INCREASING OF THE OPPORTUNITIES FOR A CLASS OF MACHINE TOOLS WITH DIGITAL PROGRAM CONTROL

Zhilevski, M.
Technical University of Sofia, Bulgaria
E-mail: mzhilevski@tu-sofia.bg

Abstract: *In this paper the basic requirements for the modern machine tools with digital program control are formulated. The main directions of modernization of a class of machine tools are shown. The practical applications of the modernized machines are presented with the machining of parts with complex geometric shapes in different mechanical operations. The research held as well as the results obtained can be used in the practical study of machine tools with digital program control.*

KEYWORDS: *MACHINE TOOLS, MODERNIZATION, DRIVE SYSTEMS*

1. Introduction

Globally, mechanical engineering sector is extremely important to the economies of all leading countries. The process of globalization and integration of countries in the international business community enforces high demands on the sector for competitiveness and technological development. The stable positions in the global marketplace require high productivity, consumer-oriented solutions, new business models and quality of human capital. Significant costs for the production and repair of machine tools are invested each year. This demands the modernization of existing machines through searching for new solutions, methods and algorithms for control, adding new devices and others [1].

Machine tools constitute about 70% of the total operating manufacturing machines in industry. They are designed to achieve the maximum possible productivity and to maintain the prescribed accuracy and the degree of surface finish over their entire service life [2].

Machine tools with digital program control are used for machining of parts with various complex geometric shapes. There are different configuration of machines and ways of processing. Machining operations are among the most flexible and accurate manufacturing processes in terms of its capability to produce diverse and complex geometric features [3, 4, 5].

Mechanical operations are characterized by a great variety and the specific requirements that are attached to them. For this reason, specialized machines are usually used for each of the mechanical operations. This leads to: the cost of the workpieces becoming more expensive; the inability to achieve the set accuracy; reducing speed; productivity and more [3, 5].

There are two main principle of all machining process. The first principle is to provide suitable relative motions between the cutting tool and the workpiece to produce the characteristic geometry. The second one is to impart the shape of the cutting tool to the workpiece in order to create part geometry [6, 7, 8, 9].

With increasing demands for better machining accuracy and higher productivity, methods and algorithms are constantly sought to improve the performance of machine tools [3].

The trend in the future is to increase the accuracy of machining. This in turn leads to increased requirements for the machine tools and the components that make them [10, 11].

The modernization and the development of machine tools with digital program control are processes of continuous innovation and advancement of existing technologies, machining processes and systems. A general trend as regards the growth of production in this technological developed world is more and more based on modernization and application of new machining systems and technologies, flexible automatization, computer-integrated production, what is the main aim to achieve a higher-quality, cheaper and faster production. Modern concept of the machine tools design are characterized by development: machine tool modules, intelligent and integrated manufacturing systems, reconfigurable machines and systems, parallel kinematic mechanism of machine tools and high speed machines [12].

In this paper the basic requirements for the modern machine tools with digital program control are formulated and the ways for increasing the capabilities of existing machine tools are presented. Modernization of one class of machine tools with digital program control is presented and discussed. The practical applications of the modernized machines in different machine operations of parts with complex geometric shapes are shown.

2. Basic requirements

Basic requirements for modern machine tools with digital program control are related to [2, 3]:

- improving their working accuracy;
- high processing speed;
- providing heavier cutting modes;
- increasing of available power;
- high precision positioning;
- versatility;
- increasing the level of automation for the machine tool operative units and their switching elements;
- possibility for machining of parts with different geometric shapes and hardness of the material;
- increasing the traverse speed of the operative units during the non machining parts of the production time;
- adopting modern control techniques such as NC and CNC;
- reliability;
- productvity;
- reduction of energy consumers;
- easy maintenance;
- long service life;
- acceptable level of vibration;
- adequate damping capacity;
- low rates of wear in the sliding parts;
- low thermal distortion of the different machine tool elements;
- economy;
- low design, development, maintenance, repair, and manufacturing cost;
- maintainability.

Increasing the capabilities of the existing machine tools are achieved by:

- modernization of electric drive systems;
- the appropiate choice of CNC systems;
- developing a reliable ladder diagrams;
- adding new devices and systems;
- development of a control panel for these machines.

The electric drive systems for machine tools include feed, spindle and auxiliary drives. The feed drives are used for positioning of the tool and the workpiece at the desired locations and they participate in the machining process [13, 14, 15]. The spindle drives are involved in the machining process, greatly affecting the quality of the parts and the productivity of the entire machine [3, 16, 17]. The auxiliary drives are used for the additional systems and mechanisms that serve and support the proper operation of the machine tools. In some cases, the introduction of auxiliary drives significantly performance improvement of the machine, the accuracy, economy, cost, and can provide mechanical machining of parts with significantly more complex geometric shape and higher requirements [18].

3. Modernization of a class of machine tools

The modernization is one of the ways operating parameters of existing machine tools to be approximated to those of the modern models [3].

In the modernization of a class of machine tools with digital program control are introduced: two additional controlled axes, namely a table rotation as axis *c* and rotary table tilting as axis *a* and devices for solid angular positioning of the workpieces in 30° and for machining of spline channels.

These machines allow the following mechanical operation: milling, drilling, boring, reaming, processing of spline channels. The introduced devices and systems have achieved the flexibility of machining parts with significantly more complex geometric shapes and machining requirements for various mechanical operations.

Milling is metal cutting performed with a rotating, multi- edge cutting tool. Each of the cutting edges remove a certain amount of metal with a limited in-cut engagement, making chip formation [19].

Drilling process covers the metods of making cylindrical holes in a workpiecewith metal cutting tools [19].

Boring operations involving rotating tools are applied to machine holes that have been made through methods such as pre-machining, casting forging, extrusion, flame-cutting, etc. Typically, boring operations are performed in machining centeres and vertical boring machines [19].

Reaming is the finishing of an existing hole. This method involves small working allowances to achieve high surface finish and close tolerance [19].

One machine from the studied class of machine tools is shown in fig.1. The basic notations are as follows: 1- body of the machine; 2- control panel; 3 - motor for coordinate axis *x*; 4 - device for solid angular positioning of the workpiece in 30°; 5 - rotary table, performing angular movement along a coordinate axis *c* and tilting along *a* coordinate axis; 6- instruments; 7- spindle motor; 8- motor for axis *z*; 9 - a metal box for the CNC system and parts of the electrical drives of the respective coordinate axes and spindle; 10 - guides on the *z* axis; 11 - spindle gearbox; 12 - processing tool; 13 - horizontal mass, performing movements along *x* and *y* coordinate axes.

The instruments are eight pieces and some of them are situated in: I1 – for spline channels; I3, I5- for milling operation; I7- for drilling operation; I8 – for boring operation.

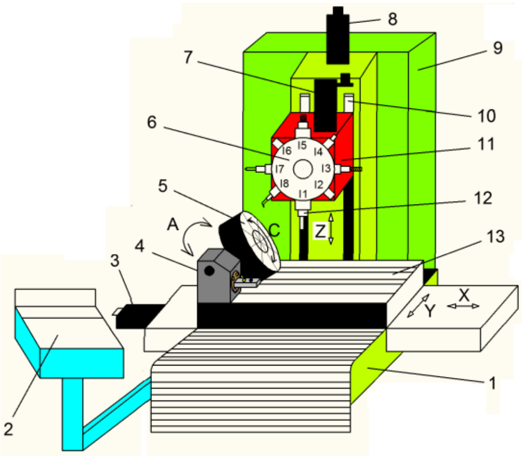

Fig. 1. *One machine from the studied class.*

The feed drives for the modernized machine can be linear and rotary. The linear feed drives are the axes *x*, *y*, *z* and the rotary feed drives include axes *a* and *c*.

In the drive system of studied class machines are researched the different mechanical operations. On this basis are selected the motors, power converters, mechanical gears and sensors.

A block diagram of the drive system is shown in [14, 16].The main requirements of the drive systems of the modernized machine tools can be formulated as follows [14, 16, 20]: smooth speed regulation in a wide range; good dynamics; high position accuracy; formation of the necessary position cycles; providing the required speed and torque in machining; reversible speed and torque control; compensation of the disturbances in materials with different hardness; easy maintenance; dual-zone speed regulation for spindle drives; oriented braking with high accuracy; solid angular positioning of the workpiece with high precision of additional introduced device; a subsystem providing choice of the desired tools; dosing lubrication of the machine coordinate axes; cooling subsystem with option for automatic and manual braking and starting from the control panel.

The calculations were performed under the heaviest cutting regimes. The methodologies for selection of the feed and spindle drives in different mechanical operations are presented in [14, 16, 18, 21, 22, 23].

In table 1 are shown some results from the choice of feeds and spindle drives in machining of unalloyed steel [24, 25, 26, 27].

Table 1. *Some results from the choice of feeds and spindle drives.*

Linear feed drives with parameters: - a ball screw with nominal diameter 0.04 m with step 0.02 m; - DC motors with nominal parameters: $M_{fnom} = 5.4$ Nm , $\omega_{fnom} = 209.34$ rad/s ; - power converter SA-12; - encoder – model 7L with 2500 imp./ rev.
Rotary feed drives with parameters: - worm gear with coefficients: $g_a = 3^{\circ}$/rev and $g_c = 2^{\circ}$/rev ; - DC motors with nominal parameters: $M_{nom} = 2$ Nm , $\omega_{nom} = 314$ rad/s for axis *a* and for axis *c*: $M_{nom} = 1.6$ Nm , $\omega_{nom} = 314$ rad/s ; - power converter - model SA -8; - encoder – model 7L.
Spindle drive with parameters: - mechanical gear with ratio 1.3 =1.5; - DC motor with parameters: $P = 7.5$ kW ; $\omega \approx 230.3$ rad/s - power converter - model SA.

The digital control system is widely used for control of the drives in machine tools, as well as for implementing the various modes of operation. The control of the auxiliary drives and the activation of the desired modes are done with the help of the ladder diagrams, which are introduced into the programmable logic controller of the machine. Designing and developing of ladder diagrams is essential for reliability, productivity, and technology [29, 30].

The auxiliary drives for the studied class machine include: instruments subsystem; dosing lubrication; the device for solid angular positioning of the workpiece in 30°; hydraulic subsystem; cooling subsystem.

For control of the additional introduced device for solid angular positioning of the workpiece in 30° is used similar ladder diagram presented in [29]. The ladder diagram make improvements to: increase its operational life; ensure more secure and solid positioning of the selected position; protect the motor from overload.

The hydraulic subsystem is related to the subsystem for choosing instruments. The development ladder diagram is presented in [30]. As a characteristic feature, it can be noted that the hydraulic subsystem works only while selecting an instrument. This leads to a significant reduction in energy consumption, an increase in the service life and the reliability of the entire machine.

The dosing lubrication subsystem provides oil lubrication to the guides along which the coordinate axes move [31]. This subsystem is very important for increasing the service life of the feed drives and hence the entire machine. This system is implemented by switching on a three-phase induction motor that drives a hydraulic pump to provide a circular lubrication. Decoded timers in the ladder diagram provide automatic lubrication of the guides for a period of 20 minutes.

The cooling subsystem in machine tools is particularly important as it affects the quality of the workpiece and the energy consumption of the entire machine. In machining, it is almost always necessary to use cooling. By inserting additional buttons on the control panel, as well as decoded commands in the ladder diagram, it is possible to start and stop the operation of the cooling system as needed.

Fig. 2. Control panel for the modernized machine.

Fig. 2 presents the development control panel for the modernized machine from fig.1.

4. Practical applications

To meet the high requirements placed on the workpieces and to achieve higher machine speeds and performance, the need for precise coordination of the movements of the coordinate axes, spindle and auxiliary drives is applied. This is accomplished by using CAD/ CAM systems based on geometric part models [32, 33].

In the next figures are presented the practical applications of the modernized machines in the machining of parts with complex geometric shapes.

In fig. 3 is shown the subsystem of the instruments with the next mechanical operation: drilling, milling, boring and machining of spline channels.

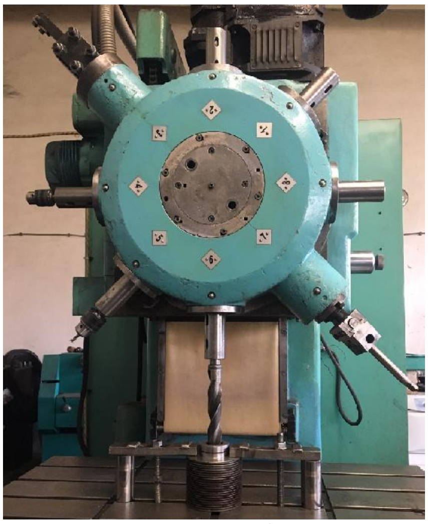

Fig. 3. The subsystem of instruments.

In fig. 4*a* and fig. 4*b* are presented the processes in rough and fine milling respectively.

a) *b)*

Fig. 4. The milling processes.

The drilling processes with the device for solid angular positioning of the workpieces in 30° are shown in fig. 5*a* and fig.5*b*.

a) *b)*

Fig. 5. The drilling processes in different workpieces.

Fig. 6*a*, fig.6*b*, and fig.6*c* present the processes of reaming, boring and machining of spline channels respectively.

a) *b)* *c)*

Fig. 6. Different mechanical operations.

Fig. 7 shows some the processed workpieces after machining.

Fig. 7. The processed workpieces.

The modernized machine achieves high requirements for accuracy, speed, productivity and reduces the cost of the workpieces in machining processes.

5. Conclusion

In this paper the basic requirements for the machine tools are formulated and this basis modernization of one class machine is made with purpose to increase the capabilities.The different mechanical operations enable to be achieved the accuracy, speed, technical and economic parameters of the workpieces.

The practical applications of the modernized machines are shown with the machining of parts with complex geometric shapes.

The research as well as the results obtained can be used in the development of such machine tools with digital program control.

This work is supported by the Technical University of Sofia, Bulgaria under Research Project No. 191PR0002-08/2019.

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