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Practical Applications Performed by a Stepper Motor CNC Router

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Abstract

In the machine tool construction industry, the necessity to manufacture geometrically complex parts and also the need to serially produce in an alert manufacturing rate imposed the use of the CNC machines tools at a larger scale.

The present paper displays the design and manufacturing of a milling CNC machine tool made by patterned and confectioned elements.

The practical manufacturing of the components demanded accurate machining operations that have been executed with the support of the company UZTEL Ploiesti, an oil equipment manufacturer which possesses all the resources to accomplish these mechanical tooling operations.

Key words: *router, CNC, stepper motor*

Introduction

A CNC machine tool that makes translational movements on all the three axis of the Cartesian system (X, Y, Z) is known as a router.

The CNC machine tools present different structures (construction configurations) depending to the mechanical operations they can perform (turning, milling, drilling), but their functional principle is common. A CNC machine tool is basically made of the actual machine tool and the numerical control equipment which interact one to the other through the actuating system and the information collecting system (sensors, transducers) [4].

In practice there are two process control principles [3]:

- closed loop – when the control equipment (computer, PLC) receives information's regarding the consequences of its actions on the machine tool;
- open loop – when no information is received about the displacements made by the machine tool (there is no feedback).

For this project, the second controlling method was chosen and for implementing this driving procedure, the use of the stepper motor actuation was needed [1]. The stepper motors are DC motors which require a more complicated driving than the conventional motors, but which offer the advantages of a better accuracy and the lack of a displacement checking system (it only needs an open loop control system), because the positioning error is not accumulative (it doesn't increment with every step). This actuating method is practicable for the smaller machine tools, but also as a solution for modernizing conventional machine tools and transforming them into pretty efficient CNCs.

Settling the Constructive Method

Certainly, an industrial CNC contains complicated and performant actuating systems, but they are also expensive, while the stepper motor actuating is much more affordable for an enterpriser who has a lower financial power, but still offering good technical performances and a high reliability due to the simplicity of the system. Another advantage is that the stepper motor systems do not demand adjustments, which are required for the servomotors and that sometimes involve difficult operations.

As for the performances, the precision (the positioning accuracy) and the reproducibility of a stepper motor CNC are close to the ones of an industrial CNC using servomotors. The accuracy of a stepper motor CNC machine can get up to 0,0001 mm [6], due to the lack of the inertia, being from this point of view superior to the more “performant” method that uses servomotors.

The differences emerge at the displacement speed and at the acceleration, where the performant servomotors are superior. For example, the speed of movement for an industrial vertical machining centre can reach 40 m/min, relative to a maximum of about 10 m/min for a stepper CNC [9]. The problem for the stepper motors is the low revolution speed at which they can work, as while the spinning speed increases, the torque decreases. Therefore, in order to achieve high displacement speeds, compromises regarding the accuracy and the torque must be made. Usually, high movement speeds are necessary for the cutting machine tools (plywood, MDF, wood, glass sheets, metal plates) where a precision of tens of a millimeter is acceptable.

The stepper motors are limited [8] from the dimensional point of view, because their performances increase proportional to the dimensions up to a point where they start decreasing (at a bigger stepper motor the torque decreases more precipitous once the rotational speed increases). Therefore a bigger motor might have a reduced torque than a smaller motor at the same speed [9].

Functionally, the routers have the role of accomplishing simultaneous translational movements on all the 3 axis of the Cartesian system. From the structural point of view, the routers do not essentially differentiate one form another, but the differences appear when choosing the elements that realize the movement. So, the work-table might be fixed or mobile on one up to 3 axis [8]. Each constructive method has its advantages and disadvantages, especially regarding the stiffness of the structure and the dimensions of the working space [10].

The rigid structure represents the frame on which all the guiding and actuating systems and also the work-table are mounted to. It is usually made-up by stiff material plates or by special metal profiles [12]. The rigid structure is divided into three subassemblies (one for each axis –fig. 1) and also the board which will hold the tool.
For the present project, the rigid structure is made up by polyethylene boards having the width of 196 mm and the length of 3000 mm, cut-out on a Daewoo Puma vertical machining centre with the support of UZTEL Ploiesti.

The guiding system has the role of maintaining the axis assembly onto the direction of the Cartesian system axis, very important being the perpendicularity between the axes. The requirements imposed to this system are to guide the assembly onto o direction as close as possible to the ideal one (having as low deviations as possible from the axis linearity) and to realize the movements with low friction, so the actuating effort is as reduced as possible.

The actuating system is composed by the motor and the lead screw–actuating nut assembly.

The embraced motor is a stepper one. The threaded rod turns being rotated by the motor and sustained at its ends by radial bearings. The nut is being fixed onto the holding plate of the corresponding axis.

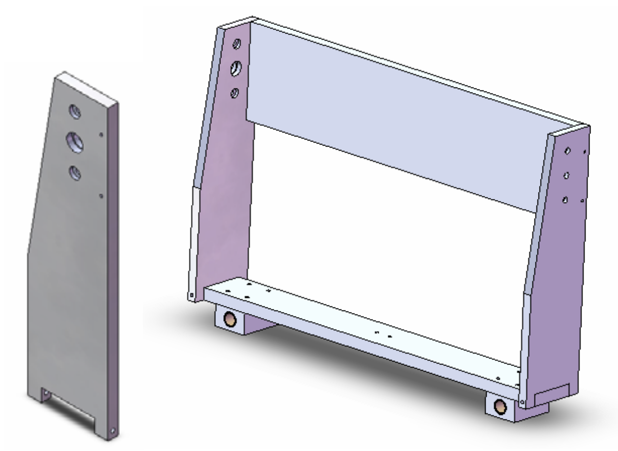

Fig. 1. The X axis rigid structure assembly.

The design of the mechanical structure started by choosing the actuating and guiding solutions (and obtaining the composing elements) [15], [16]:

- *The stepper motors* together to the *transmission systems* (gears, pulleys and transmission belts) and the *motor holders.* The motors make 200 steps/revolution, so they have a resolution of 1,8° which can be reduced to 0,9° by half-step driving [4].
- As *lead screws* the following were purchased: one M16 threaded rod for the Y axis and two M12 threaded rods for the X and Z axis.
- *The guiding shafts* were bought in the following configuration: two pieces having the outside diameter of 20 mm and the length of 0,8 m for the Y axis and two pieces having the two of 16 mm at a length of 1 m for the X and Z axis.
- *The bushings* (6 pieces) have been manufactured by turning, made out by bronze, with the support of UZTEL Ploiesti. The two bushings for the Y axis have the inside diameter of 20 mm and the other four bushings (for the X and Z axis) have the ID of 16 mm.
- *The radial bearings* were bought from specialized shops; 9 bearings were needed: 6 for the threaded rods ends and 3 for stiffening the structure by adding an auxiliary gliding system [2], [14].
- *The work-table* is made-up by polyethylene and it was the one that actually determined the size of the machine tool. The obtained plate's size is 624x824 mm. For holding the machined pieces, 48 equally distanced holes were practiced into the upper face of the work-table. Into the holes, bushings threaded on the inside and also on the outside were screwed in place.
- *The rigid structure* is also made of polyethylene, out of profiles having the width of 196 mm and the length of 3 m.
- For hitching the pieces onto the table, two *straps* were made out by milling, also at UZTEL Ploiesti. The two elements can be fitted into the threaded bushings on the work-table and allows adjustments on the height and also on the depth.
- *The mill* is represented by an Einhell BGS135 dremel and its holder which was manufactured at UZTEL Ploiesti.

The whole project started by designing the machine in 3D (fig. 2) in the Solid Works 2007 software. The pieces were designed by maintaining the dimensions of the work-table plate.

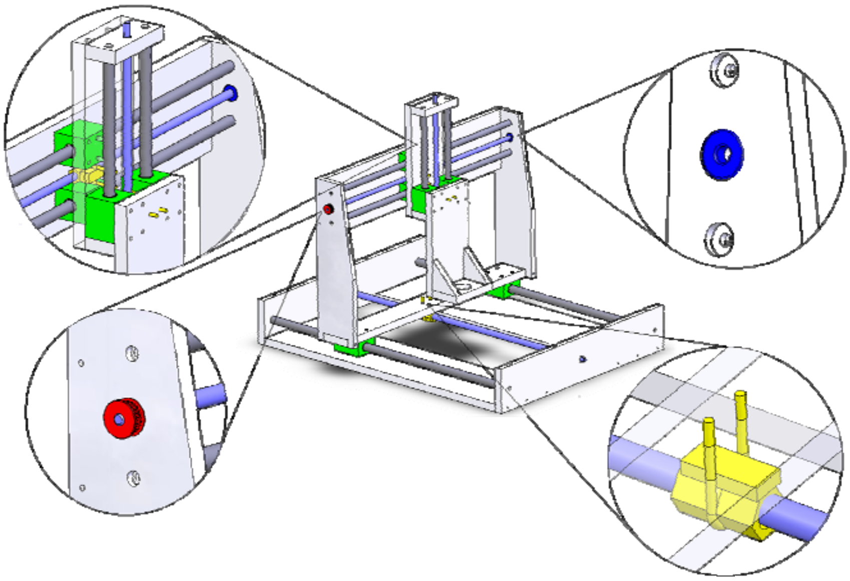

Fig. 2. The 3D CAD model of the RouteCAM SM-01 router performed in Solid Works 2007.

By building the 3D CAD model of the machine tool (fig. 3) some deficiencies (that could badly influence the router's functioning or could have made the assembling operations mode difficult or impossible) were observed and corrected from the designing stage. After finishing the 3D CAD model and studying the behavior form the cinematic point of view, by virtually making the displacements onto the axes, the manufacturing drawings for the component parts were executed (fig. 4).

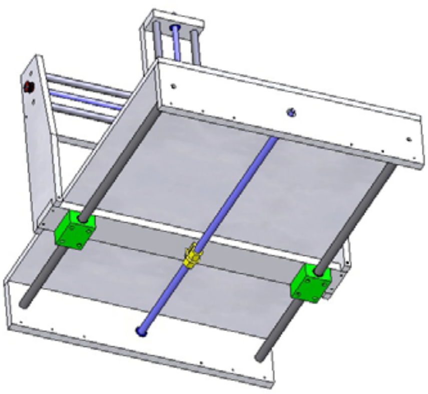

Fig. 3. CAD model.

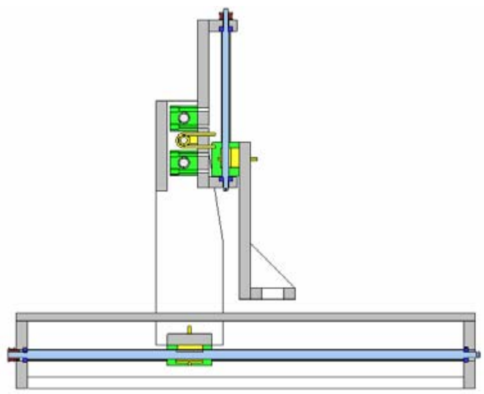

Fig. 4. Section through the CAD model of the machine tool.

Assembling the Components and Finalizing the Project

Once all the components were purchased and machined, the assembling could be performed, step in which unexpected situations emerged that demanded practical solutions.

It is mandatory that the mounting starts from the Z axis assembly, continues with the X axis and closes with the Y axis assembly, because the mounting of the guiding shafts and bushings must be made simultaneously to the assembling of the rigid structure plates. In order to eliminate the axial clearance between the lead screw and the nut (that translates in a backlash), it was needed to insert a counter nut that was tightened against the actuating nut, until the backlash was cleared and after that the two nuts were welded together in two diametrically opposed points.

A running-in of the screw-nut and guiding shafts-bushings assemblies was performed after the mounting was finished, using graphite lubricant, by spinning the screws with an electric driller.

After finishing the assembling of the whole structure, the stepper motors were mounted onto the rigid structure through the metallic holders that were fitted with M4x30 mm screws (fig. 5).

Fig. 5. The X and Z stepper motors fitted onto their holders.

Fig. 6. The X axis stiffening system.

Because during the assembling it was observed that the rigidity of the structure was not good enough (fig. 6), some stiffening elements were added (metallic angle brackets were mounted between the X axis holding plate and the side panels, in order to maintain the 90° angle when the stress arises; 25x25 mm iron edge profile was fitted on the X axis holding plate to stiffen it and to avoid its bending that would lead to the non-parallelism between the X axis side plates).

A system that increases the rigidity was added because it was remarked that the X axis guiding shafts bended under the forces that would act on the tool. The system (fig. 7) is consisted of radial bearings fitted on the X axis bushing housings (two on the upper surface and one on the lower one). The bearings roll along 20x20 mm aluminum edge profile. The system keeps a constant distance between the bushing housings and the back stiffening plate and in order to ensure the possibility to adjust this distance, the bearings are fitted with screws through bushings that have the hole excentric to the outer diameter. Using this adjustment, one can ensure a pre-tensioning that is small enough to not make the movement difficult.

Fig. 7. Tool-holding system (with the possibility to adjust the position).

Once the assembling of the mechanical parts was finished, the electrical parts could be mounted and wired (fig. 8):

- installing the sensors that sense the limits of the working strokes and installing the connecting wires;

- installing the motors and their connections to the controller board;
- fitting the ultra bright LED used for lightening the machined part and connecting it to the power source;

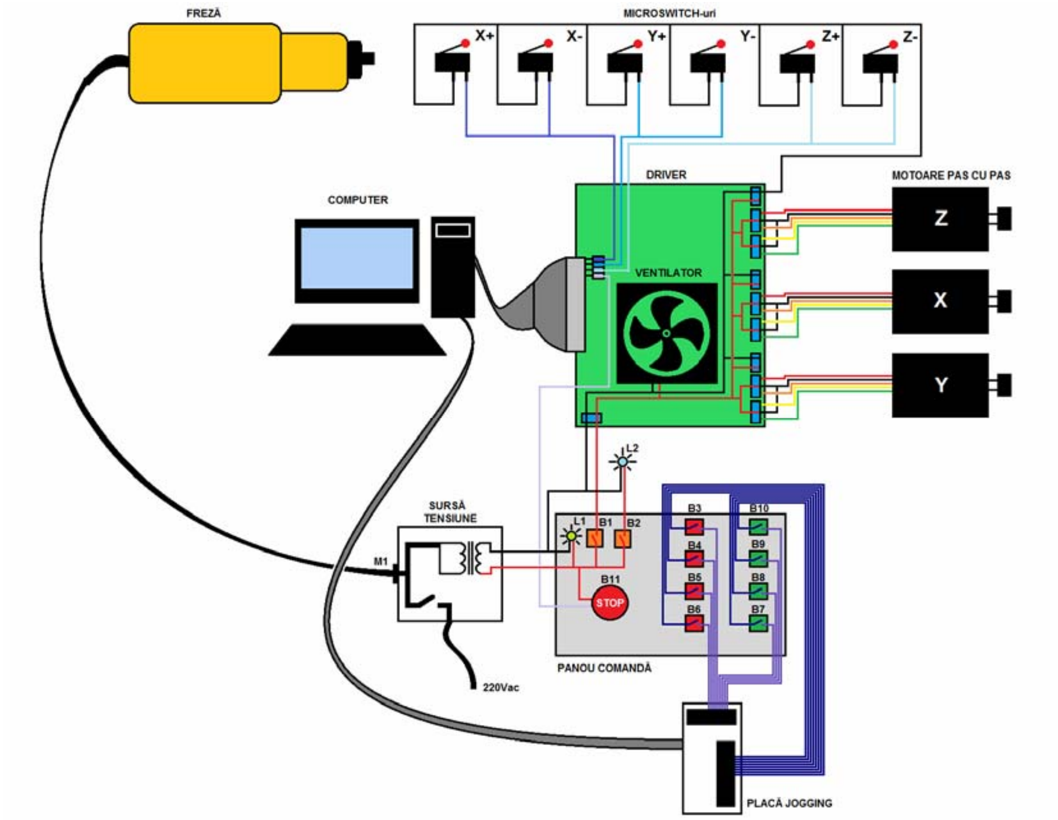

Fig. 8. The electrical components connecting diagram for the ROUTECAM SM-01 router.

- mounting the electrical dremel and wiring it to the source;
- fitting up the cable drag chains (for preventing the cables from damaging) and inserting the cables through them before adding the sockets;
- mounting and connecting the motors controller board (driver), the power source, the logical board that controls the jogging, the push buttons and the emergency button, the connecting wires and sockets.

The ROUTECAM SM-01 CNC Router Operation

CAD, CAM programming

Once the router is ready to work and the control software (Mach3) is configured, actual parts may be machined. For doing that, it is required to elaborate programs in machine language. For simple parts or operations g-code functions can be written in a text file and load it into the control software [5], but for geometrically complex parts it is needed to use a CAD software for designing the parts and a CAM software for transposing the models into machine code (a language that can be understood by the control software).

The same software used for designing the router was also utilized for designing the manufactured pieces, that is Solid Works, an easy-to-use software with advanced capabilities.

Solid CAM was used as CAM software, which is not an individual program, but comes as an add-in to Solid Works.

For generating the code, the following operations must be performed: making the model in Solid Works and importing it to Solid CAM, specifying the machining type (milling), choosing the origin and the axes of the coordinates system for the part and specifying the controller type (choose FANUC which is compatible to the Mach3 software). After that, specify the upper and lower levels on the vertical axis (Z) between which the machining should be made, then add machining operations (3D milling, contour, pocket, slot, engraving, drilling). After choosing the desired type of machining, the tooling technology must be defined and also the surfaces on which it applies. Regarding the technology, the following must be specified: the cutting tools type (face mill, end mill, bull nose mill, ball nose mill, taper mill, lollipop mill), their dimensions and parameters (number of flutes, diameter, height, other important dimensions), the order in which they are used, the type of the operation (roughing, semi-finishing, finishing), the working parameters (feeding speed, spinning rate, offset, overlap, step-down).

Following the parameter setting up, the simulation of the process (quick or detailed) may be performed for determining the total time or the time needed for each operation to complete, also for remarking some problems that can emerge while machining (and solving them) and for virtually supervising the process.

If the simulation completed without problems and the virtual part looks exactly as the designed part, the program can be saved in .txt format. This file will be later loaded in the Mach3 software, which will run the g-code instructions and will follow the specified displacements.

Control software used for commanding the CNC ROUTECAM SM-01 router

The software used for the applications is Mach3 developed by Artsoft [18], which is a complex and flexible program that allows controlling CNC milling machines, plasma and laser cutting machines and lathes. Mach3 permits controlling up to 6 axes milling machines and requires a computer with a minimum 1GHz processor, 512 Mb RAM and a parallel port (fig. 9).

In the main tab (Program Run) the coordinates system values (the machine's or the part's system) can be supervised and the reference (origin) of the system can be redefined, the program can be loaded, edited or run from a specific line, the feed or spinning speed (if the router has this feature) can be changed, the parameters of the cutting tool can be introduced (diameter, height) and also the machining parameters (number of passes and step-down) or the path of the tool can be visualized, as well the loaded program. There are buttons that allow starting, holding or stopping the program.

In the MDI tab manual directions can be introduced. These can be run one at a time or more in a row (teach mode), the cutting tool can be chosen, the feeding and spinning speed can be varied, the machine or part coordinate system's origin can be referenced and the path of the tool can be followed.

The ToolPath tab was created for the operator to better see the route of the cutting tool on a wider visualizing panel. This tab also gives the possibility to see the values of the coordinate system and to start, hold or stop the program.

The 4th tab is dedicated to adding offsets either manually or by functions.

The 5th tab is the one for Settings, where some parameters can be over-written or calibrations can be performed. Of a great importance in this page there are the 'Set Steps per Unit' button by which the axis calibration is performed and also the 'LimitOverRide' button. If a limit sensor was hit, the program stops any movement and displays a message. In this moment it is impossible to make any displacements (not even by jogging) for getting the machine off the error message, the senzor being still activated. It is required to push the 'LimitOverRide' button in order to cancel the error. By activating this option you can now resume making displacements, but the program doesn't limit the movement to the direction needed for clearing the sensor. Therefore, the operator must be careful to make the displacement in the right direction because, if otherwise, the sensor can be damaged if it is further pushed.

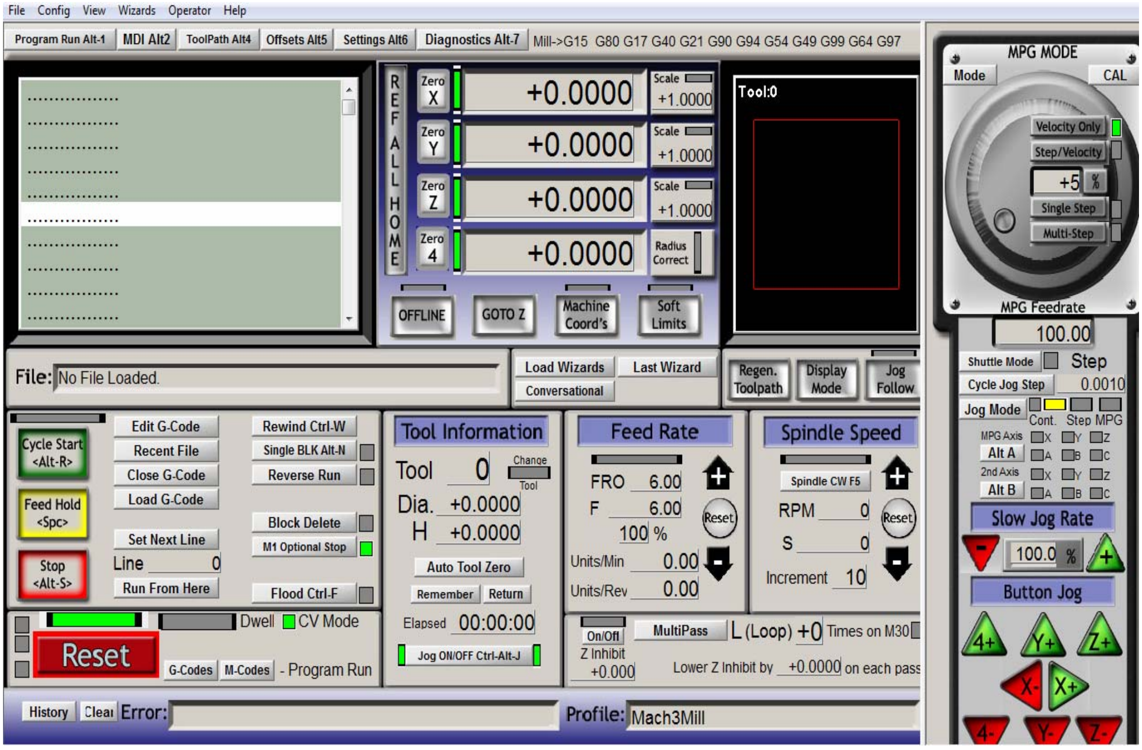

Fig. 9. Mach 3 software's main tab.

The 6th tab (Diagnostics) allows displaying the state of the some variables of the system. Here it is also possible to reference the machine coordinate system on one axis at a time and not on all of them as allowed on the first two tabs ('REF ALL HOME' button).

By pressing the keyboard Tab button, the joging panel is displayed. This panel is used for manually make axial displacements.

In every tab there is a 'Reset' button by which the program can be stopped. The resuming can be performed by pressing the 'Cycle Start' button, holding the program can be achieved by pushing the 'Feed Hold' button in the program or the Space button on the keyboard.

Aplications

Five geometrically complicated parts were machined for evidentiating the capabilities of the machine. Because soft material milling tools were used for machining (tools made for diy operations) they proved incapable to resist to endurance machining in materials like wood, plastic or gypsum. This is why the decision to manufacture the parts out of styrofoam was taken, the purpose of the project being to prove the complexity of the movement, not the cutting capability of a tool. Because the syrofoam's density is low (34 kg/m^3), the utilized cutting tools did not wear, maintaining their technological performances after machining all the five parts.

For hardening the surface of the parts the following may be applied: epoxy resins, PVA glue, cianoacrylate or other special substances mostly used in the advertising industry (for covering the volumetric letters made out of styrofoam to resist at the exterior environment).

For obtaining the manufacturing code, two CAM and one CAD softwares were utilized. The UPG plate (fig. 10) was first built in 3D using the SolidWorks 2007 CAD software and then the SolidCAM 2008 software was used for generating the g-code program.

Fig. 10. 3D CAD model of the “UPG Plate” part.

For machining the part, three cutting mills were used: a 7,8 mm end mill, a 3 mm taper mill and a 1mm lollipop mill. The 7,8 mm and 3 mm mills were used for roughing operations, while the 1mm one was used for finishing the surfaces.

At first, a flat surface was machined on the upper face of the part using the 7,8 mm mill and executing a spiral movement, with a depth of 3 mm and an overlap of 0,6 (60%). The 3 mm mill followed the 7,8 mm one and entered into the spaces in which the previous mill could not get into (especially between the letters) and improving the quality of the curved surfaces. The machining parameters utilized were: pass depth of 2 mm and the stepover coefficient of 0,5 (a stepover of 1,5 mm). The finishing operation was specified in the software for the 1mm mill, having a cutting depth of 0,2 mm. After visualizing the simulation, the 3 g-code programs were generated, using the Fanuc postprocessor. The programs were loaded and run one at a time into the Mach3 software, which controlled the machine generating exactly the same paths as in the simulation, the final part being the facsimile of its CAD model. The roughing operations were achieved at a feeding speed of 200 mm/min and lasted 2 hours and 45 minutes, while the finishing process was done at a feeding speed of 250 mm/min and required 5 hours and 10 minutes.

The CAD models of the other four pieces (fig. 11) were taken-up without charge, downloaded as free samples from the www.vectorart3d.com website [17].

The type of those files is a particular one (.v3m extension) which can only be opened by the Vector Art 3D Machinist software, also offered for free by the above mentioned site and which actually represents a CAM software that can only import v3m models.

Using this software is quite easy, the program has a simple and friendly, but also complete-enough interface. Because the program allows the use of only two tools, one for roughing and one for finishing, the 3 mm and the 1mm mills were used for the machining the parts. Some data is necessary for configuring the program: the dimensions of the stock material, the reference of the coordinates system, the upper and lower points (on the Z axis) between which the machining will be performed, the pass depth and the stepover, the mill's diameter, the feeding speed and the plunge rate, as well as other parameters. The stepover chosen for the 3 mm mill was 70% and for the 1mm mill of 40%. The pass depth was 3 mm for the 3 mm mill and 0,2 mm for the 1mm mill. In both cases, the feed rate was specified at 250 mm/min and the cutting-out was performed by the 3 mm mill.

The simulation of the processes and the estimated time can be visualized in the program. The machining time was about one hour for the roughing process and two hours for the finishing one. The dimensions of the final part can be varied from the dimensions of the CAD model by applying a coefficient to the original dimensions, but the realized parts are scaled 1:1 to the CAD model.

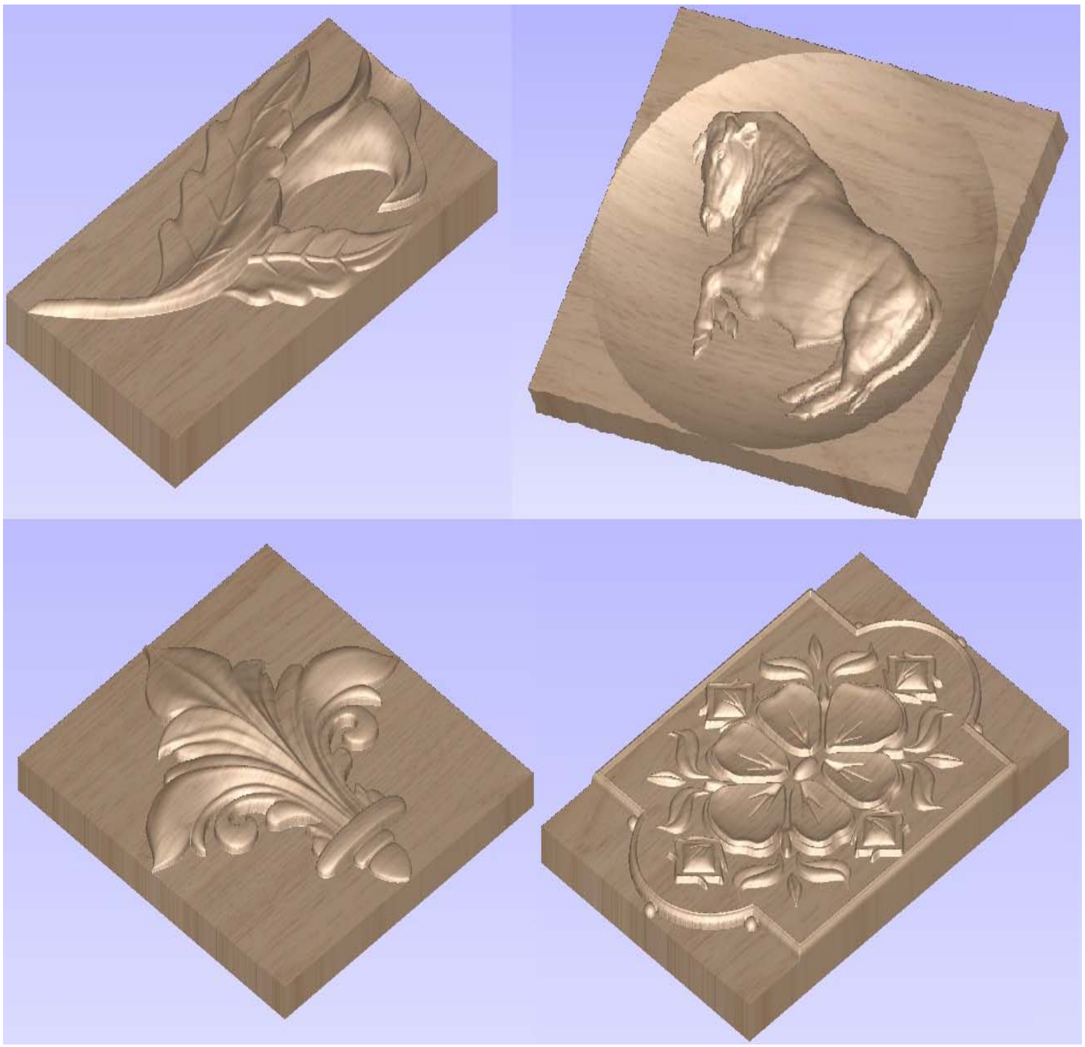

Fig. 11. The 3D CAD models of the machined parts (VA3D Machinist software).

After verifying the operations in the 3D simulation process, the programs could be saved, one for each operation, using the g-code postprocessor available in the VAD 3D Machinist software. The programs saved in .tap format were loaded in the Mach3 software which correctly executed the operations, machining the parts to look as their CAD model.

Conclusions

The utility of a 3 axis CNC milling machine for the oil equipment manufacturing industry is obvious. Because the components of a modern oil industry equipment mostly have a complex structure, they can only be machined by a CNC machine tool.

Certainly, a machine produced by a machine tool manufacturer presents a more advanced structure, but the purpose of this project is to find simpler and more affordable alternatives.
The designing and manufacturing of such a machine tool required the use of advanced design methods (CAD 3D) and the actual construction involved making some components on the CNC equipments.

For proving the aptitudes of the router, five geometrically complex parts were machined, process which involved strong knowledge about the following: CNC machine operation, machine language programming (g-code), 3D CAD design and CAM software use, operations order, cutting tools and machining.

The accomplishment of the CNC router necessitated a profound study before starting the designing stage, as well as during the project progress. The instruments used for gathering information were mostly the ones available on the Internet, on sites and forums [7], [10], [11], [13], because in the hardly accessible specialty literature the information is short. The information's needed for achieving the project are very dispersed and in order to obtain the full picture it was necessary to read many articles and threads on the numerous forums of this domain's hobbyists.

Attaining the construction was not deprived of problems, but the problems that occurred found their solving by different solutions, some being ingenious. Many solutions that were embraced inside the project are self-conceived, some were chosen after comparing the advantages/disadvantages of the methods used in producing CNC machine tools.

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Aplicații practice efectuate cu un router CNC ce utilizează motoare pas cu pas

Rezumat

În industria constructoare de maşini, necesitatea realizării unor repere cu geometrie complicată, precum şi necesitatea confecționării produselor de serie într-un ritm foarte alert a impus folosirea pe scară tot mai largă a maşinilor-unelte cu comandă numerică şi control computerizat.

Lucrarea expune proiectul şi construcția practică a unei maşini-unelte de frezat cu comandă numerică realizată din elemente tipizate şi confecționate.

Realizarea practică a componentelor a necesitat prelucrări de precizie a reperelor componente care au fost efectuate cu sprijinul SC UZTEL SA Ploieşti care posedă toate mijloacele necesare realizării acestor prelucrări mecanice.