teeth number  $z$ , circular pitch inequality, chip holding grooves at the tool edges were the variable constructional parameters. During the experiment cutting tools of the same size and type with different constructional elements were used. The experimental installation and data processing techniques have been described. During vibration analysis with Brüel and Kier apparatus average narrow range of mean square values in vibration accelerations was used. Experiment plans and processing procedure of vibroacoustic signals are represented. Linear regressive models based on experimental data allowed estimating the influence of these constructional parameters on processing vibration and surface roughness. There is a steady relation between the vibration level and surface roughness. Such parameters as cutting edge inclination, teeth number, chip holding grooves at the tool edges lessen the processing vibration and enhance the surface quality. Circular pitch inequality influence on these parameters is ambiguous. The authors think that it is necessary to determine spheres of utilization for different cutting tools depending on the timber species, wood materials, and regime parameters.

**Keywords**— *end wood-cutting tool, vibrations, vibroacoustic parameters, surface roughness, cutting edge inclination, teeth number, chip holding grooves at the tool edges*

## I. INTRODUCTION

Nowadays wood processing enterprises are equipped with numerically controlled processing centers. Multifunctional 3-5-axial numerically controlled centers with accurate position control systems, high-speed spindles, multi-seat systems for workpieces provide production flexibility and accuracy increase. Large machine-building enterprises with blank production are not an exception. For example, in large dimensional casting with loam molds, wood is the main material for pattern-core equipment. The cutting-tools stock list produced by such companies as Felisatti (Italy), Makita (Japan), Tideway (China) and others is rather wide. Cutting tools for numerically controlled lathes have more constructional peculiarities: big inclination angles of spiral

leads, ends, chip holding grooves at the tool edges, different teeth number, shaped profile. It is known that milling forces are time-variable [1, 2], that results in technological system vibration and has bad impact on the processed surface quality, tools durability, processing accuracy [3, 4, 5]. Although, modern numerically controlled systems have soft-hardware to control milling processes, comprehensive facilities for profiling curvilinear trajectories [6, 7], the issue of the wood-cutting tool rational design which will level down the processing vibration is still not sufficiently studied.

Milling is material processing with rotating cutters when the over-dimension is cut off in the form of chips [8]. Number of processing technological factors determine milling conditions and influence its efficiency parameters, such as processing accuracy, surface quality, energy consumption, tool durability [9, 3, 4]. Any modern technological machine is considered as a system of interconnected elements – “lathe-device-tool-workpiece”. Cyclic cutting forces acting on the technological system elements cause time-varying vibratory displacement “LDTW” system components. Analysis of works on tools dynamics showed [4, 5], that all vibration processes in technological systems can be divided into two groups: not related to the cutting process and caused by cutting. The first group of vibrations is caused by mechanism unbalance forced low frequency vibrations and tool unbalance. The second group are caused by the discretion of cutting operation forced vibrations and peculiarities of chip formation. The second group of vibrations is common during discrete cutting. The milling process is characterized by the intermittent contact of cutting tools and the workpiece, a different number of contacting cutters, repeated shock loads during cutters and leaving the workpiece. Milling instability in the theory of materials processing is estimated by its roughness [8]. Designing the milling technological process we can choose conditions to lowdown milling roughness. One of the ways of lowering forced vibration is increasing technological system stiffening and damping properties [9]. Also, special cutting tools and optimal cutting modes can be applied. Spiral cutting edges, the staggered arrangement of the cutters on the shaping tool surface and other can be considered as constructional peculiarities of the cutters [1, 7, 10]. Mentioned earlier producing companies suggest large inclination angle of the cutting edges of the cutters for numerically controlled lathes. For example, in [4] constructions of scroll chipping heads

with helical alternating teeth are described. For rational over dimensional milling of wood full-side mills with many modifications are applied. Cutters are used for roughing work of big surfaces and eliminate vibrations. Long cutting edges are classified edgewise by marking alternately chip holding grooves on the cutting edges or cutting blades shift relative to each other [11]. Such parameters of the wood cutting tools as teeth number  $z$ , cutting edge inclination,  $\omega$ , chip dividing grooves at the prescribed depth and width of cutting determine length, orientation and position of the cutting edges. These parameters determine the kinematic scheme of over dimension cutting, consequently, process dynamic instability. Our aim was to test the influence of cutting edge inclination, number and position of cutting blades on the shape-forming tool surface on vibration level and surface roughness. It is necessary for the cutting tool choice at the stage of technological operation modelling.

II. METHODS OF EXPERIMENTAL RESEARCH

Test to determine vibration level and surface roughness were done with numerically controlled wood-working center BIESSE ROVER 20 with the main drive capacity  $P=6.6$  kWt in workshop utilization. Rectangular pine workpieces size 40x140x450 mm were used with surface roughness not more than  $Ra$  3.6 mkm. The workpieces were fixed on the vacuum work table that provided stable clamping force. A bunch of seven experimental end wood-cutting tools produced according to AUS-standard 8994-80 was tested. All milling cutters were of the same size and type, with the same working geometry, but had different geometrical-constructional elements. Common parameters of the experimental milling cutters are shown in figure 1. The milling cutters were made of steel P6M5 with head hardness  $60\pm 63$  HRCte

Experimental variables were constructional-geometrical milling-cutters parameters: cutting edge inclination  $\omega$ , chip splitting grooves; number of teeth  $z$ , angle pitch uniformity. For cutters with circular pitch inequality the angles between teeth were

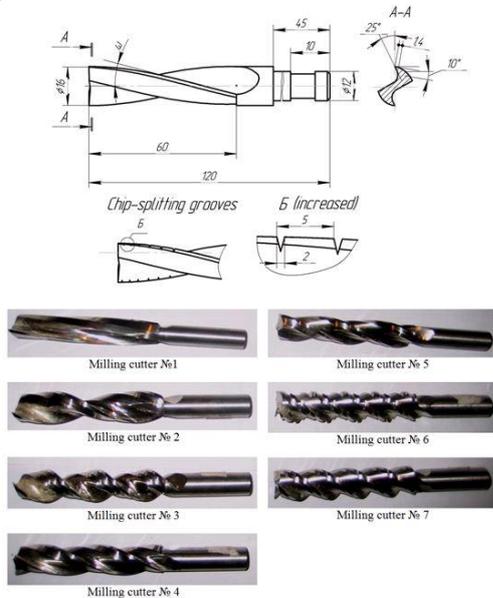


Fig. 1. The layout and basic dimensions of experimental milling cutters.

All milling cutters were coded for experimental convenience. Variable parameters of experimental milling-cutters and the numbers given to them are shown in Table I.

TABLE I. VARIABLE PARAMETERS OF EXPERIMENTAL MILLING-CUTTERS

Cutter code	number of teeth	Cutting edge inclination $\omega, ^\circ$	teth pitch, $z$	chip-splitting grooves
1	2	12	uniform	no
2	2	30	uniform	no
3	2	45	uniform	no
4	3	30	uniform	no
5	3	30	non-uniform	no
6	3	45	uniform	yes
7	3	45	uniform	no

Cutting modes in all tests were constant and had: cutting speed  $v=10$  m/s, feed  $u=2.4$  m/min, cutting depth  $t=10$  mm. To reproduce conditions of contour milling when the angle of fibre cross-cutting is changed constantly passes through length and width were done.

The level of vibrations and surface roughness were estimated as output parameters. The surface roughness was measured with profilometer Surtronic 3 (Taylor-Hobson). To characterize milling vibroacoustics gadgets of the company "Brühl and Kier" were used (Denmark). Three component accelerometers type 4321 were used as sensing devices. The signal from sensing devices was transferred to the enhancer of type 2647A, then to the multichannel analyzer Pulse 3560-C, which contained a measuring module type 3039 and the interface unit type 7539. For signal measuring, recording and processing the software draft program Pulse Lab Shop was created. Picture 2 shows the scheme of the experimental apparatus 2.

During experimental milling closed rectangular grooves were cut full mill pass. Three mill passes were done on one workpiece. Narrow spectral estimation was done in the range of 12000 Hz after signal recording with the accelerometer. The specified range overlapped a spindle rotational speed fully, the frequency of the milling cutter teeth penetration into the workpiece fundamental frequency of the spindle group. The output signal was analyzed in the following order:

- Instantaneous spectrum construction of vibration acceleration root-mean square values (RMSV) with fast Fourier transformation [12].
- Finding mean value of the spectrum for a single mill pass.
- Averaging spectra according to three-mill passes and 2-acceleration indicators:

$$D_{X,Y} = 1/6(\sum \sum D_{i,k}) \tag{1}$$

In formula (1)  $D_{X,Y}$  are mean values (RMSV) on the corresponding axes,  $D_{i,k}$  are spectral mean values (RMSV)  $i^{th}$  mill pass for  $k^{th}$  sensor.

- Determining variance in every point of the plane.
- Determining homogeneity of variance.

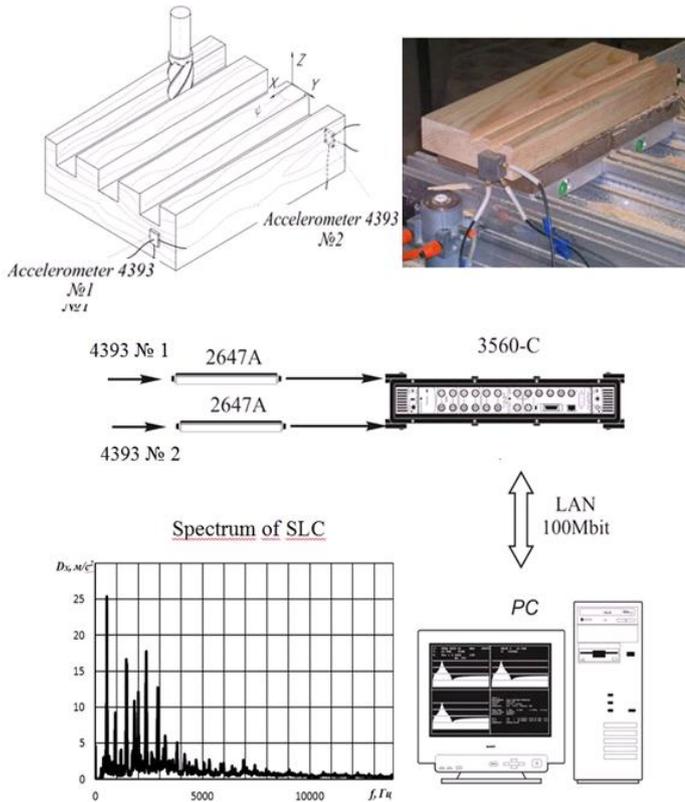


Fig. 2. Measuring chain during vibroacoustic measurements.

It should be noted that acceleration indicators, as primary detectors of signal record, fix noise from many sources, in the lathe technological system – compressor equipment, main motion drives and others. For this trial experiments with temporal processes recording of an idle mill cutter and during cutting were conducted. Idle mill cutter vibration with the unplugged compressor was less than 15 % from cutting vibration level. Basing on this it was decided not to form special reference signal for additional disturbance detachment [12].

All experiments were divided into four groups. The I<sup>st</sup> group was devoted to cutting edge inclination  $\omega$  (X1) and feed direction relative to fibres influence (X2) on vibrations level and surface roughness according to the plane 3<sup>1</sup>2<sup>1</sup>. Milling cutters 1, 2, 3 were used. The standardized parameter X1 had three values -1; 0,1; +1, that corresponded to the parameters of the milling cutters 1, 2, 3 and cutting edges inclination 12<sup>0</sup>, 30<sup>0</sup>, 45<sup>0</sup> correspondingly. The standardized parameter X2 had two values -1 and +1, that corresponded to the plank wise cutting ( $\psi=0^0$ ) and cross grain cutting ( $\psi =90^0$ ). The experiments plan is shown in Table III.

II, III and IV experimental groups were conducted according to planes 2<sup>3</sup> and 2<sup>2</sup>. The variables for the II<sup>nd</sup> group of experiments were the inclination angle  $\omega$  (X3), cutting edge number  $z$  (X4) and feed direction (X2). In the III<sup>d</sup> group of experiments chip splitting grooves (X5) and feed direction (X2) influence on processing vibration and surface roughness are studied. In the IV<sup>th</sup> group of experiments irregular circular pith (X6) and feed direction (X2) influence on the test parameters was studied. Standardized values of independent parameters are given in Table II. Experiments plan is given in Table IV.

TABLE II. INDEPENDENT PARAMETERS VARIATION RANGES OF II, III AND IV GROUPS OF EXPERIMENTS

Factors levels	Value	$\psi, ^\circ$	$\omega, ^\circ$	$z$	Thread uniformity	Groove presence
		X2	X3	X4	X5	X6
Lower	-1	0 <sup>0</sup> (along)	30 <sup>0</sup>	2	no	no
Upper	+1	90 <sup>0</sup> (across)	45 <sup>0</sup>	3	yes	yes

Statistical processing of experimental data was in determining average mean-root-value on axes X ( $D_X$ ) and Y ( $D_Y$ ) according to formula 1 and roughness mean value ( $Ra_{mean}$ ) at cut groove bottom on 5 points. Linear regressive models coefficients in standardized parameters were determined in experiments that are connected with the presence of non-numeric parameters. Beta coefficient value was estimated with the Student t-test. Model adequacy was determined with Fisher's ratio test with significance level  $p \leq .05$ . The partial correlation coefficient between average vibration level and average surface roughness value in all groups of experiments were determined ( $r_X$  and  $r_Y$ ).

### III. RESULTS OF THE STUDY AND DISCUSSION

Table III shows the results of the I<sup>st</sup> group of experiments.

TABLE III. THE PLAN AND RESULTS OF THE I GROUP OF EXPERIMENTS

milling cutter №	X1 (z)	X2 ( $\psi$ )	$D_x, m/s^2$	$D_y, m/s^2$	$Ra_{mean}, mkm$
1	-1	+1	24.0	15.6	25.7
2	0.1	+1	20.5	18.5	21.3
3	+1	+1	18.5	17.0	18.8
1	-1	-1	15.3	25.6	21.7
2	0.1	-1	13.8	15.1	16.3
3	+1	-1	11.1	9.9	14.8

Table IV shows the results for II, III and IV group.

TABLE IV. THE PLAN AND RESULTS OF THE II, III и IV GROUPS OF EXPERIMENTS

Group of experiments	№ milling cutter	X2	X3	X4	X5	X6	$D_{x,2}$ m/s <sup>2</sup>	$D_{y,2}$ m/s <sup>2</sup>	$Ra_{mean}$ mkm
II	2	+1	-1	-1	-1	+1	20.5	18.5	21.3
II	3	+1	+1	-1	-1	+1	18.5	17.0	18.8
II, IV	4	+1	-1	+1	-1	+1	18.0	19.5	19.6
IV	5	+1	-1	+1	-1	+1	11.5	8.8	20.7
II, III	6	+1	+1	+1	-1	+1	13.7	12.4	18.9
III	7	+1	-1	+1	+1	+1	11.6	8.9	17.9
II	2	-1	-1	-1	-1	+1	13.8	15.1	16.3
II	3	-1	+1	-1	-1	+1	11.1	9.9	14.8
II, IV	4	-1	-1	+1	-1	+1	11.0	12.3	15.1
IV	5	-1	-1	+1	-1	+1	11.4	9.0	16.8
II, III	6	-1	+1	+1	-1	+1	11.3	8.5	13.7
III	7	-1	-1	+1	+1	+1	11.6	8.9	13.7

<sup>a</sup>. Natural values X2 – X6 are given in Table II

Regression and correlation analyses are given in Table V.

TABLE V. REGRESSIVE AND CORRELATION ANALYSES ACCORDING TO THE GROUPS OF THE EXPERIMENTS

Gr.	Regressive models	$r_x$	$r_y$
I	$D_x = 17.19 - 2.43 X1 + 3.80 X2$ $D_y = 16.95 - 3.5700 X1 + 0.08 X2$ $Ra_{mean} = 19.76 - 3.44 X1 + 2.17 X2$	0.88	0.51
II	$D_x = 14.73 - 1.08 X3 - 1.23 X4 + 2.93 X2$ $D_y = 14.15 - 1.08 X3 - 2.2 X4 + 2.7 X2$ $Ra_{mean} = 17.73 - 0.76 X3 - 0.48 X4 + 2.33 X2$	0.92	0.86
III	$D_x = 12.05 - 0.47 X5 + 0.52 X2$ $D_y = 9.67 - 0.77 X5 + 0.97 X2$ $Ra_{mean} = 16.05 - 0.25 X5 + 2.35 X2$	0.72	0.71
IV	$D_x = 13.05 - 1.45 X6 + 1.75 X2$ $D_y = 12.37 - 3.47 X6 + 1.83 X2$	Not significant	Not significant

Processing results of experimental data showed that cutting edge inclination increase results in vibration  $D_{x,y}$  and surface roughness  $Ra_{cp}$  decrease. It is explained that when cutting edge inclination increases milling cutter teeth enter and leave the workpiece more smoothly, impact loads decrease, and, as the result, the vibration level lowers. Although, nowadays cutting tools manufacturers produce milling cutters with the cutting edge inclination  $30^\circ$ , inclination increase up to  $45^\circ$  affects vibration level and surface smoothness favorably. Teeth number increase with the same feed per minute results in feed per tooth decrease, vibration level and surface roughness lowering. It is connected with lowering of cutting irregularity

degree. It should be noted that the received coefficients of correlation between the vibration level and surface roughness are significant and take values from 0, 51 to 0,92. Chip splitting grooves also low down the vibration level and surface roughness. Significant correlation coefficients between surface roughness and vibration level evidence that this constructional element in milling cutters is well-founded. Most effective fields of utilization for these milling cutters should be determined by studying processing of different timber species in relation with operational modes [14]. The correlation analyses have been proved by [5, 13], where it is suggested to conduct cutting process vibroacoustic diagnostics for predicting some treatment, for example, tool wear and surface roughness.

Non-uniform circular pitch influence is ambiguous. Statistically non-significant values were received during these groups of experiments while determining correlation coefficients. It should be noted that vibration level during milling cutting counter fibres was greater than plank wise in all the experiments.

#### IV. CONCLUSIONS

Thus, we can say that, cutting edge inclination increase, chip-splitting grooves, teeth number increase on the cutting ends affects the overall vibrational activity of the cutting process and lowers surface roughness. It seems appropriate to conduct the research to determine the most rational fields of utilization depending on the timber species, type of wood-composite materials, and regime modes.

#### References

- [1] N.A. Kryazhev, Wood milling, Moscow: Lesnaya promyshlennost' Publ., 1979.
- [2] J. Palmqvist, M. Lenner, Si. Gustafsson, "Cutting-forces when up-milling in beech," Wood science and technology, Vol. 39, pp. 674-684, 2005.
- [3] A.A. Vorob'ev, I.N. Spitsyn, Yu.A. Filippov, "Modelling of quality of processing and dynamics of work of wood-cutting machine," *Spravochnik. Inzhenernyy zhurnal*, no. 3, pp. 37-41, 2012.
- [4] I.T. Glebov, "Dependence of the height of the microroughness of the treated surface on some factors of cylindrical milling," *IVUZ Lesnoy zhurnal*, no.1, pp. 99-104, 2010.
- [5] Z.Z. Li, Z.H. Zhang, L. Zheng, "Feedrate optimization for variant milling process based on cutting force prediction," *The International Journal of Advanced Manufacturing Technology*, vol. 24, no. 7, pp. 541-552, 2004.
- [6] P. Iskra, R.E. Hernández, "Toward a process monitoring and control of a CNC wood router: Development of an adaptive control system for routing white birch," *Wood and Fibre Science*, Vol. 42, no. 4, pp. 523-535, 2010.
- [7] K.M. Raju, G.R. Janardhana, P.N. Kumar, V.D. Rao, "Optimization of cutting conditions for surface roughness in CNC end milling," *International Journal of Precision, Engineering and Manufacturing*, vol. 12, no. 3, pp 383-391, 011.
- [8] V.M. Andreev, Perfection of cutting tools, Moscow: Mashinostroenie Publ., 1993.
- [9] E.G. Ivanovsky, P.V. Vasilevskaya, E.M. Lautner, Milling sawing wood and wood materials, Moscow: Lesnaya promyshlennost' Publ., 1971.
- [10] Y. Sun, D. Li, F. Ren, D. Guo, "Predictive Force Model Based Variable Feedrate Scheduling for High-Efficiency NC Machining," *Proc. International Conference on Intelligent Robotics and Applications*

- [ICIRA 2008: Intelligent Robotics and Applications], pp. 1076-1085, 2008.
- [11] I.T. Glebov, Cutting wood. Tutorial, Ekaterinburg: Ural'skiy Lesotekhnicheskiy Universitet Publ., 2007.
- [12] M.D. Genkin, A.G. Sokolova, Vibroacoustic diagnostics of machines and mechanisms, Moscow: Mashinostroenie, 1987.
- [13] A.A.Vorob'ev, Yu.A. Filippov, "Determination of the dependence of the roughness of the wood surface on the machine vibration parameters," *Derevoobrabatyvayushchaya promyshlennost*, Vol. 2, pp. 6-7, 2010.
- [14] P. Iskra, C. Tanaka, "The influence of wood fibre direction, feed rate, and cutting width on sound intensity during routing," *Holz als Roh- und Werkstoff*, Vol. 63, no. 3, pp. 167-172, 2005.