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COMPLEX ORNAMENT MACHINING PROCESS ON A CNC ROUTER

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Abstract:
The paper investigates the CNC routering possibilities for three species of wood, namely ash (Fraxinus Excelsior), lime wood (Tilia cordata) and fir wood (Abies Alba), in order to obtain right surfaces of Art Nouveau sculptured ornaments. Given the complexity of the CNC tool path for getting wavy shapes of Art Nouveau decorations, the choice of processing parameters for each processed species of wood requires a laborious research work to correlate these parameters. Two Art Nouveau ornaments are proposed for the investigation. They are CNC routered using two types of cutting tools. The processed parameters namely the spindle speed, feed speed and depth of cut were the three variables of the machining process for the three species of wood, which were combined so, to provide good surface finish as a quality attribute. There were totally forty six variants of combining the processing parameter which were applied for CNC routering the samples made of the three species of wood. At the end, an optimum combination of the processed parameters is recommended for each species of wood.

Key words: *ornament; CNC router; tools; feed speed; spindle speed; depth of cut.*

INTRODUCTION

The Art Nouveau Style has particular characteristics, embracing architecture, graphic art, interior design and decorative arts (jewellery, furniture, textiles) and emerged in the late nineteenth and early twentieth century. It is easily recognizable due to the sinuous lines of the highly stylized plants and floral-inspired motifs (Fig. 1). The complex curved lines, as the main characteristic of the Art Nouveau decorative art were difficult to be obtained in a mass production, so the style is in fact a return to handcraftsmanship and the human imagination. The most common forms of ornamentation of this style are: sea grasses, corals, leaves, climbing plants, buds, stylized flowers, especially poppies and lilies, tendrils of plants, grapes, branches. Being difficult to be machined in the condition of a handcraftsmanship design, the Art Nouveau ornaments can be processed nowadays only by using high-speed CNC milling in manufacturing of the products made of wood. The five axes construction of these machines on one hand and the perfect replication of the original ornament drawing in AUTOCAD on the other hand are the advantages of providing the complex tool paths imposed by the design.

Fig. 1.
Art Nouveau floral design (http://www.pinterest.com).

In the 1990s (Finzer 1999), the advantage of using high-speed machine tools emerged in reducing the cutting forces by increasing the cutting speed, generating thus better surfaces and creating the possibility of using small tool diameters for machining sculptured surfaces.

The research on CNC wood router machining was extended to wooden based materials, too. The results on MDF milling by CNC wood router (Sütcü et al. 2012) showed that higher spindle speed should be used in order to obtain larger material removal rates associated with minimal surface roughness and the high-density layers proved to produce a better surface finish. It was proved that most of the materials can be machined by high-speed milling and good result can be obtained by the appropriate selection of cutting parameters (Kauppinen 2004). The effect of various machining parameters such as spindle speed, feed rate and depth of cut was investigated by conducting research in the machining process on CNC Wood Routers for various species of wood, in terms of the quality of the processed surface (Supadarattanawong et al. 2006, Pinkowski et al. 2010). Profiles of oak wood surfaces milled on a CNC wood router were analyzed in terms of roughness parameters in order to establish the proper machining parameters (Pinkowski et al. 2010). The newest research tendencies are focused on developing mathematical models and computational procedures for optimization of feed rate at CNC routing operations of wooden furniture parts (Gawronski 2013). The procedure takes into consideration the characteristics of the solid wood and the obtained surface quality. The optimization of CNC end milling process parameters like tool feed, tool speed, tool diameter and depth of cut is also done by statistical methods -Taguchi methodology or ANOVA (Maurya *et al*. 2012, Moshat *et al*. 2010a and 2010b).

As seen hereinbefore, the optimization of CNC milling process parameters means to provide good surface finish and it depends on the processed materials. Higher densities of materials require higher spindle speeds. The CNC wood routers bring also the advantage of machining sculptured surfaces using high speed small diameter tools. The present paper investigation is based on the advantages already proved by the previous mentioned authors. It will analyze and present the results of the optimum machining parameters like feed rate, spindle speed and depth of cut for milling the complex Art Nouveau sculptured ornaments in resinous wood, softwood or hardwood.

OBJECTIVES

The present study intends to show the results of investigation of the right combination of machining parameters (feed speed, spindle speed and depth of cut) of CNC wood router, in order to obtain a good quality of the surface, when milling complex curved trajectories, as the case of Art Nouveau ornaments is. Two types of metal carbide cutting tools have been used in the investigation: the first one with a sharp tip and a milling diameter of 2mm and the other one with a diameter of 10mm. Three species of wood have been also chosen for the investigation: a resinous one - fir wood (*Abies Alba*), a softwood species - lime wood (*Tilia Cordata*) and a hardwood one - ash wood (*Fraxinus Excelsior*). The quality of the surfaces generated by CNC machining of the samples made of the three species of wood will be investigated, so to recommend the right combination of the processing parameters and the proper cutting tool for milling Art Nouveau complex curved trajectories. The improper surfaces will show fiber breakings, irregularities of trajectory due to elastic deformations or vibrations.

METHOD, MATERIALS AND EQUIPMENT

The CNC wood router, ACCORD 40TVN type (S.C.M. Group manufacturer), used for the investigation is designed for machining wood and wooden based panels (Fig. 2). The working area of the router is 3650mm x 1560mm and the maximum width of the processed part is 330mm. The maximum feed speed is 75m/min for X and Y axes and 30m/min for Z axes. The spindle speed is in the range of 600-18 000rot/min.

Fig. 2.
The CNC wood router, ACCORD 40TVN type, used for the investigation.

The tools used for the investigation are shown in Fig. 3a and b. They are router bits with small diameters, designed for high spindle speeds and for machining sculptured surfaces. The main characteristics of the tools are presented in Fig. 3.

Material:	alloy steel
Sharpness angle:	60°
Top diameter:	30mm
Total length:	120mm
Number of teeth:	2
Max. spindle speed:	24000rot/min
Max. diameter:	15mm
Min.diameter:	1mm

Material:	carbide metal
Sharpness angle:	60°
Top diameter:	30mm
Total length:	70mm
Number of teeth:	2
Max. spindle speed:	18000rot/min
Max. diameter:	10mm
Min.diameter:	2mm

a **b**

Fig. 3.
The tools used for routering the ornaments;
a – Pointed router bit; b – Metal carbide router bit.

The wood samples were sized at 400mm x 200mm x 12mm and were made of three species of wood: lime wood (*Tilia Cordata*) - as softwood, ash wood (*Fraxinus Excelsior*) - as hardwood and fir wood (*Abies Alba*) - as resinous wood. The design of Art Nouveau ornaments CNC routered on the surface of the samples is shown in Fig. 4.

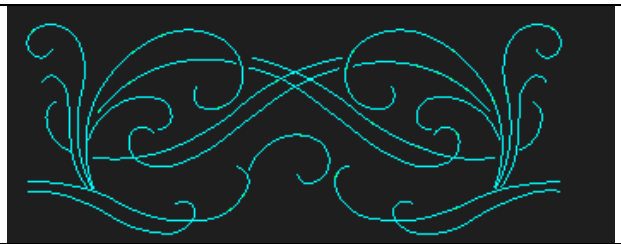
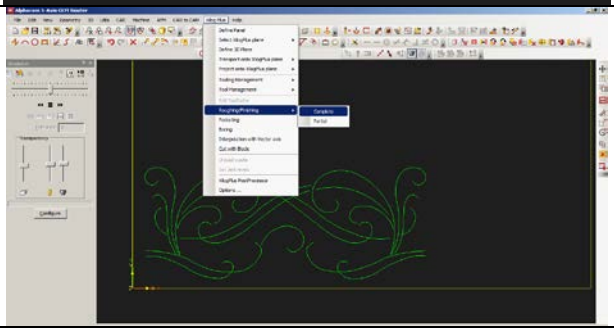
a **b**

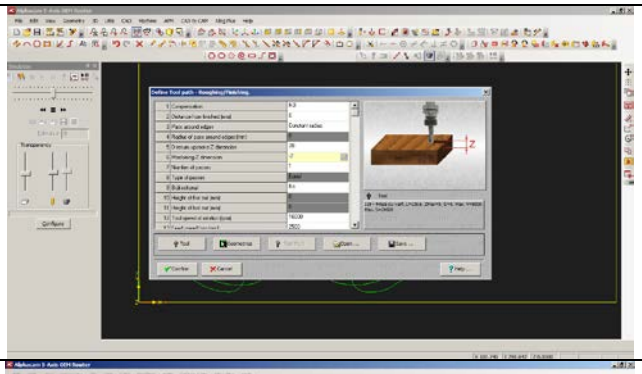
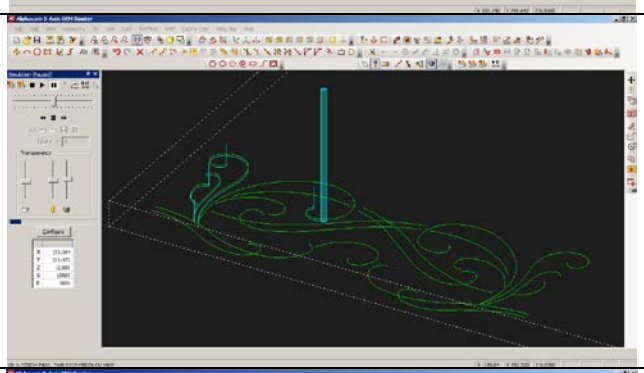
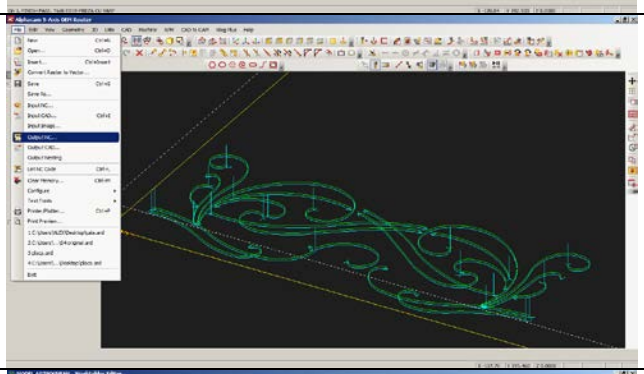
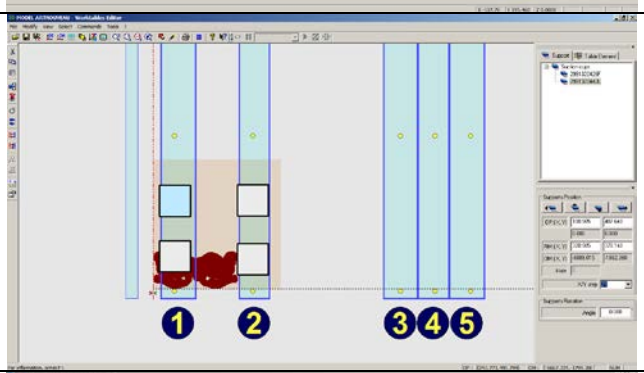
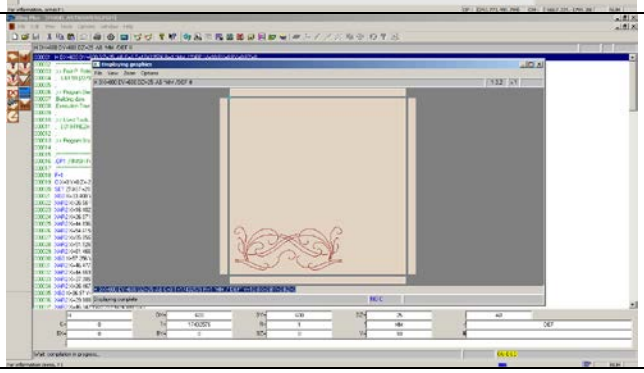
Fig. 4.
Art Nouveau ornaments designed for the investigation
a – model 1; b – model 2.

The steps to achieve the CNC processing program of the Art Nouveau ornaments are presented in Table 1.

Table 1

Steps to achieve the processing program of Art Nouveau ornaments

Step no.	Step designation	Demonstration
1.	AutoCAD drawing	
2.	Import the AutoCAD drawing in AlphaCAM	

3.	Choose the tool	
4.	Simulation of operation	
5.	Exporting the operations to XilogPlus program	
6.	XilogPlus programming	
7.	Checking the graphical program	
8.	CNC machining	

Four approaches are needed in the CNC wood machining process: to choose the right cutting tool in accordance with the processed species of wood, to optimize the machining parameters and to use the proper machining strategies. With regard to the machining parameters, a high cutting speed in combination with high feed speeds brings the advantage of reducing the cutting forces and generating better surfaces. The optimization of the machining parameters means to combine efficiently the spindle speed, the feed speed and the depth of cut in order to obtain a proper quality of the machined surface. The quantitative assessment of the quality of the surface is done by the measurement of the roughness in some cases, or sometimes only by the visual evaluation of the defects that can occur during the process. The last one was applied in the present paper. The variables used in the analysis and the range of their values are shown in Table 2.

Table 2

Variables of the machining parameters

Parameter	Measuring unit	Values
Spindle speed	Rotation/minute	12000; 18000
Feed speed	m/min	0.6, 1.5, 3, 6, 8, 10
Depth of cut	mm	1, 2, 3

RESULTS AND DISCUSSIONS

Forty six samples were CNC machined in order to obtain the two models of ornaments, on the three species of wood: ash (*Fraxinus Excelsior*), lime (*Tilia Cordata*) and fir wood (*Abies Alba*), using the two types of tools. All the species of wood were tested on two spindle speeds: 12000rot/min and 18000rot/min, varying the feed speed and then the depth of cut. The best results were registered for the ash wood, both on 12000rot/min and 18000rot/min spindle speed, for both models, at a depth of cut of 3mm for the pointed router bit tool and 2mm for the metal carbide router bit tool, as seen in Table 3 and Table 4. For lime wood, the best CNC machined surface quality was obtained for the spindle feed of 18000rot/min and 1.5m/min feed speed, at a depth of cut of 1mm. The fir wood CNC machined surfaces registered defects for all combinations of machining parameters. The smallest areas of grain tearing have been observed for a spindle feed of 12000rot/min and low feed speeds, at 2mm and 3mm depths of cut.

Table 3

Best results of samples CNC machining (Art Nouveau ornament-Model 1)

 Tool: Pointed router bit				Art Nouveau ornament: Model 1 		
Species of wood		**Spindle speed rot/min**	**Feed speed m/min**	**Depth of cut, mm**	**Work Time, h:min:s**	**Defects**
Fir *(Abies Alba)*	**Sample 1**	12000	0.6	3	0:04:08	Few grain tearing
	Sample 2	12000	1.5	2	0:02:45	Few grain tearing
Lime *(Tilia Cordata)*	**Sample 6**	18000	1.5	1	0:02:42	Perfect cutting
Ash *(Fraxinus Excelsior)*	**Sample 1**	18000	1.5	3	0:03:07	Perfect cutting without grain tearing
	Sample 6	12000	1	3	0:03:40	Perfect cutting without grain tearing
	Sample 7	12000	1.5	3	0:02:42	Perfect cutting without grain tearing
 Tool: Metal carbide router bit				Art Nouveau ornament: Model 1 		
Lime *(Tilia Cordata)*	**Sample 1**	12000	1	3	0:02:10	Grain tearing on small areas
	Sample 2	12000	1.5	3	0:02:42	Grain tearing on small areas
	Sample 8	18000	1.5	2	0:02:42	Few grain tearing
	Sample 9	18000	3	2	0:01:52	Few grain tearing
Ash *(Fraxinus Excelsior)*	**Sample 1**	18000	1.5	2	0:02:44	Perfect cutting
	Sample 2	18000	3	3	0:01:52	Perfect cutting
	Sample 3	18000	6	2	0:01:27	Perfect cutting
	Sample 4	18000	8	2	0:01:18	Perfect cutting

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Table 4

Best results of samples CNC machining (Art Nouveau ornament-Model 2)

Species of wood		Spindle speed rot/min	Feed speed m/min	Depth of cut, mm	Work time, h:min:s	Defects
 Tool: Pointed router bit				Art Nouveau ornament: Model 2		
Ash (*Fraxinus Excelsior*)	**Sample 1**	12000	3	2	0:03:05	Perfect cutting
 Tool: Metal carbide router bit				Art Nouveau ornament: Model 2		
Ash (*Fraxinus Excelsior*)	**Sample 1**	12000	3	2	0:03:05	Perfect cutting

For the second Art Nouveau ornament (Model 2), just the samples of ash wood (*Fraxinus Excelsior*) resulted with fine CNC machined surfaces. The other two species - lime (*Tilia Cordata*) and fir wood (*Abies Alba*) registered serious defects after machining, namely evident grain tearing. Examples of the finest sculptured surfaces after CNC machining are presented in Table 5. Examples of the defective sculptured surfaces after CNC machining are presented in Fig. 5.

Table 5

Examples of the finest sculptured surfaces after CNC machining

Species of wood/ Model no./ Sample no.	Machining parameters	Image
Ash wood (*Fraxinus Excelsior*)/ Model 1/ Sample 6	Feed speed = 1m/min Depth of cut = 3mm Work time: 03:40min Spindle speed: 12000rpm Tool: pointed router bit 	
Ash wood (*Fraxinus Excelsior*)/ Model 1/ Sample 4	Feed speed = 8m/min Depth of cut = 2mm Work time: 01:18 min Spindle speed: 18000rpm Tool: metal carbide router bit 	
Ash wood (*Fraxinus Excelsior*)/ Model 1/ Sample 2	Feed speed = 3m/min Depth of cut = 3mm Work time: 01:52 Spindle speed:18000rpm Tool: metal carbide router bit 	

Ash wood (*Fraxinus Excelsior*)/ Model 1/ Sample 1	Feed speed = 1.5 m/min Depth of cut = 3mm Work time: 03:07 Spindle speed:18000rpm Tool: pointed router bit 	
Ash wood (*Fraxinus Excelsior*)/ Model 1/ Sample 1	Feed speed = 1.5 m/min Depth of cut = 2mm Work time: 02:44min Spindle speed:18000rpm Tool: metal carbide router bit 	
Lime wood (*Tilia Cordata*)/ Model 1/ Sample 6	Feed speed = 1.5 m/min Depth of cut = 1mm Work time: 02:42min Spindle speed:18000rpm Tool: pointed router bit 	
Ash wood (*Fraxinus Excelsior*)/ Model 2/ Sample 1	Feed speed = 3m/min Depth of cut = 2mm Work time: 03:05 Spindle speed :12000 rpm Tool: pointed router bit 	

As seen in Table 6, the aesthetic value of the sculptured surfaces increases with the increasing of the depth of the cut. Thus, a new characteristic in the optimization of the CNC machining process occurs and this is the aesthetic value of the sculptured surface. For this reason, the most preferable ones are those obtained by CNC machining with a cut of depth of 3mm and 2mm respectively.

a *b* *c*

Fig. 5

Details of the defective sculptured surfaces (with grain tearing defects) after CNC machining; a – lime wood (Tilia Cordata), pointed router bit, n=18000rpm, u=3m/min, h=2mm depth of cut; b – fir wood (Abies Alba), pointed router bit, n=12000rpm, u=1.5m/min, h=3mm depth of cut; c - fir wood (Abies Alba), n=12000rpm, u=1.5m/min, h=2mm depth of cut (Model 2).

CONCLUSIONS

The present investigation highlights the characteristics to be considered for an optimization of CNC wood router machining process parameters in order to provide good surface finish as well as a proper aesthetic value of the sculptured surface. The surface finish and the aesthetic value of the sculptured surface have been identified as quality attributes. This preliminary study is the first step to the optimization of the quality attributes in a manner that all the above mentioned multi-criterions could be fulfilled simultaneously up to the expected level. Comparing the quality of the obtained sculptured surfaces of the resinous wood, hardwood and softwood, it can be concluded that ash wood, as the representative of the hardwood species, has behaved properly to the CNC milling of the complex trajectories of the two Art Nouveau ornaments. The other two species suffered bad grain tearing defects for almost all combinations of the machining parameters, no matter of the routering tool.

As a final conclusion, the diagram in Fig. 6 highlights the recommended CNC machining parameters for the two Art Nouveau ornaments, for each tool considered herein before. It also highlights the optimum combinations of the parameters that bring the maximum productivity for the two models.

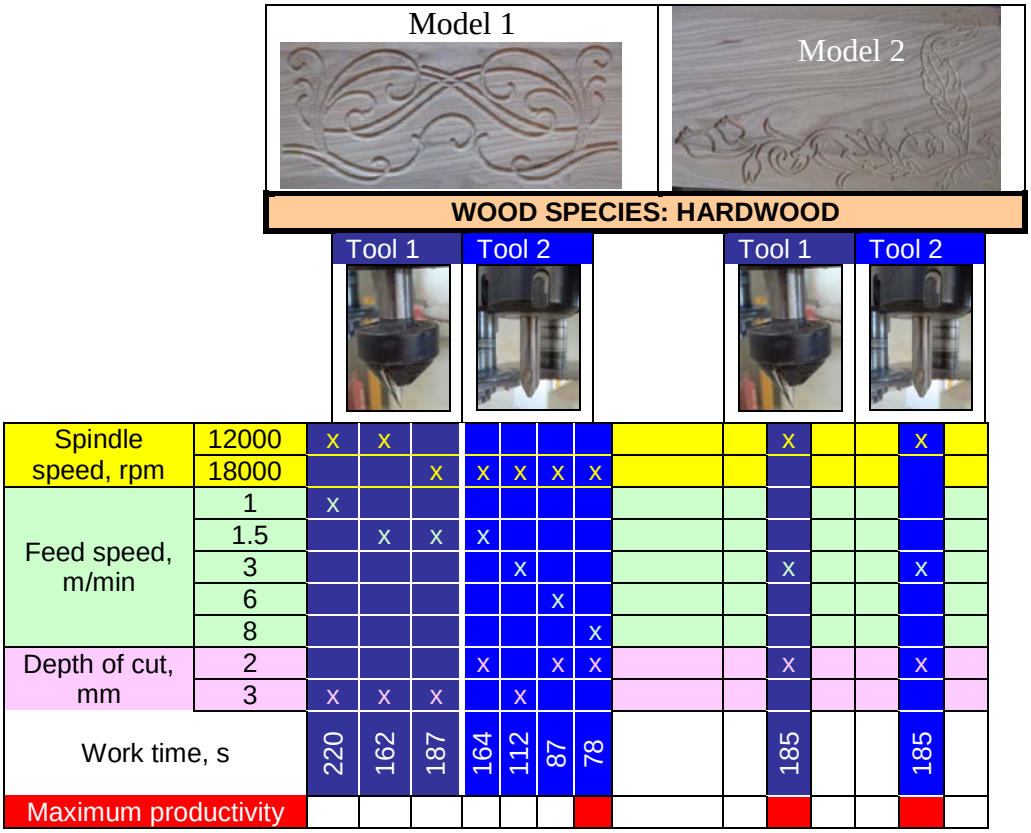

Fig. 6

The recommended machining parameters for hardwood CNC milling of Art Nouveau ornaments.

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