INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN, 2/2020 (18): 7–14

INNOVATION OF CNC MACHINERY PROGRAMMING EDUCATION AT THE FACULTY OF TECHNOLOGY

Peter Koleda, Pavol Koleda, Štefan Barcík
Technical University in Zvolen, Slovakia
e-mail: peter.koleda@tuzvo.sk, pavol.koleda@tuzvo.sk, barcik@tuzvo.sk

ABSTRACT

The paper describes the educational project ending in 2020, which is focused on increasing the quality of teaching and making the study more attractive by introducing new selective courses: CNC technology in bachelor study programs and Programming of CNC technology in engineering study programs at the Faculty of Technology of the Technical University in Zvolen, Slovakia. The solution of the project is also to create a background for building a CNC machining workplace. The article summarizes the educational machinery for teaching especially milling operations. Teaching programming takes place in professional CNC emulators that are commonly used in praxis. These emulators allow program debugging, tests, trajectory drawing and optimising and collision checking of tool and workpiece. Altogether 23 students successfully completed the introduced course. Within the project solution, 5 theses were defended.

Key words: CNC programming, CNC simulators, teaching, innovation, workplace building.

INTRODUCTION

The development of science and technology is under great pressure and is moving very fast. This is also supported by the Industry 4.0 revolution in which machines are augmented with wireless connectivity and sensors, connected to a system that can visualise the entire production line and make decisions on its own (Liao, Deschamps, Loures, & Ramos, 2017). The times of innovation production cycles are shortening (Enkel & Gassmann, 2010), which also affects university education. Students as well as graduates at universities of technology focus not only on specific knowledge in the professional field, but also on the ability to apply the acquired knowledge to practice in overlapping industry sectors (Dede, 2002) (Sujová, Čierna, & Zabinska, 2019). A graduate of the technical department with a focus on production technology, engineering of machinery and equipment and industrial management is expected to be familiar with modern technologies, production and working machines, as well as with the fundamentals of their programming, from understanding the algorithmizability of technical problems (Csongrády & Pivarčiová, 2006) to applying manufacturing techniques in the form of a program for digital technology using internet and wireless communications (Monroy, Calderon, & Miranda, 2005). Similarly, graduates are expected to know reverse engineering to create a NC (numerically controlled) program for manufacturing the workpiece (Hrčková, Koleda, & Kassai, 2017).

Graduates with broad theoretical and professional knowledge are important for industrial practice. Knowledge of the production process and technology is essential for the quality and safe realization of engineering activities (Dado, Kotek, Hnilica, & Tůma, 2018) (Hnilica, Dado, Messingerová, & Jankovský, 2013) (Hnilica, et al., 2017). The continuous advancement and improvement of digital technology requires training in the design and programming of NC machines. This brings challenges for research of

online NC teaching and related platforms (Tian, 2018). This task is complemented by higher education institutions (Čierna, Sujová, Hąbek, Horská, & Kapsdorferová, 2017). Often the emphasis is placed on learning or teaching planning, control and machining of fully automated or autonomous machines (Pai, Yap, Dawai, Ramesh, & Phoon, 2016). There is a growing demand for skilled workforce, and it is necessary to introduce innovated or new courses to adapt to the changing labour market requirements.

Numerically controlled manufacturing machines are characterized by the fact that the control of their working functions is performed by the control system with the direct support of the program. Required actions are written in the program using alphanumeric characters. These groups of characters are gradually arranged in the program into blocks or sentences. As these machines are quickly adaptable to production requirements and they use an automated cycle with numerical control, we are talking about flexible machines (Demeč, 2005) (Štulpa, 2006). The NC machining centers perform the machining operations according to the given program instructions (blocks). Also new algorithms for programming machining operations are constantly being developed. In (Sharma, Chawla & Ram, 2020), a procedure to develop an automatic CNC program for machining of different types of holes by using different machine learning algorithms is developed. Programming algorithms for production machines must also include manipulator programming from simple trajectories to complex. These activities can be designed for a progressive learning, starting with simple tasks, like programming a robot arm movement between different points in space, and concluding with more complex tasks, such as programming of palletizing cycles or manufacturing a part by machining (Trujillo, Dorado, López-García & Sevilla, 2017).

CNC machines can be divided in terms of the number and types of technological operations, further by chip removal technologies, kinematics, coordinate system (Mihalik, Duplák & Kormoš, 2016):

- the number of operations performed: for mono-professions: are capable of performing only one operation (CNC lathes, milling machines, drills, boring machines, welding and cutting machines; for more professions: performing multiple operations on one workpiece (CNC centers where according to the product type we can speak of rotary, non-rotary, shaft, flange, box).: drilling, boring, threading, turning, milling, grinding, cutting, welding, forming, for the production of gearing,
- the process of chip removal: high speed, high performance, usual, dry,
- the kinematic of operations: serial, parallel (bipod, tripod, hexapod) and combined.

The development of a progressive CNC machining centre and the introduction of new courses is a necessary fact which will clearly contribute to increase the attractiveness of engineering studies. This contribution is in the context of the study programs Manufacturing technology and management of production processes and Management of transportation and energetic technic in the bachelor's degree and the Manufacturing technology and Engineering of transportation and energetic technic in engineering degree and from the point of view of the requirements of manufacturing enterprises.

METHODOLOGY

The Faculty of Technology (FT) does not have a workshop that would bring students closer to the activities of CNC technology and where they could verify their design and programming skills in the form of simple part manufacturing. Students are familiar with machining technologies, in the last year of MSc. degree they gain knowledge about control systems used in manufacturing technology, especially in the form of programmable computers and controllers. During their studies they take practical exercises in the form of excursions in production and manufacturing facilities throughout middle Europe. However, this is not sufficient to clarify and understand the operation of modern numerically controlled machines programmed using ISO code, CAM modules or others programming means. The tangible output of the project is a modern workplace that will enable to practically verify the design activity from the drawing of the part to its production on the NC machine. The material objectives include the creation of textual and visual didactic materials for CNC machinery. The intangible contribution should be better applicability and competitiveness of faculty graduates and increase the attractiveness of the study of technical fields.

The solution of the project KEGA 005TU Z-4/2018 – Building a progressive CNC machining centre to innovate forms of education in study programs at the FT is to extend the focus of FT graduates on the knowledge of CNC engineering (NC, CNC, DNC) and its programming using ISO code and control systems. The students will acquire this knowledge in two newly introduced courses of CNC machines and CNC programming. The course CNC machines introduces students to the design of the main and auxiliary work mechanisms of the HPM tool clamping, design solution, noise reduction, vibration and dust control measures, with the general requirements for the machinery. It also provides basic information of control and programming (structure), information, and correction methods. Course CNC programming of manufacturing machinery is focused on programming of CNC production technology, programming function structure, trajectory interpolation and generation in machining process, setting tool compensation, description and analysis of preparatory, auxiliary, speed, feed functions and tool change for various production equipment.

The educational team working on the project is made up of experts in the field of mechanical engineering, design and programming of CNC technology, computer science and CAD.

To achieve the set goals, a workstation consisting of a numerically controlled machine and a robotic manipulator is required. The manipulator inserts and removes workpieces from the machine tool, making the workplace fully automated, eliminating the physically demanding and monotonous operation of the operating staff, a requirement that is also addressed by manufacturing facilities and future investment opportunities worldwide (Merková, Drábek, & Jelačić, 2015). The educational intention is to demonstrate and teach students both the possibilities of movement within the working space of the manipulator, the calculation of trajectories and speeds and also the programming of the CNC technology (production machine and manipulator) in the ISO code and by control systems.

The selection of suitable emulators and simulation programs was determined by their ability to approach the real activity of the programmer in the design of the program and also in the CNC machine. The educational

team chose the most used means for programming digital machines: Sinutrain for Sinumerik Operate, Fanuc and Heidenhein iTNC530.

Sinutrain for SINUMERIK Operate allows CNC programming on the PC as on the CNC – same operation and programming. Work preparation is possible even while the machine is still cutting: test, run in and simulate NC programs on the PC what means less time-stress at the machine. CNC training and education is realized exactly with the same programming and user interface as in the workshop without waiting for "finally getting to it", without the danger of breaking something, and with the possibility of preparing and finishing work at home or on the road (SIEMENS, AG., 2019). Job shop programming software from FANUC has advantages as: operator friendly programming environment, advanced cycle Machining (Turning and Milling), powerful profile calculation, seamless environment switching, tool management function, measurement cycles, residual cutting, and background machining simulation (FANUC Europe Corporation S.A., 2019). The programming station from Heidenhein has various advantages. The programming modes offer the same features as the control on the machine, meaning that students create programs with smarT.NC (only iTNC 530), in HEIDENHAIN conversational format or according to ISO, with graphic support for programming and test run, and with all field-proven TNC functions, such as FK free contour programming. With the programming station are working with the original control software. This ensures compatibility: Part programs created with the programming station run on any machine tool equipped with the appropriate control (HEIDENHAIN corporation, 2019).

RESULTS

Optional courses of CNC technology and CNC programming were included in the study plans. They contain fields as control systems of CNC machinery, coordinate systems, tests of programs, the modes of operations, structure of program, program cycle, absolute and incremental programming, G-functions, linear and circular interpolation, programming of turning and milling operations, robot programming Play-back, Teach-in and Off-line, measuring probes, calibration. In the subject of CNC technology students learn about the main parts of the CNC machine (Marek, 2010): Frame: main carrier of the machine tool; propulsion electric motors: electric motors for rotation of spindle or tool; ball screws: the main parts of the feed mechanism that transform the rotary movement into translation; linear sliding: they form sliding surfaces on which the slides move; tool magazine: make up the tool magazine for quick tool change; turret heads: heads for holding 6-12 driven or non-driven tools; hydraulic power unit: regulates the system pressure to the value required for the hydraulic functions of the machine; lubrication system: supplies the ball spindles of the feed and sliding axes with the necessary lubricant; cooling system: cools the used coolant in the heat exchanger and returns it to the machine tool tray. Workplace preparation for CNC programming began: the laboratory consists of 5 computer sets, purchasing of CNC machinery. FeatureCAM® CNC programming software from AutoCAD includes feature recognition and automation tools to reduce programming time. Visualize safe toolpaths with simulation. It uses manufacturing knowledge to intelligently make decisions, produce results, and remove repetitive processes (Autodesk, Inc., 2019).

As part of the financial possibilities, the research team decided to purchase a Next 3D

router with an AMB 1050FME-1 spindle from goCNC (Hemer, Germany) with parameters in tabl. 1 and tabl. 2.

Table 1: Technical specification of Next 3D router (GoCNC, 2020)

Parameter	Value
Working area X × Y × Z	330 × 295 × 110 mm
Table dimensions	335 × 420 mm
Clearance height	130 mm, 172 mm, or 205 mm without table
Tool holder	43 mm for max. 1 kW and milling spindle 1,7 kg
Maximal resolution	0,00375 mm
Feed speed	4700 mm.min^{-1}
Backlash	cca 0,08 mm (adjustable to 0,00 by software)
Machine height	420 mm
Repeatibility	0,03 mm / 300 mm
Input voltage	100-240 V

Table 2: Technical specification of spindle motor AMB 1050FME-1 (GoCNC, 2020)

Parameter	Value
Rated power	1050 W
Idle speed	10 000 - 29 000 rpm
Collet	8 mm
Clamping collar	Ø 43 mm
Weight	1,7 kg

CNC milling machines 3040 Z-DQ 3D (4D) were also purchased from the company CNCWorld (Strečno, Slovakia), which can be supplemented with control of the 4th axis.

Table 3: Technical specification of CNC milling machine 3040 Z-DQ 3D(4D) (CNCWorld, 2020)

Parameter	Value
Dimensions	610 × 480 × 400 mm
Working area X × Y × Z	300 × 400 × 75mm
Maximal thickness of material	75 mm
Table dimensions (cross section in shape of T)	320 mm ×530 mm
Frame design	Alluminium 6063 i 6061
Ball screws	SFU 1204 , 12 X 4 mm
Linear sliding	Chrome shaft and linear bearings (61 HRC)
Dimensions X/Y/Z	Ø16/ Ø16/ Ø12 mm
Stepper motors	biphasic 2.5 A
Spindle	500W ER11 air cooled

Preparation of study materials (procedures for writing ISO code for machining operations): Lectures and materials for the exercises in the subject Programming of CNC manufacturing technology are prepared. In the summer semester of the academic year 2017/2018, the teaching of the optional courses CNC Programming of manufacturing machinery was started, and 6 students applied for it and successfully completed it. In the academic year 2018/2019, 17 students successfully completed the course. In the academic year 2019/2020, 6 students. The success of the students is shown in the Fig. 1.

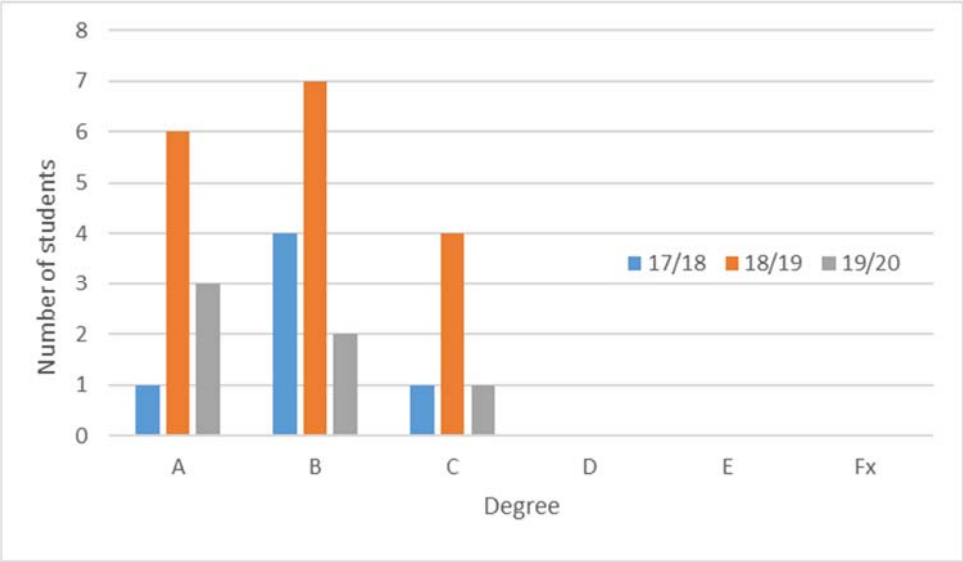

Figure 1: Success of students on the exam.

In the exercises, students become familiar with the structure and functions of the ISO code and learn to program turning operations with direct code writing. Student use Sinutrain for Sinumerik Operate for programming of turning and milling operations. In the second part of the semester, students will learn the principles and strategies of 2.5 and 3D milling using CAM software FeatureCAM from AutoCAD. Educators who program CNC technology have completed training in a certified training centre. Practical methods are used in the teaching process - practice, exercise, training. Based on learning objectives and curricula, reproductive methods of learning are used. Problem-solving teaching methods are often used in machining programming - students should correctly apply the already learned knowledge of manufacturing technologies to achieve the desired geometric shape of the machined part. Simultaneously, they will verify the correctness of their procedure (machined / unmachined surfaces, undercut surfaces, tool collision, tool holder collision, etc.).

One of the goals of the project is to identify a suitable affordable CNC machine. After considering the usefulness and feasibility of purchasing the CNC technology from the allocated funds, the research team decided to purchase software licenses to teach programming of CNC technology from EMCO. It is a WinNC software with a Sinumerik Operate emulator that has an HMI interface the same as a manufacturing machine. In the course evaluation, the subject is evaluated positively, and the students emphasize the possibilities of practical use of the learned knowledge.

The bachelor's thesis was successfully defended: Bartko, J. 2019. Programming of CNC technology – programming environment; Tomčala A., 2019. Modern CNC woodworking machines; Tysowecki, M. 2019. Modern CNC metalworking machines; Žabka, M. 2017. Programming of numerical machines; Kasáč, M. 2017. Analysis of linear drive. The work is directly related to programming and programming environments for CNC technology and will be used for the preparation and extension of textual and visual teaching aids - lectures and background papers for the subject of Programming CNC Machines. They will also be the basis for drafting and publishing scripts from this subject. Purchasing licenses for software versions for CNC programming software.

CONCLUSIONS

Within its long-term development and cooperation with industry, the Technical University in Zvolen itself supports the construction of modern laboratories. Faculty of Technology cooperates on this project with the 2nd largest university faculty - Faculty of Wood Sciences.

Successful introduction of new subjects improves students' applicability. The project solution brings improvements to the learning process: training - practicing and consolidating the curriculum presented; application - application of the subject matter in the student's practical activities. At the same time, it facilitates the transition from theory to practice in the teaching process. In the following period, the purchase of another emulators of CNC technology is planned and in the future the construction of a laboratory with professional CNC milling machines. Its building strategy should consider low cost equipment as didactic resource for training (Peixoto & Monteiro, 2019). The development of programming methods and procedures is still ahead, as evidenced, for example, by the development of CAD/CAM systems. Each programming environment brings advantages and disadvantages. It always depends on the circumstances, i.e. what area of use it is, what is the character of the work, what the main criteria and parameters should meet. It depends on the task of the desired program. In general, the advantages of modernizing CNC machine programming include, for example: increasing the quality and quantity of production, accuracy, shortening production time, efficiency, variability and software compatibility. On the other hand, the disadvantage can be high price of software, demands on professional competence, demanding technological preparation, but also incompatibility with the original already technically obsolete equipment/system, accelerated obsolescence of hardware and software equipment. Ideally, the CNC programmer has knowledge not only in computer science, computer technology, but also in machining technology, in the economy. Most of the work of the CNC machine tool programmer also includes the design of the technological process. Although CAD / CAM systems are a trend, it is not always true that the most modern programming method is the right one.

ACKNOWLEDGEMENTS

KEGA 005TU Z-4/2018 - Building a progressive CNC machining centre to innovate forms of education in study programs at the Faculty of Environmental and Manufacturing Technology.

REFERENCES

AUTODESK, INC. 2019. FeatureCAM overview. https://www.autodesk.com/products/featurecam/overview adresinden alındı

CSONGRÁDY T., PIVARČIOVÁ E. 2006. Informatization of pedagogical process. Trends in Forestry, Wood and Environmental Technology and its Application in the Production Process: International Scientific Conference on the 10th Anniversary of the FEMT Zvolen, pp. 35–36.

CNCWORLD. 2020. Strečno, Slovakia. https://www.cncworld.sk/

ČIERNA H., SUJOVÁ E., HĄBEK P., HORSKÁ E., KAPSDORFEROVÁ, Z. 2017. Learning Organization at Higher Education Institutions in the EU: Proposal for Implementing Philosophy of Learning organization – results from research. Quality & Quantity: International Journal of Methodology, 51(3), pp. 1305–1320.

DADO M., KOTEK L., HNILICA R., TŮMA Z. 2018. The Application of Virtual Reality for Hazard Identification Training in The Context of Machinery Safety: A Preliminary Study. Manufacturing Technology. Journal for Science, Research and Production, 5, pp. 732–736.

DEDE M. 2002. The Praxis Journal: Integrating Theory and Practice. Journal of Public Affairs Education, 8(4), pp. 287–297.

DEMEČ P. 2005. Automatic tool change. 2018 tarihinde https://forum.strojirenstvi.cz/download/file.php?id=13257 adresinden alındı.

ENKEL E., GASSMANN O. 2010. Creative Imitation: Exploring the Case of Cross-Industry Innovation. R&D Management (40), pp. 252–270.

FANUC EUROPE CORPORATION S.A. 2019. Job shop dialog programming guide. https://www.fanuc.eu/sk/en/cnc/shop–floor–programming/manual–guide–i adresinden alındı

GOCNC®, AG. 2020. Hemer, Germany. https://gocnc.de/shop/en/.

HEIDENHAIN CORPORATION. 2019. Programming Stations for HEIDENHAIN Controls. https://www.heidenhain.com/en_US/products/cnc–controls/programming–station/ adresinden alındı.

HNILICA R., DADO M., MESSINGEROVÁ V., JANKOVSKÝ M. 2013. The Effect of Combined Effect of Noise and Energy Expense on Man's Work Well–being. Acta Facultatis Technicae, 18(1), pp. 47–55.

HNILICA R., JANKOVSKÝ M., DADO M., MESSINGEROVÁ V., SCHWARZ M., VEVERKOVÁ D. 2017. Use of the Analytic Hierarchy Process for Complex Assessment of the Work Environment. Quality & Quantity: International Journal of Methodology, 51(1), pp. 93–101.

HRČKOVÁ M., KOLEDA P., KASSAI M. 2017. Application of Reverse Engineering Procedures for The Evaluation of Selected Characteristics of Object. Manufacturing and Automation Technology: Book of Abstracts, p. 13.

LIAO Y., DESCHAMPS F., LOURES E., RAMOS L. 2017. Past, Present and Future of Industry 4.0 – A Systematic Literature Review and Research Agenda Proposal. International Journal of Production Research, 55(12), pp. 3609–3629.

MAREK J. 2010. Construction of CNC working machines (2 b.). Praha, Czech republic: MM publishing.

Merková M., Drábek J., Jelačić E. 2015. Evaluation of Investment Management and Business Performance in Wood Processing Industry in Slovakia. Drvna industrija: znanstveno stručni časopis za pitanja drvne technologije, 66(3), pp 241–249.

MIHALIK P., DUPLÁK J., KORMOŠ M. 2016. Numerically controled working machines and ther programming. Košice, Slovakia: Technical university in Košice.

MONROY V., CALDERON J., MIRANDA J. 2005. Taking the lab into the classroom: Using mobile technology to monitor and receive data from CNC machines. Journal of Manufacturing Systems, 24(3), pp. 266–270.

PAI Y., YAP H., DAWAI S., RAMESH S., PHOON S. 2016. Virtual Planning, Control, and Machining for a Modular–Based Automated Factory Operation in an Augmented Reality Environment. Scientific Reports, 6, pp. 27380–27380.

PEIXOTO J., MONTEIRO C. 2019. Low cost CNC equipment supporting teaching/learning activities. Lecture. Notes in Electrical Engineering, 555, pp. 1111–1117.

SHARMA N., CHAWLA V.K., RAM N. 2020. Comparison of machine learning algorithms for the automatic programming of computer numerical control machine. International Journal of Data and Network Science, 4(1), pp. 1–14.

SIEMENS, AG. 2019. SinuTrain for SINUMERIK Operate. https://new.siemens.com/global/en/markets/machinebuilding/machine–tools/cnc4you/sinutrain–uebersicht.html adresinden alındı.

SUJOVÁ E., ČIERNA H., ZABINSKA I. 2019. Application of Digitization Procedures of Production in Practice. Management Systems in Production Engineering, 27(1), pp. 23–28.

ŠTULPA M. 2006. CNC working machines and their programming. Praha, Czech republic: BEN – technical literature.

TIAN M. 2018. Research and Development of NC Intelligent Online Teaching System. 2018 International Symposium on Computer, Consumer and Control (IS3C), pp. 404–407. Taichung, Taiwan.

TRUJILLO F.J., DORADO R., LÓPEZ–GARCÍA R. SEVILLA L. 2017. Design and implementation of a practical learning methodology for the control and programming of a flexible manufacturing cell. Symposium on New Frontiers in Materials Processing and Manufacturing Engineering Teaching and Learning at the 24th University Educational Innovation Congress on Technical Education (CUIEET 2016), pp. 1–8, Cadiz; Spain; 21 September 2016 through 23 September 2016.

UNIVERSITY OF FORESTRY
FACULTY OF FOREST INDUSTRY

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

2/2020

INNO vol. IX Sofia

ISSN 1314-6149
e-ISSN 2367-6663

Indexed with and included in CABI

CONTENTS