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USING 3D MODELING SYSTEMS TO CREATE A SMALL PORTABLE MILLING MACHINE CONTROLLED BY AN INDUSTRIAL CLOUD

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ABSTRACT

This paper describes the concept of unified modeling of analysis tools, as modeling is regarded as useful method for the mechanism planning of devices, machines, individual parts, and assemblies used in mechanical engineering. Modeling is one of the analysis tools that permits to preliminarily study some objects, methods, or developments at given properties; accordingly, modeling tends to understand the nature of those characteristics and then re-creates an object, process, or phenomenon that has a degree of common relationship. Thus, modeling is the process of reflecting and learning some properties with the aim of further recreating these properties and improving them if necessary. On the investigated model of the 3D model for a small-sized portable portal miller, the selection of individual parts of such a tool is shown and justified. Moreover, a diagram of a conveyable portal edge machine with Computer Numerical Control (CNC) has been generalized and developed. Through investigating the modeling and designing the necessary devices and mechanisms, a variety of systems have been studied to explain the reason for choosing the SolidWorks system for modeling types. The choice of individual components of a small-sized portable portal milling machine is demonstrated and justified using the example of making a 3D model. In addition, a generalized and developed block diagram of a portable portal milling machine with CNC has been created, where each element of such a block diagram is described and a recommended selection is made. Finally, individual components of a portable portal milling machine were modeled with CNC and the results are displayed for a detailed 3D model of the milling machine's top portal assembly with the G-PENNY MACHINE spindle fitted is also displayed.

Keywords: *Computer Numerical Control (CNC), 3D parametric modeling, Automatic Tool Change (ATC), Line Print Terminal (LPT), Universal Serial Bus (USB)*

1. INTRODUCTION

Modeling is one of the research tools that allows preliminarily studying some object, process, or phenomenon at given properties to understand the nature of these properties and then recreate such an object, process or phenomenon [1, 2]. Thus, modeling is the process of reflecting some properties and studying them with the aim of further recreating such properties and, if necessary, improving. Then, the necessary properties are explored in advance and lay these features in order to recreate the most recommended output, such as the object investigated in this paper, where modeling can also be considered as an integral part of information technology, which permits to create objects with desired properties. In this case, it is appropriate to talk about information modeling, where the possibilities of computer science are widely used [3, 4]. It is also possible to consider other aspects of modeling as a general tool of knowledge [5-10]. A special place among the various aspects and possibilities of modeling is occupied by computer graphics, in particular, computer graphics technologies and software can be used for automatic design and simulation of parametric object modeling systems. Among the various areas of modeling for automatic design systems and parametric object modeling systems, it is important to note the modeling of units and entire means of production, which makes it possible to manoeuvre when there is a shortage of replaceable parts of individual components of the production means or to create new small-sized devices and components. It should also be noted that various modeling tool systems, which are closely related to the automation of modern production, can be also used, taking into consideration that among such systems, the following aspects should be noted: CATIA, T-Flex, Unigraphics, AutoCAD, and SolidWorks [11-14], as these systems make it possible to develop 3D models of various tools, machines, individual elements and units of equipment, and simulate various loads on them in order to determine the design features and material of the part immediately before its manufacture, which ultimately determines the relevance of the chosen research topic, and its practical significance.

Computer numerical control (CNC) machines play an essential position with inside the production industry. These complicated machines are managed via a Personal Computer (PC) and offer a degree of efficiency, accuracy and consistency that could be not possible to reap via a guide process. Operations that have been not possible years in the past at the moment are smooth way to CNC machining. Just as there are numerous distinctive components that CNC machines can make, there also are diverse styles of CNC machines used to perform this. Each device differs in construction, the manner they function and the styles of product they are able to make. Keep studying to examine all approximately the distinctive styles of CNC machines and their specific functions.

CNC machining may be described as a method wherein pre-programmed computer software program dictates the motion of manufacturing unit equipment and tools. As a result, producers can produce components in much less time, lessen waste and remove the chance of human error.

This production method is used to govern a huge type of complicated equipment, in an effort to be mentioned on this article. Essentially, CNC machining makes it viable for three-dimensional cutting to be completed by following one set of prompts.

Most recent applications that imply CNC are shown in [15-20], where in [15] CNC was implemented to control a laser engraver used for remote imaging in limited space work, in [16] CNC was utilized for a 3-axiz machine for the propose of a low-cost human machine interface, in [17] provides a wide range of recent applications in mechanical processing, in [18] deep learning and internet of thing technics were implemented to monitor and secure the CNC machines against cyber-attacks, in [19] CNC was applied over the Artisanal cutting of leather accessories used to produce shoes, and Raspberry pi and cloud computing were used to achieve a dependable CNC controller was introduced in [20].

One of the most common types of CNC machines, a CNC router uses computer controls to cut various materials. Mills can translate specific programs from numbers and letters to move the spindle in different ways. This is one of the criteria that determine the scope of this study.

This paper describes the concept of unified modeling of analysis tools, as modeling is regarded as useful method for the mechanism planning of devices, machines, individual parts, and assemblies used in mechanical engineering. This makes it possible to simplify the creation of the necessary nodes, devices with specified properties. Also, costs and time are minimized when creating samples of new equipment. Therefore, it is important to first justify the need to develop a certain node, device, then develop a model, and then implement it. These determine the need for this study. On the investigated model of the 3D model for a small-sized portable portal miller, the selection of individual parts of such a tool is shown and justified. Moreover, a diagram of a conveyable portal edge machine with CNC has been generalized and developed. Through investigating the modeling and designing the necessary devices and mechanisms, a variety of systems have been studied to explain the reason for choosing the SolidWorks system for modeling types. This is also an important aspect in the rationale for this study. The choice of individual components of a small-sized portable portal milling machine is demonstrated and justified using the example of making a 3D model. In addition, a generalized and developed block diagram of a portable portal milling machine with Computer Numerical Control (CNC) has been created, where each element of such a block diagram is described and a recommended selection is made. Finally, individual components of a portable portal milling machine were modeled with CNC and the results are displayed for a detailed 3D model of the milling machine's top portal assembly with the G-PENNY MACHINE spindle fitted is also displayed.

2. RELATED WORK

There are many recent researches in which both the issues of choosing tools for carrying out the corresponding modeling process and the issues of direct modeling for the design of various components and tools are studied for machine tool elements and equipment units. Generally, modeling systems for designing various units, tools, machines, elements, and units of equipment can be conditionally divided into the several classes, taking into account the creation of a comprehensive picture of the future model [21, 22], which are as following:

First: Low-level system (two-dimensional modelling system), such as AutoCAD, CADdy, CADMECH Desktop, Master CAM, Telex CAD, Omni CAD, and Compass-Graph.

Second: Mid-level system (3D modelling), such as SolidWorks Solid Edge, Cimatron, Form-Z, Autodesk Inventor, Solid Master CAD, Mechanical Desktop, and Design Space.

Third: Top-level (3D modeling), such as ADAMS, Ansys, Catia, EucliD3, Pro/Engineer, and UniGraphics.

The more complex the model, the more the accuracy and efficiency are obtained, which requires a higher-class modeling system.

The broadest review of the relevant modeling systems is presented in [23]. At the same time, in [24] one can find a comparison of various programs for 3D modeling – modeling in systems that give a more accurate and complete description of the objects, devices, assemblies, parts, equipment in general. The work in [25] is devoted to a review of software libraries to characterize the corresponding modeling systems of different levels.

Despite the variety of modeling systems, there are two main leaders that are used to build models and design various units, tools, machines, elements and equipment units, which are SolidWorks and Autodesk Inventor [23-25], where both systems are designed for 3D parametric modeling. Despite the fact that SolidWorks is a middle-level system, it has sufficient functionality and versatility, which is noted by various researchers, such as in [24], and [26, 27], where SolidWorks expands the possibilities of three-dimensional modeling for many developers, which was achieved by the fact that SolidWorks tolerates arbitrarily changing parts directly from the assembly; consequently, the connection between the parts and the assembly guarantees their synchronous update when any parameters change. Thus, assembly drawings can be created at any stage of modeling and design. Based on this, in the proposed modeling in this research, the SolidWorks system was adopted.

Many researches in which the issues of the specific use of various systems for the corresponding modeling are considered, where the issues of creating electronic models are mainly considered to greatly facilitates the process of designing and creating new models of devices, machines, and their individual components.

A. H. A. Hassan and N. Kurgan consider the process of creating an electronic three-dimensional model of a rectangular plate in the Ansys system [28]. V. Vlajkov, E. Desnica and I. Palinkas explore the process of creating an electronic three-dimensional model in the SolidWorks system [29]. The work in [30] presents the use of CAE for numerical simulation of a multistage automatic control system that can change the speed and flow of air as per request. The paper [31] presents the CADLAB subsystem, which allows generating various details of the overall process of designing and modeling various devices, machines, and assemblies, so, both different modeling systems and different directions for their usage can be understood. Moreover, [22-31] justifies the choice of the proposed research's direction for the general design and modeling process that is associated with the development of a small-sized portable portal milling machine modeling, consequently, the investigated research is aimed at general drifts in the development of the industry segment, as well as various issues of its unification, standardization, additional opportunities in the field of automating repetitive work, solving everyday design problems, as well as in the implementation of projects, and coordination of teams with any territorial location, which makes it necessary to develop samples of small-sized equipment and devices.

3. BACKGROUNDS: CNC MODELING OF MILLING MACHINES

Nowadays, the milling machines are regarded as the most universal means implemented for surface treatment, which apply Computer Numerical Control (CNC). CNC milling machines allow producing parts with complex curved surfaces, which suites both of serial parts production and single batches. Milling machines can be divided into industrial, portal middle class and desktop machines [32, 33]. Industrial CNC machines are the largest and most expensive, with average market prices ranging from $62,000 to $700,000. A striking example is the CNC Siemens Sinumerik 808D Advanced (figure 1a) and CNC Cormak MILL 500 ECOLINE (figure 1b) [34, 35].

Though this type of industrial CNC machines have many important advantages, but they still have a number of significant drawbacks, such as: stationarity (difficulty to move due to large dimensions and weight), complexity of connection

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and configuration, and long start-up time. All of these shortcomings limit the scope of these types of CNC machines.

a) b)

Figure 1: Industrial CNC machines [34, 35]

The next class of industrial CNC machines are mid-level portable gantry CNC machines as shown in figure 2 [36].

Figure: 2. Portable milling machine, CNC Cormak C1212 as an example [36]

Mid-range gantry machines cost a lot less than low-level, but the accuracy and repeatability of these machines are significantly worse than the acceptable level for the industrial machines. More often, the low-level machines are assembled from the same components according to the same principles; however, these machines are smaller and lighter than industrial machines, and have fewer additional equipment such as Automatic Tool Change (ATC) [37, 38], where machine is usually controlled from a personal computer directly via the Line Print Terminal (LPT) [39], or using specialized controllers connected to a computer via the Universal Serial Bus (USB) or Ethernet [40, 41].

Machines of such type are popular with small businesses, individual entrepreneurs. The disadvantage of these types of CNC machines is the lack of protection against dust and chips, moreover, since the operating time and the total travel distance of the head are not large for the entire time of operation of the CNC machine, the simplification of the supporting structures and materials that are used in the design of these types of machines affects the types of materials that can be processed on them, and the last disadvantage is the need for a set of milling operations and automation elements.

After analyzing these types of CNC milling machines (Fig. 1 and Fig. 2) and studying their advantages and disadvantages, it was decided to design and a developed 3D model of the machine based on a medium-level CNC portal milling machine.

The criteria and rationale behind choosing this type of machine are as follows: the cost of industrial machines components is high, special equipment is required for its assembly, and the accuracy and repeatability of the portal machines. Moreover, due to the size of the working field, mid-range gantry machines allow producing a much larger number of parts or processing a large surface area, while providing greater flexibility and mobility in moving a CNC milling machine.

At the same time, it is important to note that the proposed work in this paper is for modeling a general design of such machines, which is the basis for building and designing a whole series of them.

4. SIMULATED DESIGN OF A 3D SMALL-SIZED PORTABLE PORTAL MILLING MACHINES: WORK COMPONENTS

At the first stage of designing a portal milling machine with CNC, it is necessary to develop its block diagram based on the tasks set. The introduced work in this paper proposes the block diagram shown in figure 3.

According to the developed block diagram of a milling machine with CNC, the selected components are as following: Control board; Stepper motor (SM); Stepper motor driver; Ball screw; Spindle; Pump (for water cooling); Inverter; Position sensor (PS), and Power unit.

To choose the correct control board, the CNC milling machine, as determined from the analysis, is recommended to be of the portal type, so the total

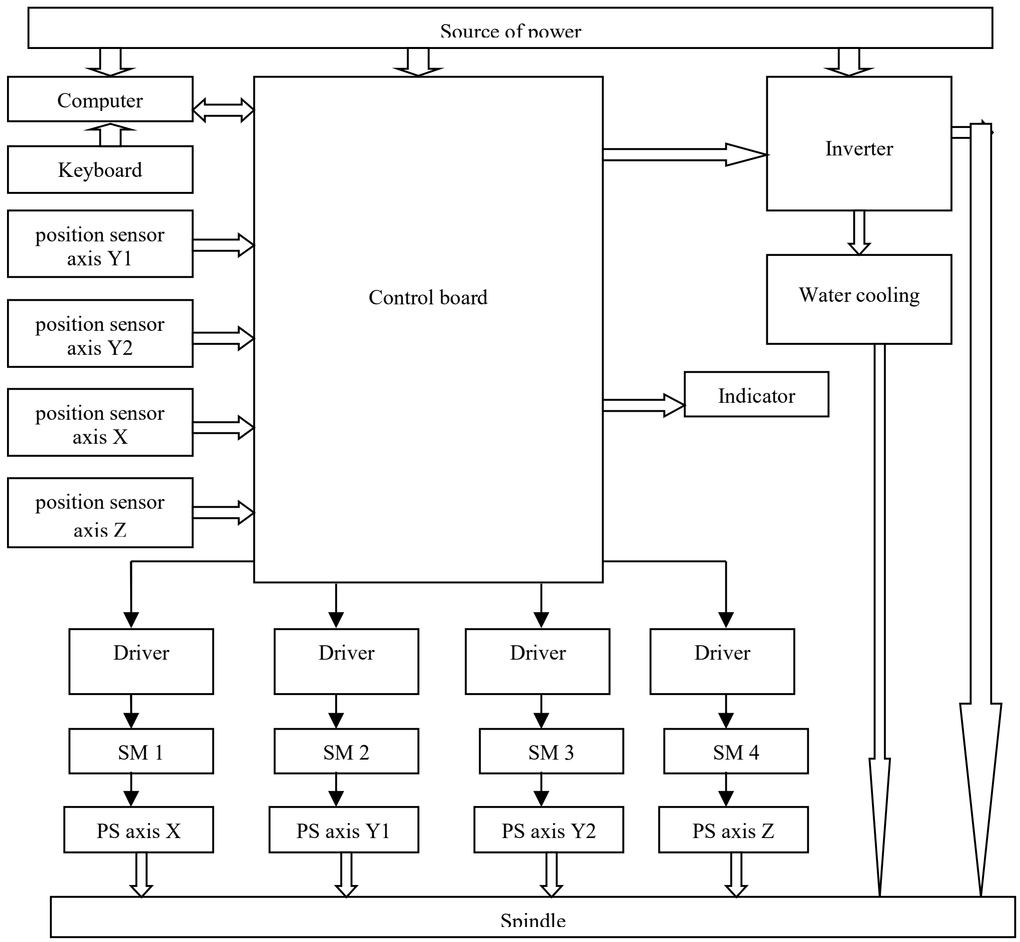

Figure 3: Structural diagram of a portal milling machine with CNC

number of stepper motors on the axes will be 4 pcs., as well as the number of sensors. In this case, it is necessary to realize the possibility of connecting and controlling the speed of the spindle. Considering all the above limitations, it is proposed to use the BSMCE04U-PP board as a control system for a CNC milling machine [42]. The main characteristics of the BSMCE04U-PP board are presented in Table 1.

Table 1: Key features of the board BSMCE04U-PP [42]

№	Parameter	Values
1	Microcontroller	STM32
2	Working voltage	5B
3	Supply voltage	12-24B
4	Number of axles support	4
5	Maximum stepping impulse purity	100 kHz
6	Interface	USB
7	Number of relay ports	8
8	Size	81.5x77.5 mm

As a stepper motor, it is proposed to implement a hybrid stepper motor, since hybrid motors combine the best features of variable reluctance stepper motors and permanent magnet motors [43]. The rotor of a hybrid engine has teeth arranged in an axial direction, which provides a small step size, more torque and more speed. The typical number of steps per revolution for hybrid engines is from 100 to 400 (step angle 3.6 - 0.9 degrees) [43]. Based on the above parameters, it is proposed to choose a NEMA 23 hybrid stepper motor model of 57HS1003004D8 [44]. Key features of NEMA 23 model of 57HS1003004D8 are shown in Table 2.

Table 2: Main characteristics NEMA 23 models 57HS1003004D8 [44]

№	Parameter	Values
1	Number of phases	2
2	Type of winding	Bipolar (4- wired)
3	Step	1.8^0
4	Winding current	3A
5	Torque	25 kg * cm
6	Holding moment	2.5 H* m
7	Size	57x57x100 mm

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Based on the characteristics of the selected NEMA 23 stepper motor, the driver is selected. After analysing the available drivers on the market, the DM542 driver with a phase current margin was chosen as in [45, 46]. The main characteristics of the DM542 stepper motor driver are shown in Table 3.

Table 3: Key features of the driver DM542 [45, 46]

№	Parameter	Values
1	Mode support	PUL/DIR and CW/CCW
2	Microstep	200-25600 Impulses
3	Motion stresses	20-50B
4	Frequency	To 200 kHz
5	Resonance suppression function	Yes
6	Size	118x75x34 mm

The main working tool for a CNC milling machine is the spindle, which enables processing not only wood, but also soft metals such as aluminum, with taking the power, speed, and spindle collet into consideration. The best spindle option would be a water-cooled spindle, as opposed to air-cooled, such spindles are better cooled, sealed and most importantly quiet. Thus, the G-PENNY MACHINE water-cooled spindle was chosen as in [47, 48]. Table 4 shows the main characteristics of the G-PENNY MACHINE spindle.

Table 4: Main characteristics of the spindle G-PENNY MACHINE [47, 48]

№	Parameters	Values
1	Supply voltage	AC220 B
2	Working rotation speed	0-24000 Revolution per minute
3	Max Torque	0.54 N*m
4	Power	1500 W
5	Maximum speed	400 Hz
6	Dimensions	80*260 mm

As already known, the spindle cannot work directly from the regular outlet, since the maximum outlet frequency is 50 Hz, where the frequency for the maximum spindle speed is 400 Hz, as a result, it is necessary to choose an inverter that is selected depending on the characteristics of the selected spindle (Table 4). Analysing the characteristics of the spindle, within the framework of these studies, it is proposed to use the HY01D523B inverter, the main characteristics are shown in Table 5 as in [49].

Inductive position sensors LJ12A3-4-Z/BX [51] were chosen to control the position of the tool of a CNC milling machine in space or to control the boundaries of the working field of the machine.

Table 5: The main characteristics of the inverter HY01D523B [50]

№	Parameters	Values
1	Incoming voltage	AC220 B
2	Outgoing voltage	AC220 B
3	Input frequency	48-63Hz
4	Output frequency	0-400 Hz
5	Output phase	3-phase
6	Dimensions	170x125x163 mm

A general view of the selected elements for the development of a portal-type small-sized CNC milling machine is shown in figure 4, which are as following: a – Control board BSMCE04U-PP [42]; b – stepper motor NEMA 23 model 57HS1003004D8 [44]; c –Driver DM542 [45, 46]; d – Spindle G-PENNY MACHINE [47, 48]; e – Inverter HY01D523B [49], f – Position sensor LJ12A3-4-Z/BX [50].

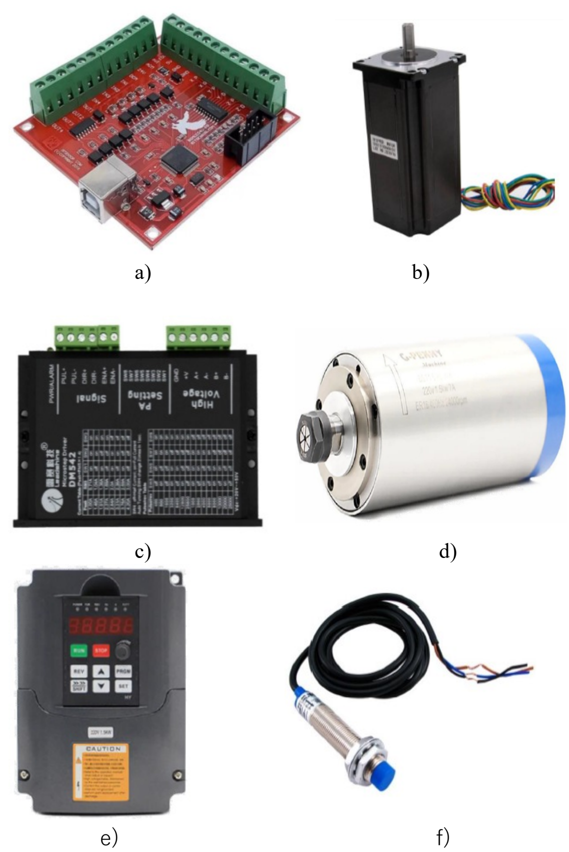

Figure 4: General view of the selected elements for the development of a small-sized CNC milling machine of portal type [42, 44-50]

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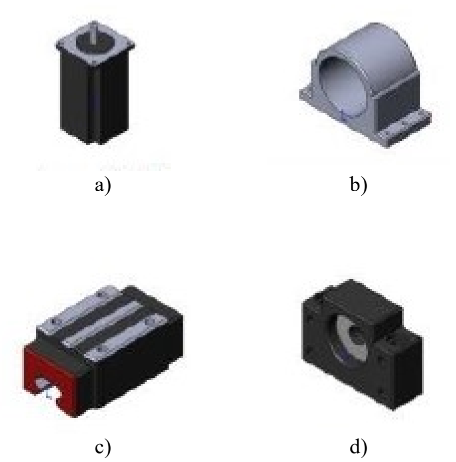
5. DETAILED 3D MODEL OF THE ASSEMBLY LAYOUT OF THE MILLING MACHINE

The next step in the development of a portal-type CNC milling machine is the design and creation of a detailed 3D model of the layout assembly, which is proposed to use modern Computer-Aided Design (CAD) systems for industrial 3D modeling [11-14]. As part of these studies, the author suggests using CAD SolidWork 2020 [23-25]. Besides the above-mentioned limits, the rationale for the choice is the fact that CAD SolidWork 2020 supports modern approaches to solid modelling, which suports developing 3D models of any complexity and design detailed 3D models of structural assemblies, on the basis of which you can get drawings of parts for their production at enterprises [14]. Figure 5 shows examples of 3D models of parts of a small-sized CNC milling machine of a portal type developed in CAD SolidWork 2020, on the basis of which a detailed assembly model of the machine will be designed. Figure 5 shows the following developed parts:

a – Stepper motor model Nemo 23 model 57HS1003004D8;
b – Spindle mount G-PENNY MACHINE;
c – Carriage;
d – Support;
e – Screw;
f – Spindle G-PENNY MACHINE;
g – Support profile;
h – Left corner;
i – Bracket for cable stacker;
j – Stepper motor mount Nemo 23.

All presented models are obtained directly in the SolidWorks system.



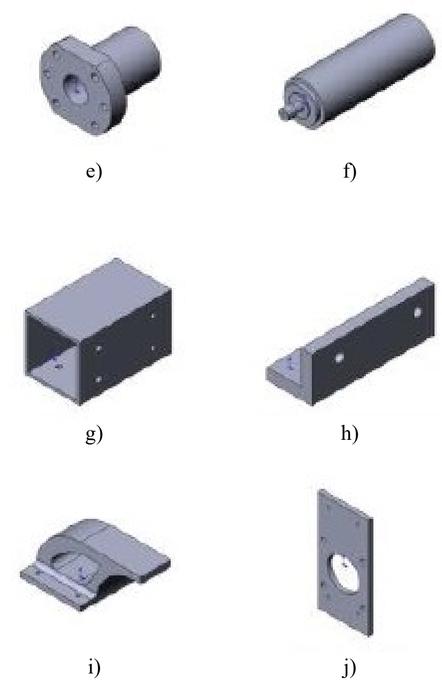


Figure 5: Examples of 3D models of parts of a small-sized CNC portal milling machine developed in CAD Solid Work 2020

Based on the developed 3D models of the parts, the next step is to design a detailed assembly 3D model of a portal-type CNC milling machine. To do so, the built-in Assembly module in CAD SolidWork 2020 presented in [23, 24] is implemented.

An example of the developed detailed assembly of a small-sized portal-type CNC milling machine is shown in figure 6, which shows a simulated upper portal of a milling machine with a G-PENNY MACHINE spindle installed and Nemo 23 stepper motors, which validates horizontal and vertical movement of the milling head.

Based on the developed detailed 3D model of the assembly of the upper portal of the milling machine with the installed G-PENNY MACHINE spindle and Nemo 23 stepper motors, it is recommended for future work to run simulations in the Nostrum module to assess the reliability of the developed structure.

Finally, it is important to understand that the designed model has the ability to be connected and controlled through the industrial could; to do so, the work presented in [51, 52] can be implemented. Indeed, in [51] a blind scalable edge-guided reconstruction filter can be used in a smart

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environment to monitor the green IoMT-UAV networks, where in [52] the network packet classification can be enhanced by using GPU, as a result from improving the performance of the aggregated bit vector algorithm.

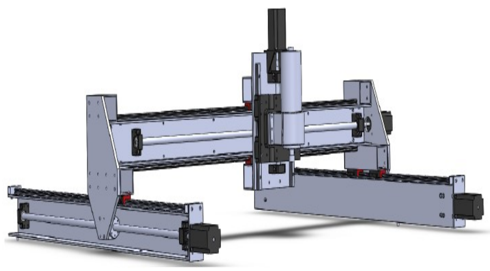

Figure 6: Detailed 3D model of the assembly of the upper portal of the milling machine with the installed G-PENNY MACHINE spindle and Nemo 23 stepper motors

In [53], a bidirectional GRU network-based next POI category proposed for healthcare, can be implemented in the proposed design to improve the safety of the network system. In [54] and [55], a long short-term memory-based model and an attention-based category-aware GRU model were proposed for Greenhouse climate prediction and next POI recommendation, respectively. Table 6 compares the obtained results with the STM6060 well-implemented machine.

Table 6: Comparison between STM6060 and the proposed model

Specifications	***CNC milling machines***	
	Model STM6060	***The designed model***
Frame	Steel Structure	Steel Structure and composite materials
Working area	600×60×100mm.	1000×1000×100mm.
Spindle Speed	0-24000 RPM	0-24000 RPM
Spindle Power Motor	1.5KW water cool	2.2KW water cool
Repositioning Positioning	0.05mm	0.043mm
Operation Power	300W	240W
Voltage	AC220V/50Hz	AC220V/50Hz
Command Language	G-code	G-code
Price	2500-4000$	1000-1300$

It should be noted that, according to a number of criteria, the proposed modeling and its implementation make it possible to obtain an appropriate machine with parameters no worse than for the STM6060 model. At the same time, the cost of the developed machine is much less than the model STM6060. We also note that we offer a simulation process and machine development for standard software tools. Moreover, such a process can be implemented in the field.

6. CONCLUSION

The article describes the concept of modeling as one of the research tools. The proposed work considers modeling for the design of various mechanisms, devices, machines, individual components and assemblies that are used in mechanical engineering. We are considering a portable milling machine. This choice is based on the importance of using this mechanism in the implementation of projects in various applied research areas for the behavior of routine maintenance. In addition, the issue of replacing individual parts in the field is also relevant. This highlights the need for the conduct of this study.

In the proposed work, various systems for modeling and designing the corresponding devices and mechanisms were also considered. The choice of the SolidWorks system for the modeling process is substantiated. This choice is based on the simplicity of modeling implementation, the possibility of analyzing three-dimensional models, and the availability of functions for analyzing the obtained models of individual nodes. We also note that the SolidWorks system is the most common and easy to use. This indicates the possibility of using standard software to develop complex mechanisms in the field.

A block diagram of a portable CNC portal milling machine has been generalized and developed. The results of modeling of individual units of a portable CNC portal milling machine are presented. This confirms our assumptions about the possibility of modeling complex structures based on the use of SolidWorks.

Among the limitations of the described modeling process, it is necessary to highlight the limitations at the assembly stage of the developed model. Since such limitations can be significant, we say that the field of use should be portable mechanisms and components that can be developed in the field.

Among the future directions of research, it is worth highlighting the additions to the module for analyzing stability and reliability diagrams for the proposed designs of individual units and machines. This will expand the use of standard software to carry out relevant work in the field.

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