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To cite this article: V Holovnia *et al* 2021 *J. Phys.: Conf. Ser.* **1840** 012043

View the article online for updates and enhancements.

Students training for numerical control machines programming by means of computer-aided manufacturing tools

V Holovnia, M Horodyskyi and A Tkachuk

Zhytomyr Polytechnic State University, 103 Chudnivska Str., Zhytomyr, 10005, Ukraine

E-mail: v.holovnia@ztu.edu.ua

Abstract. The article describes the analysis of computer-aided manufacturing systems introduction for the control program machines preparation with the numerical control into the technical students' educational process. The main stages of teaching students the basics of control machines programming by means of addressing to manual programming and CAM-systems are considered. Recommendations for the control programs testing implementation without a numerical control machine, by means of numerical control machine simulators introduction into the educational process are given.

1. Introduction

Traditionally, studying at a technical higher education institution is related to the development of technical (design and technological) documents in order to manufacture parts, assemblies and products. The development of the documentation is possible only in case of an expert having a developed special reasoning, being experienced in solving positional and metrical problems, being aware of the rules, conventions and simplifications in accordance with the current standards for technical documentation, understanding of applications functioning principles, their classification and application possibilities, being skillful in working with the system [13].

Recently, an indisputable issue is the importance and efficiency of design, manufacture, improvement and modernization of any technological operations and products by using computer systems. Automated computer systems increase efficiency; significantly changing the content of any technological process variety of stages, significantly affect the design methods, technology, manufacturing improvement and its organization. It is especially topical in the field of computer-aided design systems (CAD).

An up-to-date CAD-system is a complex organizational and technical complex, including three main components [12]:

1. Computer-aided design is a technology aiming at applying computer systems in order to facilitate the projects creation, modification, analysis and optimization.

2. Computer-aided manufacturing (CAM) is a technology that lies in applying computer systems with the aim of planning, managing and controlling manufacturing operations through a direct or an indirect interface with the manufacturing resources of the enterprise.

3. Computer-aided engineering (CAE) lies in applying computer systems in order to analyze the geometry of CAD, modeling and studying the product behavior with the aim of its further design improvement and optimization.

Thus, CAD/CAM/CAE technologies are to automate and increase the efficiency of certain stages of the product life cycle. Developing independently, these systems require the integration of design and manufacturing processes. A new computer-integrated manufacturing (CIM) technology was suggested in order to solve the problem. CIM technology presuppose using a computer database to more effectively manage the entire enterprise, including accounting, planning, delivery and other tasks, not just the design and manufacturing covered by CAD, CAM and CAE systems. CIM is often considered to be a business philosophy rather than a computer system as CIM technology performs separate engineering, manufacturing, marketing and support functions of the manufacturing enterprise.

Using the above technologies for preparing bachelor degree students in higher education requires the introduction of new conditions at all stages of learning, from engineering graphics to technological processes of machines with numerical program control (computer numerical control, CNC), because basically young professionals in enterprises, design and technology bureaus are required to have knowledge and practical skills of professionally-oriented information technology implementation in engineering and, especially, skills in CAD/CAM/CAE-systems.

2. Literature review

In the process of science and technology development, man-made technical systems, devices, structures become increasingly complex. At the same time, the requirements for the timing of new products design are increasing, competition on the market of machine-building products is intensifying. Under these conditions, traditional non-automated design methods are ineffective. To reduce the manufacturing and technological cycle of machines duration, the widespread use of application development environment (ADE) system has become an urgent need.

Scientific and methodological aspects of ADE system implementation into the educational process are revealed in the works [2], [4], [7], [11], [16], [17]. They note that to ensure fundamental and special training in the field of computer-aided design, the student must be prepared for the following types of professional activities: design, manufacturing and technological, organizational and managerial, research, operational.

Modern tasks of higher educational institutions can be performed through programmed learning once the continuing computer training is implemented for students, starting with general and technical disciplines of the first year and ending with a diploma project in specialized departments [15].

End-to-end computer training [5], [15] of students of machine-building specialization improves their graphogeometric knowledge and skills, promotes the development of spatial thinking by introducing CAD/CAM-systems into the educational process.

The authors propose a method of production processes integration [8] into the traditional process of preparing students by means of CAD/CAM will let combine the study of different special subjects in a project being a good basis for work in manufacturing sphere [1].

The article is focused on developing the method of improving the quality of technical students' preparation for programming CNC machines by using CAM-systems and emulators of CNC machines in the learning process.

3. Outline of the main idea

Engineering education is mainly tasked to do provide staff with training having both professional knowledge and modern information technology idea. Due to the high scientific intensity of training courses and the simultaneous reduction of teaching hours (basic engineering disciplines), the solution of this problem requires new approaches to teaching methods such as preparing students to design modern CNC machines and work on them using CAM-systems and simulators.

To be able to be highly competitive in the labor market, graduates of technical institutions of higher education must be able to:

- search for information (regulatory, reference, economic, etc.) in databases and on the Internet;
- perform the simplest technical and economic calculations [14];
- carry out design and technological design operations; calculations using CAD/CAM systems;
- know text-processing programs;
- be able to adapt software products to specific design and technological developments.

Modern manufacturing is characterized by the widespread use of machines with numerical program control − a system controlling all the drives of process equipment, including facilities. CNC systems are used in various industries, in particular: metals, wood, plastics processing, sheet blanks cutting, pressure treatment, etc. CAD and CAM-systems are used in the process of technological preparation of manufacturing allowing automate the design of control programs. Users of systems like that must have a thorough computer geometric and graphical knowledge, the foundation of which is in the relevant disciplines related to computer geometric modeling.

Developing a control program for the CNC machine is one of the preparation stages of technological manufacturing, ensuring the manufacturability of the product, design of technological processes and means of technological equipment, calculation of technically sound material and labor standards, the required number of equipment and manufacturing areas, implementation of technological processes and their manufacturing management. These mentioned above are the set of works allowing start manufacturing of a new product in the given volume [3], [10].

Thus, the introduction of CAM-systems into the educational process and the creation of virtual production processes through the use of emulators with CNC machines will significantly improve the quality of student training.

3.1. Methods of preparing students for programming CNC machines by means of CAM

Bachelor students training at Zhytomyr Polytechnic State University in 131 "Applied Mechanics" specialty is firstly possible through studying the following subjects: "Descriptive Geometry, Engineering and Computer Graphics", "Computer-Aided Design and Modeling", secondly, on the basis of the acquired knowledge – special design subjects, technology, operation and repair with extensive use of computer technology. In particular, in the process of studying "Technological processes of CNC machines" subject students get acquainted with the structure of modern CNC machines, 3D modeling systems and control program development (CAM).

When programming the machining of parts on modern CNC machines and developing control programs the following methods are used:
- manual programming;
- programming using a CAM system;
- programming on the control panel of the CNC system.

Teaching the basics of programming CNC machines can be divided into the following stages:

1st stage. Study the CNC machines programming and the basics of control programs for machining parts.

During this stage, students get acquainted with the programming language of CNC machines and master the method of manual programming.

A lot of different software are used in the workplace, where different CNC machines perform, but in most cases, all control programs use the same control code − G-code. It is a kind of communication language between the machine equipped with a CNC system, a computer and an operator.

G-code is the language developed in the 1950s, upgraded in February 1980 and standardized as the RS274D standard. The ISO Committee approved the G-code as ISO 6983-1: 2009 [9].

Since then, this standard has been actively used by manufacturers of CNC machines (Siemens, Sinumerik, FANUC, HAAS, HEIDENHAIN, Mazak), extending it at their discretion, but the basic codes and structure of the programs remain unchanged. The reason is that a program written using G-code has a rigid structure. All control commands are grouped into frames − groups consisting of one or more commands. Each command consists of words − the basic elements of the program consisting of a Latin letter's combination and some numerical value (positive or negative, fractional or integer).

Manual programming is a long-lasting, monotonous lesson. However, all programmer technologists must be aware of the manual programming technique being the basis for further training. There are still a lot of companies in Ukraine using the method of manual programming. Indeed, if the plant has several CNC machines, and it is engaged into the manufacturing of simple parts, then a competent programmer is able to work quite successfully with no addressing to the automation means in his work performance.

Students study the basic G-code commands and reinforce the acquired knowledge through manual programming is the basis for further stages.

2nd stage. Acquaintance with the CAM-systems and their use for the control programs for machining parts manufacturing on CNC machines preparation.

The study of "Technological processes of CNC machines" subject presupposes the student' acquaintance with the method of manual programming and mastering the basic provisions of ISO 6983-1: 2009; later they proceed to dealing with CAM-systems.

Zhytomyr Polytechnic State University has the following licensed CAM-systems:

- Delcam ArtCAM − CAD/CAM-system for 3D-modeling and manufacturing of art products;
- Delcam PowerMill − an expert solution for programming high-speed and multi-axis machining on CNC machines and robots;
- Delcam FeatureCAM − a system covering all manufacturing stages − from product design to the development of complex control programs for cutting, CNC lathes, as well as EDM process;
- SolidCAM − an integrated CAM system being able to work directly in SOLIDWORKS and Autodesk Inventor systems, including patented iMachining technology, while supporting all the necessary turning and cutting functionality, as well as functionality for programming multifunctional cutting machines, including longitudinal turning machines of the Swiss type.

Students start working with CAM-systems during practical classes, because practical training, as one of the most important forms of the educational process, is the "student – program – electronic model" system matter. In this system, the second element complements and, under certain conditions, for example, in independent working process or distance learning, replaces the teacher.

In the process of performing practical tasks, students get acquainted with the interface of the CAM-system, learn the basic methods of machining trajectories construction, tool selection, as well as optimize machining by visualizing the machining process and making adjustments to a particular trajectory. In the result, they get a ready control program for a specific (depending on the selected postprocessor) CNC machine.

Since the CNC machine implements part of the technological process for the parts manufacturing, the control program must include all the features of machining, in particular:

- know the characteristics of the CNC machine (power of the main drive, the maximum weight of the workpiece that can be installed on the machine, the feed and speed ranges, the number of tools in the store or turret, etc.);
- know the characteristics of the CNC system (programming language, the number of controlled axes and the number of simultaneously operating axes, the of built-in cycles and macrocycles presence, a list of machine functions that can be reprogrammed, etc.);
- know the way to achieve a given accuracy and roughness of treated surfaces;
- know the features of the displacement task and methods of forming individual design and technological elements on the CNC machine;
- know the features of programming a particular machine.

While dealing with the SAM system, students need to use the documentation to CNC machine.

3rd stage. Control programs check-up on CNC machines.

In the process of this stage implementation there occur difficulties associated with the lack of modern machines with higher CNC in higher education institutions, in particular at Zhytomyr Polytechnic State University, because of these machines being costly.

The analysis of the modern CNC machines market showed that their cost can reach several tens of thousands of dollars, for example:

- HAAS Super Mini Mill 2 − € 35000;
- DMG MORI CMX1100V − € 73000;
- Vm3020 Education CNC Cutting Machine − $ 13000;
- Xh7118 Education Mini CNC Vertical Cutting Machine − $ 7000.

The presence of a modern CNC machine in a higher education institution solves the problem just partially, because in addition to the machine itself, you need to have the base of the cutting tool, its fastening elements and special devices, which, as a rule, the machine is not equipped with. That is, for laboratory (practical) classes on programming cutting; there must be appropriate sets of cutters, drills, boring heads, etc. in the laboratory. Accordingly, sets of cutters, holders, etc. are required for programming turning process.

3.2. Analysis of integration of production processes in learning
One of the problem solutions to the lack of modern CNC machines in higher education institutions is the conclusion of contracts for practical training at enterprises in the region having the appropriate equipment in their store.

The second solution is to use simulators of modern CNC machines in the study process, because learning directly on the machines is a very important and mandatory component of the study process, but also dangerous because incorrectly designed control program or incorrectly entered settings on the machine control panel can lead to catastrophic consequences.

The task of the simulator is to identify potential programming errors while working offline, before the control program is generated and transferred to the machine. Recently, simulators have become so successful in detecting errors that small and large industrial enterprises using them call simulation a vital factor in maintaining profitability.

There exist two types of simulators: a simulator in the form of a physical machine control panel, and in the form of a program.

CNC machines (FANUC, HAAS, etc.) manufacturers offer simulators of their machine control systems in the form of a full control panel with a basic set of functions corresponding to the CNC equipment of a real machine.

CNC systems simulators in the form of programs have a number of advantages in comparison with those offered by machine tool manufacturers, such as:
• lower license cost for a workplace;
• a large number of machines that are simulated in one program.

The existing on the market software simulators of CNC machines are the following:

SSCN control Simulator (figures 1, 2) (http://www.swansc.com/en/products/SSCNcontrol.html) − software simulator for CPN control machines from Nanjing Swan Software Technology Company, including 21 types, 76 systems and 163 control panels, including: FANUC, SIEMENS (SINUMERIK), MITSUBISHI, FAGOR, HAAS, PA, Romi, GSK, HNC, KND, DASEN, WA, GREAT, SANYING, RENHE, SKY, JNC, Decekel, GTC2E, NCT & Mazak.

This simulator for educational institutions is offered in the form of a package "CNC Smart Class" with a lifetime license and a free upgrade to new versions. The cost of a license for one workplace is determined individually.

With the help of "CNC Smart Class" based on SSCN control Simulator it is possible to conduct both theoretical and practical parts of learning directly on classroom computers, significantly saving time and increasing the efficiency of classes, because visual learning is much better perceived by students.

In SSCNC control Simulator, you can control the machine using the virtual control panel, enter control programs, perform machine debugging, set the workpiece dimensions of the workpiece, or load the workpiece geometry as a 3D model. In addition, it is possible to perform a complete simulation of the machining process on a three-dimensional model of the machine.

This simulator for educational institutions is offered in the form of a package "CNC Smart Class" with a lifetime license and a free upgrade to new versions. The cost of a license for one workplace is determined individually.
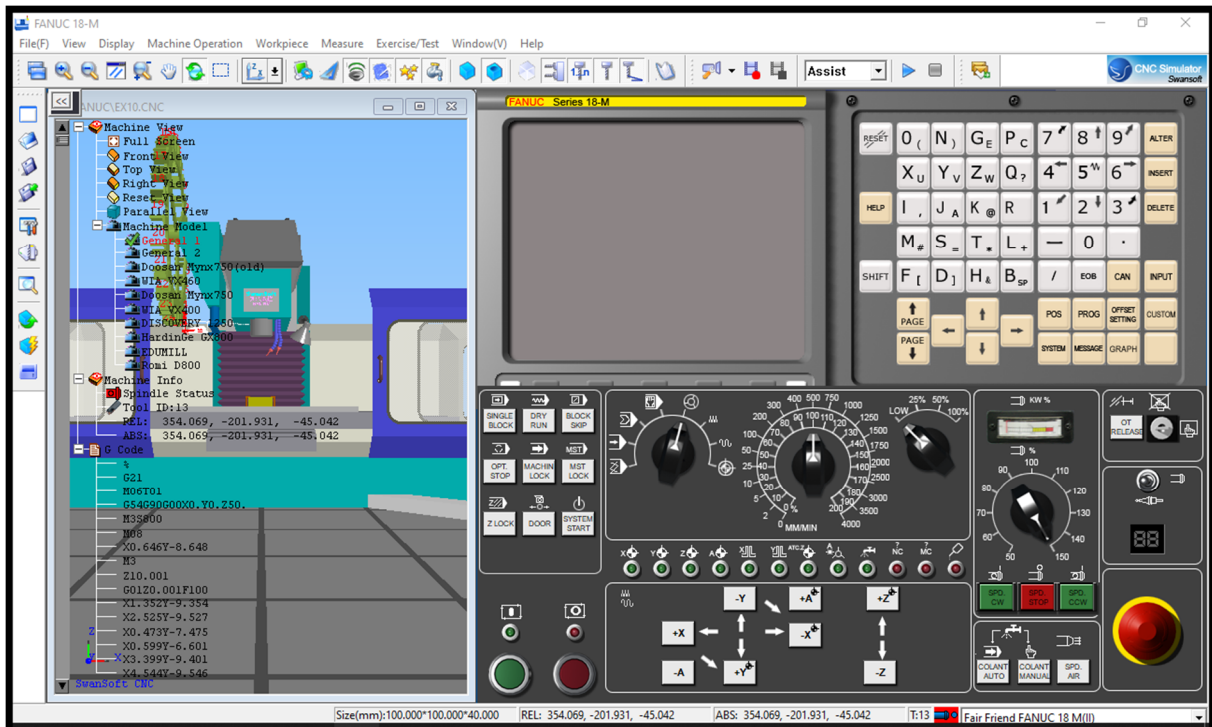
Figure 1. Simulation of a vertical cutting CNC machine in SSCN control Simulator program.
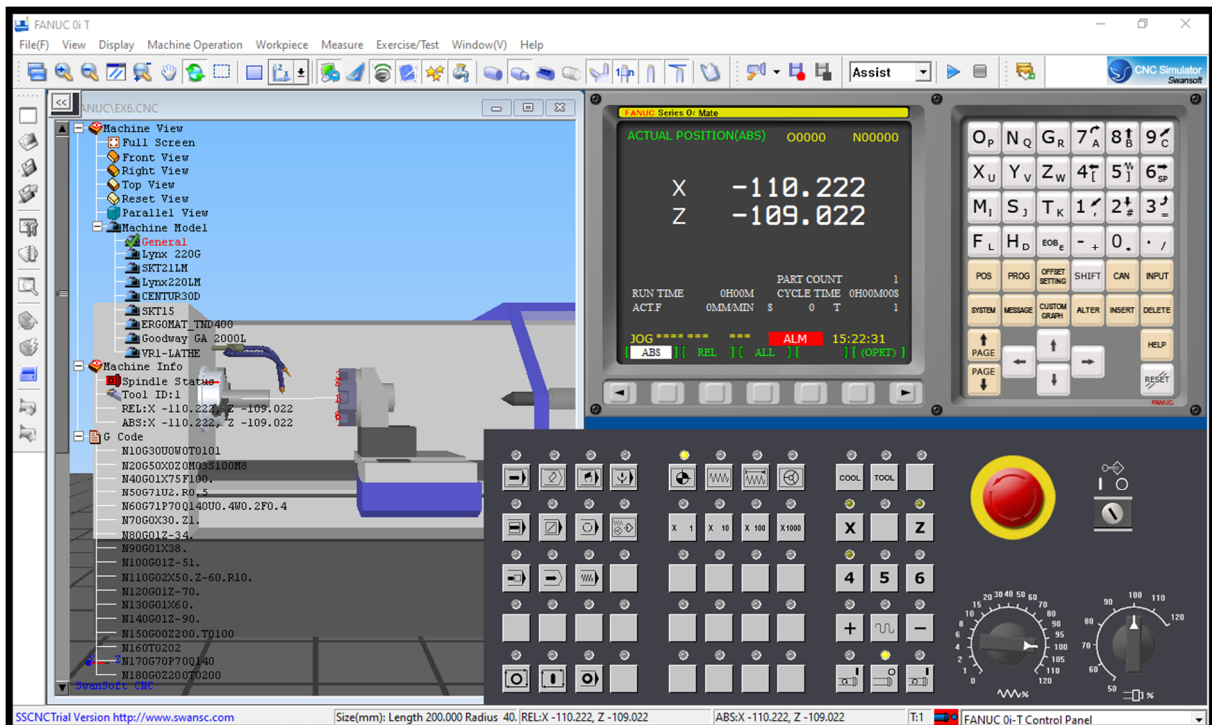

**Figure 2.** Simulation of a lathe screw-cutting CNC machine in SSCN control Simulator program.

As soon as "CNC Smart Class" is installed in the local network, the teacher gets access to control the simulator on students' computers, allowing the following:

- perform general management of the computer class;

- upload practical classes to the program server;
- broadcast the teacher's computer screen to students' computers in real time;
- perform testing of students within the system with automatic sorting of results;
- manage test data, testing process and results.

By means of "CNcontrol Smart Class" based on SSCN control Simulator it is possible to conduct both theoretical and practical parts of learning directly on classroom computers, significantly saving time and increasing the efficiency of classes, because visual learning is much better perceived by students.

CNcontrolSimulator (figures 3, 4) (https://cncsimulator.info/) − includes not just a simulator of CNC machines, but also a CAD/CAM-system SimCam, a tool for cutting 3D-models 3D Maker, a tool for gears Gear Maker gear, as well as a host of other tools and features with the annual subscription for 12 jobs costing $ 360.
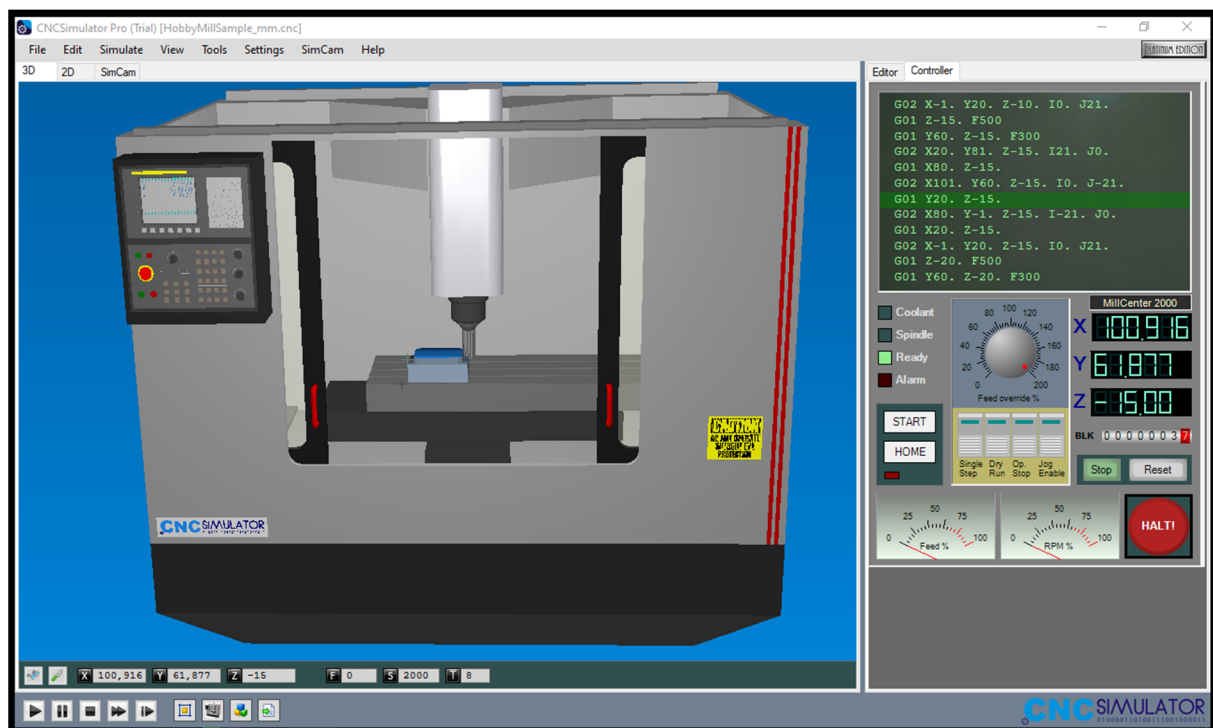
Figure 3. Simulation of vertical lathe CNC machine in CNcontrolSimulator program.

CNC Simulator allows you visualize the following CNC systems: FANUC, SIEMENS (SINUMERIK), MITSUBISHI EZMotion-NC, HAAS, FAGOR, GREAT, RENHE, etc.

In addition, it is possible to visualize a range of control panels of CPN control machines, in particular: KND operation panel, DASEN operation panel, GSK series standard panel, BAOJI machine operation panel, etc.

SSCN control Simulator and CNcontrolSimulator have some of the same functionality such as:

- 3D processing visualization;
- standard sets of preparatory functions (G-codes) support;
- standard sets of M-codes support;
- polar programming, spiral and cylindrical interpolation for FANUC and SIEMENS systems support;
- full animation of the workpiece, tool, stroke of the caliper;
- vertical and horizontal CPN control machines simulation;

- software and manual control;
- machining with cooling, metal processing sound effects;
- base of measuring instrument: templates, micrometers, calipers, etc.;
- a large database of processing tools, operating parameters and management;
- the ability to create and configure custom databases;
- three-dimensional design of products upon the manufacturing cycle.
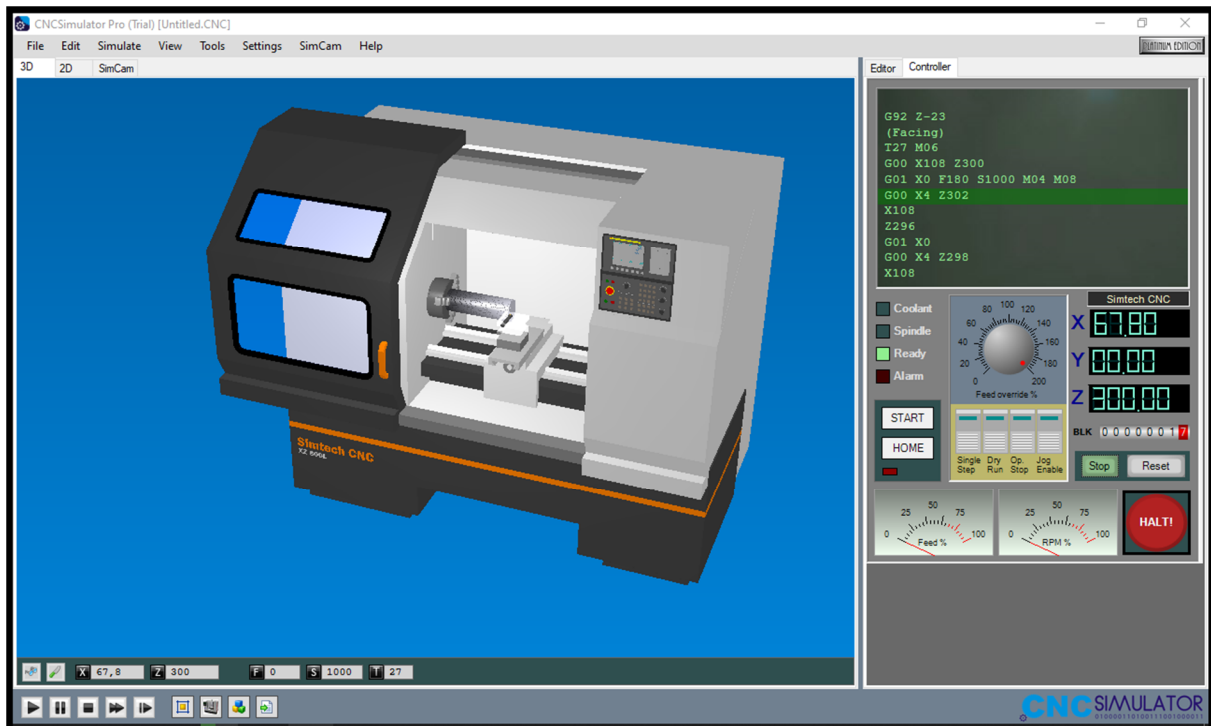
Figure 4. Simulation of vertical screw-cutting CNC machine in CNcontrolSimulator program.

Unlike SSCN control Simulator, CNcontrolSimulator does not implement the network control of the study process. But the availability of additional modules allows effectively perform student training.

4. Expected results

Integrating CNC machines simulators into the educational process results in:

- the learning process intensification through repeated development of control programs without any risks for students or machines;
- reducing the cost of training equipment by emulating different combinations of CNC machines and tools while developing a control program for a specific part;
- the ability to simultaneously teach more students both in the computer classroom and by means of the Internet, providing access to the software of the CNC machine simulator;
- simulation of the CNC machines working process, including tools and special equipment;
- students' performance with different types of CNC machines and their control panels;
- control program errors correction right in the workplace;
- students' opportunity to receive both individual and group consultation of the teacher, as an important component of the educational process is the student's independent work with different types of CNC systems to solve specific problems in the process of further study.

5. Discussion

The method of CAM-system simulators and CNC machines introduction into the educational process was discussed at a round table meeting, attended by scientists and teachers of Zhytomyr Polytechnic State University and representatives of leading Zhytomyr region industrial enterprises. As a result, it was agreed that the proposed method will significantly affect the adaptation speed of a higher education institution graduate on the workplace and reduce the time of his preparation for work on specific technical CNC equipment.

6. Conclusion

The simulators integration into the educational process is more cost-effective comparing to the purchase of full-featured CNC machines. Besides, while working on simulators, students will not be afraid to get the costly machine, instrument or tool out of order. Having processed the part on the machine simulator, it can be then transferred to a real machine with CNC. Eventually, comprehensive solutions − training students in CAM-systems and CNC machine simulators will provide them with the latest knowledge, as well as increase their competitiveness on today's labor market.

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