THE CONCEPT OF FEEDBACK BETWEEN NUMERICAL CONTROLLED MACHINE TOOL AND THE CAM PROGRAM

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Summary

In the article, the examples of mismatching of the CAM (Computer Aided Manufacturing) programs and CNC (computer numerical controlled machine tools), problems of the simulation of CNC work and difficulties with implementing CAM at the workshop are discussed. The authors cooperation with the industry in the field of training and the implementation of CAM, which has now been continued for 11 years, and which is also related to the development of many postprocessors (serving for the conversion of versatile processing record in the CAM program into the controlling program for a particular CNC) has led up to the development of the concept of the so-called CNC/CAM Integrator (the system acting as feedback between CNC and the CAM) [1, 2]. The practical development of the module of the CNC/CAM Integrator (in terms of software and hardware) will shorten the implementation time of the CAM programs for production and improve the quality of technology design of CAM off-line and the simulation of the process.

Keywords: CAM, CNC, postprocessor

Koncepcja sprzężenia zwrotnego od obrabiarki sterowanej numerycznie do programu CAM

Streszczenie

W artykule przedstawiono przykłady niedopasowania programów CAM (computer aided manufacturing) i obrabiarek sterowanych numerycznie CNC (computer numerical controlled machine tools). Omówiono problemy symulacji pracy obrabiarek CNC oraz trudności z wdrożeniem CAM w praktyce. Doświadczenia wieloletniej współpracy z przemysłem w zakresie wdrożeń CAM oraz opracowania postprocesorów (do zamiany uniwersalnego zapisu obróbki w programie CAM na format programu sterującego dla konkretnej CNC) są podstawą opracowania koncepcji tzw. Integratora CNC/CAM – układu spełniającego funkcję sprzężenia zwrotnego między CNC i CAM [1, 2]. Praktyczne opracowanie modułu Integratora CNC/CAM (programowe i sprzętowe) wpłynie na zmniejszenie czasu wdrożenia programów CAM do produkcji oraz poprawi jakość projektowania technologii CAM off-line i symulacji procesu.

Słowa kluczowe: CAM, OSN, postprocesor

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1. Introduction

Majority of computer numerical controlled machine tools (CNC) in the world is programmed with the use of computer aided manufacturing (CAM) programs. Such an approach makes it possible to shorten the preparation time of the controlling program (NC), using effective strategies of tool movement, optimization of processing parameters (a_p, a_e, feed rate, cutting speed), and also of other qualities of the processing, influencing tool (T) durability or the quality of the surface of the processed object (PO).

It seems that the substantial technical possibilities of CAM are used only partly in CNC, and that mechatronically-advanced CNC do not utilize 100% of their possibilities, performing programs developed in CAM. The CAM software supplied by many producers in many varieties is a versatile solution, the market performance of which will be the better, the larger number of varied CNC machines will it be able to work with. In turn, CNC are specialized solutions which exist in many versions and possess a number of parameters and special functions, which are configured with the needs of a particular user in mind. Even if they are supplied by the same producer, they differ in terms of drive solutions, construction systems, versions of controlling systems and parameters set by the service department, or the working modes selected by the user.

Taking into consideration the ever more complicated structure of CNC and ever more advanced CAM programming, the correct matching of the both of these elements is of crucial importance [3]. The so-called CNC/CAM Integrator, described further in this text, is to support the process of the adjustment of CNC and CAM and, simultaneously, reduce a negative impact of so-called „human factor”, particularly in the period of implementation.

2. Mismatching of CNC and CAM

Many inconveniences in the cooperation of CNC and CAM are difficult to prevent. Some typical examples that may be mentioned include:

• **The loss of time related to the approach movement and retract of the Tool (T)**. High dynamics of the work of the CNC drives makes it possible to reduce the time of formative movement and auxiliary movements. Theoretically, the tool (T) forward movement to the **processed** object (PO) may be performed at any speed until a contact between them takes place. In reality, the way of the arrival of T to PO of the several mm size material is left, and T covers it with a small headway. This movement is caused by a possible difference between the theoretical and actual size of the PO and stems from the knowledge and experience of the operator of CNC (danger of collision). This effect is of small significance, when the road of T to PO takes place sporadically or perpendicularly to the material. In case of the tool at an angle (tangent, helixshaped movement, with a typical inclination usually amounting to 2-3 degrees), the road of the tool even with a deviation of 1 mm along the axis tool actually amounts to 19-28 mm. In case of processing related to a frequently interrupted contact of T and PO, ineffective time of the arrival of T to PO may amount even to as much as several tens of percent of the entire time of processing.

- **Virtual simulation of CNC (VR CNC) work does not take into account the dynamic of the machine, its geometric and movement precision.** A vast majority of programs simulating CNC in so-called virtual reality (VR) excellently presents the kinematics of the generating process (moving objects of zero weights), not entering the area of the dynamics of CNC (although such attempts are taken [4, 5]). It causes, among others, important differences in theoretical and actual times of processing.

- **Difficulties with the simulation of cycles and special machine functions in the off-line mode (CAM).** The controlling systems of CNC possess a number of functions specialized with the view to serve a particular type of users. The user's interface and extended functionality of controlling systems (making it possible to define typical actions quickly and briefly) are rather focused on manual operating than cooperation with a CAM program. However, more and more frequently workshop practice compels the designer of CAM to use refined cycles and special functions directly from the level of a CAM program, which are prone to easy modification by an operator directly on the machine tool. Due to their variety of their methods of recording, problems with their interpretation, simulation and verification of in a CAM occur during processing.

- **Lack of up-to-date information on availability, numbering and parameters of tools in a CNC warehouse.** Preparation of technologies in a CAM program and development of the controlling program of CNC takes place in the off-line mode. A list of tools and their up-to-date numbering in the CNC tool warehouse (declarations on a tool chart CNC) are determined by the designer of CAM and forwarded to the operator or developed by the designer of CAM upon the basis of the data received from the operator. In both cases, a mistake may occur, the consequences of which can only be verified on CNC.

- **Difficulties with acquiring by CAM complete information on configuration parameters of CNC.** The course of processing on CNC depends on its kinematic configuration (directions, turns, coordination and ranges of axis movement), dynamic possibilities, kind and configuration parameters of CNC and controlling program (NC). Lack of up-to-date information on the location of typical points connected with the movement of tool (basis points, position of T exchange, up-to-date position of rests, tailstock and other moving parts of CNC such as e.g. fixing elements of a PO, location of tool probe and others) is particularly dangerous during rapid movements, especially for many-axis systems.

• **Optimization of off-line parameters in CAM is not 100% effective.** A wide range of machining strategies, the multi-criterion optimization of parameters in CAM programs, which are available in the off-line mode of processing programming, is verified only experimentally in the course of processing. Whilst in case of serial production, more and more frequently effort to increase the effectiveness of processing – taking under consideration such parameters as: minimal time of performing the commission, the quality of surface after processing, durability and price of the tools, rigidity of the system, dynamic parameter of CNC etc., in case of the elementary production (e.g. tool-room) there is not enough time for this. In particular, it applies to the following cases:

- choice of parameters of machine cutting based upon the material and geometry of T, material of PO and the conditions of machine cutting [5],
- comparisons of efficiency of processing with the use of various movement strategies of T [4, 6, 7],
- dynamic optimization of parameters of machine cutting in reference to current conditions of machine cutting [8, 9],
- applying special processing [6, 9].

• **A long time of implementation of CAM to cooperation with CNC**. Connection between CAM versatile software and a particular CNC is created by a postprocessor. During the period of adjustment of the postprocessor to a particular CNC, the simulation of processing is particularly important. The simulation of CNC work may be conducted in several ways [10], (Fig. 1):

a) the first way of simulation utilizes a versatile technology record (of the movement of T), which is the internal format of the data of a given CAM program (APT/CL data). Con: the simulation entirely omits the influence of a postprocessor. Errors in its work will not be shown in the simulation.

b) the second way of simulation utilizes so-called reverse postprocessor. The simulation is based upon the NC program which will, then, be started on CNC. The quality of the simulation depends on the correctness of the reverse postprocessor and the precision of the virtual definition CNC.

c) the third way of simulation applied to starting of the NC program on CNC is the simulation mood. Unlike the previous simulations, it should take into account the correct dimensions of tools and basis points. Con: the simulation is conducted already after developing a NC program and corrections to the program require, in principle, returning to a CAM program. It requires implementation in the workshop (with the participation of the operator of CNC), is quite time-consuming and frequently still limited functionally, although ever greater progress is visible in this field.

The simulation of processing is an important element of implementation, but the ultimate verification of the correctness of the work of postprocessor is

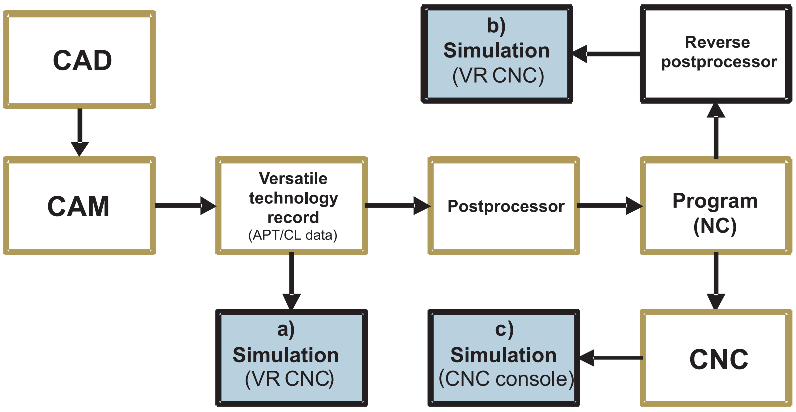

Fig. 1. Typical information flow CAD-CAM-CNC and examples of location of the systems of simulation of CNC work

related to trials on a CNC machine. Starting a new type of it requires particular care of the operator of CNC and, not infrequently, making changes to an NC program (e.g. the numbering of tools, numbering of processing bases, correction of coordinates entered by the operator). Every change involves so-called „human factor", which is not taken into consideration in the off-line simulations of processing and may cause irregularity. Testing of a CAM program on a machine tool is difficult and dangerous (possibility of a collision occurrence). Due to this fact, trials are performed very carefully and the movements of the teams of CNC are performed at minimal speed. Ultimately, there are:

- losses connected with the break period in the production on a given CNC,
- hazard of damage to machine, tool and tooling,
- stress for personnel, waste of an CAM operator's and designer's time.

The elimination of „human factor" is very difficult, that's why using all forms of automatic monitoring is highly justified in such cases.

3. Project of the CNC/CAM Integrator

At the Institute of Manufacturing Technology of the Warsaw University of Technology, works aiming at the limiting the negative phenomena described above are conducted. The result of these works is the design of the so-called CNC/CAM Integrator, which functions as feedback between CNC and CAM (Fig. 2). The CNC/CAM Integrator is made up of a set of sensors and program:

- the role of the sensors is collecting data on shifts and orientation of PO and T in the course of performing NC program,

• software (Matlab, C++) makes it possible to archive the above-mentioned data, compare them with theoretical data which served for developing the controlling program of CNC and sending the results of the analysis to CAM.

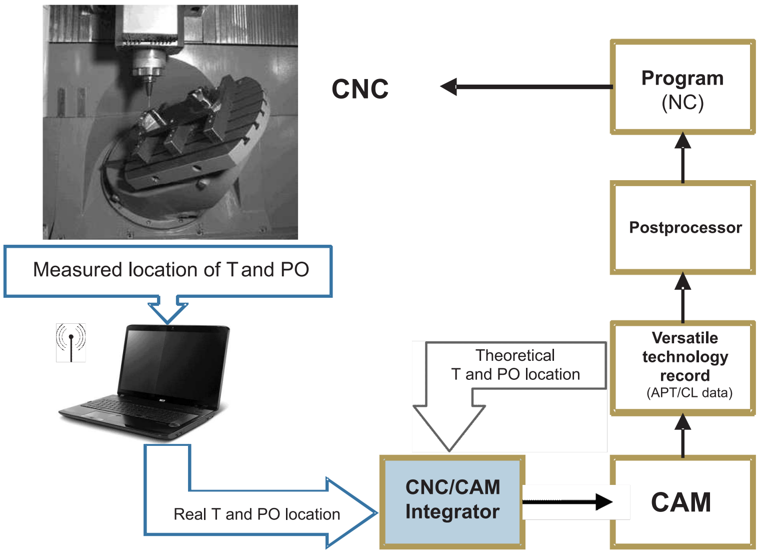

Fig. 2. The principle of functioning of the CNC/CAM Integrator

As part of the works, a few solutions in the field of the system structure were taken under consideration.

A natural approach seems to be the measurement of movement coordinates in the axis (X, Y, Z, A, B, ….) of the machine with the use of proper connection with the controlling system CNC. Such an approach, however, is jeopardized by the following limitations:

• technical difficulties occur in acquiring these data (a limited access to the controlling system of production CNC, technical problems connected with a variety of the equipment solutions US, …),

• the problem of data interpretation (macros, special functions US, working modes, correction of N, basis points, …),

• the necessity of defining the correct (!) kinetic model of CNC, which will be interpreting the data above properly.

The above-mentioned difficulties would make an CNC/CAM Integrator working in this manner a system of little versatility, requiring complicated actions in the field of configuration of the system for work with various CNC. Consequently, the design of the CNC/CAM Integrator was based on a different approach.

CAM software records the path of the tool in relation to the processed object in space in relation to reference point. This record is in an internal data format of the CAM (APT/CL data) program. Upon the basis (APT/CL data), the postprocessor generates the record understandable for the machine tool after taking into consideration its kinematic system and the specific character of CNC. It was suggested that the data from the CAM program be used and that they be compared with the actual relative location of the tool and the PO in the respective phases of the movement of CNC. This task is performed by the CNC/CAM Integrator regardless of the kind of the kinematic model of CNC.

There occurred a problem of technical implementation of the measurement of the relative location of T and PO. Possibility of using standard measurement and calibrating devices was considered, however, this solution was burdened with such cons as limited measurement range, limited functionality and a number of analysed movements. Another solution was constructing a special measurement device (e.g. based upon the structure of the hexapod type). This approach was not selected due to difficulties with the implementation on CNC (overall dimensions) and because of the limited range of the device work.

At the current stage of the research, two gyroscopic orientation sensors and angular acceleration (MicroStrain 3DM-GX1) have been selected. They record deviations and acceleration in three axis. Their features include low weight (in the order of 75 g), small overall dimensions (65 mm x 90 mm x 25 mm), precision in the order of ±0.5° and substantial movement range (±90°, ±180°, ±180°). Fixed near PO and T with the use of adapters (magnetically), they record the angular location respective to T and PO in the course of processing. The data are recorded with the use of radio connection with the computer („bluetooth”).

Due to the need to complete the information on the shift of T and PO, the system is completed with 3 straight edges for shift measurement. Every one of them is connected with the proper mechanisms of the machine in the axis: X, Y and Z. Due to the treating of these mechanisms as rigid solids in relation to the machine body, the place of location of the sensors shifts may be selected in terms of convenient access for the operating staff. Sensors are fixed magnetically. Recording of data on PC is also performed with the use of radio connection („bluetooth”).

Assuming the precision of the measurement devices at the level: shift ±0.1mm and rotation ±0.5°, we will obtain analysis parameters approximate to those of measurements based upon the visual method (operator observing the movement of T and PO) or the simulation VR CNC (taking into consideration the summarized flaw of the kinematic, dynamic, 3D modeling and tolerance of movement calculations model structure). Using magnetic fixing without a special reference positioning will not be precise. However, every of the devices is „set to zero” at the initial location of the mechanisms of CNC and only the relative shift (linear and angular) will matter.

The advantage of the proposed solution is passing by the errors resulting from the influence of the reverse postprocessor and the errors of the model VR CNC. The work of the CNC/CAM Integrator will make it possible to identify functionally the process (cycle and some of special functions performing) and associate and compare theoretical path of the tool in relation to the PO with the actual.

Researching the relations T-PO with the CNC/CAM Integrator also provides new opportunities of comparing the effect of processing, depending on the CNC kinematic system. For various CNC, the relation T-PO will be the same during the processing, but the manner of obtaining it will depend on the kinematic system CNC: it will be different if a turn-tilting table is used, and different for a turntable in the two axis of spindle, and yet different if rotation movements are divided between T and PO. What might be particularly important, is the data referring to the large acceleration values of the mechanisms of the machine tool. The analysis will make it possible to discover those more difficult cases (estimate the problem, point to a difficult stage in the process of processing). The same experiments may be conducted on different varieties of the kinematic system CNC.

Ultimately, using the CNC/CAM Integrator in three stages (Fig. 3) is planned [3]:

a) **Stage one** is connected with collecting the configuration data of CNC for the needs of defining of the postprocessor correctly. Configuration data (such as: the ranges of movements in particular axes, direction and turn of the axes, location of characteristic points, settings of important parameters) are defined upon the basis of test movements using the current coordinates of the units of CNC and data from the measurement with a probe (tool or processed object).

b) **Stage two** applies to teaching the off-line CAM program the qualities of processing carried out on CNC.

This phase is of particular importance, and, as it seems, provides new opportunities, as it makes it possible not only to verify the correctness of the implementation of the first phase, but also, by means of comparing the coordinates of the theoretical movement (versatile record) and the coordinates of the actual movement (X_r, Y_r, Z_r, A_r, B_r,…) and the kinematic parameters of theoretical and actual movement it provides an opportunity to define the kinematic and dynamic properties of CNC in the CAM program. This, in turn, causes a dramatic change in favour of the quality of the simulation VR CNC (upon the basis of the versatile record of the APT/CL data). In this case, the influence of possible incorrectness of the postprocessor is compensated experimentally. The simulation VR CNC will be compatible with the work of the real CNC, because the process of learning in the second stage of the work of the CNC/CAM Integrator may be performed until the intended level of compatibility is reached.

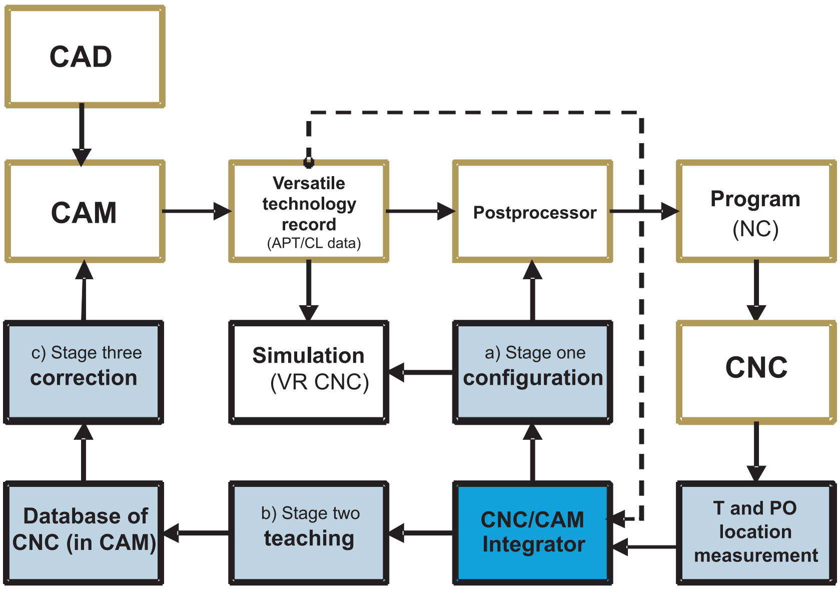

Fig. 3. Three stages of the application of the CNC/CAM Integrator

The comparison of the theoretical and actual data of performing refers to:

- the path of the movement of T and PO,
- the speed of the movements,
- the acceleration of the movements,
- the performance of processing cycles and special functions.

Correlating up the theoretical data (APT/CL data), describing the relation T-PO and information, acquired from the sensors of the CNC/CAM Integrator will make it possible to add to the analysis more precise measurement devices, e.g. vibration sensors. Thanks to using the CNC/CAM Integrator, an additional measurement signal may be connected with the APT/CL data. It means, for example, simulating a particular process of processing and marking on a theoretical path of the tool the actual shift (with certain precision) in relation to the basis of time as well graphic marking on the amplitude of vibrations in chosen surfaces on the same path of the tool. Through assigning such a qualitative parameter to the designed operations of machining in CAM, next designer operations may be corrected properly.

c) **The third stage** involves using the database of the CNC/CAM Integrator in the course of designing the new CAM [3] technology, i.e.:

- designing the path of the movement of T according to the abilities of a particular CNC (so-called „adaptive programming CAM”),
- simulating compatible kinetically and dynamically with CNC (speed, acceleration, cycles …),

• off-line reports compatible with the performance on CNC (e.g. time of processing, estimated surface quality).

4. Summary

The purpose of the project is achieving the improvement of the cooperation of the CAM programs and the CNC machine tools with the use of the so-called CNC/CAM Integrator [3]. Using the CNC/CAM Integrator (in terms of program and equipment) in the workshop should bring such benefits as:

- shortening the period of implementation of the CAM programs in production (limiting the influence of human factor),
- qualitative improvement of the development of the NC program in the off-line mode by means of the credible VR (Virtual Reality) simulation of the course of processing,
- possibility to take into consideration in the course of designing of technology off-line disturbances of systematic character in the work of a particular machine („adaptive programming CAM"),
- possibility to take into consideration the limitations, resulting from the kinematic system of CNC at the stage of designing the technology.

The advantages of the proposed solution:

- versatility and independence of the kinematic variation of the machine,
- lack of necessity to build classic kinematic model of CNC,
- lack of necessity to intervention in the construction system and controlling system of CNC,
- straightforward assembling and use on various CNC (assembly time max. 30 minutes, without special adjustment of CNC).

The limitations of the CNC/CAM Integrator:

- lack of presentation of the main movement: rotation of PO during lathe machining, rotation of T during milling and drilling,
- requiring additional data for the interpretation of movements, described parametrically (cycles, interception, rotation, …),
- requiring additional data about tools,
- the comparatively low precision of measurement.

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