THE ANNALS OF “DUNĂREA DE JOS” UNIVERSITY OF GALAȚI
FASCICLE V, TECHOLOLOGIES IN MECANICAL ENGINEERING, ISSN 1221-4566
2007

Manufacturing Embedded Control Systems – a New Approach

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Abstract

CAM software system is processing CAD model building the source code through G-code specification. This ISO-G code is describing the trajectory to be reached by tool, while working parameters are set by the user. After this step is completed, the code is processed by a interpreters, line by line, and using an interpolator, it outputs trajectory variables for the current source code line. Afterwards, motors are controlled to reach, point by point, the programmed trajectory. The idea of the proposed approach is represented by a embedded control system, in order to minimize programming effort, and secondly the control is to be optimized, meaning that, in order to meet a restriction set, process productivity to be maximized and the cost minimized.

Keywords*: manufacturing embedded control system, optimization, adaptive control, CAD/CAM .*

1. Introduction

Nowadays, programming language of common machine tool control system is ISO G-code. According to this programming language, every part program contains elementary actions, which are operated by machine tool, to complete work cycle. For each elementary action it is needed informations such as particular state variable values (feed rate, cutting speed), in order to meet technical requirements for final product (roughness or precision). Workpiece program it is read and executed one instruction at a time by CNC machine system.

There are several approaches and solution to undermine the issues generated by ISO-G code standard represented by a new programming language standard called STEP-NC [1], [2] and also simplifying of CAD-CAM-CNC chain. The some, there are various approaches for process optimization [4], [5], [6].

The authors consider the idea of introducing optimal control in the CNC programming is viable.

The operator is monitoring workpiece geometry and machining process and if needed, modifies argument of certain functions (e.g. S function argument), changing accordingly the data values. For instance, when monitoring workpiece geometry, it is ascertain that one dimension it is not accordingly to the design or is about to increase errors, the operator modify tool correction value. Another scenario could be that of vibration emerging during the process, when operator is decreasing cutting speed, to avoid vibrations.

Numerical manufacturing control system described above has the following disadvantages:

- some of the changes performed by operator (for instance tool correction) determines entire processing cycle changing of a surface. An example will be that in the case of a line controlling cutting of a cylindrical surface, tool correction implies diameter changing for all length. As a result, the conicity of the cylindrical surface cannot be corrected. Furthermore, the feed rate variable is constant, though addition material is varying on the length of the surface.

- part program is representing actions to be executed in order to meet technical restrictions. That means that the programmer needs to know accurately the rapports between argument functions programmed and restrictions of the final product.

- varying manufacturing system behavior in time and space does not imply a change in the part program

- part program describes nominal model of the part. Accepted deviation raported to nominal dimensions are not argument for functions used for programming.

Firstly, the idea of this approach is represented by an embedded control system, in order to minimize programming effort, and secondly the control is to be optimized, meaning that, in order to meet a restriction set, process productivity to be maximized and the cost minimized. Secondly, the control is to be adaptive, that is to take into account the evolution in time and space of system behavior and the characteristics of workpiece.

In the second chapter it is presented the approach, and in the 3rd chapter an example using it for turning systems is described. The 4th chapter summarizes the main conclusion resulted after using this approach.

2. The new approach proposed

The new approach is voiding the above stated disadvantages as a result of the following: a) informational content of the part program is represented by the requirements of the part to be manufactured, and not by successive actions to be followed to meet these, b) machine cycle of the manufacturing machine is divided in many sequences, in such a manner, that during a sequence, state value modifications to be considered constant, c) for each sequence, by virtual processing, the optimal values for control variable are found, and after d) the list of these control variable are representing the part program and are used to control to the machine actuators, e) process monitoring implies optimal value correction for the control variable, according to the manufacturing system behavior.

By comparison with the nowadays CAM system, the new approach proposed, provide as output state variable values, containing all informations, including parameter process, needed for all processing operation.

As shown in Figure 4, manufacturing embedded system database contains several information sets concerning the available tools, such as: tool profile, acceptable force (Fadm), accepted width wear (Ladm), accepted wear section (Aadm) and accepted chip thickness (aadm), for different materials. These informations stored in the machine database, along with informations defining input data, above mentioned, are used for information processing in the optimization phase, virtually performed, before process beginning. During the current operation, force F, tool wear, and initial surface profile are monitored, to be used in the adaptive control phase. The embedded control system is generating processing cycle for the part, using the two mentioned phases, as described below.

Our proposed architecture reconfigurable lathe is composed of cutting computing module (virtual processing planning), a machining database, and "plug-and-play" hardware modules. Our specific architecture advantage for this approach is represented by an additional freedom degree represented by the rotary tool assembly (Fig.1).

Having a supplementary degree of freedom represented by rotation of rotary tool assembly, as shown in fig.1, it is an advantage for tool orientation according to surface profile, and using interpolation for x and z axes and the rotation of the tool it can be achieved peculiar surface processing.

Optimization phase begins with data input for point coordinates on the nominal surface, allowable deviation for the current point, the required roughness for final part, points coordinates on the initial surface, point coordinate on the tool, and acceptable Fadm, Aadm, aadm, Ladm, as well as material characteristics Cmat.

Coordinate points on the nominal surface are from processing of CAD model stored in AutoCAD software format. To each of the point is attached the following informations: allowable deviation, roughness and points coordinates. Similarly, there are inputted data to describe initial surface, represented by remarkable profile points. As shown in Fig.3, cutting edge profile is divided defining remarkable points; when we addressing to a current remarkable point on the cutting edge as j point. Similarly the workpiece profile is divided in remarkable points and we referring to a current remarkable point on the work piece profile as i point.

In the machine database are stored as well remarkable points on the tool profile. The optimization phase is represented by offline evaluation of the optimal parameter processing control values

Adaptive control phase it is represented by the following steps, firstly a) executing the optimization algorithm before every part (as the real dimensions are considered) and secondly b) online modification for the optimum state variable values according to evolution in time and space of system behavior and the process one.

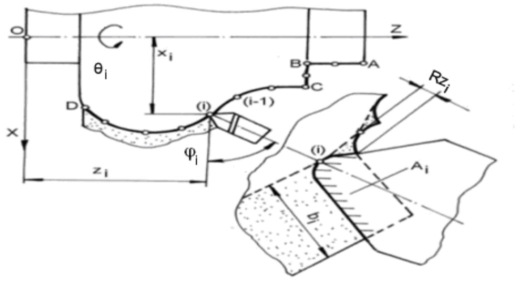

Fig. 1. *Rotary assembly additional freedom degree*

Initial surface profile it is measured using on-machine measuring system. These measurements are taking into account the optimization phase, virtually performed.
Concerning the tool wear measurement, this can be achieved using different devices such as mechanical devices or artificial vision. The measurement frequency is variable, it is to be executed after each part or after several parts processed.

3. Example for the proposed approach

In fig 2 it is shown a processing task, for turning cutting. According to this approach, the working machine cycle it is divided in several sequences. At working cycle initiating, the tool is moving from the reference point RP, to SP position, and afterwards moving according to the program for part processing. The processing task is to process the surface with the profile defined by 1…6 point, satisfying requirements for precision and roughness. Part program is containing the successive description of all current processing task.

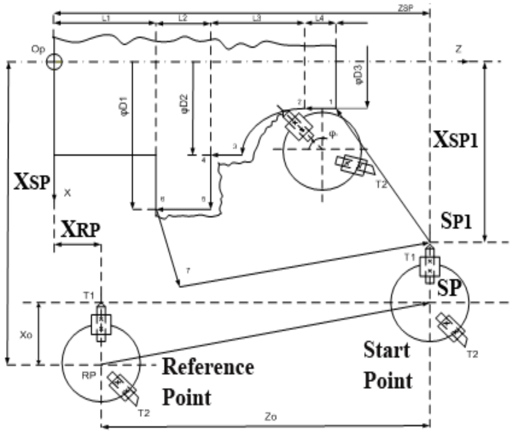

Fig. 2. *Processing task*

Final surface generation it is performed by moving tool profile along helicoidally generating path, with it is obtain by combining revolution of the part and the translation of the tool. The cover of the helicoidally path it is divided, by coordinate computing of a many successive i points to control motors that perform movement actions of the machine.

Tool profile position in a point i from the generating helicoidally it is given by the following coordinates: X, Z, φ_i and θ as it is displayed in Fig. 1

The informational content of a processing task for the embedded control system it is represented, as shown in Fig. 5:

- coordinate points of the processing nominal profile, as well as deviation;
- part material characteristic, Cmat;
- roughness Rz required for final surface;
- tool to be used in optimization phase.

The main idea of the optimization algorithm is that, starting with the current remarkable i point on the profile part generated by remarkable j point on the tool, it is searched the next point on the part profile and the next point on the tool profile, taking into account the restrictions (Aij<Aadm, Lij<Ladm, aij<aadm, Rzij<Rz) and also that the generating point on the tool to be in the active area on the profile (in order to be possible generation). The gold is to reach the maximum area of chip volume, in order to maximize productivity. For generation of a certain i point on the tool profile, the tool must positioned tangent to this profile in a j point. When I and j points coordinate are equal, the tool is positioned tangent to the blank profile.

For this current tool position, it is computed the values of controlled variables Aij, Lij, aij, Rzij. Afterwards it is tested restrictions constrained Aij<Aadm, Lij<Ladm, aij<aadm, Rzij<Rz and also if it is satisfied restriction that j point is on the active area of the tool. At a current i point on the part profile, it is consequently tested and the results of the testing are stored.

Figure 3 depicture the generation sequence for final surface, using optimization algorithm of the embedded control system. For instance, the point i=21 on the final surface profile and point j=16 on the tool profile describes the starting point for the searching of next point after a 360 revolution.

To achieve this, it is tested one at a time tool position for i=22 and the points that verifies restrictions are stored. The searching it is finalized when it is found a point in the final surface profile, with all points on the tool profile, tangent, that do not verifies conditions, as it is shown in Fig. 3. Points i=25 and j=15 it is the pair points for which chip area is maximized for the given points. It is considered that the new i point, in this case, i=25 is the correct point and the search algorithm is continued searching for the next point.

Trajectory from point i=21, j=16, to point i=25, j=15, it is described by the points i=22, 23, 24, dividing the propeller resulted from one revolution, in 4 intermediary steps, with coordinate X, Z and $\Delta\theta$. At each of the intermediary step revolution speed n it is computed and the value of $\Delta\theta$ for the intermdiary step.

Revolution n it is multiplicated with Ks factor that is considering h real value of tool wear. The intermediary $\Delta\theta$ value it is multiplicated with Kf coeficient that is taking into account the real value of force. Revolution difference between the intermediary steps **Δθ**, in the the cover of the optimisation phase, both coeficients are equal to 1.

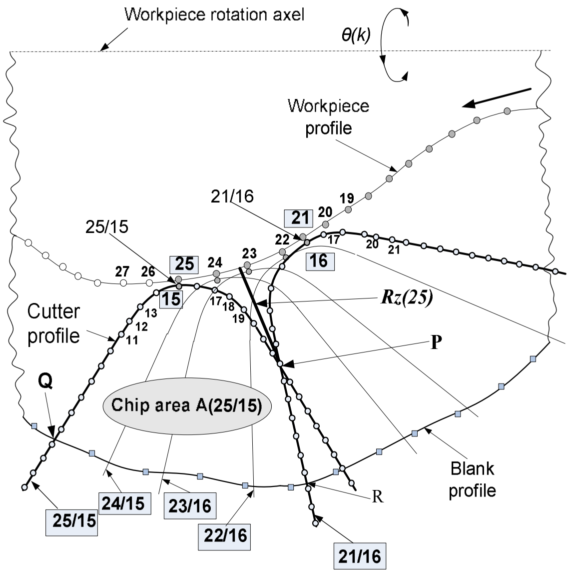

Fig.3. *Surface generation successive position*

These values are to be changed in the adaptive control phase, accordinggly to monitoring data input, as depicted in Figure 4.

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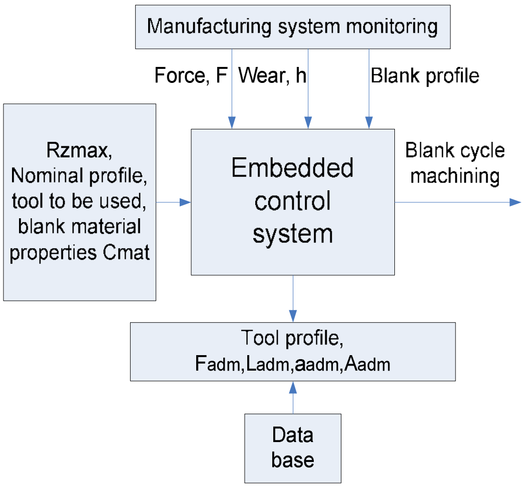

Fig. 4. *Manufacturing embedded control system*

The some, at every step all values resulted are stored. *Adaptive control phase* During the process, there are monitored cutting force, wear, and initial surface profil. Profile initial surface modifications determines the repeating of the optimizing phase for every new part. Tool wear means changing rotation spped with an coeficient $K_s = \frac{h_e}{h} \cdot t$, where h_e is the known economical speed for wear tool and t is the time for emergent H wear tool.

When Ks is sub-unit, revolution speed is minimized, to reach an economical speed for wear tool speed. Process force monitoring it is performed using a sensor installed on cuting tool. It is computed $K_f = \frac{Fadm}{F}$, where F_{adm} is the accepted force for the currect cut tool and F is measured. If Kf is sub-unit, **Δθ** is diminushed**,** representing rotatino angle for a intermediary step. K_s and K_f value is equal to 1 in the optimizing offline phase, these values are tp ne modifies online as a result of adaptive control.

4. Conclusions

The new proposed approach for the embeded system control architecture is bringing the following avantages: a) operator intervention in the process control is minimized; b) there are information concerning final product wanted in the part program, therefore does not contains any information of the step needed to achieve the task. c) varations of the system behaviour of the manufacturing system implies part program changing, subsequently, the control is adaptive, as implies periodic changing of the mathematic model that describes program modifications according to state variable monitored.

Acknowledgement

The authors gratefully acknowledge the financial support of the Romanian Ministry of Education and Research through grant CNCSIS 520/2005.

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Sistem de control încorporat a maşinilor-unelte

Rezumat

Sistemele CAM actuale procesează modelul CAD al semifabricatului si generează codul sursa G-code pentru comanda maşinilor unelte CNC. Acesta descrie traiectoria pe care trebuie sa o execute scula, urmând ca parametrii tehnologici sa fie introduşi in cod de către utilizator cu ajutorul funcțiilor specifice. După ce programatorul intervine in codul generat de către sistemul CAM, interpretorul maşinii CNC procesează programul linie cu linie, si folosind un interpolator, generează valorile variabilelor de comanda corespunzătoare. In continuare, motoarele sunt comandate sa poziționeze scula pe traiectoria programata. Ideea abordării prezentă în aceasta lucrare consta intr-un sistem de control embedded, care in primul rând minimizează efortul de programare, si in al doilea rând realizează o comanda optimala, in condițiile respectării cerințelor asupra produsului, obținându-se o productivitate maximizata cu costuri minimizate.

Rekonfigurierbar Fertigungssysteme - das folgende Erzeugung

Zusammenfassung

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