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# DESIGN OF CNC DEVICE DESIGNED FOR AUTOMATION OF THE APPLICATION OF VISCOUS MATERIALS

*This article deals with the design and practical realization of a CNC device designed for the application of viscous materials, such as a thermal conducting paste. Nowadays, growing trend of usage of electronic circuits in transportation systems is observed. Switched mode power supplies are widely used in all types of means of transport and their infrastructure. For correct operation of power converters, produced heat must be dissipated. Thermal conducting paste is used for better heat dissipating but its application on surface can be an issue. Designed CNC device serves for easier and more accurate application in production process in transport industry.*

**Keywords:** automation in transportation systems, CNC design, CNC control, ball screw, stepper motor

## 1. Introduction

At present, we are monitoring the growing trend of CNC devices deployment in the production process. Transport industry is not an exception. Automation generally increases productivity. Human factor is limited, which means that products are better and more accurate, and the number of manufacturing errors is rapidly declining. Another very important advantage of automation machines is to relieve people from physically strenuous, monotonous and psychologically dysfunctional work, what is a genuine issue in automotive industry. For this reason, requirement for the CNC dispensing machine, which is the subject of this article, arises. From semiconductor converters, the heat generated by the dissipation power of semiconductor components must be drained, in most cases by passive heatsinks. Very often during the production a thermal conducting paste, which is often stored in tubes, is applied to the radiator by a piston pistol. The problem arises if the operator is not physically enough disposed to be able to apply the paste to the surface during the entire working shift. The role of the designed CNC device is therefore to automate the application process using standard tubes.

The basic requirements include:

- X-axis positioning: min. 300 mm
- Y-axis positioning: min. 400 mm
- Z-axis positioning: min. 80 mm with manual offset adjustment
- Positioning accuracy  $\pm 1$  mm in all axes
- Self-calibration at zero point
- Ability to position 5 kg tube
- Extraction from standardised 1x400 ml and from 2x400 ml tube, too
- Tolerance in dispensing two - part paste  $<0.1\%$
- Usage worm gear for extrusion
- Ability to perform any trajectory
- Configuration via GUI for standard PCs running MS Windows 7 or higher

- Configurable parameters: positions in X, Y, Z, positioning speed, adjustable amount of paste applied

## 2. State of the art

Nowadays, there are currently many CNC dispensing solutions available on the market. For example, we can present professional solutions of dispense devices from Bdttronic. Beckhoff offers excellent software solutions for them. Fisnar also offers dispensing machines using worm gear instead of air pressure but only for small cartridges. Another option is modular solution. For example, Mitsubishi offers interesting PLC-based CNC solutions M70 or C70 series [1]. However, no company on the market offered a solution that would fully satisfy our requirements. The main problem was that the devices were not able to work directly with standard tubes, and the offered solutions required additional development, which increased the price dramatically. In addition, the SW configuration of the device and the programming of the correct behavior of the device in various operating situations was also required, e.g. during the tube replacement. Very popular among hobby enthusiasts is Mach3. However, SW is not compatible with Windows 7 and it is not an open source, too. Frequently the drivers used for stepper motors include breakout boards for the MPS MP6500, Allegro's A4988 or TI's DRV8825 [2]. However, their power is poor for our application. That's why we decided to try to develop our own device, as cheap as possible. Block scheme of our proposed solution is shown in Figure 1. In next chapters are described additional information of separate blocks.

## 3. Mechanical construction

We have decided for the Compass H-1000 GS KIT from CauCau company. It is shown in Figure 2. This is a construction

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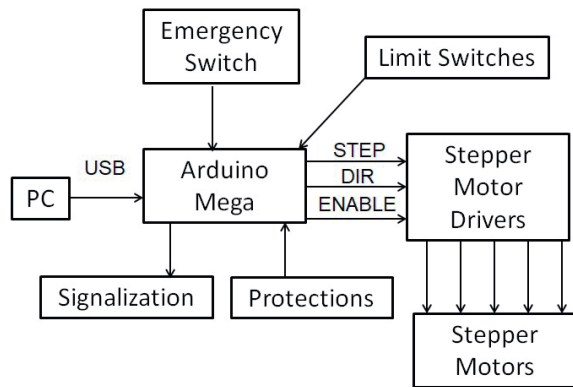


Figure 1 Block scheme



Figure 2 Selected mechanical construction [3]

with a movable portal frame that performs a working movement. On the portal, there should be a spindle, in our case a paste extrusion module (Figure 3).

When designing the paste extrusion module, we decided to use the SBR16S. It is a system of a support rod on which there are carts with linear ball bearings with open cases. The support rod is turbid and its support is made of aluminium. The lead pair is mounted on a supporting aluminium plate. We have decided to use the ball screws to transform the rotational motion of the motor on the linear motion, because it has a higher load ability, durability, efficiency and accuracy [4], which is essential for our application.

#### 4. Actuator selection and power electronics design

In our application, we decided to use two-phase hybrid stepper motors with bipolar winding. All motors work in open position loop [5]. For positioning needs MotionKing motor 23HS2430 was selected, with step angle  $1.8^\circ$ . 4 motors were needed, namely 2 on the X axis and one on the Y and Z axes.

When choosing the extruding motor, we firstly needed to know the amount of force needed to reliably push the paste out of the tube. We calculated the parameters from a pneumatic pistol used for this purpose. Working pressure is 600 kPa at the actuator area of  $5.67 \cdot 10^{-3} \text{ m}^2$ . It follows that in case of omission of friction, pistol is able to develop the force according to the equation:

$$F_a = p \cdot S = 6 \cdot 10^5 \cdot 5.67 \cdot 10^{-3} = 3402 \text{ N} \quad (1)$$



Figure 3 3D model of paste extrusion module

The total required torque  $M_c$ , which the motor must overcome, consists of several components [6].

$$M_c = M_{acc} + M_d + M_p + M_f \quad (2)$$

where  $M_{acc}$  – acceleration torque [Nm],

$M_d$  – the torque necessary for load movement [Nm],

$M_p$  – torque caused by pretension of the nut [Nm],

$M_f$  – torque caused by friction in bearings and carts [Nm].

Torque  $M_{acc}$  directly depends on the momentum of the inertia of the system (extrusion pistons, flange, ball screw, rotor) and acceleration [4]. Since both components are low in our application, we can neglect the acceleration torque to simplify the calculation. The nut pretension is zero. We consider friction torque and it is reflected in the resulting formula as efficiency. For the final calculation of the total torque,  $M_c$  is therefore valid [7]:

$$M_c = \frac{F_a \cdot p \cdot o}{2000\pi \cdot \eta} = \frac{3.4 \cdot 10^3 \cdot 5 \cdot 0.5}{2000\pi \cdot 0.9} = 4.5 \text{ Nm} \quad (3)$$

where  $F_a$  – axial force [N], we calculated it in Equation (1),

$p$  – screw thread pitch [mm],

$\eta$  – efficiency of screw drive [-], although [4] states 95%, we chose 90%, because we consider not always ideal conditions of power transfer. Practically maintenance is often neglected which means that the lubrication of the bolt and nut contact will not always be ideal,

$o$  – oversizing of the entire drive by 50% recommended by [8].

Motor SX4570 from Microcon company fulfills torque requirements. Like 23HS2430 its step angle is  $1.8^\circ$ . As we can see in the Figure 4 [8], it is possible to achieve 2.5 rot/s with enough torque at divided step.

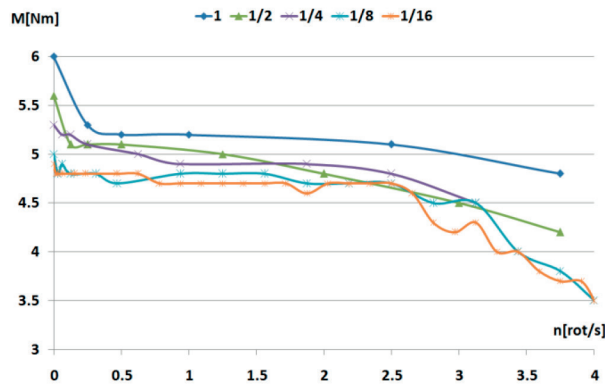


Figure 4 Torque characteristics of motor SX4570 for current amplitude 3.8 A

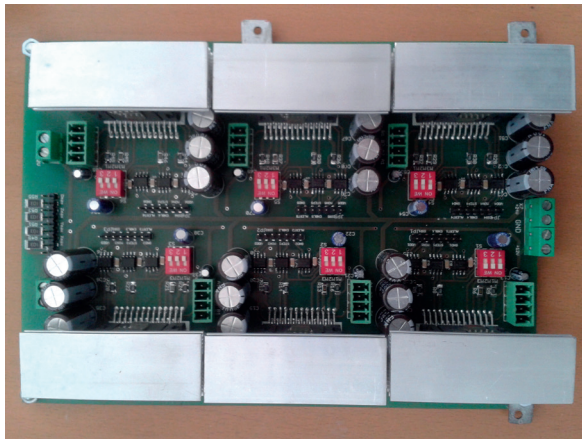


Figure 5 Mounted PCB, top view

There are many topologies of stepper motor driving circuits. According to [9], for maximum efficiency, we have chosen circuits with PWM current control. We decided to use integrated circuits and therefore IC TOSHIBA TB6600 was chosen. It provides integration of logical circuits and two power H-bridges capable of working with a peak current up to 4.5A. The logical part provides sequential changes in the current reference, depending on the chosen step size division. Around this reference, the output current is switched by a hysteresis controller (Figure 6) [10]. IC allows the stepper motor to be controlled by three signals only, namely STEP, DIR and ENABLE [11]. Rising edge of STEP signal causes motor to move one step. Logic level of signal DIR determines direction of motor rotation. Low level is for CW direction and high level is for CCW direction. The designed PCB allows to connect 6 stepper motors (Figure 5). The size of the step angle is possible to divide up to 1/16 using DIP switch. Digital isolators ISO722x isolate apart power and logic parts of circuit. As a power supply was used FNP300-1024, which provides 24V for power part and 12V for logic part. Using voltage regulator LP2950CDT-5.0 we lowered 12V to TTL level, which is suitable for TB6600 [11].

## 5. Selection of control electronics and firmware

As can be seen in Figure 1 choice of control electronics fell on Arduino Mega based on ATmega 2560, which is 8-bit

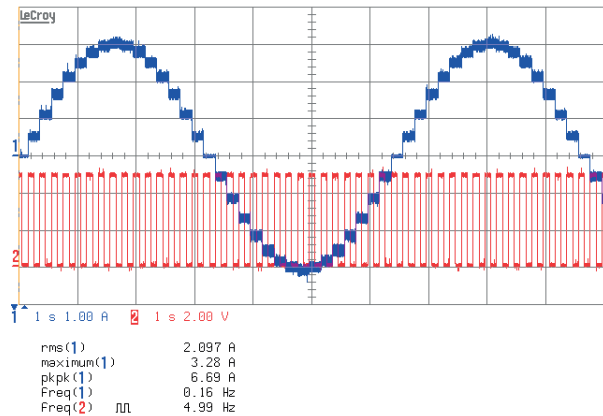


Figure 6 Phase current of motor 23HS2430 for 1/8 step (blue) and signal STEP (red)

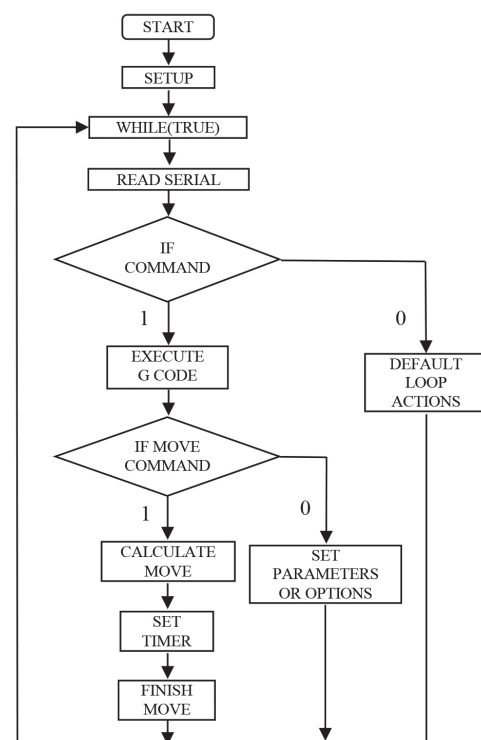


Figure 7 Simplified Repetier flowchart

microprocessor from Atmel. Because we are unable to debug program using boot loader, we used AVR Dragon board. This requires the OCD feature that the ATmega2560 meets. As a base for the control program, we chose open source firmware Repetier, made for 3D printers, as we needed to configure the device behavior [12].

In Figure 7, there is shown a simplified Repetier flow chart. It operates in an infinite loop. After start of program all registers and GPIOs are set. Then communication with PC can start. Commands are in ISO code language. It is a standard for CNC machines. If no command is sent to the processor, then the flag interrupts, temperature of hot end or the state of communication is controlled. But if the command is present in the communication buffer, processor decides whether it is moving instruction or instruction for setting some parameters or options. At moving instruction processor calculates amount of steps to reach the desired point in space according to the desired velocity

and acceleration. The logical level of DIR signal and other attributes are also set. The timer makes appropriate PWM signal for the motor control. After the finish of the move the processor reads the serial communication link again.

Because of industrial application we had to implement security features. We connected emergency switch to the Reset pin. Pressing it will bring logical 0, which will cause processor to reset and to shutdown the device immediately.

Overheating of the circuit is solved by the interrupt. When the chip temperature reaches 160°C, IC switches the ALERT signal from log.1 to log.0. The falling edge causes interrupt. In service routine all ENABLE signals first switch to log.0. Subsequently, the green LED on the signaling device goes off and the red signal starts lighting to indicate the fault condition. Before the program remains stuck in an infinite loop, the GUI application will show message that overheating has occurred. Since interrupts are used to communicate with PC, they firstly must be enabled. ATmel processors automatically disable all interrupts when the program is in the service routine of one of them. After GUI message all interrupts are again disallowed with the cli() command. The only way to get a device from an endless loop is to reset the processor after cooling of the drivers.

The role of the infrared gate is to tell the processor that a foreign body, most often a part of the human body is in the working area of the machine. The processor must respond with an immediate break of the motion activity. Engines must be stopped throughout the presence of the body in the detected area. We tried to use an interrupt but then there was a loss of steps, so we had to change the method where Bresenham interpolation algorithm is calculated. Return value of this method is the value of the comparator register for the timer. The output compares register changes for each step, depending on which axis the movement to reach the desired point in space is performed. It also depends on the required speed and acceleration. The timer then generates the appropriate STEP that signals for the individual motors to be rotated with respect to the required acceleration ramps by changing the pulse width. The current calculated ISO code line is pointed by pointer named as cur. Its private attributes include initial speed, desired speed, acceleration, accelerator steps, and so on. The Bresenham algorithm calculates some of its attributes, mainly the difference and deviation, but also the direction. Some of these attributes changes with each step, so this method is called by the processor when one of the motors moves and recalculates the attributes again and therefore performed the implementation here. So before processing the next step, the processor checks the logical level on the input from the gate. If the log. 1 level is there, the red LED goes on, the green goes off, and the processor executes blank "nop" instructions until the logic level changes again to log.0. All motors are stopped at that moment. After the change of logical level, the green LED lights up again and the red goes off. Then the attributes to which the pointer points are reset by the command cur = NULL and then recalculated, when the program is resumed. This has resulted in a ramp increase of the rotation speed, which prevents the steps being lost.

When the device operates, it may happen that the tube is emptied. Therefore, we also implemented algorithm for this case. In the method with Bresenham algorithm, is monitored whether or not a switch is activated. The switch is activated

when the push pistons reach the lower position. If so, the attributes pointed by the 'cur' pointer are reseted and the red LED lights up, and the green goes off. In the GUI is then printed "Change\_Tub" message. Current values of the STEP, DIR and ENABLE signals of the extruder are stored in auxiliary variables. Subsequently, the ENABLE signal is set to log.1 as well as the DIR signal is. The rising edge of the STEP signal in the cycle is generated until the pistons reach the top position. Next switch gives the processor information that the pistons are in the upper position. Consequently, it is necessary to change the level of the logical signal DIR back to log.0 to be able to move the pistons downwards. Then the device waits for the human operator to replace the tube. The operator sets the pistons to position where the paste starts to flow from the mixer by pushing the button. If everything is ready to continue the application process, operator presses the OK button. Next, for cycle, which generates rising edge of STEP signal, stops and the LED lights switch to the original combination. STEP, DIR, and ENABLE signals are rewritten to the original logical values. By doing so, the tube replacement algorithm is terminated and the device can continue its work.

## 6. Practical realization and evaluation of achieved results

We attached the paste extrusion module onto the Z-axis aluminium plate of positioning mechanism. For the connection of the selected motors to the structure, we used spacers in combination with flexible couplings. To control the actuators, we used the proposed PCB. It works reliably. The positioning motors are operated on a 1/8 step at a current amplitude 3.3 A. For a more fluent tube extrusion, we chose for the SX4570 1/16 step at a current amplitude 3.8 A. We placed the wires in the energy chains to prevent them from being twisted (Figure 8). The demonstration of the application over the circular trajectory is shown in Figure 9. As far as the specification in Part I is concerned, we have successfully fulfilled all the requirements. Reached dimensions of the workspace and maximal values of axes speeds are stated in Table 1.

The ability of manual Z axis offset adjustment is possible thanks to the appropriate design. The change range is 364.5 mm. The overall positioning accuracy is given by the precision of the stepper motor, the ball screw and the nut. After counting all deviations, we obtain maximum deviation that approximately is  $\pm 0.0014$  mm, which does not exceed the required accuracy of  $\pm 0.1$  mm.

Calibration at zero point was achieved by using limit switches on each axis. During the tests, we were able to reliably position 5 kg of weight. When designing a paste extrusion module, we used a worm gear with accentuate on making possible to rework the module as easily as possible for the use of both one and two-part tubes. During the application of two-part paste, both pistons are set in one plane and driven by the same motor, so there is no deviation in the application. By selecting the appropriate firmware, we have determined that the device is able to perform any trajectory whether it is a straight line or a circle. Thanks to the Repetier Host GUI application, compatible with Windows 7 and



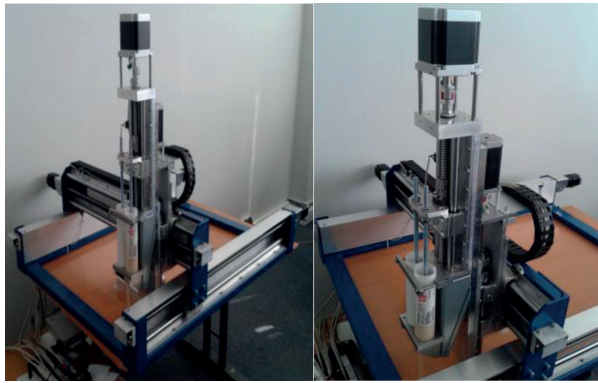


Figure 8 Practical realization of the CNC device



Figure 9 Result of paste application along the circular path.

Table 1 Reached dimensions of the workspace and maximal values of axes speeds at the selected acceleration  $500\text{mm/s}^2$

Axis	Required dimension [mm]	Reached dimension [mm]	Maximal reached speed [mm/s]
X	300	665	185
Y	400	570	242.5
Z	80	80	51

higher, we are able to easily configure all the required parameters. These are the positions in the  $X$ ,  $Y$ ,  $Z$  axes as well as the position of the motor for extrusion purposes, the speed and acceleration of the drives. It is also possible to show the path in the application. The amount of applied paste can be adjusted to a certain level by changing the speed of the extrusion motor.

## 7. Conclusion

We have built a functional device capable of applying viscous materials according to the specified specification. We have selected mechanical construction on which we have attached the designed module for the paste extrusion. The selected motors are controlled by an open source firmware which was improved according to our needs. The control algorithm for the tube exchange and some safety features were added. The device will

serve to automate the application process in the production process. In the future, the device will be placed in the cage and the only accessible area will be covered with an infrared gate. It is also necessary to program the device so that there is not too much paste dispensed during the application of the material.

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