

FOUR-AXIS CNC MACHINE WITH MICROCONTROLLER FOR CUTTING POLYSTYRENE WITH HOT WIRE

HELGA SILAGHI, VIORICA SPOIALĂ, SIMONA VERONICA ABRUDAN CACIORA, D. SPOIALĂ

University of Oradea, Romania, Department of Control Systems Engineering and Management,
Faculty of Electrical Engineering and Information Technology, University Street, 1, 410087 Oradea, Romania
E-Mail: hsilaghi@uoradea.ro, vspoiala@uoradea.ro, dspoiala@uoradea.ro

Abstract. *Numerically controlled machines require precise control, because it is always necessary to know the placement of the effector. Control involves the use of electric motors that can be checked with precision. Therefore stepper motors are preferred. A further advance in stepper control is to incorporate a reaction mechanism for the rotor (for example, an encoder) so as communication is optimal for generating the torque, depending on the position of the rotor. This turns the motor into a servo mechanism with very high torque and very good position resolution. An advance in this technique is to operate the motor in a closed loop only if the error of rotor positioning becomes too high. This will allow the system to avoid oscillation while searching for a position, a problem that commonly occurs with servos. The supervision of a numerically controlled tool is limited to the control of electric motors that actuate mechanical assemblies. Control can be implemented by using specialized integrated circuits or microcontrollers. This paper presents a numerically controlled (CNC) machine with microcontroller.*

Keywords: numerically controlled machine, microcontroller, stepper motor, cutting

1. INTRODUCTION

In a CNC machine, the number of motors that can be individually driven for the tool positional control, means the number of axis [8].

For example, a simple CNC lathe has only two axes for positional control of the tool. These axes are the X and the Z axes. Therefore it is a two axes machine.

Another example is a simple vertical milling centre (VMC), that is a 3 axes milling machine. This machine can be used to machine planar and some convex shaped 3D jobs [5].

Although, this cannot machine a helical groove of varying thickness on the curved surface of a cylinder. For this, we need an additional rotary axis which rotates the job as the VMC provides the other tool motions.

So, a VMC that has an additional rotary axes is a 4-Axis machine. This paper presents the implementation of a four-axis CNC machine with microcontroller for cutting polystyrene with hot wire.

First, is related the mechanical and actuation solution of the machine. Then, is presented the electrical diagram of the microcontroller board, the block diagram of the system, the control software, an example of use and the conclusions.

2. MECHANICAL AND ACTUATION SOLUTION OF THE MACHINE

Figure 1 presents the mechanical solution chosen for the CNC.

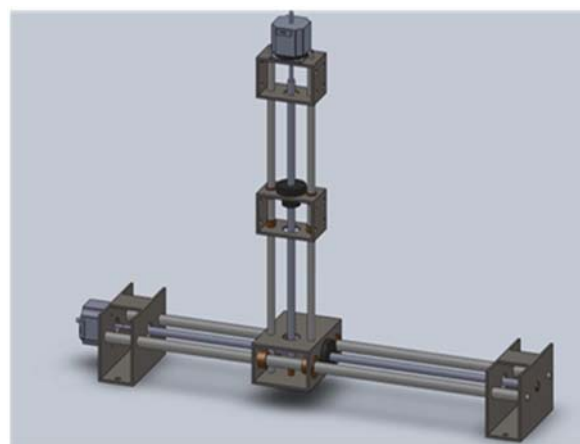


Figure 1. Four axis CNC machine

The device we have chosen, though not suitable for production at industrial scale, has enough accuracy, given its metallic structure and the fact that its guides are based on precision shafts, the transmission of motion being acquired by means of trapezoidal threaded screws.

The assemblies specific to each axis slide on precision shafts by means of graphite bronze bushings.

The motors move the assemblies by means of trapezoidal threaded screws [1]. The choice of trapezoidal threaded screws is the most common compromise at this level, ensuring the required rapidity of the movement, without losing too much engine torque [2].

Though obviously not the most efficient solution, it is the best compromise for this project, which aims to reach a semi-professional level.

The device will be able to accurately cut shapes of any kind in small, medium or even large-density polystyrene, though at the cost of losing some speed in the last case.

Despite the fact that their power is not really appropriate for an application of this kind, stepper motors have been chosen by reason of their low price; however, in conjunction with the mechanical solution chosen (threaded rods acting as reducers), the engines are able to cope with the physical movement of the cutter.

The chosen motors allow for both unipolar and bipolar equipment in circuit. Though easier to control in the unipolar version, they have been used as bipolar motors, since more torque can be generated in this way [4].

For facilitating control, we have used specialized integrated circuits. We started from the assumption that, if a high torque is not necessary, those integrated control circuits will always enable us to choose another method for generating control waves so as to reduce power consumption, thus making the use of supply/control circuits less demanding [9]. The motors in question have been chosen on grounds of such versatility.

A microcontroller has been chosen as initial test solution. It communicates via a serial data transmission protocol with the program generating commands on the computer [3].

We have implemented a computer program that allows for the introduction of basic instructions (formulating a set of actions for the plant item) and sending instructions for interpretation to the microcontroller. The microcontroller interprets those commands and generates the actual signals for moving the engines that operate the working head.

We have chosen a PIC16F870 microcontroller [7]. It operates at a frequency of 20 MHz, which is sufficient for the current application. The microcontroller has the possibility of generating interrupts, analog inputs, and three input/output ports.

We also needed a circuit for the amplification and, where applicable, for the inversion of the current applied to the coils of motors. We have chosen L 298 circuit, namely a double-lead lag H circuit, capable of voltages up to 46V and currents of 4A.

3. THE ELECTRICAL DIAGRAM OF THE MICROCONTROLLER BOARD

The diagram presented in Figure 2 shows the microcontroller, the B and C ports, with protection resistors (for test purposes, two LEDs have been connected to two of the eight C port terminals), the A port that has no protection resistors as these inputs also serve as analogue/digital converters for the microcontroller.

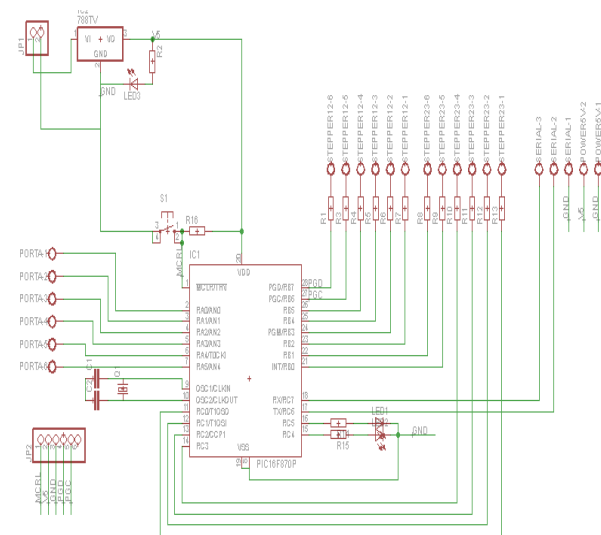


Figure 2. Electrical diagram of the microcontroller board

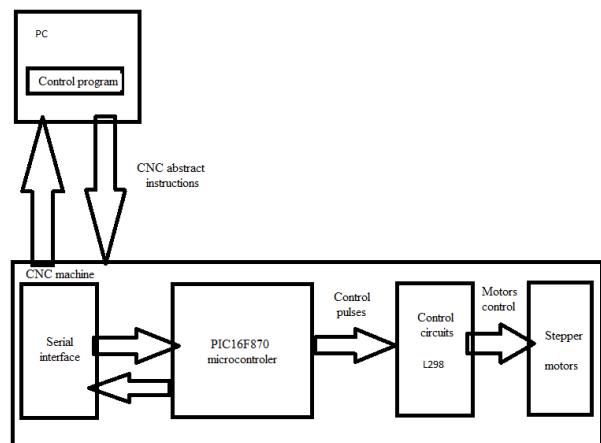


Figure 3. The block diagram of the system

A 5V voltage regulator for power, an oscillator (20 MHz quartz and associated capacitors) are also represented above. Besides the two port C terminals that are connected to the LEDs, there are two other C port terminals, used for serial communication. Eight outputs of port B and four outputs of port C (12 altogether - 4 for each engine) remain available for motor control signals.

The block diagram indicating the main interconnection elements of the CNC machine is shown in Figure 3. Control instructions come from a computer by means of some user-interface software [6]. These abstract instructions will be sent to the CNC machine.

First signals received via serial communication will go through an interface circuit in order to be turned from standard RS-232 to a logical level, a level that the microcontroller can work on. Once the abstract commands have been interpreted, the microcontroller generates low power control signals.

These signals go further to control circuits, which are largely made up of L298 integrated circuits. If necessary, these power circuits amplify and reverse the current,

applying it to the motor terminals. It can be seen that there is a two-way communication between the microcontroller and the PC, as a protocol is used, where the microcontroller will signal the computer whether instructions were successfully received or if errors occurred.

4. THE IMPLEMENTATION OF THE 4-AXIS NUMERICAL MACHINE FOR CUTTING POLYSTYRENE WITH HOT WIRE

For the mechanical part of the machine we used, as base material, steel profiles with a thickness of 3 mm.

Cost reasons determined our choice of steel profiles instead of aluminum.

Steel made the machine heavier but also more stable on the work bench, the only disadvantage becoming relevant when the device had to be transported.

Processing consisted in drilling and cutting metal profiles on professional machine tools, in order to ensure the parallel and exact placement of precision shafts, of trapezoidal threaded screws and of motors.

Precision shafts and trapezoidal threaded screws also needed turning operations.

Since metal was chosen as working material, precision was crucial in designing the machine, so as to ensure that no restoration of specific parts during the final assembly phase might be necessary (a time consuming and relatively expensive process).

Therefore the entire machine was designed in a CAD (Computer Aided Design) environment. In this way we could see and correct any problems during the early stages.

FoamWorks (Figure 4) and JediCut (Figure 5) software were used for direct machine control through computer parallel ports because they allow a much broader set of instructions and thus the device becomes more versatile.

Both software presented above function in a similar way. They allow for the uploading of files containing sequences of coordinates for each of the two towers (x1, y1 respectively x2, y2).

Depending on the set speed, the software calculates the number and speed of control motor impulses, thus moving the machine and implicitly the copper-nickel hot wire that cuts polystyrene.

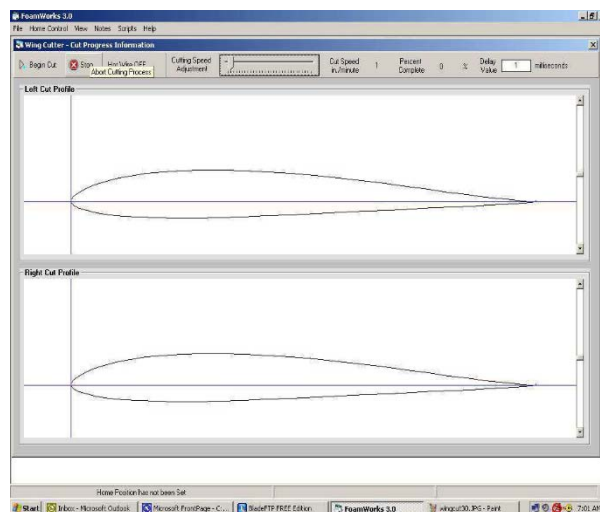


Figure 4. The FoamWorks control software

When operating the system, problems that arose were mainly related to the L 298 amplifier circuit.

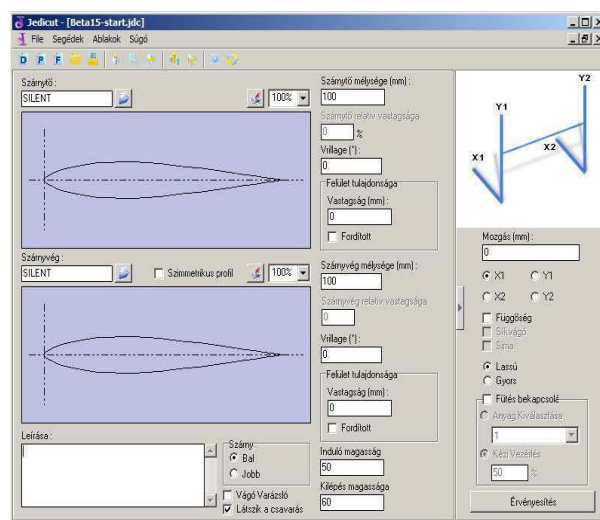


Figure 5. The JediCut control software

The original designed card had no diode and thus the coils of engines eased back around the circuit, which generated a lot of heat and ultimately burnt the circuit, although the 2.5 amps value was not reached – the maximum value, according to catalog sheets of the integrated circuit.

An alternative we tried was decreasing the motor control pulse width.

This solution was not effective since the motors no longer had the necessary force to move the mechanical assemblies. The final solution was to equip the circuit with auxiliary components, diodes and 2 comparators for each coil; when detecting a current that was higher than the one allowed by coils, the comparators disabled voltage on that particular coil.

The microcontroller and the L298 integrated circuit proved to ensure a safe and reliable way to implement control. In Figure 6 is shown the printed circuit card for microcontroller.

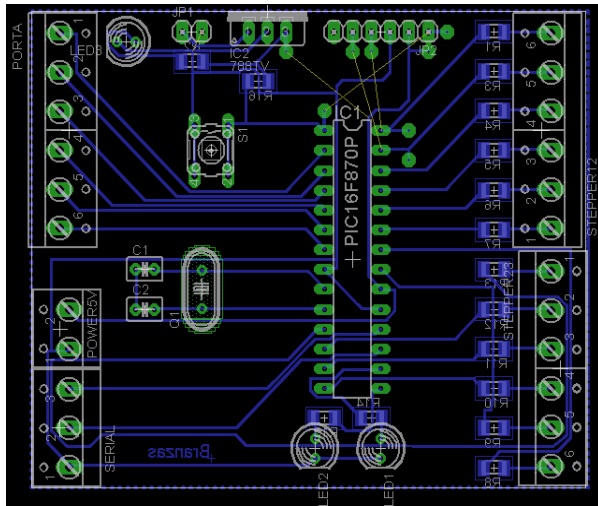


Figure 6. Printed circuit card for microcontroller

The device created for the purpose of this project is relatively simplistic with very few instructions.

Thus, for using the machine, it has to be connected to a PC and to a serial port. Since serial ports start to become less and less directly accessible on the back of the motherboard, one can opt for a USB to RS-232 adapter. If this adapter is installed correctly it will be seen by the operating system as a serial port.

The control program needs to install NET framework on the computer on which it is desired to run.

Once the sequence of instructions required is introduced, "Send" button is pushed and the device starts working effectively.

After successfully completing the instructions, an appropriate message appears or, if operations have not been successfully performed an error is signaled.

4.1 Example of use

As example we shall assume that we want to engrave, on a piece of material, the outline of a rectangle with the size of 10x5 cm, having an etching depth of 4 mm. The initial corner of the rectangle will be 10 centimeters away from the edges. We assume that the processed material has a thickness of 5 cm.

Depending on the chosen head for the cutter, more or fewer passes to etch a trench with a depth of 4 mm will be necessary. In case we use a little cutter, multiple passes through the material, at successively greater depths, are required. In this case we assume that the cutter installed can grave at a depth of 2 mm at a time. Thus we need two passes to get the final depth of 4 mm. To ensure that errors are not transmitted further if stepper motors lose steps, we shall use the home function at some point in the middle of the program.

At the end of the operation, or if an error has occurred, the response section will show a corresponding message.

Instead of *lineto* (x, y, z) command, one could have used the command *line* ($X1, Y1, Z1, X2, Y2, Z2$) with the same result. Order *lineto* () is preferable when lines to be followed are one after the other.

So we succeeded that the supervision of a numerically controlled tool to be limited to the control of electric motors that actuate mechanical assemblies.

5. CONCLUSIONS

Nowadays, the need for precision has become prominent in all areas of activity. We have reached the level where human beings are no longer able to manufacture, by traditional methods, components that would meet the rigors needed for obtaining parts that may be subsequently used in advanced systems. Here computer-assisted processing becomes useful. This will ensure a perfect identical result every time, which would be better and more accurate than what can be obtained using traditional methods.

Technology is advancing rapidly. Initially, numerically controlled machines were only available at industrial level and at prices far beyond the possibilities of a common customer; now CNC machines are used by hobbyist as well. This development has been stimulated by the presence of more and more manufacturers of related components, designed to enable ordinary people to build such machines. Electronic control is becoming increasingly simpler and cheaper.

Another factor that helps in the development of this area is the existence of a community interested in the numerical control of machines. This community is growing constantly as it is relatively easy to find such a device on a small scale, but with high reliability and precision.

For the command part we used a microcontroller, along with all options that such a circuit can provide.

We tried and managed to find the components that are needed for amplifying current in such an application. Once the component was found (IC L298), we managed to understand its operation and linked it to the rest of the system.

However there are still obstacles in building a CNC machine. The quality of operation is dependent upon the range of potential compromises every designer/builder is ready to accept. Although building such a machine has become available to the general public, it still involves a significant financial effort.

The purpose of this scientific paper has been to achieve a 4-axis CNC machine, aimed at the semi- professional level, able to carry the specific functions of

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