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DESIGN OF LABORATORY 3-AXIS CNC MILLING MACHINE BY MODULAR APPROACH „LABROS 100S“

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Abstract: *In this paper, the results of the research of the modular approach to the design of lab 3-axis CNC milling machine, the basic module of the support structure including the drive systems and the measuring systems, module of the main spindle and the control unit are presented. The parameters of the support structure and of the main spindle of the lab milling machine are indentified, because of the modular approach to the desing of the machine. The goal of this research is to develop our own hardware and software system of the control unit that will enable direct entry and recognition of the G-code according to ISO 6983.*
Keywords: *CNC milling machine, modular approach, design*

INTRODUCTION

By developing and applying CNC machine tools a big progress, with an efficiency in preparation, organization and performance of manufacturing operation, is made. CNC machine tools are controlled by a computer, that is by a computerized control unit that is placed on the machine.

As the control unit contains of a computer, programs can be saved, modified and upgraded, and the results of these intervention can be simulated and verified instantly on the machine, before production begans. Programming of the CNC machine tool is made via a computer, and the program is most often transferred with a USB storage device or through a computer network.

There is aslo the possibility to program directly on the machine using the keyboard and screen, that are components of every CNC machine. The control unit support 3D geometric models as there are the basic of automatically generating of programs. The goal of this work is to desing a 3-axis CNC laboratory educational milling machine by using a modular approach.

MODULES OF THE CNC MACHINE TOOL

The structure of the CNC machine consists of the following systems: mechanical, drive, measuring and controlling. The modular approach in designing is the foundation of design of contemporary machine tools. The modules are constituent parts of the machine tool. The kinematic modules – a module of the main movement (module of the main spindle) and a module of the linear support movement in the direction of the NC coordinates have the most important role. These two modules allow the implementation of the basic function of the machine tool: the relative movement between the tool and the workpiece and the realization of the process. Onto the kinematic modules (supports, stands, bearing support system) functional systems are built in: drive systems, the system for leading (sliding and roller guides) and measuring systems for circular and linear movement.

Most of the functional systems can be found on the market as ready-made and can be adjusted fast, with some modification, to the requirements of the projected machining system. This fact in designing of the mechanical system of the 3-axis CNC milling machine was used, therefore the design of the control unit of the 3-axis CNC milling machine was the brunt of this work.

Thus, when designing the module of the linear movement in the direction of the NC coordinate axes BOSCH profiles with corresponding cross *section and BOSCH guides are used. The relative movement between the modules is realized over wormshaft and nut rack with recirculating ball bearing. Step motors with rotational movement with precisely determined functional characteristics are used to drive the bandages spindle (support linear movement).*

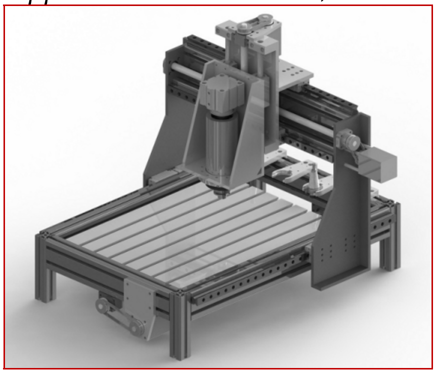

Figure 1. 3D model of the lab 3-axis CNC milling machine

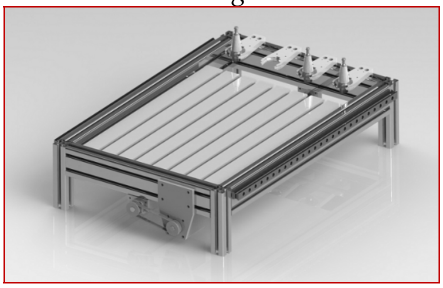

Figure 2. The module of the X axis (basic module of the support structure)

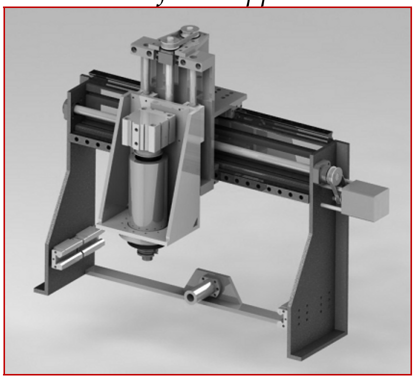

Figure 3. The module of the Y axis (gantry module)

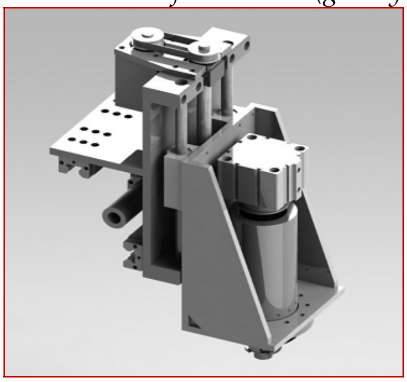

Figure 4. The module of the Z axis

The module of the main spindle consists of several basic functional parts: housing, spindle shaft, axially spaced roller bearings, electric drive motor, system for clamping and releasing tools and internal cooling system.

CONTROL UNIT

The control unit is to enable direct entry of the G-code and reading of the codes over USB interfaces, and to generate control signals for step motors based on the code. The control unit is based on a PC platform along with ARDUINO microcontrollers for every controlled axis. The interface between a machine and an operator is realized over controlling tasters and industrial LCD screen, and with the help of the interface the operator can access different regimes of programming and work of the machine, but also access and control auxiliary functions of the machine.

The relative movement between the tool and workpiece of the CNC machine is defined with the resultant which consists of the components of the movements in direction of axes of the coordinate system of the machine. According to the Figure 1, the relative movement of the tool in regard to the workpiece should follow the contour of the workpiece that is marked with the line A-B.

The real path of the tool, thus the real shape of the contour of the workpiece will not follow the contour marked with the line A-B, because in reality this is not achievable. The real path of the tool, thus the real shape of the contour of the workpiece are replaced with an approximate contour of polygonal shape. The interpolation of the real contour, by using contours of polyginal shape, is realized in the Interpolator of the CNC machine. The Intepolator is placed in the control unit. The Interpolator coordinates the movement in the direction of the axes of the machine so that the resulting movement coincide with the directions of the tangent in certain points of the contour.

Linear movement

In the structure of the G-code two basic types of linear movement are differed: rapid motion mode and the linear movement during the processing (feed motion mode). Two standard codes are used to set up these motion modes: G00 specifies rapid motion mode and G01 specifies feed motion mode.

The machine is placed in the wanted position in the shortest route with the maximum speed by using the function of the rapid motion mode. The function of the rapid motion mode is realized by giving the coordinates of the last point of the trajectory. Giving the coordinates of the last point of the trajectory the direction of the relative movement is defined and the number of the signals on the step motor, with the maximum frequency, is generated, thus the maximum speed of the step motor is achieved. This movement is realized for every axis individually (without interpolation) and lasts till the moment of the achievement of the wanted position on every axis.

¤ ***The linear interpolation***

According to the Figure 6 the movement of the tool from point A to point B is realized in a straight line with the speed V. The distance between the points is marked with D and has the value:

$$D=\sqrt{(x_B - x_A)^2 + (y_B - y_A)^2 + (z_B - z_A)^2} \quad (1)$$

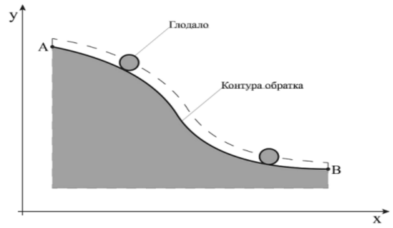

Figure 5. The movement of the tool in regard to the workpiece

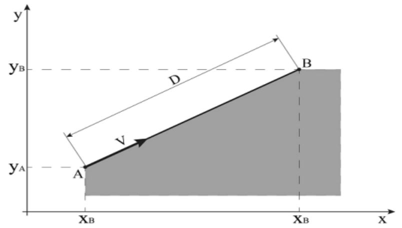

Figure 6. Process of the linear interpolation

The time interval in which the tool moves from A to B, by knowing the distance D that the tool has to exceed with the speed V, can be found: T=D/V

The movement is projected onto the coordinate axes, and the current coordinates of the tool can be expressed in the function of time:

$$x(t) = x_A + \int_0^t x dt = x_A + \int_0^t \frac{x_B - x_B}{T} dt$$
$$y(t) = y_A + \int_0^t y dt = y_A + \int_0^t \frac{y_B - y_B}{T} dt \quad (2)$$
$$z(t) = z_A + \int_0^t z dt = z_A + \int_0^t \frac{z_B - z_B}{T} dt$$

If the time interval T is devided in a large number of little intervals N, the time interval has then the value Δt = T/N, and the expressions for the current coordinates of the tool become :

$$x(t) = x(n\,\Delta t) = x_A + \frac{x_B - x_A}{N} n$$
$$y(t) = y(n\,\Delta t) = y_A + \frac{y_B - y_A}{N} n \quad (3)$$
$$z(t) = z(n\,\Delta t) = z_A + \frac{z_B - z_A}{N} n$$

where is : n = 1,2...N

According to this, the tool makes an elementary move in the direction of the axes x, y and z for every elementary step. The accuracy of the interpolation is conditioned by the maximum size of the elementary move. The maximum values of the elementary movements are given with these expressions:

$$\left|\frac{x_B - x_A}{N}\right|; \left|\frac{y_B - y_A}{N}\right|; \left|\frac{z_B - z_A}{N}\right| \quad (4)$$

¤ ***The circular interpolation***

The interpolation of a circular path is realized by defining the coordinates of the points of the circle in the function of time. This is done by the Interpolator. The controls of the G-code for doing the circular interpolation are: G02 - for the circular interpolation clockwise (CW) and G03 for the circular interpolation counterclockwise (CCW). There are defined with ISO 6983. Geometrical parameters that are given with these functions are: the current position of the machine (known from the previous line of the G-code): XA, YA and ZA, the coordinates of the last point of the arc: XB, YB and ZB and the value of the radius of the interpolated circle R. The value of R can be given with a positive or negative sign, so there are two solutions: two possible arcs.

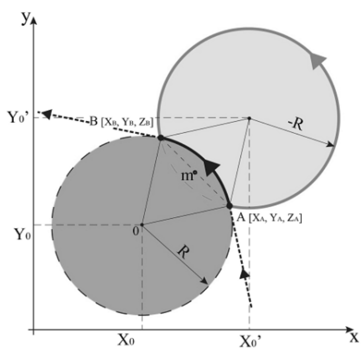

Figure 7. The circular interpolation CCW; G03

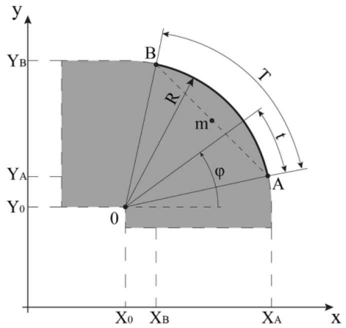

Figure 8. The process of the circular interpolation

In the formulas for parametric description of the arc values of the coordinates of the centar of the circle: X_0 and Y_0 figures. These values are defined by using the previous defined values of the coordinates of the first and the last point and the value or the radius of the arc. The relations between these mentioned parameteres are given with these following relations:

1. For the positive sign of the radius R (Figure 7 and Figure 8):

$$x_0 = x_m + \sqrt{R^2 - (D/2)^2}\,\frac{Y_A - Y_B}{D} \qquad (5)$$

$$y_0 = y_m + \sqrt{R^2 - (D/2)^2}\,\frac{x_A - x_B}{D}$$

2. For the negative sign of the radius R (Figure 7 and Figure 8):

$$x_0 = x_m - \sqrt{R^2 - (D/2)^2}\,\frac{Y_A - Y_B}{D} \qquad (6)$$

$$y_0 = y_m - \sqrt{R^2 - (D/2)^2}\,\frac{x_A - x_B}{D}$$

where X_m and Y_m are the coordinates of the centar of the straight line which connect the points A and B:

$$X_m = \frac{X_B - X_A}{2};\; Y_m = \frac{Y_B - Y_A}{2} \qquad (7)$$

D is the shortest distance between the points A and B:

$$D = \sqrt{(x_B - x_A)^2 + (y_B - y_A)^2} \qquad (8)$$

and the value of the radius R of the interpolated arc is taken as the absolute value.

According to the Figure 8 the relations of the parameterization of the arc are:

$$x = x_0 + R\cos\varphi;\; y = y_0 + R\sin\varphi \qquad (9)$$

As it is $\varphi = \frac{2\pi}{T}t$, it will become

$$x = x_0 + R\cos\left(\frac{2\pi}{T}t\right);\; y = y_0 + R\sin\left(\frac{2\pi}{T}t\right) \qquad (10)$$

DRIVE SYSTEM

The drive system provides the drive of: the main spindle, of the support of the tool, of the support movement and of the other systems and devices that are parts of the structure of the machine. According to the principles of the control in the machining process of the CNC machines the drive of the main movement and the drive of the support movement are separated, thus the conditions for an autonomously control of some drives are made.

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