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Modeling and Simulation of CNC Feed System Using MATLAB/Simulink Software Package

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Abstract: *The CNC feed system is one of the most important mechatronics assemblies in CNC machine tools. That is why it is of great importance, in the education of future engineers, to pay special attention to analysis of CNC feed systems through the modeling of its components and the simulation of its control structure. This paper presents an educational laboratory setup - a simulator of CNC machine tools, modeling of the drive system of the laboratory setup, and control of CNC feeding system within the MATLAB/Simulink software package. Also, the control simulation of the execution of some program instructions of the G code was presented, as well as the connection of the Simulink model with the microcontroller of the CNC machine tool simulator.*

Keywords: *CNC systems; MATLAB/Simulink; Arduino; modeling; simulation*

1. INTRODUCTION

CNC machine tools, as typical mechatronic systems, are dominant and indispensable factors in production engineering, in many branches of industry [1,2]. Like any mechatronic system, CNC machine tool has their own control system, which is the "brain" of production automation and its value is about 30% of the total value of the machine tool [3]. In the industry there are CNC control systems from various renowned global manufacturers such as Siemens, Fanuc or Heidenhain, which are very expensive. In addition to professional CNC machine tools, the market for "hobby" solutions of these machines is increasingly developing [4,5]. Accordingly, it is of great importance, in the education of future engineers, to pay special attention to the analysis of the architecture of CNC machine tools (mechanical components, drive systems, sensor techniques, control system).

This work aims to present an educational setting that enables students to become better acquainted with CNC systems through control software visualization and its implementation in the mentioned education setting.

2. SIMULATOR OF CNC MACHINE TOOLS

The simulator of CNC machine tools was developed as part of teaching activities at the Faculty of Technical Sciences in Čačak, with the idea of having a modular character. So, depending on the choice of the manufacturing process, the machine can be transformed into a desktop CNC milling machine, 3D printer, laser cutting machine, etc. A CAD model of the CNC simulator with a motor for machining, which makes it a desktop CNC milling machine as a whole, is given in Figure 1a, while Figures 1b, 1c, and 1d show the X, Y, and Z axis CAD model views, respectively.

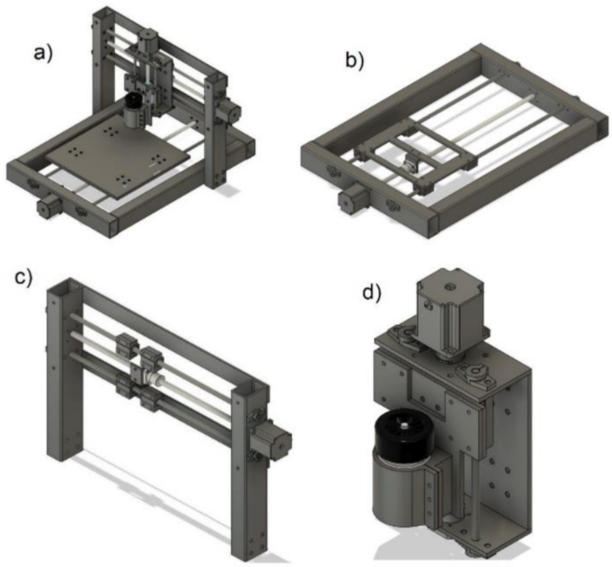

Figure 1. *a) CAD model of desktop CNC milling machine, b) CAD model of X axis, c) CAD model of Y axis, d) CAD model of Z axis*

There is a work table on the X-axis, and the length of the maximum stroke along the mentioned axis is 300 mm. The X-axis drive system is a NEMA23 servo stepper motor. The translational movement of the table is realized using linear guides and a threaded spindle (pitch 5 mm) with a nut. The connection between the threaded spindle and the motor rotor is achieved with the coupling. The construction consists of a frame made of aluminum box profiles with dimensions of 60x40 mm.

The Y axis is essentially no different from the X axis. Aluminum box profiles 60x40 mm were also used. As with the X axis, the drive is a NEMA23 servo stepper motor. The working stroke of the Y-axis is 300 mm.

The Z axis is intended to carry the machining motor or some other tool of the machine, depending on the purpose. The drive of this axis is a NEMA17 stepper motor, and the working stroke of the Z axis is 100 mm. All other components are identical to the previous axis, with the necessary dimensional adjustment.

The machine is powered by a 500W AC/DC converter, which outputs 24VDC and that voltage is used to power the drive, the drive driver, and the control unit, which in this case is the Arduino Uno board. Also, the machine has integrated limit switches and an all-stop button (latching mushroom type emergency stop switch). Figure 2 shows the layout of the laboratory simulator of CNC machine tools.

Figure 2. *Laboratory simulator of CNC machine tool*

3. DRIVE AND CONTROL SYSTEMS FOR X AND Y AXIS

As already mentioned, the drive system consists of NEMA23 servo stepper motors (X and Y axis) and NEMA17 stepper motor (Z axis). In this paper, the emphasis will be on modeling and simulation of control of the X and Y axes, so the characteristics of the Z-axis motor - NEMA17 will not be analyzed. The servo stepper system for X and Y axis NEMA23 allows to achievement of very high positioning resolutions, using the micro-stepping technique, and with the help of an incremental encoder (resolution 4096), the number of steps can be reliably increased from 200 per revolution to 4000 per revolution, resulting in a resolution of 25μm to a resolution of 1.25μm.

The HBS57 driver is used for the NEMA23 drive system. Its basic characteristics are given in Table 1 [6]. The driver has printed plates on its surface that explain the setting of current limiting and micro stepping using the microswitches located on the side.

Figure 3. *NEMA23 hybrid servo stepper motor with driver*

Table 1. *Characteristics of the HBS57 driver*

Parameters	**Min.**	**Typically**	**Max.**
Current per phase	0 A	-	8 A
Supply voltage	9 VDC	36 VCD	40VDC
Signal current	7 mA	10 mA	16 mA
Pulse frequency	0 kHz	-	200 kHz
Isolation	500 MΩ	-	-
Micro-stepping/1.8 °	200	-	4000

The control system is an Arduino Uno microcontroller on which there is a CNC shield that facilitates the connection of the driver with the Arduino Uno microcontroller pins. Table 2 shows the basic characteristics of the Arduino Uno controller, and Figure 4 provides a graphical show of the Arduino Uno controller.

Table 2. *Characteristics of the Arduino Uno controller*

Input voltage (recommended)	7-12VDC
Digital inputs/outputs	14
PWM digital inputs/outputs	6
Analog inputs	6
Current per pin (maximum)	20mA
Flash memory	32kB
SHAME	2kB
EEPROM	1kB
Oscillator frequency	16 MHz

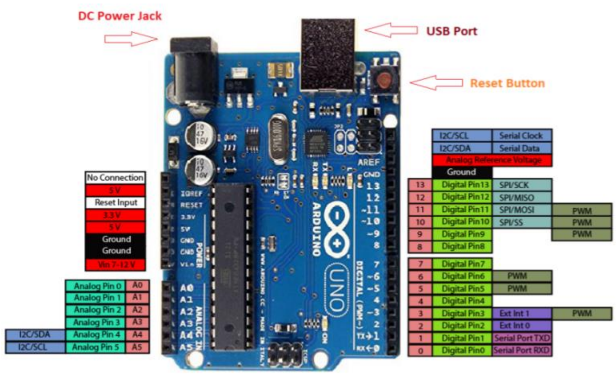

Figure 4. *Arduino Uno controller layout with pin labels and functions*

4. MODELING AND SIMULATION OF MOTION CONTROL

Modeling of the CNC positioning system for the X and Y axis was performed within the MATLAB/Simulink software package. All the mentioned drive and control components are represented by the corresponding blocks, and their characteristics are entered as values in the variables of the corresponding blocks (Figure 5).

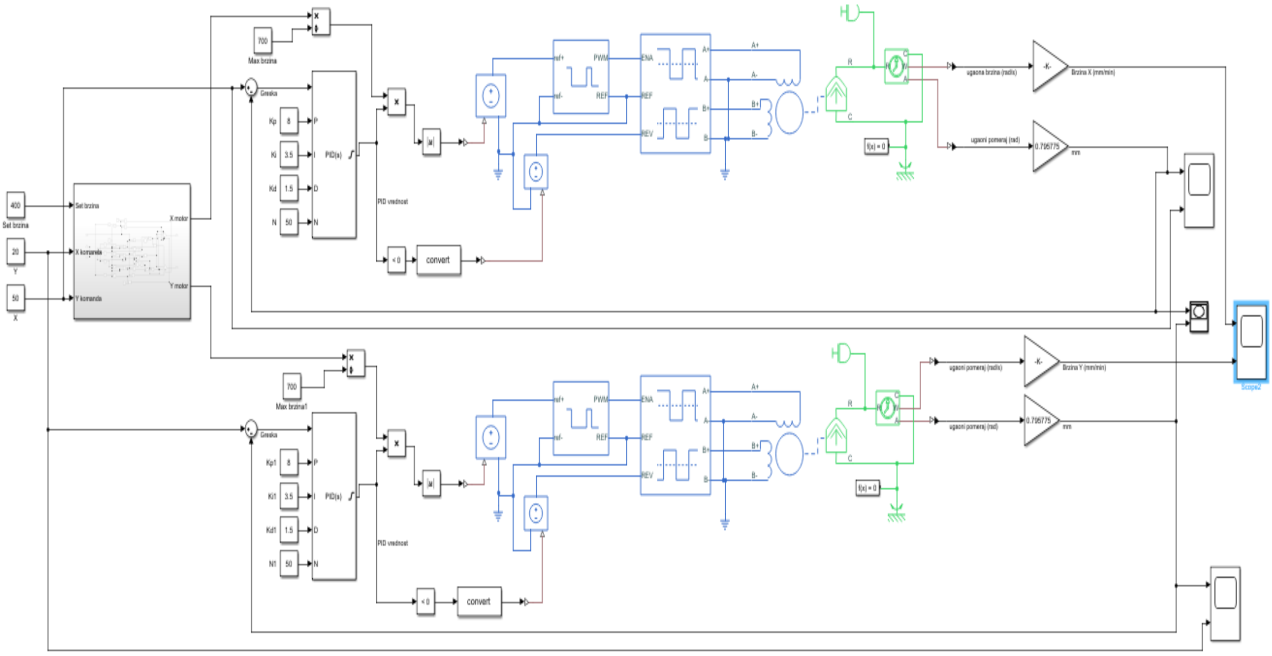

Figure 5. *Simulink model of CNC positioning system for X and Y axis*

As the components for both observed axes are identical, their Simulink interpretation is also the same, so in Figure 5 it can be noticed that the upper and lower half of the picture have the same elements. The "Controlled PWM voltage" block represents the Arduino microcontroller that sends impulses to the "Stepper Motor Driver" which represents the HBS57 driver. The driver outputs are connected to phases A and B of the "Stepper Motor" block, which is a NEMA23 motor located on the X and Y axes. This shows the electronic connection and control, marked with blue lines. Green lines indicate mechanical connections. The "Inertia" and "Ideal Rotational Motion Sensor" blocks are attached to the motor rotor, representing the inertia seen by the motor from the side of the rotor and the position sensor representing the encoder, respectively. The output from the sensor block is the position in radians, so by simply multiplying with the constant 0.795775 (knowing that the pitch of the threaded spindle is 5 mm and the transmission from the rotor to the threaded spindle is 1:1), the output is translated into millimeters. Also, in Figure 5, you can see the PID block related to PID regulation, and the constants used are P=8, I=3.5 and D=1.5, which were obtained by advanced software setting of the mentioned constants. If the program instruction G1 X50 Y20 F400 is written, it practically means that, after its execution, the work table will be at a distance of 50 mm along the X axis and 20 mm along the Y axis from the coordinate origin. The display of linear interpolation specified by the specified program instruction is given in Figure 6.

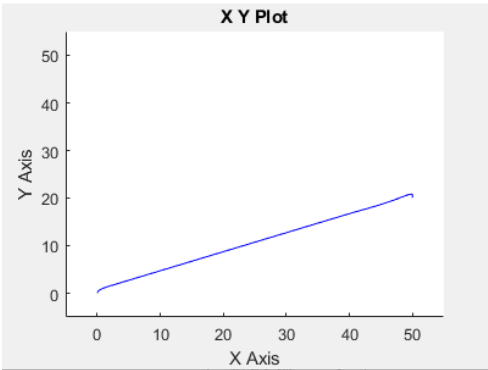

Figure 6. *Linear interpolation - function G1*

The speed profiles along the X (yellow color) and Y (blue color) axes are given in Figure 7, where it is clearly seen that the speed along the X axis is significantly higher, which is logical given that the distance along the X axis is greater.

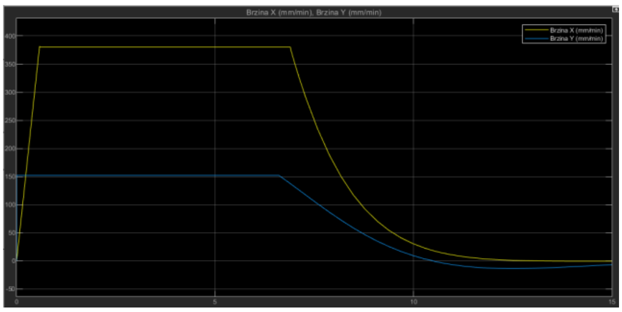

Figure 7. *Speed profile of two axes during execution of program instruction G1*

Also, it is possible to software test the behavior of the system for different types of interpolation, so if you write the program instructions G2 X80 Y80 CR80 F700, whose representation is given in Figure 8, you get speed profiles along two axes (X and Y) that differ significantly in compared to linear interpolation. The axes speeds shown in Figure 9 produce uniform movements of the work table at a speed of 700 mm/min in a circular arc of radius 80 mm.

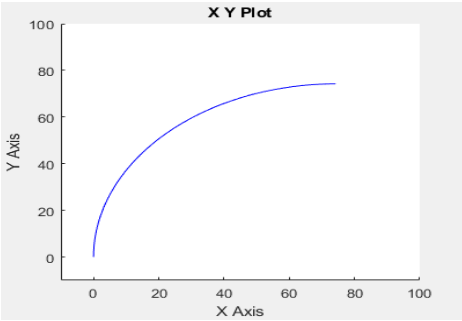

Figure 8. *Circular interpolation - function G2*

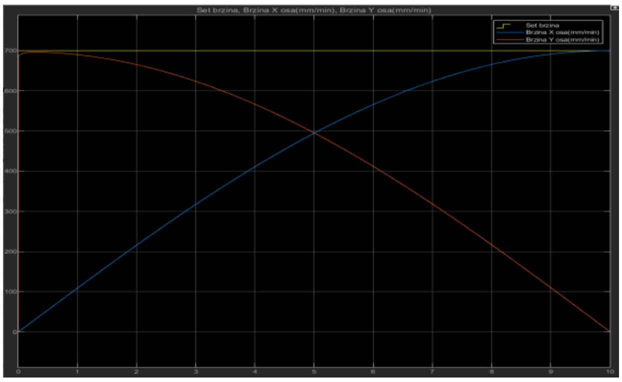

Figure 9. *Speed profile of two axes during execution of program instruction G2*

In addition to software simulations of control, with great possibilities of its visualization that facilitates the understanding of cause-and-effect relationships in the CNC position system, in MATLAB/Simulink it is possible to embed an Arduino block and thus control the simulator shown in Figure 2. Figure 10 shows a view of connecting the Simulink model of one axis to the pins of the Arduino microcontroller.

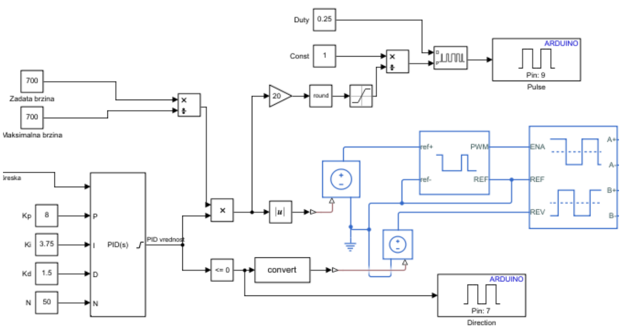

Figure 10. Connecting control functions to Arduino controller pins

5. CONCLUSION

The presented MATLAB/Simulink models are extremely important for the education of future engineers. With knowledge of the MATLAB/Simulink software package, students can simulate the operation of a CNC positioning system for various instructions defined through standard G code. The developed models provide the opportunity for students to see the importance of PID regulation in CNC systems, and to adjust PID regulation constants using standard techniques, but also in some more advanced ways such as phase adjustment of PID constants. The special value of the presented models and educational settings is that they are connected using Simulink Arduino blocks and everything that is demonstrated by simulation in the software can be implemented in real-time on a laboratory simulator of a CNC machine tool.

ACKNOWLEDGEMENTS

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