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TOPOLOGICAL SYNTHESIS AND OPIMIZATION OF MACHINING PROCESSES STRUCTURES

Summary. The paper presents the topological approach to the modelling, vizualization and structural and parametrical optimization of machining processes. Directed cycle free graphs which have the properties of mathematical lattices enable the proper representation of important structural features and give the convenient foundation for the process optimization. Admitted approach is adhered to the large scale production process es where the process planning and machine synthesis or choice are strictly connected problems.

1. Introduction

The aim of the paper is to present some ideas of topological (i. g. using graphs and networks) modelling of machining process structures. Topological models enable the vizualization of important features of modelled objects. The synthesis and optimization of the machining process can be considered from the point of view of topological models transformations.

The manufacturing process of a machine component is usually divided into several parts. A part containing a sequence of machining operations can be called the machining process (MP). Various stages of the MP are usually accomplished in separate machining stations (MS). The structure of a MP is characterized by a set of graphs or networks and their transformations. A directed cycle free graph (DCFG) denoted as K-graph represents a strict order relation in a set E of elementary machining operations. K-graph depictures the workpiece oriented elementary operations set structure (nodes of the graph correspond with the elementary operations).

The K-graph can be used as a starting point for the synthesis and the opimization of the machining process structure.

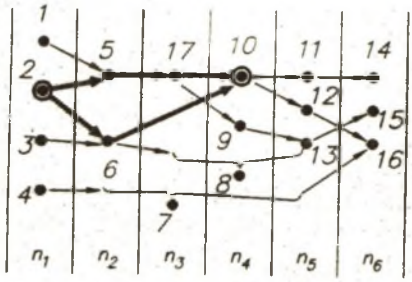

Fig.1 A K graph after the topological sorting. E = {e1,...e17}

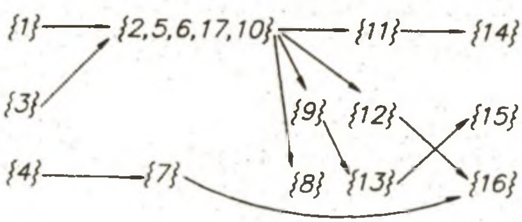

Fig.2 A pre-L-graph giving the order of partition classes

{1} → {3} → {4} → {7} → {2,5,6,17,10} → {8} →
→ {9} → {11} → {12} → {13} → {14} → {15} → {16}

Fig.3 Example of L-graph as an element of the set {L}

{1,3,4,7} → {2,5,6,17,10} → {8,9} → {11,12,13} → {14,15,16}

Fig.4 Another L-graph as an element of the set {L}

2. Synthesis of the machining process structure

Every partition [5] of the K-graph nodes set E, preserving the order relation defined by this graph, leads to the partition of the MP on operations accomplished in the seperate MS. A generalized rule for the dividing the K-graph nodes set into partition classes can be given [7]:
- suppose $P_1, P_2, \ldots, P_i, \ldots, P_m$ are partition classes, if $e_j \in E$ and $e_k \in E$ are elements of P_i -class (i, e. $e_j \in P_i$ and $e_k \in P_i$) then every e_l belonging to every path linking e_j and e_k ought to be element of P_i . E. g. :

1) after the topologicial sorting [2] the partition on the niveaux [4] can be obtained - Fig. 1 (n_1 - n_6 niveaux of the nodes (i. e. elementary operations)); the niveaux are the partition classes and their ordering corresponds their enumeration;
2) if e_2 and e_{10} belong to the same partition class then e_5, e_6, and e_{17} belong to the same partition class - Fig. 1 (thickned lines); the order of partition classes is given on the Fig. 2.

The two above given examples illustrate the possibilities of the MP structures generation and form the basis for the principles of the artificial intelligence approach for the search of the optimal structure using heuristic methods presented e.g. in [1], [3].

3. Synthesis of the machining and workpiece stations lay-out

DCFG mapping the order of partition classes (denoted as pre-L-graph) -Fig 1 and Fig 2- defines the set of admissible structures of MS lay-out. Every admissible MS lay-out structure can be obtained as a result of a linear arrangement of the pre-L-graph nodes, e.g.: Fig. 3 and Fig. 4 giving L-graphs as elements of the set {L} of graphs obtained from the pre-L-graph Fig. 2.

Graphs showing admissible matching of MS and workpiece stations (WS) - Fig. 5 and Fig. 6 - are denoted as M-graphs. A DCFG depicturing an elementary operations order for a given process machine (a machine tool, a machining centre, a transfer machine) denoted K' - graph can be obtained as a result of K-graph transformations by means of operators defined by L- and M-graphs.

E.g.: suppose the K-graph after the Fig.1, the pre-L-graph and the L-graph for topologically sorted nodes of K, the M-graph after the Fig. 6b, if number of MSs $\geq$ 6 then the K'-graph showing the possibility of parallel executing all the elementary operations is given on the Fig.7.

K-,L - and M- graphs enable the mapping of structural features of the machining process, i. e. they are connected with the structural opimization; K' - graph enables the parametric opimization of the process.

The proceeding in the above descripted manner leads to the following expression:

$$K' = T(L,M)\,K \tag{1}$$

where T(L,M) denotes the operator transforming the graph K to the graph K'. The operator T(L,M) depends on the graphs L and M and thus on the structure of the process machine. E.g. the parallel machining requires the structures after the Fig. 6, the sequence and the sequence - parallel machining requires the structures after the Fig. 5 or the mixed structures according the Fig. 8. M-graphs are connected with the fundamental features of the process machine (one

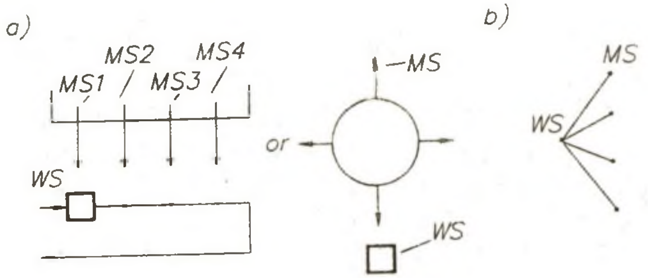

Fig.5 Example of M-graph (b) for a sequence working process machine (a)

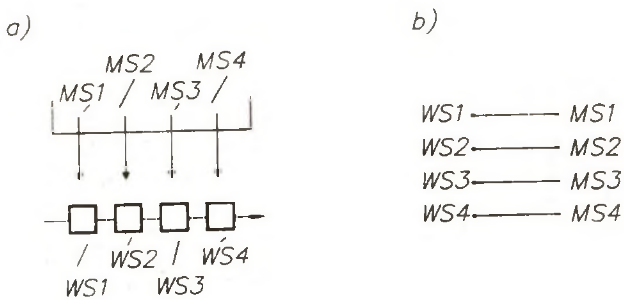

Fig.6 Example of M-graph (b) for a parallel working process machine (a)

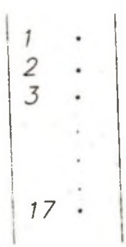

Fig.7 K'-graph as a result of a transformations of the K-graph from the Fig.1.

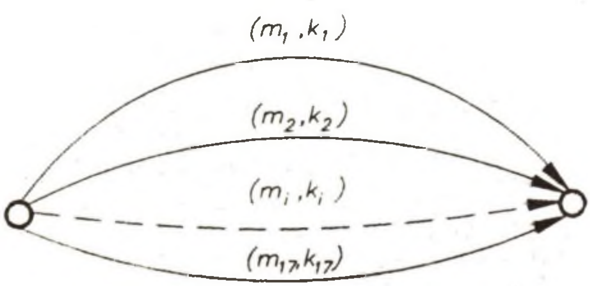

Fig.9 Network corresponding the graph from the Fig.7.

or more machining stations, one or more workpiece stations, possible combinations or both sets of stations). L-graphs on the other hand are connected with the associations of the elementary operations to the machining stations building links between the process planning and the process machine synthesis or choice. With the aid of the knowledge base it is possible to select the matching L-graphs and M-graphs structures leading to the set of admissible structural solutions. Topological synthesis constitutes here an important component of the computer aided machining process synthesis and opimization.

4. Parametric optimization for a given structural solution

A structural solution can be parametrically optimized, both the structural synthesis and the parametrical optimization should create a locally optimal variant belonging to the search space.
For the parametrical optimization the topological methods have the great importance. Networks based on the K'-graphs enable the simple and descriptive formulation of the analytical optimization modells. E.g. for the graph from the Fig. 7 a corresponding network (containing functions m_i, k_i connected with the arcs, where m_i - machining time and k_i - cost per workpiece for the elementary operation with the index i, i=1,2...17). Now a multicriterial optimization problem can be considered:

$$W = \kappa_m \cdot m + \kappa_k \cdot k \quad ; \kappa_m + \kappa_k = 1, \ \kappa_m \geq 0, \ \kappa_k \geq 0 \qquad (2)$$

$$m = m_1 + \sum_{i=1}^{17} e_i \, m_i \, r_i^{-1} \qquad (3)$$

$$k = x \, m + \sum_{i=1}^{17} y_i \, m_i \, r_i^{-1} \qquad (4)$$

$$m_i \leq \eta_i \, m_1 \ ; \ i = 2,3...17 \qquad (5)$$

$$r_i = r_i(v_i, f_i, a_i) \ ; \ i = 1,2...17 \qquad (6)$$

where: m and k denotes multi-tool operation machining time and cost respectivly; w-auxiliary function for Pareto optimum seeking; e_i - tool change time; r_i - tool life; x - machine tool cost per minute, y_i - tool cost ; functions (5) express the "critical path constraints" [6], $0 \leq \eta_i \leq 1$ auxiliary coefficients; v_i - cutting speed, f_i - feed, a_i - cutting depth, r_i can be assumed as any tool life relationship (e.g. Taylor, Tiemcin or Kronenberg tool life equation). Some additional constraints besides (5) can be introduced (e.g. for the cutting power, cutting forces, surface roughness). The solution contains the set of polyoptimal cutting parameters $\{(v_i, f_i)\}_{popt}$. A defined and parametrically (poly)optimized structural variant of machining process constitutes an element of the search space on which the global (poly)optimization problem can be formulated and resolved by means of AI-techniques.

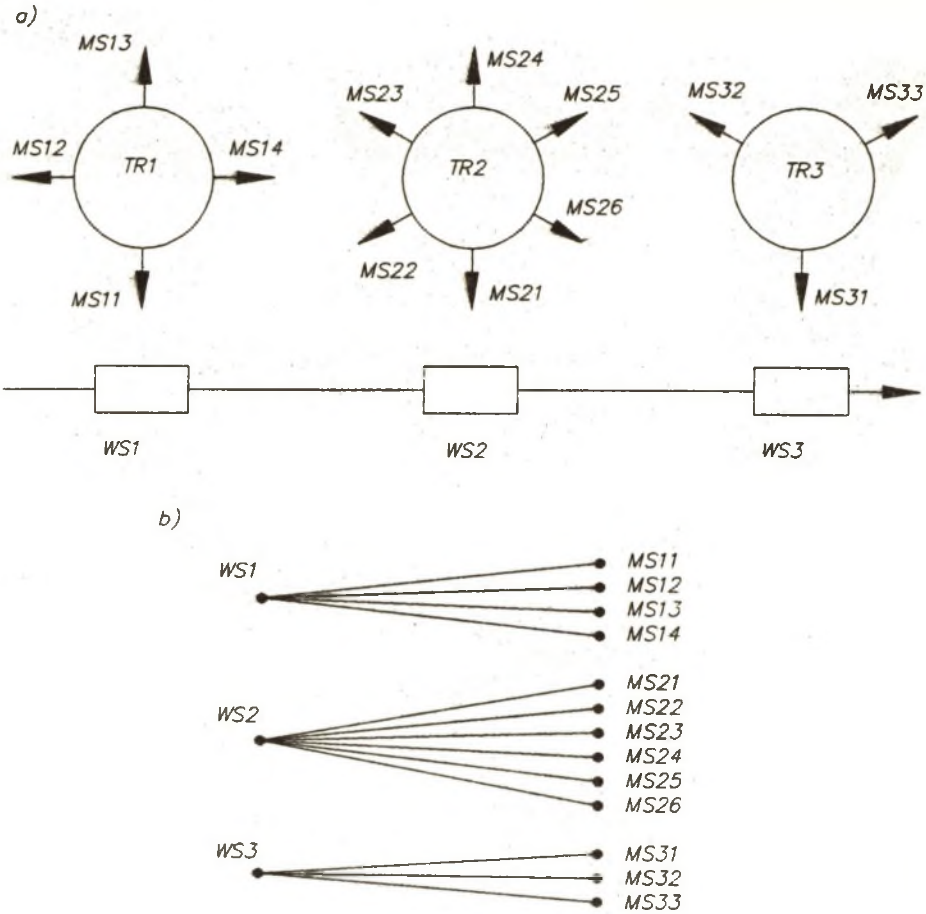

Fig.8 Example of M-graph (b) for a sequence-parallel working process machine (a)

5. Concluding remarks

Topological means like graphs and networks offer a helpfull tool for modelling, vizualization and optimization of machining processes variants. Especially problems concerning the chronostructure [8] of the process can be descriptively defined, decomposed and prepared for such procedures as the optimal structure search and the parametrical (poly)optimazation. Problems concerning the stereostructure of the process [8] ought to be treated by more developped tools of geometry and computer graphics.

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TOPOLOGISCHE SYNTHESE UND OPTIMIERUNG VON ZERSPANPROZESSENSTRUKTUREN

Zusammenfassung

Der Inhalt umfasst die Anwendung von direkten schleifenlosen Graphen für das Modellieren, Visualisieren und Optimieren der Strukturen von Zerspanprozessen. Presentierte Methoden sind für Projektierungs- und Optimierungsaufgaben von Mass- und Grossserienfertigung bestimmt, wenn die strenge obwohl komplizierte Zusammenhaenge zwischen der Prozessstruktursynthese und der Werkzeugmaschinestruktursynthese bestehen.

SYNTEZA TOPOLOGICZNA I OPTYMALIZACJA STRUKTUR PROCESÓW OBRÓBKI SKRAWANIEM

Streszczenie

Przedstawiono zastosowanie grafów skierowanych nie zawierających pętli oraz zbudowanych na nich sieci do celów modelowania, wizualizacji oraz optymalizacji strukturalnej i parametrycznej procesów

obróbki skrawaniem. Omówione podejście jest przeznaczone dla zadań projektowania i optymalizacji procesów produkcji masowej i wielkoseryjnej, kiedy istnieją bardzo mocne, choć złożone, związki pomiędzy syntezą struktury procesu i syntezą struktury (albo wyborem struktury) obrabiarki lub linii automatycznej.

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