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PRODUCTION OF WOODEN HOLLOW SPIRAL BALUSTERS ON TURN-MILLING CNC MACHINES

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ABSTRACT

The esthetic perception of a hollow baluster with spiral grooves, the influence of the spiral line elevation angle value and number of passes on perception are presented in the paper. The variants of balusters implementation depending on the direction of the mill and workpiece feed during machining are demonstrated. The formulas characterizing the cross-section geometry with odd and even amounts of grooves are given.

It is shown that the elevation angle of, approximately, 45˚ provides the most favorable esthetic perception. The production of balusters from wood and medium density fiberboard on a turn-milling CNC machine is examined. The recommendations on the groove milling sequence are proposed, the values of cutting depth and mill feed for certain typical sizes of balusters from birch and beech are recommended.

Key words: wood, baluster, milling, groove, esthetic perception.

INTRODUCTION

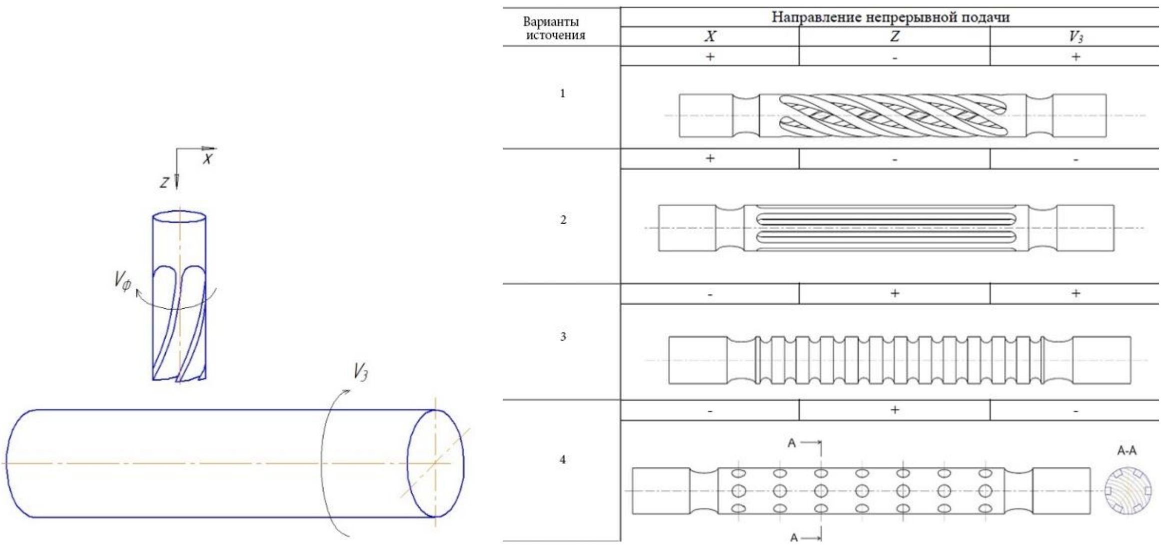
Barrier railings with balusters are popular in interiors and exteriors of buildings.

Balusters are distinguished by the material type – from wood, metal, stone, concrete, etc.; by shape – rotation bodies, flat, sculptural; by implementation style prevailing in a certain time period – gothic, baroque, renaissance, modern, art-deco, etc. Depending on the material type, several techniques are used to produce balusters – turning, milling, forging, casting, manual engraving.

The production of balusters from wood, esthetic and environmentally friendly material, has certain peculiarities. Universal lathes allow forming decorative elements in the form of rotation surfaces on balusters (PILIKINA 2005), (SIKLIENKA *et al*. 2016). The use of turn-milling machines gives additional opportunities for decorating balusters due to the formation of longitudinal and spiral grooves (channelures) on them. And the availability of computerized numerical control (CNC) in turn-milling machines (Figure 1) provides the identity of baluster sizes, formation of relief patterns on rotation surfaces and improved productivity (CHERNYKH *et al*. 2018, VITCHEV 2019).

Fig. 1 Turn-milling machine “Robor-D” (Semil, Russia) with computerized numerical control.

When processing on turn-milling machines, the mill rotation is the main motion, its movement in coordinates X, Z and workpiece rotation are the feed motion (Figure 2, a). The look of channelures is defined by the availability or absence of one or another feed movement (Figure 2, b).



a) b)

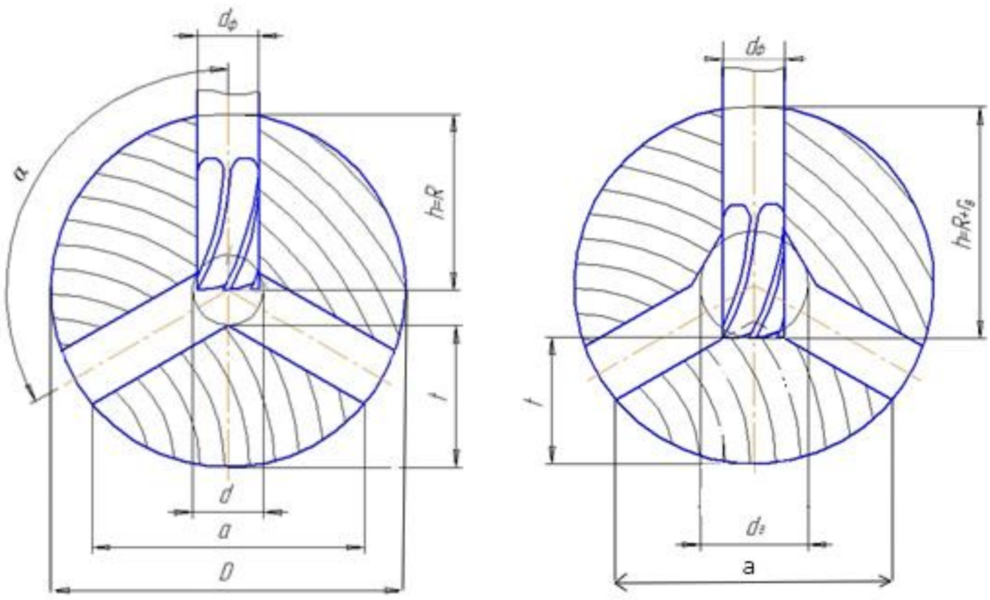
Fig. 2 Scheme of processing workpieces on turn-milling machines (a) and implementation of balusters produced with different directions of the mill and workpiece continuous feed (b).

The paper investigates the production possibilities of the most decorative and, at the same time, the most complicated by design and production technology, hollow balusters with spiral channelures on turn-milling CNC machines, their geometry and esthetic perception.

MATERIALS AND METHODS

Geometry of hollow baluster cross-section

If the milling depth h is not less than R (half of the external diameter D of the baluster), the opposite channelures link up inside the baluster (Figure 3) forming the longitudinal cavity, which produces the effect of decorative grid and improves the esthetic expressiveness of the baluster and barrier railings in general. The obtained cavity can be also used for placing lighting elements providing a new decorative effect for the barrier railings.



a) b)

Fig. 3 Cross-section of the hollow baluster with the odd number of channelures with the different milling depth h: equaled to (a) and more than (b) the half of external diameter D of the baluster.

The diameter of circumference $d_в$ inserted into the cavity is defined by the diameter of mill $d_ф$ and angle α between the axes of adjoining channelures (Figure 3, a). With the odd number of channelures the cavity can be extended due to cutting off the apexes of the opposite load-carrying (supporting) elements of the baluster (Figure 3, b). There is no such possibility with the even number of channelures.

The main ratios of sizes of cross-section of hollow balusters are given in Table 1.

Tab. 1 Main ratios of sizes of the cross-section of hollow balusters.

Size	With the even number of channelures, as well as with their odd number and uncut apexes of opposite load-carrying elements	With the odd number of channelures and cut off apexes of opposite load-carrying elements
Angle between the axes of the adjoining channelures α, degrees	$\alpha = \frac{360°}{N}$, where N – number of passes	
Diameter of the circumference inserted into the cavity $d_в$	$d_в = \frac{d_ф}{\sin\frac{\alpha}{2}}$, where $d_ф$– mill diameter	$d_в = d_ф(ctg\frac{\alpha}{2} + \frac{1}{\sin\frac{\alpha}{2}})$
Cross-section area of one load-carrying element S	$S = \frac{\pi D^2}{4N} - \frac{Dd_ф}{2} + \frac{d_ф^2}{4}ctg\frac{\alpha}{2}$, where D – baluster external diameter	$S = \frac{\pi D^2}{4N} - \frac{Dd_ф}{2}$

Assessment of esthetic perception

The sizes of baluster elements should be selected due to their estheticism and functionality, as well as the milling mode. When describing the parameters of spiral balusters, the terms characterizing the spiral line are used for the terminology unification – elevation angle φ and number of passes N, which equals the number of both the channelures and load-carrying elements of the baluster.

The influence of elevation angle φ and number of passes N onto the esthetic perception of balusters was investigated on 3D models of balusters by the method of expert assessment (GUTSYKOVA 2020) to decrease the investigation costs. The method of expert assessment is applied when it is difficult or impossible to measure the studied parameter instrumentally. This is appropriate for aesthetic perception of design objects, balusters, in particular. The method involves information processing by a complex expert group. When forming the group, the collective assessment of each expert's competence was used. The collective assessment is used for experts in aesthetic areas. The experts had backgrounds in design, experience in artistic works and information of each other as specialists. The three-point competence assessment system, with 1 – as the highest level, 0.5 – average and 0 – low, was applied. The coefficient of each expert's competence level exceeded 0.5 being appropriate for the method requirements. The assessment was carried out by 20 experts on a scale from 1 to 5. Thus, the maximum possible values of the total points for each value of the elevation angle, as well as the number of passes, were 100.

The elevation angle changed from 15 to 75 degrees in increments of 15 degrees, and the number of passes – from 1 to 9. The models had the similar length to diameter ratios of 5:1. 45 models were studied.

For the convenience of the experts' work, the background and lighting for all models were the same, and the view plane was placed vertically in accordance with the actual location of the baluster in the barrier railings.

Samples, equipment and tools

Based on the experts' assessment results, the balusters were worked out and produced (Figure 4) from wood of birch, beech and pine with 12% humidity and from the medium density fiberboard (MDF). The ultimate strength of the materials was found by GOST 16483.5-73 on three samples for each material. The baluster diameter was 70 mm, length – 690 mm, elevation angle – 45 degrees, width of channelures – 12 mm, width of load-carrying elements (size "a" in Figure 3, a) – 20 mm, thickness of load-carrying elements with the cut-off apex (size "t" in Figure 3, b) – 50 mm. The number of passes was taken as 5.

a)  b)  c) 

Fig. 4 – Balusters produced from wood of different species: a – birch, b – beech, c – pine.

The workpieces for balusters were produced from edged boards. The boards were sawed by disc mills into lumps on sawing machines. The lumps were planed from four sides on the thickness planer and glued with wood glue by GOST 18992-80 on hydraulic press "Elbrus" 2G 3000 (Russia). The wood fibers were placed along the baluster axis. The balusters were processed on turn-milling CNC machine "Robor-D" (Figure 1) produced by Semil (Russia). The machine characteristics: power – 3.2 kW, overall dimensions – 2,500 × 1,100 × 2,100 mm, workpiece continuous rotation – 0…3,200 rpm, workpiece programmable rotation – 0…10 rpm, mill rotation – up to 20,000 rpm, range of operating feeds – up to 3.5 m/min, mill movement accuracy – ±0.15 mm, discreteness of mill movement set up – 0.1 mm, maximum diameter of the workpiece machined – 250 mm, maximum length of the workpiece machined – 1,400 mm.

The machining was performed by new sharp mills. The cylindrical surface was machined by the straight double-helical mill 12 mm in diameter at 16,000 rpm of the mill and 2,000 rpm of the workpiece, and mill feed of 4 mm/sec. The profiled surfaces of rotation were machined by the spiral mill with a spherical head 8 mm in diameter in the range of 9,000…20,000 rpm of the mill and 650…1,300 rpm of the workpiece. The channelures were machined by the quadruple-helical mill from the tool steel 12 mm in diameter with chip splitter – toothed-like cutting edges on the side surface – in the range of 12,000…20,000 rpm of the mill and its feed – from 0.5 up to 3 mm/sec. The workpiece turning speed during the grooves machining was defined by the mill feed and elevation angle φ taken for one pass, the allowance was from 0.5 up to 2 mm.

RESULTS AND DISCUSSION

The ultimate strength of the materials investigated is given in Table 2. The data obtained comply with the known results (UGOLEV, 2004).

Tab. 2 Average values of the ultimate strength based on the results of shear tests along the fibers, MPa.

Material			
Birch	Beech	Pine	MDF
5.95	7.18	2.79	1.33

The total of expert assessments of esthetic perception of the models (total scores) is given in Table 3 and Figure 5.

Tab. 3 Total expert assessments of the balusters esthetics, scores.

Number of the model group	φ [degrees]	Number of passes, N							
		1	2	3	4	5	6	8	9
1	15	27	31	43	55	61	51	46	38
2	30	47	74	71	78	64	74	61	49
3	45	80	87	70	55	54	51	66	57
4	60	62	62	51	40	39	44	53	59
5	75	54	46	35	35	25	34	50	53

From the graphs it is seen that regardless of the number of passes the overall tendency of changing the esthetic perception with the change in the elevation angle φ is observed. With the increased angle value, the esthetic perception, at first, increases reaching the maximum, then it decreases. From the point of esthetic perception, the elevation angle φ equaled to, approximately, 45° is the most favorable.

The number of passes does not significantly influence the esthetic value of the baluster (Figure 6). It can be only pointed out that with the increase of N the range of assessment spread is narrowed, since the difference in the number of passes becomes less visible.

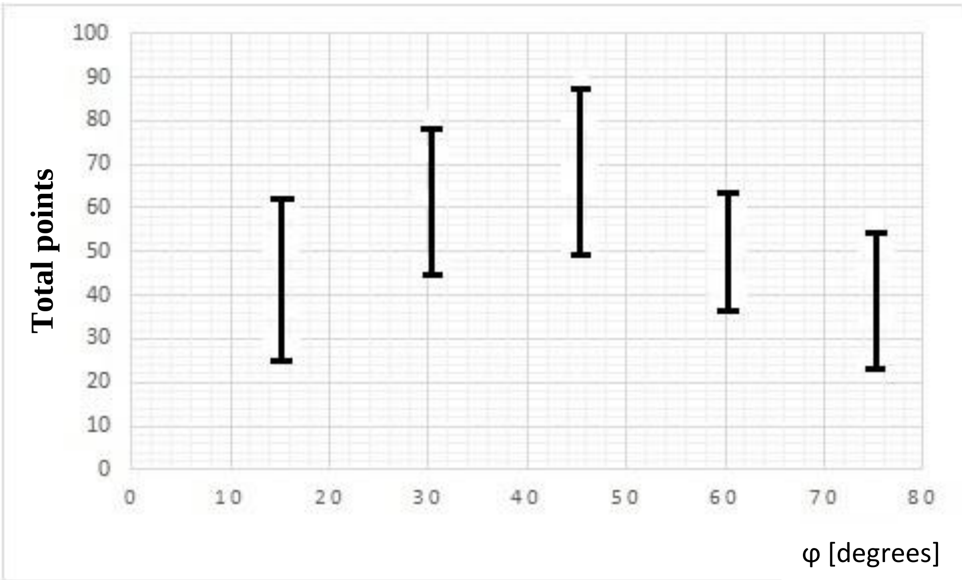


Fig. 5 Dependence of esthetic perception of the spiral baluster from elevation angle φ for models with different number of passes (from 1 to 9).

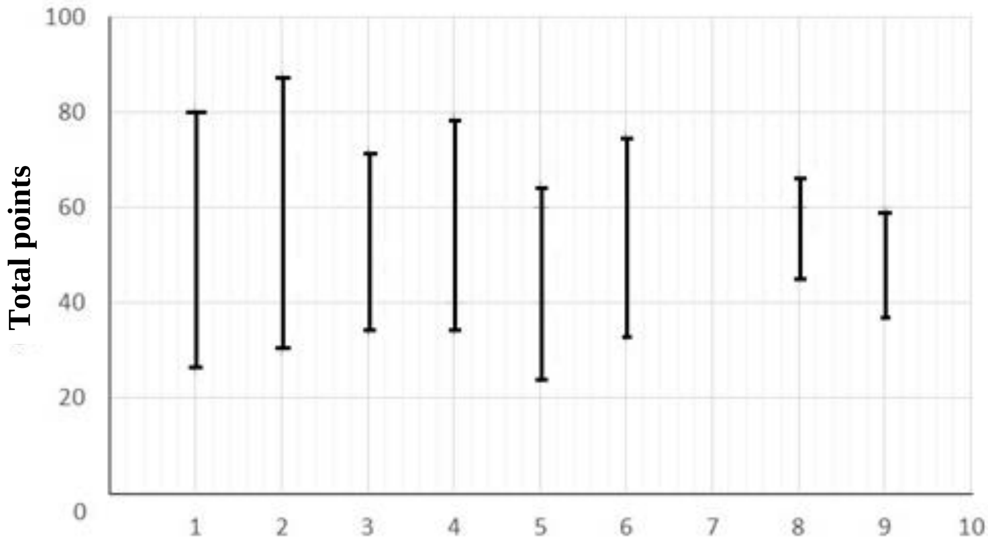


Fig. 6 – Influence of the number of passes onto esthetic perception of the spiral baluster with elevation angles changing in the range of 15º…75º

With the decreased size of the cross-section of the load-carrying elements of the balusters, its decorativeness increases. However, the minimum values of sizes are limited, moreover, rather by the load emerging in the process of grooves milling than the functional load onto the baluster in the barrier railings, where the load is distributed between several balusters and in the baluster – uniformly between all load-carrying elements. The cutting forces act mainly on those two load-carrying elements of the baluster, which contact the mill. The elements deform under the action of the cutting forces and the baluster bends producing vibrations. Due to the fibrous composition of wood, the high values of the cutting mode and machining productivity are limited, first of all, by the material ultimate shearing strength along the fibers. With the excessive cutting depth and feed values the load-carrying elements can chop off along the fibers (Figure 4, b). The theoretical calculation of the cutting mode elements – cutting depth, cutting speed and feed – due to the baluster design complexity and variation of the material strength properties is a complicated task and is not considered in this paper. The experimental investigation allowed finding out the following.

When selecting the material from the investigated ones, the birch and beech should be preferred. The balusters from MDF were destructed when milling the grooves even at the small cutting depth (0.3 mm) due to the low material ultimate strength. The balusters from pine were also destructed at the cutting depth of 0.4 mm due to the pine inclination to chopping and insufficient ultimate strength. Positive results were achieved on the workpieces from birch and beech.

To decrease the possibility of destructing the baluster load-carrying elements by more uniform distribution of cutting forces along the baluster cross-section, the groove should not be milled to the whole depth at once. First, the groove should be deepened to one value turning the workpiece step-by-step to angle α, then to another one, then to the third one, etc. until we get a through hole.

Due to the baluster decreased rigidity when the depth of the grooves increases while milling, the work rest should be used, and the cutting depth, i.e. the material layer thickness removed during one pass, should be decreased with the groove depth increase. At the same time, the cutting is performed both with the feed in straight direction, i.e. from left to right, and in reverse direction, i.e. from right to left (Figure 1).

For the investigated typical size of the balusters from birch and beech the following values of the cutting modes are rational. The cutting depth, i.e. the wood layer thickens removed by the mill at the feed in one direction (both in straight and reverse) equals 1.0 mm at the beginning of the groove formation and 0.5 mm – in the end; the feed equals 1 mm/sec. The values less than the indicated ones result in decreased productivity, the greater ones – to decreased machining quality, the baluster vibration increase and increased destruction possibility. The number of mill revolutions was 19,000 rpm and was limited by the machine characteristics. Operation at the mode ultimate for this machine (20,000 rpm) will result in accelerated wear. To improve the milling quality, as indicated (DZURENDA, 2008), it is practicable to use high-speed machines.

CONCLUSION

The sizes of the baluster elements should be selected due to its estheticism and functionality, as well as the milling mode.

The cross-section geometry analysis allowed finding the dependence of the cavity diameter of hollow balusters with odd and even amounts of channelures on their number and mill diameter. It is demonstrated that in balusters with odd number of channelures the cavity can be extended when cutting off the apexes of the load-carrying elements of the baluster opposite to the channelures. The formula for finding the cross-section area of the baluster load-carrying element is obtained.

With the increased elevation angle of the baluster spiral groove its esthetic value first increases reaching the maximum at the angle of, approximately, 45˚, then – decreases. The number of passes does not have significant influence on the esthetic value. It is pointed out that with the increased number of passes the range of the experts' assessment spread is narrowed, which is explained by the less visible difference of large number of passes for human eyes.

The minimum cross-section area of the load-carrying element is limited by the cutting forces emerging when milling the grooves. The destruction of load-carrying elements at the excessive cutting depth and feed values occurs with their chopping off along the fibers.

From the investigated materials (MDF, wood of pine, birch and beech) the positive results are achieved with birch and beech.

To decrease the destruction possibility due to more uniform distribution of cutting forces between the load-carrying elements, each groove should be milled in several steps, first, to one depth, then, after milling all the grooves, to another depth, then – to the third one, etc. gradually decreasing the cut off wood layer with the increased groove depth.

For the investigated typical size of the balusters from birch and beech the rational cutting depth at the first milling stage is 1.0 mm, at the final stage – 0.5 mm, and the feed is 1 mm/sec. The values less than the indicated ones result in decreased productivity, the greater ones – in decreased machining quality, the baluster vibration increase and increased destruction possibility.

REFERENCES

PILIKINA, N.N. Wooden architecture of the North. Arkhangelsk: Pravda Severa Publishers, 2005. 160 p.

SIKLIENKA, M., JANDA, P., JANKECH, A. 2016. The influence of milling heads on the quality of created surface. In Acta Facultatis Xylologiae Zvolen, 2016, 58(2): 81–88. ISSN 1336-3824.

CHERNYKH, M., OSTANINA, P., STOLLMANN, V. 2018. Aesthetic properties and quality of relief surfaces of wooden products in automated manufacturing. In Acta Facultatis Xylologiae Zvolen, 2018, 60(2): 153–160. ISSN 1336-3824.

VITCHEV, P. 2019. Evaluation of the surface quality of the processed wood material depending on the construction of the wood milling tool. In Acta Facultatis Xylologiae Zvolen, 2019, 61(2): 81–90. ISSN 1336-3824.

GUTSYKOVA, S.V. 2019. Method of expert assessments: theory and practice. 2nd edition. Moscow: Institute of Psychology of RAS Publishers, 2019. 144 p. ISBN 978-5-9270-0209-2. Text: Electronic E-library system IPR BOOKS: [webpage] – URL: http://www.iprbookshop.ru (BB 355.html (refernce date: 02.02.2020).

UGOLEV, B.N. 2002. Wood and Forestry Commodity. Moscow: Publishiny Center The Academy, p. 272.

DZURENDA, L. 2008. English Impact of technology on the quality of split and machined wood. Zvolen: Technical university in Zvolen, p.140. ISBN 978-80-228-1923-7.

GOST 16483.5-73. Wood. Methods for determination of ultimate shearing strength parallel to grain. M.: IPK Standard Publishers, 1999. p. 6.

GOST 18992-80. Polyvinylacetate homopolymeric coarse breakup dispersion. Specifications. M.: IPK Standard Publishers, 2001. p. 19.

Robor model "D" [E-resource]. Accessible at: https://semil.ru/machine_tools_wood (refernce date: 27.02.2020).

Hydraulic press Elbrus 2G 3000 [E-resource]. Accessible at: https://tiu.ru/P97609184-press-gidravlicheskij-elbrus.html (refernce date: 27.02.2020).

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