PRELIMINARY INVESTIGATIONS UPON THE INFLUENCE OF CNC MILLING STRATEGY ON HARDWOOD SURFACE PARAMETERS

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Abstract: *Manufacturing of high precision parts in small and medium batches is more and more accessible nowadays due to the use of CNC machines. The present study aims to analyze the influence of machining strategies upon the surface parameters and dimensional accuracy of hardwood parts. For the experimental investigations, several circular and rectangular pockets were milled on the surface of a beech wood blank by aid of a calibrated home-made CNC router, using three different tool-path strategies. Surface parameters were evaluated optically, while geometric and dimensional accuracy was determined by aid of a Coordinate Measuring Machine (CMM). The cutting regime and the wood fibers orientation were maintained the same for all considered situations. All the cutting operations were made with a 4mm milling cutter and a 40% overlapping of the passes was imposed in all cases. The influence of wood fiber orientation by report to cutting trajectory was also investigated.*

Keywords: *CNC, milling strategy, hardwood, surface parameters*

1. Introduction

At present, manufactured parts must comply with strict conditions regarding surface quality and dimensional precision. These requirements are no longer so difficult to achieve by using Computerized Numerical Control (CNC) machining. Such equipment are usually produced by specialized companies, but due to large scale availability of the main components, they can also be “home-made”. It is however true that home-made CNCs are mostly suitable for the production of a relatively small number of parts, as they require more often recalibration, depending on the processed material and the process parameters. The calibration can be done using direct methods such as the ones presented in [Khan 2009], [Hazir 2019], which take into account the quantification of errors on dependent and independent parameters. From a construction point of view, the accuracy of the machine can be increased by increasing the frame rigidity, the precision of the guiding elements and the use of stepper motors with higher resolutions to drive the axles.

Several studies can be found in literature that investigate the influence of cutting parameters on roughness, both in metal and wood parts, [Selvam 2012], [De Deus 2015], [Sütçü 2013] , [Bal 2020], [Koc 2017]. These studies take into account variations of the main cutting parameters such as feed rate, cutting depth, speed, degree of overlap between passes, etc. Generally, such studies are carried out using a complete Taguchi operation plan, and it was determined that surface quality increases with the decrease of the feed rate and the depth, combined with an increase of the machining speed.

Studies regarding the construction and performances of home-made CNCs are also present in literature, such as [Pahole 2009], where a static rigidity analysis is conducted as well as a positioning accuracy analysis over the whole surface of the worktable, or [Wei 2013], where the construction of small CNC milling machines is described.

The present study uses confocal microscopy in order to investigate the surface parameters resulted from machining of rectangular and circular pockets in beech hardwood blanks. The machining was performed using a home-made CNC router further described in the paper. The cutting tool used for the present study was a roughing 2-teeth milling cutter with a 4 mm round head, made from AK44 carbide with a hardness of 92.5 HRA and a cobalt content of 10%.

The considered pockets were machined using various tool-paths, while maintaining the same cutting regime parameters. Calibration of the CNC axle drives was conducted prior to the experiments.

2. Experimental equipment

For the present study, a home-made CNC router was used. The machine was designed for milling and engraving operations conducted on wood and aluminum parts.

Figure 1 *CNC router components*

As shown in Fig 1, the router presents a sturdy frame made from a thick aluminum sheet, on which the stepper motors (4) are attached. These motors are used to drive the mobile tool holder (11). The linear motion of the tool is obtained by means of ball screws (5). The tool holder motion is guided by means of linear bearings (7) and precision rods (6). The CNC router uses a 1.5kW air-cooled spindle motor (1). This allows the use of tweezers for cutters (2) up to 8mm. On the machine frame, an MDF plate, (9), was fixed and used as worktable. In order to attach hold the hardwood blanks on the worktable, a fixing device, (10) was used.

The spindle motor is controlled by a computer (12), and a frequency converter (13), which allows tool speeds ranging from 0 to 20000 rpm.

3. Methodology and results

In order to ensure good dimensional and shape accuracy of the machining, a calibration of the three stepper motors 57BYGH115-003 with 200 poles, 3A used by CNC was performed. For said calibration, an electronic dial indicator with a 1μm accuracy, placed in a magnetic holder, as shown in Fig.2, was used. Measurements were conducted to determine the precise number of steps per mm, made by the stepper motors, in order to optimize distances travelled along each axis, as well as by imposing the respective speeds and optimal accelerations.

In determining optimal speeds and accelerations for each axis, the free version of Match3 software was used. For the present study, rectangular and circular pockets were machined in beech wood blanks. It should be noted that the fiber direction of the blank was maintained parallel to the X axis of the CNC for all processing. This, together with imposing of the cutting strategy, in terms of tool-path and constant maintenance of the working regime, were considered in order to highlight the influence of adopted wood fiber orientation and tool-path on surface quality.

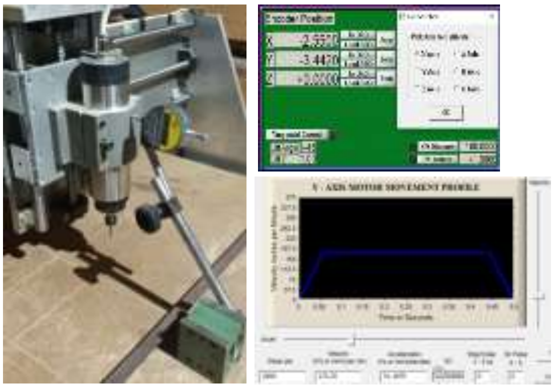

Figure 2 *Stepper motor calibration*

In the case of rectangular pockets, three tool-paths were considered, as illustrated in Fig. 3: "Contour", "Zig" and "Zig-Zag". The G code for all machining was generated using the NX software. The regime parameters were maintained constant, as follows: Spindle speed - 18000[rpm], Speed - [226m/min], Feed - 300[mm/min] and Step down - 0.5[mm], with a 40% overlapping of passes.

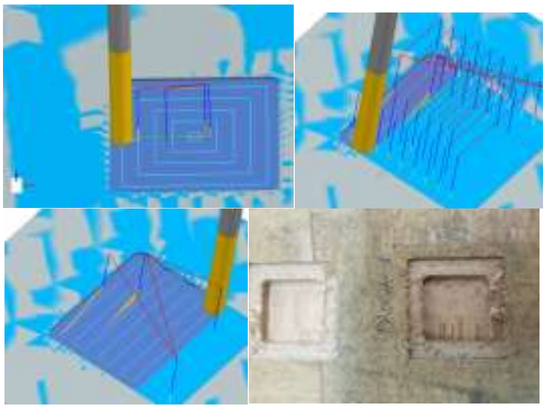

Figure 3 *Rectangular pocket*

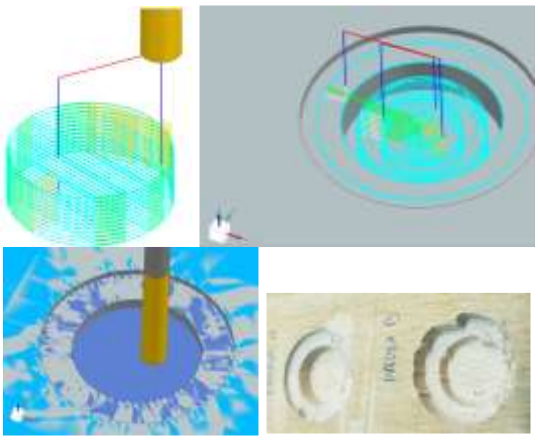

Figure 4 *Circular pocket*

For the considered pockets, an initial roughing was performed over a larger area, in order to eliminate any irregularities of the blank surface. The same procedure was respected for the circular pockets, Fig. 4.

For the circular pockets, however, only Contour and Zig-Zag tool-path strategies were considered.

The obtained pocket's surfaces were optically investigated using a MarSurf CWM100 confocal microscope, Fig. 5.

Figure 5 *Confocal MarSurf CWM 100 Microscope*

Profile roughness parameters Ra and Rz, as well as surface roughness Sq were measured over a 1.5×2mm area in the central region of the obtained pockets.

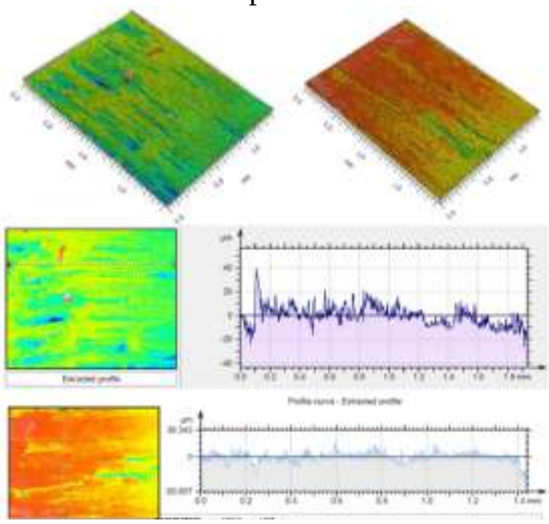

Figure 1 *Profile and surface roughness*

3D representations of surface micro-topography as well as roughness profiles are shown in Fig.6 for two samples, one measured inside a rectangular pocket and the other in a circular one.

The obtained measurements showed some material tears along the harder wood fibers. The obtained surface parameters were synthesized in Table 1, and several conclusions were drawn on the basis of these results.

Table 1: Summary data

Tool path	Sq [µm]	Rz [µm]	Ra [µm]	Pocket type
Contur	12,560	23,691	4,1417	rectangular
Zig	16,487	27,659	5,0852	rectangular
Zig-Zag	12,355	21,794	4,0981	rectangular
Contur	14,719	20,204	3,5569	circular
Zig-Zag	11,371	18,555	3,3673	circular

4. Conclusions

Although the experimental data showed a relatively small influence of the tool-path strategy upon the measured roughness parameters values in most cases, a decrease in roughness could be observed when a “zig-zag” tool-path is employed;

Fiber orientation by report to the machining direction was found to influence the surface parameters;

Some material tears were observed along the fibers, both in the processing of circular and rectangular pockets, regardless of the tool trajectory, probably due to variations in the wood structure;

The obtained surface finishes showed overall surface parameters that can be considered acceptable for the use of a homemade CNC router.

ACKNOWLEDGMENT

This work was supported by Romania National Council for Higher Education Funding, CNFIS, project number CNFIS-FDI-2021-0357.

This paper has been financially supported within the project entitled "DECIDE-Development through entrepreneurial education and innovative doctoral and postdoctoral research", project code POCU/380/6/13/125031, project co-financed from the European Social Fund through the 2014–2020 Operational Program Human Capital.

References

1. [Selvam 2012] Selvam, M. D., Dawood, D. A. S., & Karuppusami, D. G. (2012). Optimization of machining parameters for face milling operation in a vertical CNC milling machine using genetic algorithm. IRACST-ESTIJ, 2(4).;
2. [Khan 2009] Khan, A. W., & Chen, W. (2009, February). Calibration of CNC milling machine by direct method. Proc. Of SPIE Vol. 7160, p. 716010, https://doi.org/10.1117/12.807066;
3. [Pahole 2009] Pahole, I., Rataj, L., Ficko, M., Klancnik, S., Brezovnik, S., Brezocnik, M., & Balic, J. (2009). Construction and evaluation of low-cost table CNC milling machine. Scientific Bulletin Series C: Fascicle Mechanics, Tribology, Machine Manufacturing Technology, 23, 143.
4. [De Deus 2015] De Deus, P. R., de Sampaio Alves, M. C., & Vieira, F. H. A. (2015). The quality of MDF workpieces machined in CNC milling machine in cutting speeds, feedrate, and depth of cut. Meccanica, 50(12), 2899-2906.
5. [Kilic 2006] Kilic, M., Hiziroglu, S., & Burdurlu, E. (2006). Effect of machining on surface roughness of wood. Building and environment, 41(8), 1074-1078.
6. [Sütçü 2013] Sütçü, A., & Karagöz, Ü. (2013). The influence of process parameters on the surface roughness in aesthetic machining of wooden edge-glued panels (EGPs). BioResources, 8(4), 5435-5448.
7. [Bal 2020] Bal, B. C., & Gündeş, Z. (2020). Surface roughness of medium-density fiberboard processed with CNC machine. Measurement, 153, 107421.
8. [Koc 2017] Koc, K. H., Erdinler, E. S., Hazir, E., & Öztürk, E. (2017). Effect of CNC application parameters on wooden surface quality. Measurement, 107, 12-18.
9. [Wei 2013] Wei, Q. (2013). Design and analysis of a small-scale cost-effective CNC milling machine.
10. [Hazir 2019] Hazir, E., & Ozcan, T. (2019). Response surface methodology integrated with desirability function and genetic algorithm approach for the optimization of CNC machining parameters. Arabian Journal for Science and Engineering, 44(3), 2795-2809.