SIMULATIONS OF MACHINING BASED ON STEP-NC

Saša Živanović[1], Miloš Glavonjić[2]

Summary: *This paper presents the possibilities of application of a new method of programming based on STEP-NC standard, which was developed as an alternative to the G code. This paper discusses the possibilities of application in the field of simulation and verification of the program before machining and machining on the available machines. The paper shows the possible methodology for simulation and verification of programs based on the STEP-NC using IDEF0 diagrams, as well as links between softwares STEP-NC Machine, CAD/CAM systems and CNC simulator. The presented methodology is verified by machining of the test workpiece NAS979, based on STEP-NC program.*
Keywords: *STEP-NC, machining simulations, IDEF0, CAD/CAM, CNC simulator*

1. INTRODUCTION

At present, in order to survive and develop in the drastically competitive global market, manufacturing enterprises need to meet the requirements of the shortest product development cycles, the best product quality, the lowest manufacturing cost, and the best technical support and after-sales service. In achieving these requirements, numerical control (NC) machining simulation technology plays an important role [1].

For more than half a century machine tool programming was based on the G code, (ISO 6983). Further developments, however, are now being significantly limited by the current programming language. Machine tools have evolved from simple machines with controllers that had no memory, driven by punched tape to today's highly sophisticated Computer Numerically Controlled (CNC) machine tools. There are contemporary softwares for high-quality machining simulation such as: (i) tool path simulation, (ii) simulation of material removal, (iii) simulation of the kinematics of machines during machining process and spotting the potential collisions, (iv) simulation of the kinematics of machines during machining process including the simulation of the cutting process. In this way it is possible to verify program before machining process. Machine tool programming using G code is characterized by a low level of information

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content. These low level information describe elementary actions and tools trajectories, strongly reducing possibilities at the CNC level. It also breaks the CAD→CAM→CNC numerical chain, and obtaining feedback from the shop floor is hardly possible [2]. It is necessary to prepare the tool path for each type of CNC machine tools individually using appropriate postprocessor.

Nowadays a new standard, informally known as STEP-NC (Standard for Product Model Data Exchange for Numerical Control) [3, 4], is being used as the basis for development of the next generation of CNC controller for new generation of machine tools. This new standard is ISO 14649 and ISO 10303 AP 238. In the field of machine tool programming an open challenge is the new programming method using standard known as STEP-NC. The development of a new method of programming has started [5-9], but it is still an unfinished work. The subject of this paper is machining simulation based on STEP-NC program, using software to verify the program before machining on CNC machine tool. This is discussed in three environments: STEP-NC Machine, CAD/CAM system (Pro/Engineer and Creo2), and CNC simulator.

NC machining simulations are divided into two categories: geometric simulation and physical simulation. Geometric simulation is used to graphically check whether the cutters interfere with fixture, workpiece and machine tools, damage the part, or leave excess material behind. As the name implies, physical simulation of an NC machining process aims to reveal the physical aspects of a machining process, such as cutting forces, vibration, surface roughness, machining temperature and tool wear [1]. The subject of this paper refers to the geometric simulation only.

2. STEP-NC

The STEP-NC AP238 standard is the result of a more than ten years long international effort to replace G code ISO6983 standard with a modern associative language that connects the CAD design data used to determine the machining requirements for an operation with the CAM process data that solve those requirements [8]. The STEP-NC provides new opportunities to support high level information from design to CNC controller. It allows bi-directional data flow between CAD/CAM and CNC without any information loose. STEP-NC does not describe the tool trajectories for specific CNC machine tool as G code does, but it provides a feature based data model (Fig.1). A STEP-NC file is not machine tool specific and can be used on various machine tool controllers [2]. Figure 1 show the comparison of current G-code programming method (ISO 6983) and new STEP-NC high level programming method (ISO 14649).

The method of programming using the STEP-NC is object-oriented view of programming in terms of manufacturing features, instead of direct coding of sequences of axis motions and tool functions as defined in ISO 6983 [9]. The fundamental principle of the new Data Model is programming in terms of manufacturing features (hole, pocket,…), instead of direct coding of sequences of axis motions and tool functions. The combination of manufacturing features and technological information is referred to as a “working step”. Working steps represent the essential building blocks of the machining process. Each working step describes a single manufacturing operation using one tool and one strategy [4].

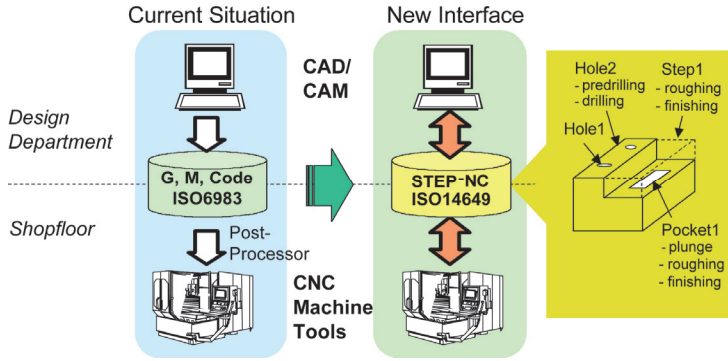


Fig. 1 *Comparison of current ISO 6983 and new interface ISO 14649 for programming CNC machine tools [9, 10]*

However, classical programming is still there and object-oriented programming has not been introduced to the full extent. These two methods exist simultaneously as illustrated in Fig. 1.

3. MODEL OF STEP-NC BASED MACHINING SIMULATIONS

IDEF0 is a method designed to model the decisions, actions, and activities of an organization or system. It is useful in establishing the scope of an analysis, especially for a functional analysis [10]. IDEF0 is used to produce a "function model". A function model is a structured representation of the functions, activities or processes within the modeled system or subject area.

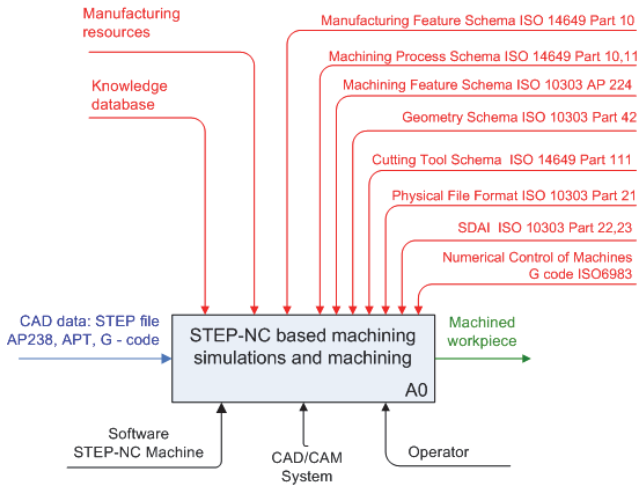


Fig. 2 *Top-level IDEF0 diagram for STEP-NC based machining simulation*

In this paper, function STEP-NC based machining simulations and machining, are described by using the IDEF0 diagram. The special case of one-box IDEF0 context diagram, containing the top level function being modeled along with its inputs, controls,

outputs and mechanisms, is shown in Fig. 2. The single function represented on the top-level context diagram may be decomposed into its major sub-functions by creating its child diagrams. Each child diagram contains the child boxes and arrows that provide additional detail about the parent box. The child diagram that results from the decomposition of a function covers the same scope as the parent box it details. Top level child diagram A0 describes basic flow of activities and it is illustrated in Fig.3. According to the IDEF0 methodology, by analyzing diagram A0, we get the basic flow of activities shown in Fig. 3 The basic activities are: A1 - CAD/CAM NC simulations, A2 - STEP-NC machining simulations, A3 - Postprocessors, A4 - CNC simulator and A5 - Machining.

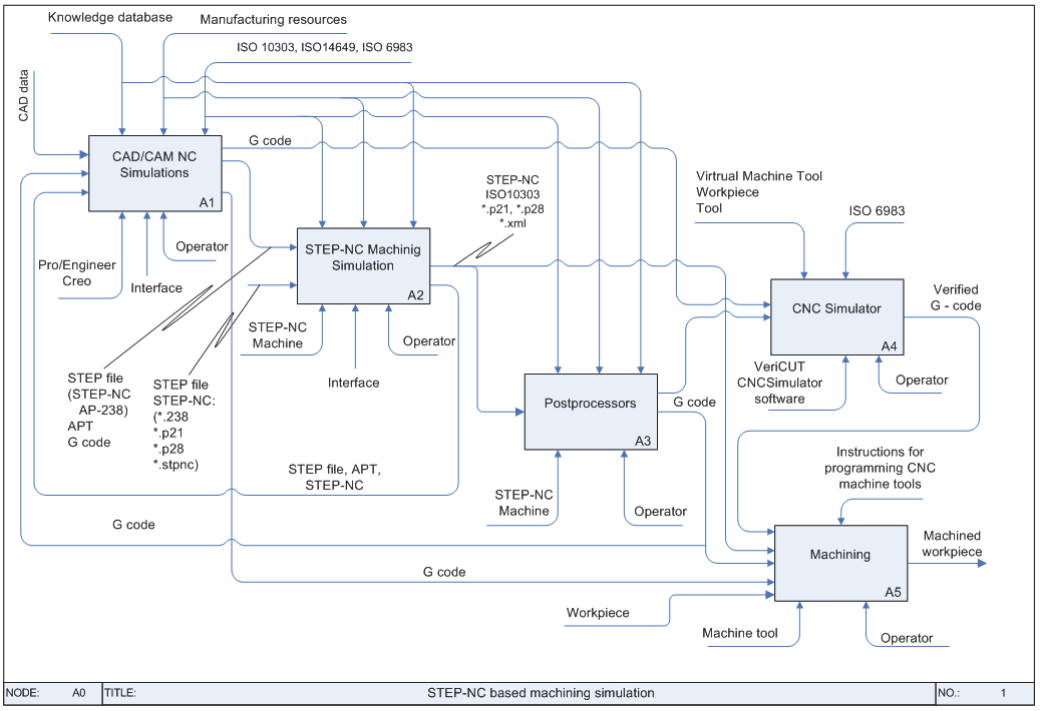


Fig. 3 *The basic flow of activities for STEP-NC based machining simulations*

The activity A1 is performed by machining simulation in CAD/CAM system. Input into the activity A1 can be CAD models of workpieces, tools in STEP format and programs in the APT format or G code obtained from the software STEP-NC Machine. Output from the activity A1 can be CAD model of the workpiece, tools in STEP format, APT program (CL file), G code or STEP-NC file if CAD/CAM system can generate it. These outputs are all inputs for activity A2. The activity A2 is performed by machining simulation in software STEP-NC Machine. Input into the activity A2 can be an original STEP-NC program in *.stpnc, *.238, *.p21, *.p28 formats. The activity A2 allows the machining simulation of the available CNC machine tools and generation of STEP-NC program according to ISO10303 as output. Software STEP-NC Machine implements the activity A3, that allows translation of STEP-NC program into G code for machining on the existing CNC machine tools. Thus obtained G code can be directed to additional verification in the CAD/CAM system or in some of the CNC simulators (activity A4).

Some of used simulators are VeriCUT [11] and CNC Simulator [12]. After verification of the program in G code, one can safely pass over to the activity A5, where the machining is realized on CNC machine tools. The application of this methodology is presented in Chapter 4 using an example of machining test workpiece NAS979.

4. MACHINING SIMULATIONS IN STEP-NC MACHINE, CAD/CAM SYSTEM AND CNC SIMULATOR

For the analysis of the machining simulation and experiment on the machining test workpiece based on STEP-NC program, we have used the source program in STEP-NC format for a test workpiece NAS979 [3]. Test workpiece NAS979 was first machined during a presentation in Orlando (Florida, USA) [13]. Test workpiece NAS979 is oftenly used as an example in promotions of STEP-NC. The source program in STEP-NC format without any corrections can be used for simulation of the different CNC machine tools, which are available in the software STEP-NC Machine, activity A2 from the Fig. 3. Examples of some machining simulation on the different available CNC machine tools, in software STEP-NC Machine, are shown in Fig. 4.

Fig. 4 *Machining simulation in software STEP-NC Machine*

For now, machining process using STEP-NC programs is possible in an indirect way by translating into the G code. This experiment was carried out using available equipment at the Laboratory for Machine Tools - industrial prototype of 3-axis vertical parallel kinemtic milling machine LOLA pn101_4 V2 [14].

The application of STEP-NC which is described by IDEF0 methodology is experimentaly verified using two examples. In the first example, the format of STEP-NC program is translated into APT using the Export option of software STEP-NC Machine.

Utilizing APT program, the machining technology is reconstructed in CAD/CAM system Pro/Engineer Wildfire 4 (or Creo) as described in activity A1, Fig.3. Tool path is verified by simulation of material removal in module NC Check, Fig.5 a, b). In the final part of the experimental verification, postprocessing into G code has been carried out. In the second experiment, the format of STEP-NC program for test workpiece NAS979 was directly translated into Fanuc G code, using the Export option of software STEP-NC Machine, the activity A3, from Fig. 3. The obtained G-codes were further verified in the activity A4 - CNC simulator, Fig. 5c, d). Verified G codes were used for the machining of test workpiece, on the industrial prototype of 3-axis vertical parallel kinemtic milling machine LOLA pn101_4 V2. Machined test workpiece is shown in Fig. 5e, f). Besides the simulation of machining in the software STEP-NC Machine which is based on the source STEP-NC programs on different CNC machines tools, the simulation of machining is carried out in softwares VERICUT and CNC Simulator, as well.

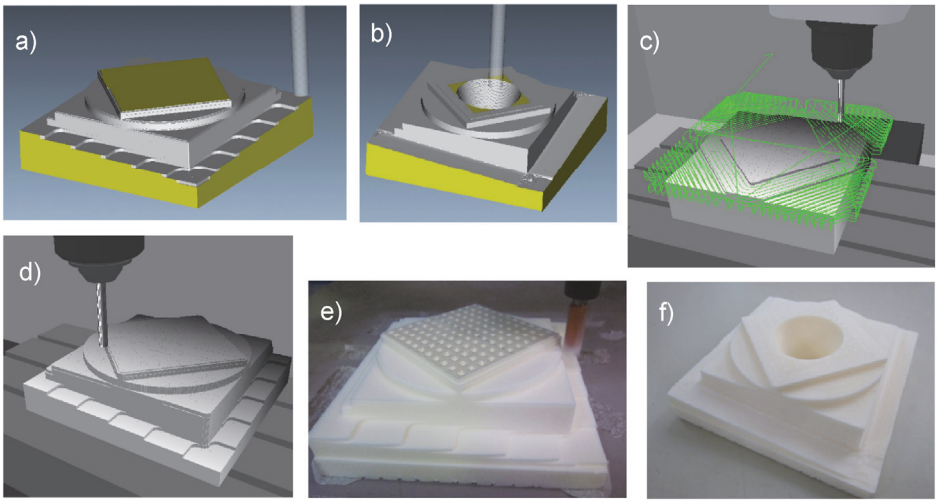


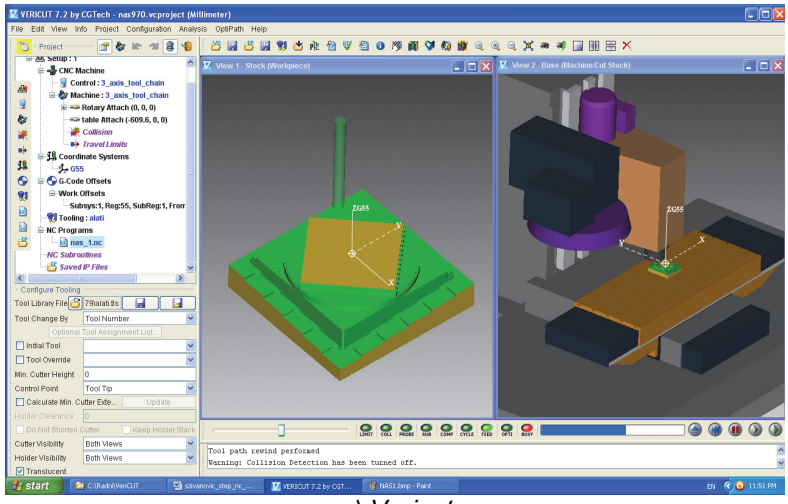
Fig. 5 Machining simulation and machined workpiece NAS979: a, b) simulation in Vericut, c,d) simulation in CNC simulator, e,f) machined workpiece)

Vericut software is developed by CGTech. This software operates with NC programs regardless the software type they were created by. It allows checking them, taking into consideration specific features of CNC Systems and G-codes. Vericut is efficient together with Pro/Engineer: this allows using capabilities of both softwares' advantages to the fullest extent. Vericut can be directly called from Pro/Engineer menu and one can work with it either interactively or in the mode of batch processing of NC program files. Machine simulation solution allows you to realize realistic simulation of any CNC machine tool or its separate components, to use ready-made models from the extensive library (including lots of machines of the most well-known suppliers), as well as to import models in IGES, STL and VERICUT formats.

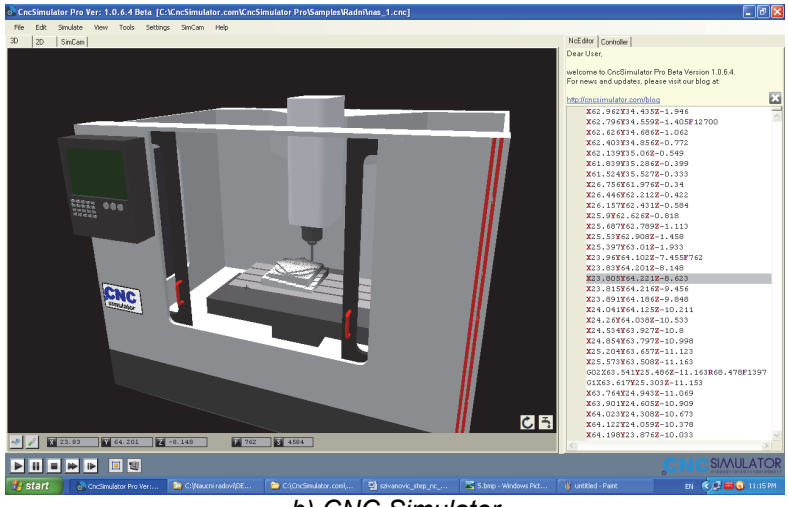
In this paper machining simulation in software Vericut is conducted based on G code, which is derived from the source STEP-NC program. An example of machining simulation In Vericut software for a given test workpiece is shown in Fig. 6a. The CNC machine in this simulation was included from the extensive library of machine tools.

Besides Vericut software, in this paper we also used the software CNC simulator for machining simulation on the 3-axis CNC vertical milling machine tool with serial kinematics. In software CNC simulator, for machining simulation, one can chose the available CNC machine tools, tools, workpieces and achieve faithful simulation of material removal, based on G code, which is derived from the source STEP-NC program.

Application of CNC simulators is important to verify the obtained G codes, and it is also important for the education of students and training operators to work on CNC machine tools. In this way the possibilities of application of the new format for programming such as the STEP-NC are demonstrated, using examples of the machining simulation on different machines and in different environments, such as softwares: STEP-NC Machine, CAD/CAM system Pro / Engineer (or Creo), Vericut and CNC simulator. The final verification is carried out, by machining test workpiece shown in Fig. 5e, f.



a) Vericut



b) CNC Simulator

Fig. 6 *Machining simulation in software Vericut and CNC Simulator*

5. CONCLUSION

Nowadays, machining simulation plays an important role in modern manufacturing, and this paper presented integration of STEP-NC based machining simulation with CAD/CAM systems and CNC Simulator.

The paper presents the possibility of application of the new method of programming based on ISO14649 and ISO10303 standards, known as STEP-NC. Since there is still no sufficient available CNC machines that can directly interpret the STEP-NC program, preparing for this method of programming is reduced to the machining simulation and translation into G code, which can be realized on the available CNC machine tools.

STEP-NC standard is almost finalized, and in the future we can expect the first shop-floor application of STEP-NC program. Existing CNC machine tools in the future will be replaced by machines, whose control systems can receive and execute programs in the STEP-NC format.

Our future research will be focused on the building of CNC machine tool with open architecture control system, which can download and directly execute programs in some of the STEP-NC formats.

ACKNOWLEDGMENT

The authors would like to thank the Ministry of Education, Science and Technological Development of Serbia for providing financial support that made this work possible.

LITERATURE

[1] Zhang, Y., Bai, X-L., Xu, X., Liu, Y-X. (2012). STEP-NC Based High-level Machining SimulationsIntegrated with CAD/CAPP/CAM. *International Journal of Automation and Computing*, vol. 9, no.5, p. 506-517.

[2] Rauch M., Laguionie R., Hascoet J.Y., Suh S.H. (2012). An advanced STEP-NC controller for intelligent machining processes. *Robotics and Computer-Integrated Manufacturing,* vol. 28, p. 375–384.

[3] STEP NC-MACHINE, Step Tools, Inc., from http://www.steptools.com/products/stepncmachine, accessed on 2012-02-24.

[4] STEP-NC Newsletter, Issue 2, from *http://www.step-nc.org/data/newsletter2.pdf*, accessed on July 2000.

[5] Zhao, Y., Habeeb, S., Xu, X. (2009). Reserach into integrated design and manufacturing based on STEP. *International Journal of Advanced Manufacturing Technology*, vol. 44, p. 606-624.

[6] Suh, S.H., Lee, B.E., Chung, D.H., Cheon, S.U. (2003). Architecture and implementation of a shop-floor programming system for STEP-compliant CNC. *Computer-aided Design – CAD*, vol. 35, no.12, p. 1069-1083.

[7] Xu X.W., (2006). Realization of STEP-NC enabled machining. *Robotics and Computer-Integrated Manufacturing*, vol. 22, p. 144–153.

[8] Ranđelović, S., Živanović, S. (2007).CAD-CAM Data Transfer as a Part of Product Life Cycle. *Facta Universitatis, Series: Mechanical Engineering,* vol. 5, no.1, p. 87-96.

[9] Xu X.W., He Q. (2004). Striving for a totalintegration of CAD, CAPP, CAM and CNC. *Robotics and Computer-Integrated Manufacturing*, Vol. 20, p.101–109.

[10] Kim, S.H., Jang, K.J. (2002). Designing performance analysis and IDEF0 for enterprise modelling in BPR. *International Journal of Production Economics*, vol. 76, no.2, p. 121-133.
[11] VeriCUT, from *http://www.cgtech.com/*, accessed on March 2013
[12] CNCSimulator Pro Ver:1.0.6.4 Beta, from *http://cncsimulator.com/OnlineHelp/OnlineHelp.html*, accessed on March 2013
[13] STEP-NC Pilot Demonstration OMAC STEP-NC Working Group Meeting, from http://www.isa.org/Content/ContentGroups/OMAC2/Documents67/Machine_Tool1/pilot-scenario.pdf, accessed on February 2005
[14] D. Milutinovic, M. Glavonjic, V. Kvrgic, S. Zivanovic. (2005). A New 3-DOF Spatial Parallel Mechanism for Milling Machines with Long X Travel. *Annals of the CIRP,* vol. 54, no.1, p. 345-348.