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THE IDEA OF MACHINING PROCESS PLANNING WITH ALTERNATIVE ROUTES IN FORM OF NON-CYCLIC GRAPH FOR CAPP IMPLEMENTATION

PLANOWANIE PROCESÓW TECHNOLOGICZNYCH OBRÓBKI Z ZAPISEM WARIANTÓW W FORMIE GRAFÓW NIECYKLICZNYCH DLA POTRZEB CAPP

A b s t r a c t

The paper presents the formal method of recording the alternatives of machining process plan. This method based on levels distinguished in hierarchical structure of process, where alternatives can be created. The algorithm for linking intermediate states of workpiece was developed. It enables to change series of linear processes into one network of alternative plans in the form of non-cyclic graph.

Keywords: *CAPP*, *alternative process plans*

S t r e s z c z e n i e

W artykule przedstawiono metodę zapisu wielowariantowych procesów technologicznych dla obróbki skrawaniem. Podstawą tego zapisu było wydzielenie poziomów, na których w hierarchicznej strukturze procesu mogą powstawać warianty. Następnie opracowano algorytm łączenia stanów pośrednich, dzięki któremu z początkowo liniowych wariantów procesów tworzona jest sieć wariantów w postaci grafu niecyklicznego.

Słowa kluczowe: *CAPP*, *wariantowe procesy technologiczne*

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1. Introduction

Nowadays planning and production management is still difficult. Competitive market forces to verify all possible methods which lead to shorten product cycle time and reduce manufacturing cost. From the production management point of view, among the product life-cycle, there is one critical stage: manufacturing process planning, which have considerable influence on making the cycle time shorter. One of encouraging directions to extend flexibility of this stages relies on adding decision alternatives.

Manufacturing process planning can be aided by CAPP (Computer Aided Process Planinng) systems [2]. Previous implementations of CAPP were focused on single process plan creation method e.g. with manufacturing knowledge utilization [1]. Next generation of CAPP systems were focused on generation process alternatives [9, 12], what gives decision flexibility. Nowadays researches are going to use CAPP as a tool, which can be a data source to solve more complex problems. Many examples of integration of process planning and e.g. scheduling can be found [10, 11].

The main goal of this paper is to find out the possible alternatives in machining processes and its structure recording type. The idea of process alternative is still not fully defined. Moreover there is the problem how to record the structure of process alternatives?

2. Characteristic of CAPP system implementation

Manufacturing process planning can be supported by many CAx systems [2]. At that stage we have to separate assembly and any other manufacturing methods (e.g. machining). This paper will take into consideration only machining methods as an assumption. Including that assumption we can find in literature many examples which describe CAPP systems implementation [1, 9, 13].

The CAPP system is a tool used to create the process plan. It could aim at different manufacturing methods, but typical application is to aim at machining process planning [1, 9]. In that case, an input information is a workpiece data. This data can be entered into CAPP system manually or can be retrieved from CAD system (based on e.g. feature recognition procedures) [9, 10]. The machining process plan, recorded and presented in different forms, is the output from CAPP.

The CAPP system implementation depends on the selected method. Following methods can be distinguished [2]: variant, generative and semi-generative.

The *TechPlan CAPP* system is an example of using the semi-generative method. TechPlan system was developed at Production Engineering Institute on Cracow University of Technology. Authors developed the architecture of semi-generative CAPP system [3, 5]. Key features of the developed system are: (i) manufacturing knowledge divided into: (a) *production knowledge* (decision rules representation) which defines conditions to apply machining method, (b) *classification knowledge* (tree representation) which allows to features recognition and (c) *control knowledge* (hierarchical decision networks and frames representation) which defines process route alternatives as a process template [3, 6]; (ii) the EXSYS expert system shell used to store production knowledge and allow to the exchange of data between other modules; (iii) control mechanism of decision making with backward reasoning [3]; (iv) object oriented and feature based formal workpiece (part and its intermediate states) representation with automated procedures of feature recognition and translation from CAD [6,8]; (v) formal description of manufacturing activities which allows to define manufacturing capabilities of resources [4]; (vi) database of manufacturing system capabilities and resources [4, 7].

The TechPlan CAPP system runs in three stages [3]: (i) the workpiece type recognition; (ii) generation of blank design and intermediate states of workpiece using reverse method; (iii) detailed generation of machining operation's properties.

At the first stage, based on classification knowledge, the system recognizes the type of workpiece. This stage is significant, because in semi-generative method, the different knowledge templates are created for different workpiece types (part families).

At the second stage, based on control knowledge, what in fact is a general template of process plan for given set of similar workpieces (e.g. shafts), and production knowledge, the possible alternatives of intermediate states of workpiece and alternatives of final blank design are generated.

The last stage is a generation of manufacturing process alternatives. The main rule is to utilise intermediate states of workpiece generated at second stage and try to find (using three sources: workpiece feature oriented database, database of manufacturing system capabilities and manufacturing knowledge recorded in expert system) all possible alternatives. It is possible thanks to, defined before, manufacturing activities stored in database of the manufacturing system capabilities [4, 7].

3. Representation of machining process structure

Manufacturing process can be, in general, described as follow. Given *part*, which has to be machined from selected (or designed) *blank* (semi-finished product or raw material), is passing through successive stages of that process. As a result, the *ready part* (final product), which fulfills quality requirements, is processed. The *workpiece*, passing through the process, is changing its *state* (Fig. 1), what will be named as *intermediate state of workpiece features* S_f, where f is an index of intermediate state and $f = 0 \dots F$, where F is the highest number of recorded S_f. There are two special states: *initial state* S_0, given by blank design and *final state* S_F, given by ready part drawing.

To perform manufacturing process, for each stage, selected *manufacturing resources R* are required. In typical manufacturing system environment (based on cells and work stations), resources R can be defined as a set of *processing resources RP* and *part flow resources RF*:

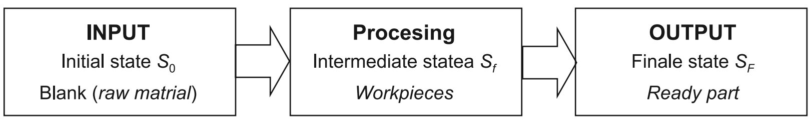

Fig. 1. General model of manufacturing process and intermediate states of workpiece

Rys. 1. Ogólny model procesu wytwarzania i stanów pośrednich przedmiotu obrabianego

$R = \{RP, RF\}$. Processing resources can be defined as a set of *machine tools* (metal-working machines) *RM,* and a set of *exchangeable equipment RE*: $RP = \{RM, RE\}$. In machining operation the following RE types can be utilized: *work holding devices RW* (e.g. three-jaw chucks, dead or live centers, face drivers, etc.) and *cutting tools* with tooling system (together form a *tool assembly*) *RT*, which can be defined as a set: $RE = \{RW, RT\}$.

Machining process plan MP combines all needed activities to change the blank into ready part. That defines main function of machining process as intended change of workpiece characteristics, starting from initial state S_0, passing through intermediate states S_f, and finally reaches the state of ready part S_F. Because it is a discrete process, the following manufacturing process components can be distinguished: (i) *machining operation MO*, which is performed on single workstation *RM* on a single workpiece or batch without interruption; (ii) *workpiece setup SU*, which concerns the fixing type with *RW*, understood by applying clamping forces to the workpiece to ensure the stability of its position during the machining (position of a workpiece can be changed only by unclamping and reclamping it again); (iii) *machining cut MC*, which is the main element of machining operation, performed by the same resources *RT* and with unchanged cutting parameters. These components create the *hierarchical structure*, where above component can consist of a set of below components, with one-to--many relation. It is assumed also that each parent component of that hierarchy can has a set of child components with different number of members.

Formally it can be noted as follow. Each *i*-th part *PT* has at least one machining process plan *MP*. The *i* is an index of part, and $i = 1\ldots N$, where the *N* is the total number of recorded *PT*. By definition the machining process consist of machining operations. In general: $MP_i = \{MO_1^i, MO_2^i, \ldots, MO_j^i\}$, where each *i*-th machining process consist of a set of machining operations MO_j^i. The *j* is an index of machining operation in *i*-th process plan and the *J* is the total number of recorded MO_j^i. Important to notice is possibility to define different *J* number of operations for each *i*-th process.

Then each machining operation MO_j^i can consist of a set of workpiece setups SU_k^{ij}: $MO_j^i = \{SU_1^{ij}, SU_2^{ij}, \ldots, SU_K^{ij}\}$. The *k* is an index of workpiece setup, where the *K* is the total number of recorded SU_k^{ij} in MO_j^i.

Finally, in each setup SU_k^{ij} can be performed a set of machining cuts MC_l^{ijk}: $SU_k^{ij} = \{MC_1^{ijk}, MC_2^{ijk}, \ldots, MC_L^{ijk}\}$. The *l* is an index of machining cut, where the *L* is the total number of recorded MC_l^{ijk} in SU_k^{ij}.

4. Possibilities of machining process alternatives creation

Omitting the creation process plan method, the question is how to create alternatives of manufacturing process plan? The most important is an idea of *intermediate states of workpiece*. The intermediate state S_f of workpiece defines the state of all workpiece features.

The state of workpiece feature can be defined as a set of: dimensions, shape type, surface quality and physicochemical properties. Because the intermediate state can be reached by implementing different machining methods, it causes possibility to create some alternatives.

To create *machining process plan alternatives MPA*, it is needed to distinguish places where that alternatives can be defined. From the theoretical point of view, alternatives can be found on each level of machining process hierarchy. The structure of MP depends on the following factors: (i) possessed manufacturing resources RP and their capabilities; (ii) manufacturing knowledge of the process engineer or CAPP; (iii) production size and selected type of blank.

At that stage following assumption has to be made: set of resources RP of manufacturing system and their capabilities are known. It means that process engineer, based on his experience and manufacturing knowledge (or control mechanism of CAPP system), can change the structure of MP only by selecting different machine tools route (with different number of operations in MP) or by selecting another type of blank. Based on such rule, the machining process alternatives MPA can be created.

In general, the five levels of *alternatives* can be defined: **level 1** of MP structure, where each *MPA* has a different set of machining operations MO; **level 2** of MO structure, where alternatives *MOA* can be created by selecting other machine tool RM or by changing MO internal structure on lower levels, what causes a difference in implementation, number of used resources RE, time and cost; **level 3** of SU structure, where alternatives *SUA* can represent different alternatives of workpiece setup by using different exchangeable equipment RW to clamp workpiece and it causes division of machining operation on different number of setups; **level 4** of MC sequence *MCS* in given SU, what is the most complex. There are two reasons to create MCS alternatives: (i) SUA defines different number of MC in each, (ii) in given *SUA* is possible to change or optimize the sequence of machining cuts MCS; **level 5** of MC implementation, where each MCA can be realized by using different tool type RT (e.g. solid, brazed or indexable tool) and each MCA can be realized by applying different cutting parameters.

From the shop floor control point of view only first two levels are important to take for further consideration. But typical structure of MP is not sufficient and must be changed. The main reason is the difference in interpretation of operation.

By definition machining operation is connected with only one workstation (machine tool), but there is possibility to change position of workpiece by changing setup SU. To realize this other resources RF are needed (e.g. robot). Moreover it makes necessary to stop machine tool and e.g. change some RE or upload new NC program. Taking this into consideration, the new definition of machining operation has to be established. It will be called *machining activity*.

Machining activity MA is an ordered set of basic activities (e.g. machining cuts) realized in one machining operation MO and one setup SU on given machine tool RM. MA has own NC program. For that assumptions, the new definition of operation as machining activity was adopted. Moreover the new way of operation identification and *MPA* recording was developed.

Each part PT_i can has a set of machining process alternatives MPA_v^i (with different route and set of machining operations): $PT_i = \{MPA_1^i, MPA_2^i, \ldots, MPA_V^i\}$. The v is an index of machining process alternative MPA and the V is a total number of recorded MPA_v^i.

Then each MPA_v^i can consist of a set of machining activities MA, but each can be defined as a set of its alternatives. To simplify the model naming, these alternatives will be further called as *operation alternative* OA_{rw}^{vijk}: $MA_{jk}^{vi} = \{OA_{r1}^{vijk}, OA_2^{vijk}, \ldots, OA_{rW}^{vijk}\}$. The *w* is an index of operation alternative OA and the *W* is a total number of recorded alternatives OA_{rw}^{vijk}. Moreover each operation alternative OA can be defined as 8-tuple:

$$OA_{rw}^{vijk}(MPA_v^i, PT_i, MO_j^i, SU_k^{ij}, RP_r, TP, CP, NC) \tag{1}$$

In (1) additional parameters are defined: *TP* – standard time of part processing; *CP* – processing cost; *NC* – identifier of NC code file to upload to the machine tool control system. First five elements are defining the place of OA in MPA hierarchical structure. Figure 2 presents all used indexes to identify the operation alternative OA.

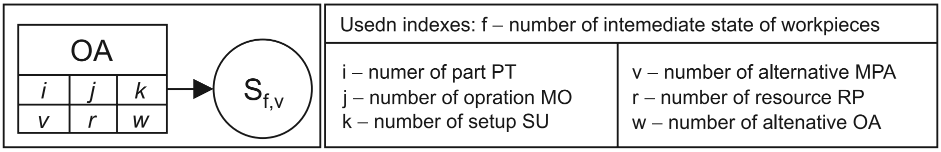

Fig. 2. Indexes of operation alternative OA identification

Rys. 2. Oznaczenia identyfikujące wariant operacji OA

5. Example of recording machining process alternatives

As mentioned before, the typical structure of machining process has hierarchical form. This representation is inconvenient for process plan generation and also for further analysis (from the algorithmic point of view). Moreover in that representation, hierarchical tree is made of nodes, which represent different process elements (operation, cut etc.) on different levels of this hierarchy. It is also not consistent.

The new way of process representation, which remove above weaknesses, was developed. First of all, the structure of alternative process will be recorded as a network in form of non-cyclic graph. Secondly, what is the most important here, nodes will represent intermediate states S_f of workpiece and edges will represent operation alternatives *OA*.

To verify the *MPA* recording structure, series of testing examples was introduced. Because the TechPlan system possess manufacturing knowledge only for rotational parts, only for that kind of parts was verified. Also tests were limited to defined set of manufacturing system resources RP (12 different machine tools RM, with minimum two different standard RE).

For selected part (id: shaft_01) the following alternative process plan was designed. The process has two initial states S_0, because this shaft can be processed from rolled bar or forging. Then there were 3 different routes created (2 for rolled bar and 1 for forging). For example route 1 (for rolled bar blank type) has following six operations: (i) cutting off, (ii) facing and centering, (iii) rough turning, (iv) medium turning, (v) milling and (vi) grinding. In each route different setups in machining operations were added. Finally 6 different linear routes of MPA were created (with total 37 different OA), what defines set of alternatives: $PT_1 = \{MPA_1^1, MPA_2^1, MPA_3^1, MPA_4^1, MPA_5^1, MPA_6^1\}$.

Figure 3 presents linear alternatives for selected shaft01. Each alternative process plan MPA has its internal structure of operation alternatives OA, where each MPA has different number of operations and setups. Each operation OA has assigned needed recourses RP. This can be written: $MPA_4^1 = \{OA_{1.1}^{4111}, OA_{7.1}^{4121}, OA_{17.1}^{4131}, OA_{16.1}^{4141}, OA_{18.1}^{4151}, OA_{22.1}^{4161}\}$, and it is only one example of alternative route number 4.

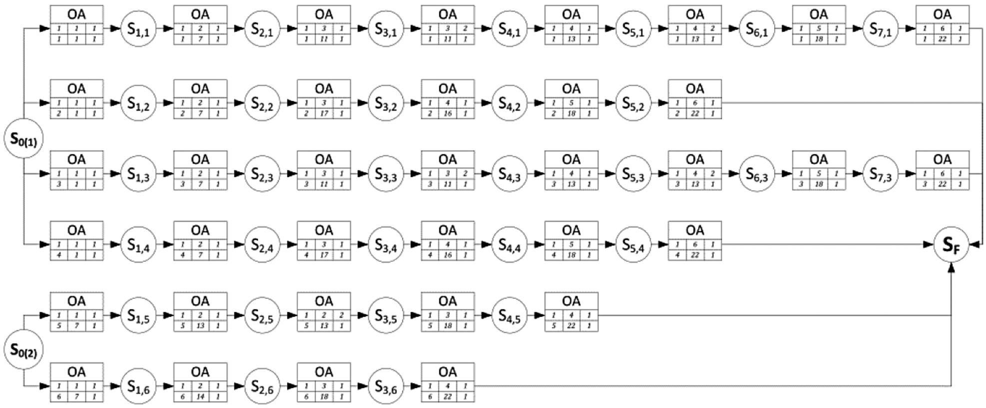

Fig. 3. Linear machining process plan alternatives – an example

Rys. 3. Liniowe warianty procesu technologicznego obróbki – przykład

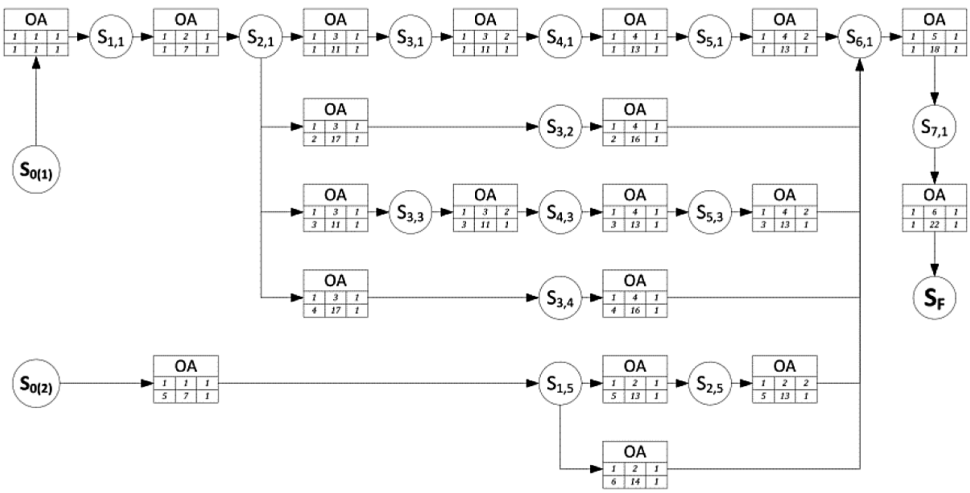

Fig. 4. Nonlinear machining process plan alternatives as a non-cyclic graph

Rys. 4. Nieliniowy wariantowy proces technologiczny obróbki w postaci grafu niecyklicznego

Important to notice is that each OA changes the intermediate state of workpiece S_f. That means, even when we start with different input states S_0 (blanks), there is possibility that some of S_f states are the same. Because the S_f states are represented as a set of parameters, it is possible to built procedure to compare S_f states, what was made. The applied procedure was comparing, generated operation alternatives OA and S_f states. If some are the same, algorithm links them and final number of OA and S_f is smaller than at the beginning. That procedure creates non-linear process plan as a non-cyclic graph of operation alternatives.

6. Conclusions

The representation of machining process plan with alternative routes in form of non--cyclic graph was worked out. The most important idea was to define the intermediate states of workpiece. This approach gives possibility to record all alternative routes of machining process plan in one non-cyclic graph, where node represents intermediate state of workpiece and transition represents operation alternative. Moreover the formal description of machining process plan alternatives MPA was also worked out. Based on this notation the logical structure ERD of database was also developed. The next step will be integration with CAPP TechPlan system. The worked out representation gives many possibilities to utilization, like the integration with online shop floor control system. Moreover, based on generated alternatives can be applied optimization procedure to find the best process route based on given criteria.

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