TOOLPATH GENERATION AND OPTIMIZATION OF MACHINING OF PINE WOOD SURFACES

Athanasios Makris, Ioannis Ntintakis
Technological Educational Institute (T.E.I.) of Thessaly, Greece
e-mail: amakris@teilar.gr; ntintakis@teilar.gr

ABSTRACT

In this paper are presented methods for wood working milling machining, specially we are going to use samples of pine wood. In the beginning a sculpture surfaces will be designed in a CAD/CAM software Fusion 360 and tool paths will be generated using four different strategies for finishing stage, these are: a) parallel, b) scallop, c) radial and d) pencil. On the upper machining surface of the final physical parts we measure the roughness in order to check the produced quality for each strategy. Each strategy compared according the total machining time, the cutting conditions and the geometric accuracy. Physical models will be produced with the use of a rapid prototyping machine ROLAND MDX- 40A for evaluation and tool path comparison.

Key words: CNC, wood machining, tool path, CAD/CAM, milling, optimization, pine wood.

INTRODUCTION

Since 1954 when the first milling machine tool could be controlled numerically (NC), thereby representing one of the greatest industrial advances of the twentieth century. Nowadays advanced CAD/CAM systems offer a number of functionalities with a broad range of operations and upgrades which contribute to machining quality in CNC (Computer Numerical Control) machines.

The strengths of CNC machines can be utilized in the processing of complex paths and consequently the creation of complicated tool paths. In the last decades milling has improved significantly. Most of innovations involve new clamps, machine functionality and improvement in the cutting tool performance. The main goal of all these improvements is the reduction of production cost without affecting the quality of produced surface.

Advanced CAD/CAM programs offer a majority of improvements in order to produce the machining surface. In this paper we are going to compare different milling techniques which focus in finishing stage. Broadly, sculptured surface machining is done in two stages, 1. roughing and 2. finishing. The majority of the material is removed in the roughing stage using larger tool(s) while the left over material is removed in the finishing stage (Misra *et al*. 2003). Therefore, generating the optimum cutting parameters is crucial to obtain high productivity in the manufacturing process of complex geometries and to reach the desired tolerance values (Gok *et al.2017*). Most of the available CAD-CAM systems often do not generate optimum tool path in CNC operations (Mwinuka *et al. 2015*). Thus many experiments and settings have to be implemented in the tool path generation process in order to achieve the optimum results in the machining area. The selection of the appropriate tools and tool paths directly depends upon the shape, the material and the precision of the object to be machined (Saglio *et al. 1994*).

In experimental stage we are going to use Fusion 360 CAD/CAM software which is offered from Autodesk. Fusion 360 is integrated CAD/CAM software which is compatible with the most known CNC machines and G-code formats. Directly from Fusion 360 a G-code format will be exported to Rolland MDX 40-A 4/axis Rapid Prototyping (RP) milling machine. For the machining process we are going to use a zhs-400 which is an ordinary stainless steel tool Wooden material will be used for the machining. Tooling technology goes along with the investigation of appropriate machining conditions for wooden materials, as for any other material (Krimpenis *et al.*, 2014). The wooden material that we are going to use is Black pine wood the mean of hardness is 2.6, the modules of elasticity is 12.900 MPa, during the machining process it doesn't need a special tool (CIRAD, 2017).

Surface measurements were conducted with the portable surface roughness tester Mitutoyo Surftest SJ-210. The SJ-210 its belongs to the Linear Roughness testers, which requires the splinter to be in contact with the checked material surface. According to EN ISO 4287 and EN ISO 16610-21 we are going to measure the surface roughness though of three different roughness parameters, Ra – Arithmetical mean roughness value, Rq – Root mean squared and Rz-Mean roughness depth.

2. EXPERIMENTAL METHODS

2.1. DIGITAL MANUFACTURING

A digital typical model has been designed in the Fusion 360 CAD software using the free form technology. The model consists of complex geometry in order to be machined in the CAM environment. This software is used in industries and has the capability of creating part geometries as well as generating tool paths and NC codes. The dimensions of the model are (92x82.5x13.5) mm. Definition of the work piece is needed to proceed with the digital manufacturing. The dimensions of the stock are (95x85x14) mm.

A roughing strategy is applied for clearing large quantities of material and as the part is being machined layer by layer an amount of material will remain in both on the walls of the part (radial stock to leave 0.5mm) and on the floors of the part (axial stock to leave 0.5mm). A table with data being used for 3D pocketing is following along with outputs (table 1, table 2). For the experiment a soft wood (pine) has been selected.

Table 1: Roughing data conditions

Material	Straight Flute Tool dia [mm]	Spindle Speed [rpm]	Maximum Feed rate [mm/min]	Maximum Roughing Stepdown [mm]	Maximum Stepover [mm]
Pine wood	4	13000	900	0.6	4

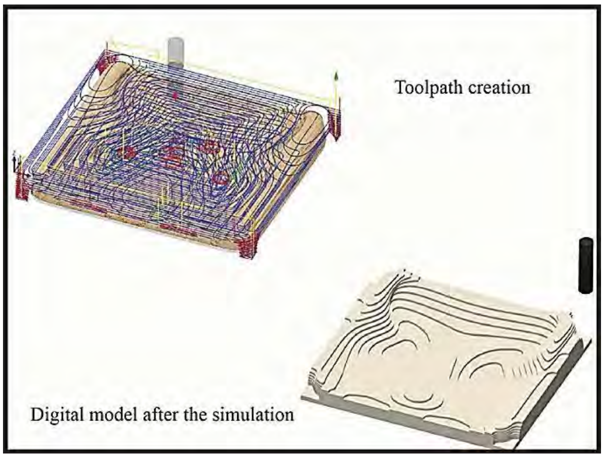

Figure 1: Tool path creation of roughing strategy

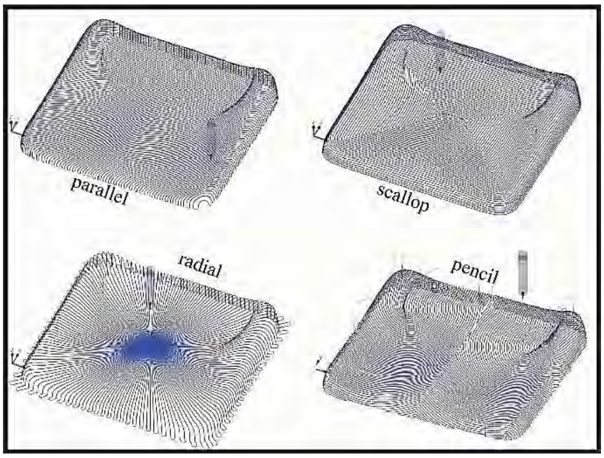

Figure 2: Finishing tool path operations

In most of CAD/CAM software, programmer has usually more than one option to create tool paths for finishing strategy. In Autodesk Fusion 360 there are four finishing strategies: a) parallel b) scallop c) radial and d) pencil. We are going to use the different strategies under the same assumption, that each machining process will finish in the same time, about (12) twelve minutes. Using these strategies in Fusion 360 tool paths are being generated automatically from the software. Differences from each strategy may occurred in the quality of the machining surface. Dimensional accuracy, however, depends on many other variables and factors as well. One of them is the preceding manufacturing operation. There are smooth transitions between various parts of 3D surfaces, exhibiting different slopes and characters, depending on the surface complexity (Kroft, *et al. 2015*).

The parallel finishing strategy creates passes in the XY plane as the tool follows the model surface design in the Z axis. An angle of 45 degrees has been applied for the pass direction. The tool moves continuously while finishing the surface. Scallop finishing sometimes also called constant step over finishing, creates passes that are at a constant distance in 3D space in the machining surface. Radial toolpath cuts radial spokes out from a center point. In our case the spokes are arrayed with equal space for 1.9 deg angular steps. Pencil operation creates toolpaths in corners and fillets with small radius.

A table with the data being used for 3D finishing is following along with output data (table 3). The tool that is going to be used for finishing is the ball nose with 4mm diameter.

Table 2: Finishing conditions

Strategy	Spindle Speed [rpm]	Maximum Feed rate [mm/min]	Surface Speed [m/min]	Feed per revolution [mm]	Maximum Stepover [mm]	Angular Step [deg]
Parallel	14000	900	175.929	0.0142857	0.88	
Scallop	14000	900	175.929	0.0142857	0.95	
Radial	14000	900	175.929	0.0142857		1.9
Pencil	14000	900	175.929	0.0142857	0.94	

Table 3: Finishing data output

Strategy	NC program [kb]	Feed Distance[mm]	Rapid distance [mm]	Feed time [h:mm:ss]	Tool Change time [h:mm:ss]	Estimated Cycle Time CAM [h:mm:ss]	Real time Machining [h:mm:ss]
Parallel	275.5	10916.5	0	0:12:08	0:00:15	0:12:25	0:12:25
Scallop	403.4	11255.1	49.844	0:12:30	0:00:15	0:12:35	0:12:35
Radial	279.2	10867.1	43.644	0:12:20	0:00:15	0:12:35	0:12:35
Pencil	1040	10744.7	403.845	0:11:58	0:00:15	0:12:28	0:12:28

According to table 3, strategies have been optimised so they have the same machining time, close to 12minutes for everyone. The tool has been defined to move in both directions, conventional and climb in all operations. The retraction policy has been set in full retract mode for scallop, radial and pencil strategy and shortest path for parallel. A maximum stay-down distance of 5mm has been also defined for all operations. As a result of those parameters, feed distance which is the length of the cutting movement is greater in scallop strategy and minimum in the pencil. Parallel strategy has zero rapid distance and pencil the greater.

2.2. PROTOTYPING

The Roland MDX-40a desktop machine has been used for this study. Two different kinds of NC codes have been extracted from the Autodesk Fusion CAM software one for the roughing operation and one for each of the finishing strategy. NC code is loaded in the Roland Machine through VPanel which control the CNC machine. The NC code has been extracted using a post processing file from the Autodesk Fusion database and has been evaluated for the compatibility with the Roland CNC desktop machine.

Figure 3: Physical model after roughing operation

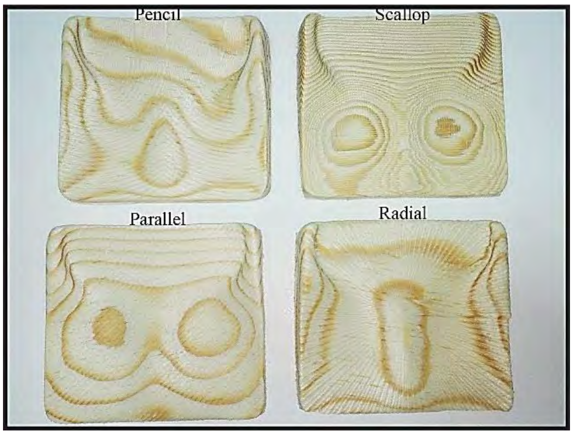

Figure 4: Physical model after finishing operations

In Fig. 4 there are the four machining samples, in roughing phase where all samples are machined with the same way. In finishing phase for each sample a different strategy is selected, Pencil, Scallop, Parallel and Radial. After the sample production we are going to measure the machined surface roughness with the use of roughness tester in four different areas in each sample. In order to have better results we are going to measure the selected areas in two directions, horizontally and vertically. Totally we will get thirty-two

(32) different measures in order to evaluate the surface quality that can be produced for each finishing strategy.

3. RESULTS

As we see above all finishing techniques almost needs the same machining time for each sample. At a first glance Radial finishing technique seems to have better quality surface in the center of the model and roughly enough at corners. Although stepover parameter in the parallel strategy is minimum (0,88mm) from the others, however it doesn't seem to produce better quality surface.

After the machining process finished we take a careful check to the samples to see if there is any unexpected effect. After that we have to check the surface roughness with the tester. Firstly, we have to calibrate the tester with the use of a calibrated plate. Then we have to decide in which model areas we will select to measure the roughness. Because of, the samples are symmetrical in vertical axis we choose four areas to check, two in the front and two to the back of the upper half surface (Fig. 5). The four selected areas are two on the front: i) First Area, ii) Second Area, and two in the back: iii) Area three and iv) Area fourth

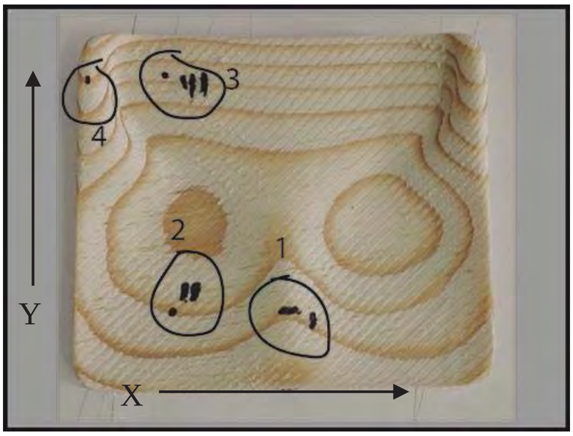

Figure 5: Physical model after finishing operation with selected areas

Figure 6: Physical model during the roughness test

In figures 7 and 8 are presented the results of roughness profile for each sample in *area 1* in vertical direction (Y axis). In figures 9 and 10 are presented the results for *area 1* in the horizontal direction. In table 4 are presented the whole results for *area 1*.

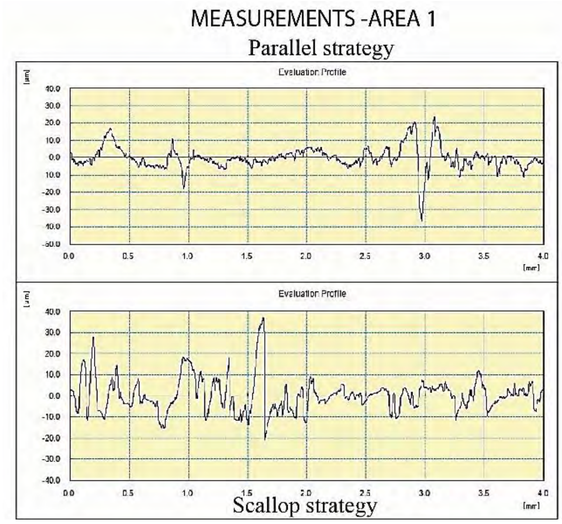

Figure 7: Roughness profile in area 1in vertical direction for parallel and scallop strategies

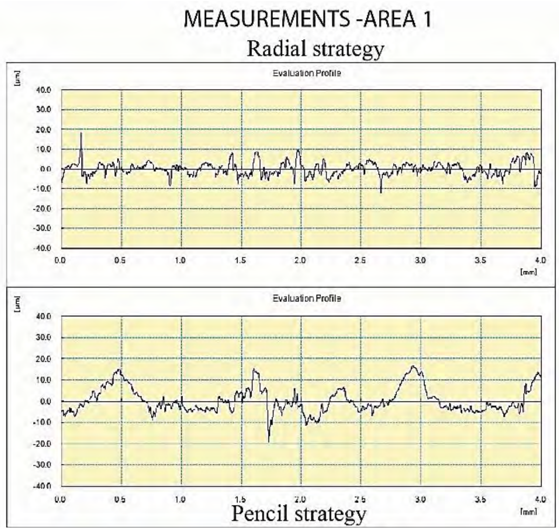

Figure 8: Roughness profile in area 1in vertical direction for radial and pencil strategies

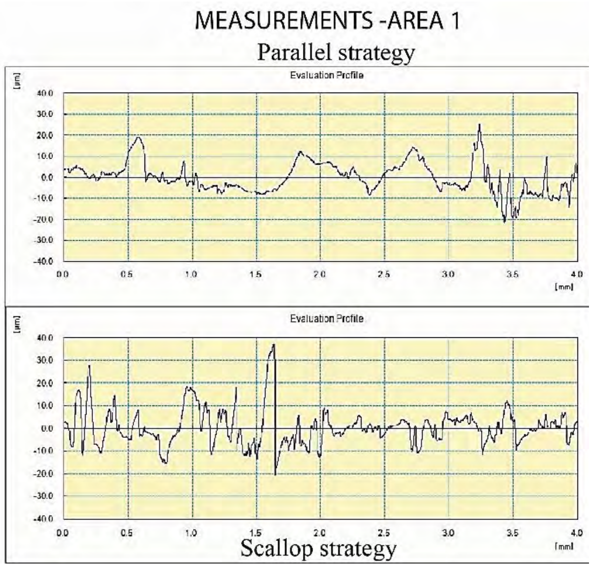

Figure 9: Roughness profile in area 1in horizontal direction for parallel and scallop strategies

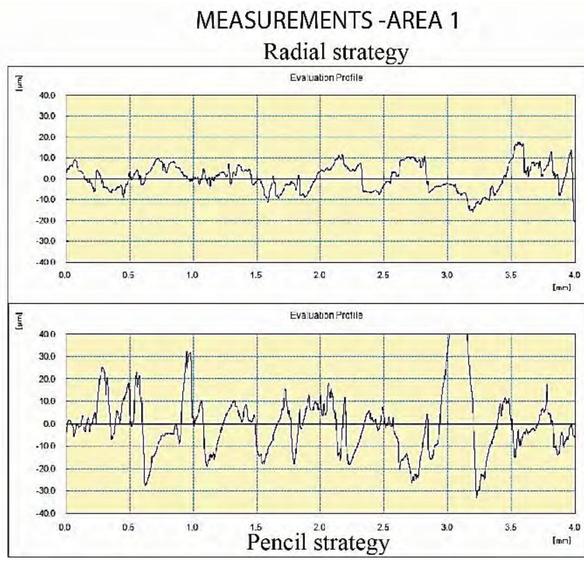

Figure 10: Roughness profile in area 1in horizontal direction for radial and pencil strategies

Table 4: Results of roughness parameters for measuring area no1,

	y –axis measurements			x –axis measurements		
Strategy	**Ra [μm]**	**Rq [μm]**	**Rz [μm]**	**Ra [μm]**	**Rq [μm]**	**Rz [μm]**
Parallel	4.212	5.760	28.517	5.680	6.996	25.775
Scallop	9.145	11.386	46.291	5.649	7.543	38.070
Radial	2.529	3.205	19.214	5.252	6.139	24.889
Pencil	4.630	5.803	24.559	10.526	13.756	54.883

In figures 11, 12 are presented the results of roughness profile for each sample in *area 2* in vertical direction (Y axis). In figures 13, 14 are presented the results for *area 2* but in the horizontal direction. In table 5 are presented the whole results for area 2.

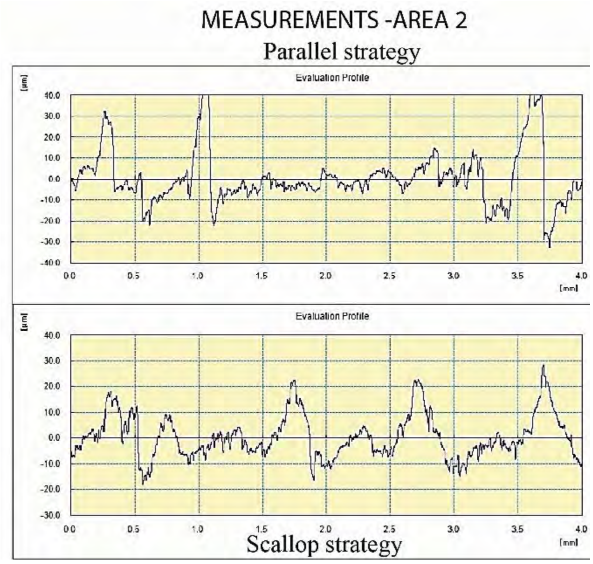

Figure 11: Roughness profile in area 2 in vertical direction for parallel and scallop strategies

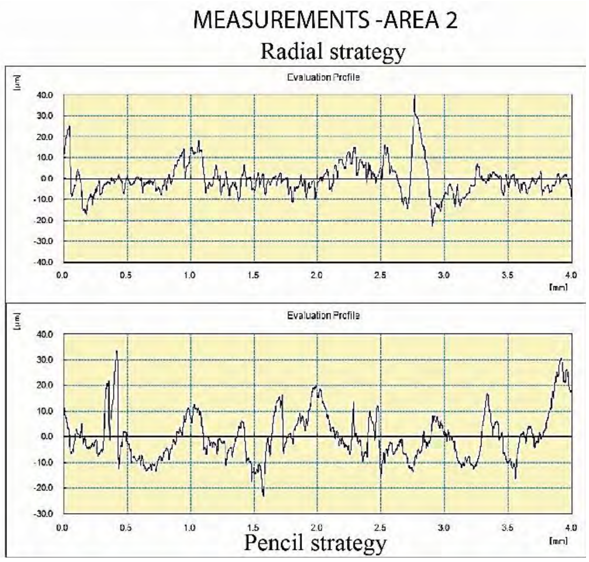

Figure 12: Roughness profile in area 2 in vertical direction for radial and pencil strategies

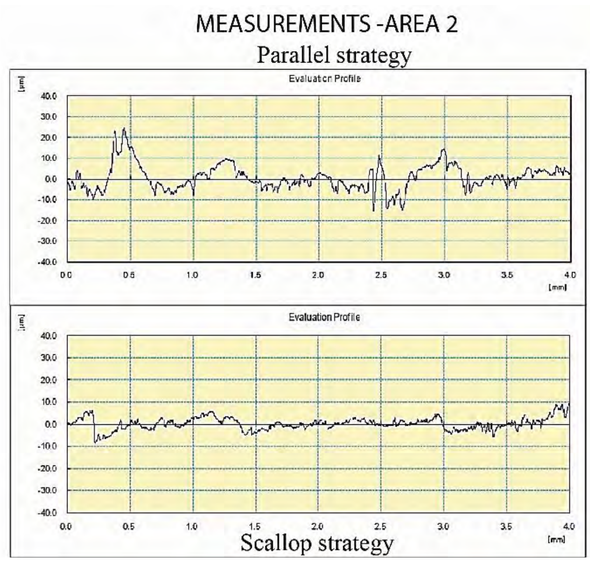

Figure 13: Roughness profile in area 2 in horizontal direction for parallel and scallop strategies

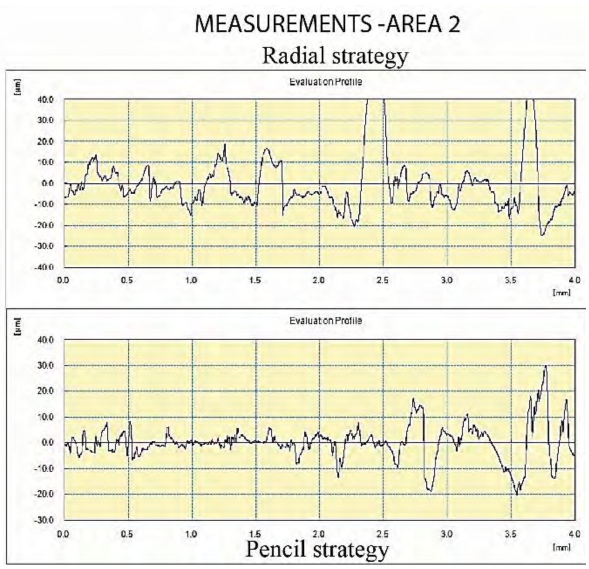

Figure 14: Roughness profile in area 2 in horizontal direction for radial and pencil strategies

Table 5: Results of roughness parameters for measuring area no2

	y –axis measurements			x –axis measurements		
Strategy	**Ra [µm]**	**Rq [µm]**	**Rz [µm]**	**Ra [µm]**	**Rq [µm]**	**Rz [µm]**
Parallel	8.799	11.599	49.785	4.583	5.586	21.102
Scallop	6.550	8.272	33.343	2.070	2.623	11.011
Radial	5.432	7.117	35.771	9.063	12.333	50.503
Pencil	7.224	9.163	37.330	4.431	5.732	26.230

In figures 15, 16 are presented the results of roughness profile for each sample in *area 3* in vertical direction (Y axis). In figures 17, 18 are presented the results for *area 3* but in the horizontal direction. In table 6 are presented the total results for area 2.

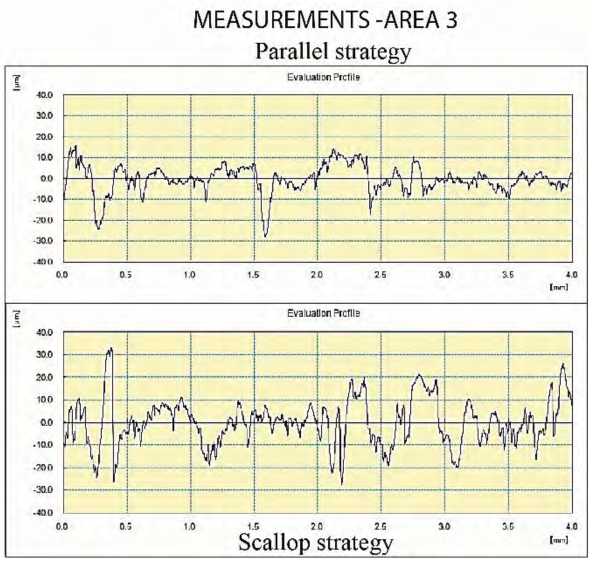

Figure 15. Roughness profile in area 3 in vertical direction for parallel and scallop strategies

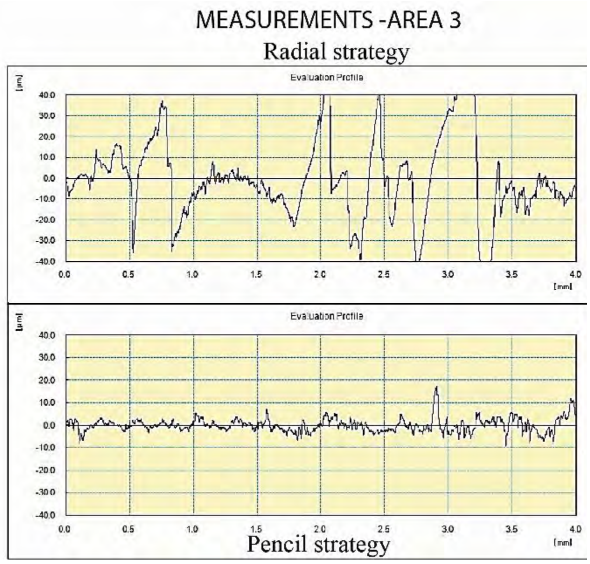

Figure 16. Roughness profile in area 3 in vertical direction for radial and pencil strategies

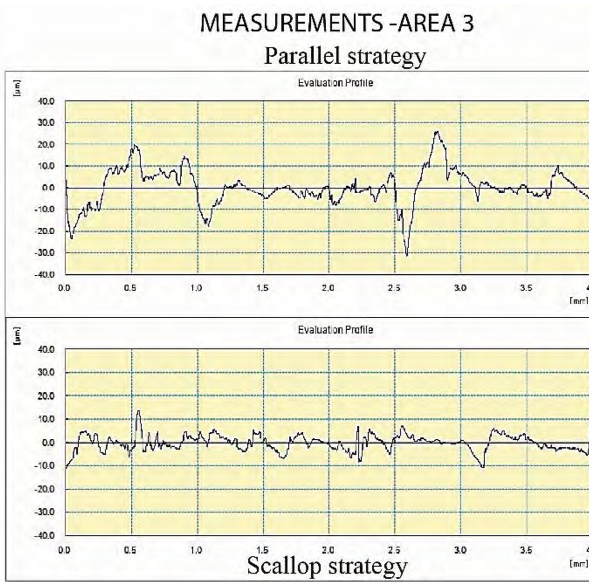

Figure 17: Roughness profile in area 3 in horizontal direction for parallel and scallop strategies

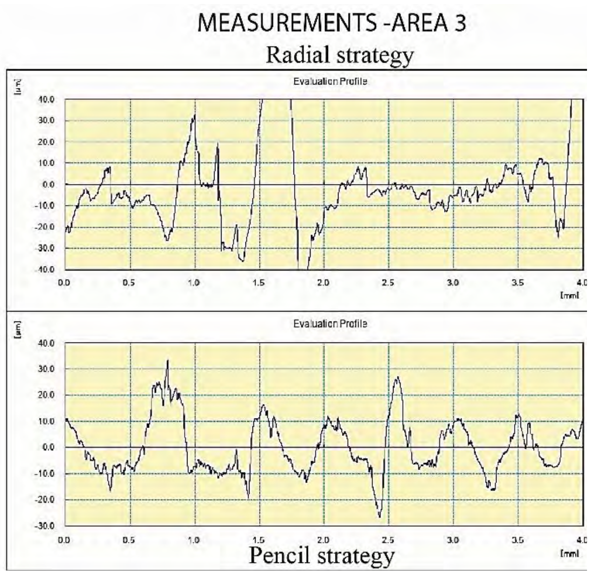

Figure 18: Roughness profile in area 3 in horizontal direction for radial and pencil strategies

Table 6: Results of roughness parameters for measuring area no3

	y –axis measurements			x –axis measurements		
Strategy	**Ra [μm]**	**Rq [μm]**	**Rz [μm]**	**Ra [μm]**	**Rq [μm]**	**Rz [μm]**
Parallel	4.676	6.253	31.482	5.899	7.396	32.526
Scallop	7.901	10.066	44.072	2.647	3.381	15.872
Radial	14.877	20.233	90.372	14.192	19.080	71.424
Pencil	2.237	2.939	15.638	8.461	10.069	41.738

In figures 19, 20 are presented the results of roughness profile for each sample in *area 4* in vertical direction (Y axis). In area 4 the surface curvature was too big to measure the roughness in horizontal direction (X axis). In table 7 are presented the roughness results in vertical direction for *area 4*.

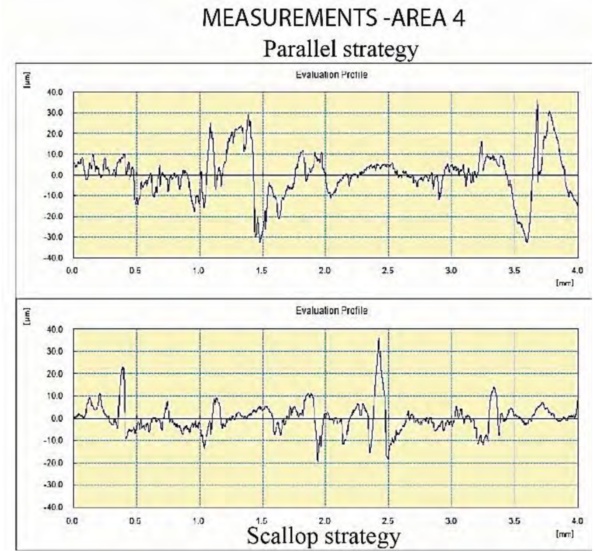

Figure 19: Roughness profile in area 4 in vertical direction for parallel and scallop strategies

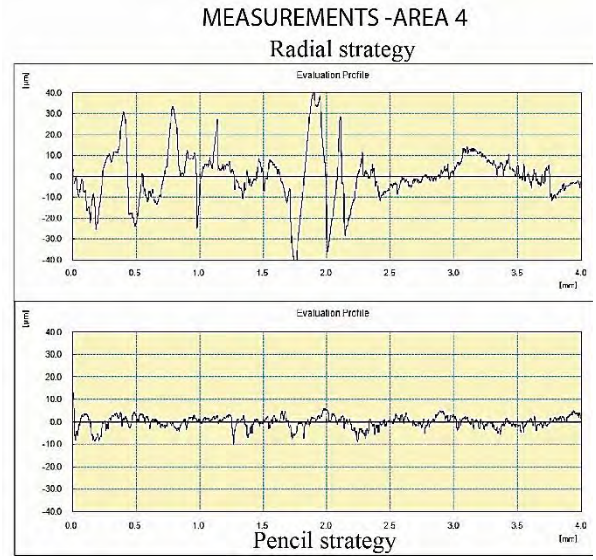

Figure 20: Roughness profile in area 4 in vertical direction for radial and pencil strategies

Table7: Results of roughness parameters for measuring area no4

	y –axis measurements		
Strategy	**Ra [μm]**	**Rq [μm]**	**Rz [μm]**
Parallel	7.637	9.490	41.279
Scallop	4.272	6.108	35.014
Radial	8.770	11.107	50.073
Pencil	2.008	2.593	14.134

4. CONCLUSIONS

Very often design engineers have to decide which the appropriate strategy is during machining process. For roughing process, the selected strategy is not very crucial for the quality of the surface because most of times follows the finishing process. In the other hand for finishing process the selected strategy is a very crucial decision because it depends the quality of final surface. Modern CAD/CAM programs like Fusion 360 offer couple of strategies for the finishing stage. Four different strategies are available, pencil, parallel, radial and scallop. In current study we had to decide which the appropriate strategy is for the production pf a very common model in furniture industry. We choose an ordinary wood material the Black pine wood and for the machining process we use the Rolland MDX 40-A 4/axis Rapid Prototyping (RP) milling machine. For the machining process we set same constrains for all strategies. The first constrain is the machining time, all process's had to finish in twelve (12) minutes, also we set the same tools in all process's.

The main criteria in order to select the best strategy is the roughness of the machining surface. So, we measure the surface roughness in four different areas in two directions horizontal and vertical with the use of tester Mitutoyo Surftest SJ-210. The surface roughness measured though of three different roughness parameters, Ra – Arithmetical mean roughness value, Rq – Root mean squared and Rz-Mean roughness depth with Ra to be the most important. From the results important conclusions come off. On *area 1* the minimum Ra value occurs with pencil strategy in vertical direction. In horizontal direction the scallop and radial technique are very close with radial to have the min value again. On area 2 in vertical direction the min Ra value was measure with radial technique but in horizontal direction in the minimum value was measure in scallop technique. On area 3 in vertical direction the minimum Ra value was measure with pencil technique but in horizontal direction in the minimum value was measure in scallop technique. On area 4 in vertical direction the minimum Ra value was measure with pencil technique.

In conclusion on much curved surfaces, like areas 1 and 4, radial and pencil techniques have much better surface quality. On a more planner surfaces, like areas 2 and 3, scallop and pencil techniques has better surface quality. Engineer must identify the most critical area of the machining part in order to select the most appropriate strategy for better finishing results. For further research it would be very interested to measure the surface roughness on the surface on different kinds of wood of different wood hardness.

REFERENCES

CIRAD. 2017. Technical properties of European pine wood.

GOK, A., GÖK, K., B. BILGIN, M., & A. ALKAN, M. 2017. Effects of cutting parameters and tool-path strategies on tool acceleration in ball-end milling. Materiali in tehnologije (Vol. 51). https://doi.org/10.17222/mit.2017.039.

KRIMPENIS A., N. A. FOUNTAS, T. MANTZIOURAS, AND N. VAXEVANIDIS. 2014. Optimizing CNC wood milling operations with the use of genetic algorithms on CAM software.

KROFT L., J. HNATÍK, AND K. BÍCOVÁ. 2017. The Effect of the Strategy of Finishing on Dimensional Accuracy.

MISRA D., V. SUNDARARAJAN, AND P. K WRIGHT. 2003. Zig-Zag Tool Path Generation for Sculptured Surface Finishing, vol. 67.

MWINUKA, T. E., AND MUSSA MGWATU. 2015. Tool Selection for Rough and Finish CNC Milling Operations Based on Tool-Path Generation and Machining Optimisation. Vol. 10. https://doi.org/10.14743/apem2015.1.189.

SAGLIO, E., MANDORLI, F., & CUGINI, U. 1994. Super-finishing tool path generation for digitized models supported by super-finishing form feature recognition.

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