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A METHOD OF QUALIFICATION OF PARTS FOR PRODUCTION IN A FLEXIBLE MANUFACTURING SYSTEM

The paper presents a method for the qualification of parts for production in a flexible manufacturing system (FMS) with no need of developing technological processes of their machining. The feasibility of machining of a part is determined on the basis of its technological complexity. The machining of a part in FMS is justified when its technological complexity is not lower than the threshold technological complexity determined for the manufacturing system.

Keywords: *qualification of parts, flexible manufacturing system, technological complexity of parts, threshold technological complexity of parts.*

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МЕТОД КЛАСИФІКАЦІЇ ДЕТАЛЕЙ ДЛЯ ВИГОТОВЛЕННЯ В ГНУЧКІЙ ВИРОБНИЧІЙ СИСТЕМІ

У статті наведено методику класифікації деталей для виготовлення їх у гнучкій виробничій системі (ГВС) без необхідності розроблення технологічних процесів їхньої обробки. Рентабельність обробки деталі встановлюється, виходячи з її технологічної складності. Обробка деталей у ГВС доцільна у випадку, коли її технологічна складність не є меншою граничної технологічної складності, прийнятої для виробничої системи.

Ключові слова: *класифікація деталей, гнучка виробнича система, технологічна складність деталей, гранична технологічна складність деталей.*
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МЕТОД ПОДБОРА ДЕТАЛЕЙ ДЛЯ ПРОИЗВОДСТВА В ГИБКОМ АВТОМАТИЗИРОВАННОМ ПРОИЗВОДСТВЕ

В статье представлена методика подбора деталей для их изготовления в гибком автоматизированном производстве (ГАП) без необходимости разработки технологических процессов их обработки. Целесообразность обработки детали определяется на основе ее технологической сложности. Обработка детали в ГАП является обоснованной в случае, когда ее технологическая сложность не меньше предельной технологической сложности, определенной для производственной системы.

Ключевые слова: *подбор деталей, гибкое автоматизированное производство, технологическая сложность детали, предельная технологическая сложность детали.*

Introduction. When determining the feasibility of machining of parts in FMS, in the general case one can distinguish two variants (Swic, 1998; Swic, Lenik, Zajac, 1996):

– a flexible manufacturing system for the machining of the parts needs to be built;

– such a system already exists.

In addition it is possible that:

– the part has a basic technological process of machining and thus the developed technology of machining in the FMS can be compared with the base technology (Gola, Swic, 2011; Zawadzka, 2007);

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– there is no basic technological process, and thus there is no technology to which the developed technology of machining in the FMS can be compared (Bocewicz, Wojcik, Banaszak, 2008).

In both cases it is good to have the possibility of determining the feasibility of machining of parts in FMS without the need to develop new technological processes.

The criteria adopted for the determination of feasibility of machining of parts in a flexible manufacturing system were the cost (K) and time (T) of machining (Kanada, Sullivan, 1989; Mishra, Prakash, Tiwari, Lashkari, 2006).

Determination of feasibility of machining of parts through comparison of technological processes in the case of FMS and the base variant. Let us assume that the technological process of machining of a part is developed, and thus the data characterising costs and time of machining are known.

Comparison of machining costs and time should be made in the case of a subset of parts whose overall dimensions fall within specific ranges, so that in the group of machine tools under analysis there is a theoretical possibility of machining all the parts included in the subset (Swic, Mazurek, 2011; Wang, Shaw, Chen, 2000).

The process of machining of parts in a FMS is characterised by a certain specifics, namely they are machined in accordance to a flexible technology, and thus even parts from the same batch can be machined along different pathways understood as an ordered set of machine tools of the system through which they pass. Therefore, some of the process characteristics can be obtained only after the determination of the machine tool subset and after simulation of the process of machining of the parts in the FMS. The data obtained (from the simulation) permit the determination of the cost of machining (K) and the time (T) in the case of the groups of parts under analysis. Comparison of the data with those of the base process permits the elimination, from further analyses, of those groups of parts for which parameters K and T in the base process are lower than the corresponding parameters of the FMS being designed (Taranenko, G., Taranenko, W., Swic, Szabelski, 2010).

For each of the analysed variants of machine tool subset we determine the cost of machining of each batch of parts:

$$K_{ESP} = \frac{GK_{PO}}{W_Z \times UPO_{KS}} \times \frac{T_P}{60} + IKR \times IPS \times W_S + IKM \times IP + GKP \times WP, \quad (1)$$

where: K_{ESP} – cost of machining of the batch of parts in the FMS,

K_{PO} – per hour costs of operation of the subsystem of machine tools (based on single-shift operation),

W_Z – number of shifts of system operation,

UPO_{KS} – share of the machine tool subsystem in the costs of the system (entered by the design engineer),

T_P – time of machining of a batch of parts in the system,

IKR – unit cost of labour,

IPS – number of workers required for the system;

W_S – reduction factor of the number of workers required for the system relative to the base variant,

IKM – unit costs of material,

IP – number of parts in production batch;

GKP – per hour operation costs of one square metre of shop area occupied by the system,

WP – shop area occupied by the FMS.

The time of machining a batch of parts in the flexible manufacturing system can be obtained from the control program of machining of a batch of parts in the FMS (Kanada, Sullivan, 1989).

The cost (*K*) and time (T) in the base variant are equal to:

$$K_b = IKP \times IP, \quad T_b = IKP \times IP, \tag{2}$$

where: *IKP* – unit costs of manufacturing of parts (from data bases on casing-type parts) (Swic, 1998),

IP – number of parts in batch (from data bases on casing-type parts),

t_{pz} – preparation-completion time (from data bases on casing-type parts) (Swic, 1998),

t_j – time norm (from data bases on casing-type parts).

In each group of machine tools under consideration, parts for which $K_{ESP}>K_b$ and $T_{ESP}>T_b$ are eliminated, and for the remaining ones (per machine tool group) we calculate:

$$K_{RO} = \sum_{i=1}^{n} K(ZP_n) \text{ and } T_{RO} = \sum_{i=1}^{n} K(ZP_n), \tag{3}$$

where: K_{RO} – cost of machining of parts for a given machine tool group,

T_{RO} – time of machining of parts for a given machine tool group.

We choose the machining process realized on a group of machine tools in the case of which, for the parts under consideration, a better effect is achieved than in the case of machining on other groups of machine tools, and therefore:

$$K_{RO} = \min \sum_{i=1}^{n} K(ZP_n) \text{ and } T_{RO} = \min \sum_{i=1}^{n} K(ZP_n), \tag{3}$$

For the sets under analysis, these equations determine the rational group of machine tools.

Determination of feasibility of machining of parts in FMS without designing the technological process of their machining. In the case of new parts introduced for machining in a FMS there is no technological process (base variant) to which the technology being developed can be compared.

The criteria that should be adopted in the determination of the feasibility of machining include the cost and time of machining, that depend on the part (the degree of its technological complexity), the production program, and the batch size.

Therefore, the feasibility of machining a part in a FMS can be determined if we determine its technological complexity and the functional relation between the cost and time of machining on the one hand, and between technological complexity, production program and batch size on the other. For a part with a specific production program and batch size there exists a threshold technological complexity Z_{gr}, the achievement of means that the machining of the parts in the FMS is feasible. In the case of a specific class of parts, we need to determine the threshold technological complexity Z_{gr} and the technological complexity Z of the part being introduced for machining, from the batch under consideration.

The technological complexity of a part is the degree of complication in the achievement of the required form, dimensions, roughness and mutual positioning of surfaces of the part in accordance with the adopted technical requirements of its machining on the technological equipment available. The measure of the technological complexity is the time of machining the elementary surfaces of the part:

$$Z_i = t_{wi}, \tag{4}$$

where: Z_i – technological complexity of i-th elementary surface of the part,

t_{wi} – time of machining of i-th surface of the part.

The technological complexity of the whole part is the sum of technological complexities of its elementary surfaces:

$$Z = \sum_{i}^{n} Z_i, \tag{5}$$

where: Z – technological complexity of the part,

i – surface number,

n – number of surfaces.

A part whose technological complexity Z is greater than the threshold technological complexity Z_{gr} complies with the conditions of machining in a FMS (its machining is feasible). The threshold technological complexity is the complexity of parts machined in the system, in the case of which, at a given volume of production program and production batch size, their production in the system is feasible. In the case of technological complexity of a part being equal to the threshold technological complexity the cost of its production in FMS (K_{ESP}) is equal to the cost of its production on conventional machine tools (K_{OK}) - $K_{ESP} = K_{ok}$.

We can determine the threshold technological complexity Z_{gr} in the case of parts of a given class, as well as their technological complexity, and compare it with Z_{gr}.

The algorithm of qualification of parts for machining in a FMS is given in Fig. 1.

Determination of rational application of FMS. The process of machining of parts can be presented as a system, the model of which is shown in Fig. 2 (Swic, Gola, 2013).

The best process of machining is such as a result of which the maximum effect is achieved (K_{min}, T_{min}). The quality of that effect is defined by the input parameters: RO – group of machine tools on which the machining is performed; Z – as above; P – production program, N – batch size, O – environment (organisation-economic and technical conditions in the company). Practice shows that only in rare cases input parameters K and T can simultaneously assume values corresponding to the maximum effect. Usually the values of the variables (RO, Z, P, N, O) at which the most desirable values of one of those variables are achieved do not permit the achievement of such values in the case of the other variable. The maximum effect is achieved at compromise values of the input variables.

Estimation of the values of input variables corresponding to the best process of machining is reduced to the analysis of the functions:

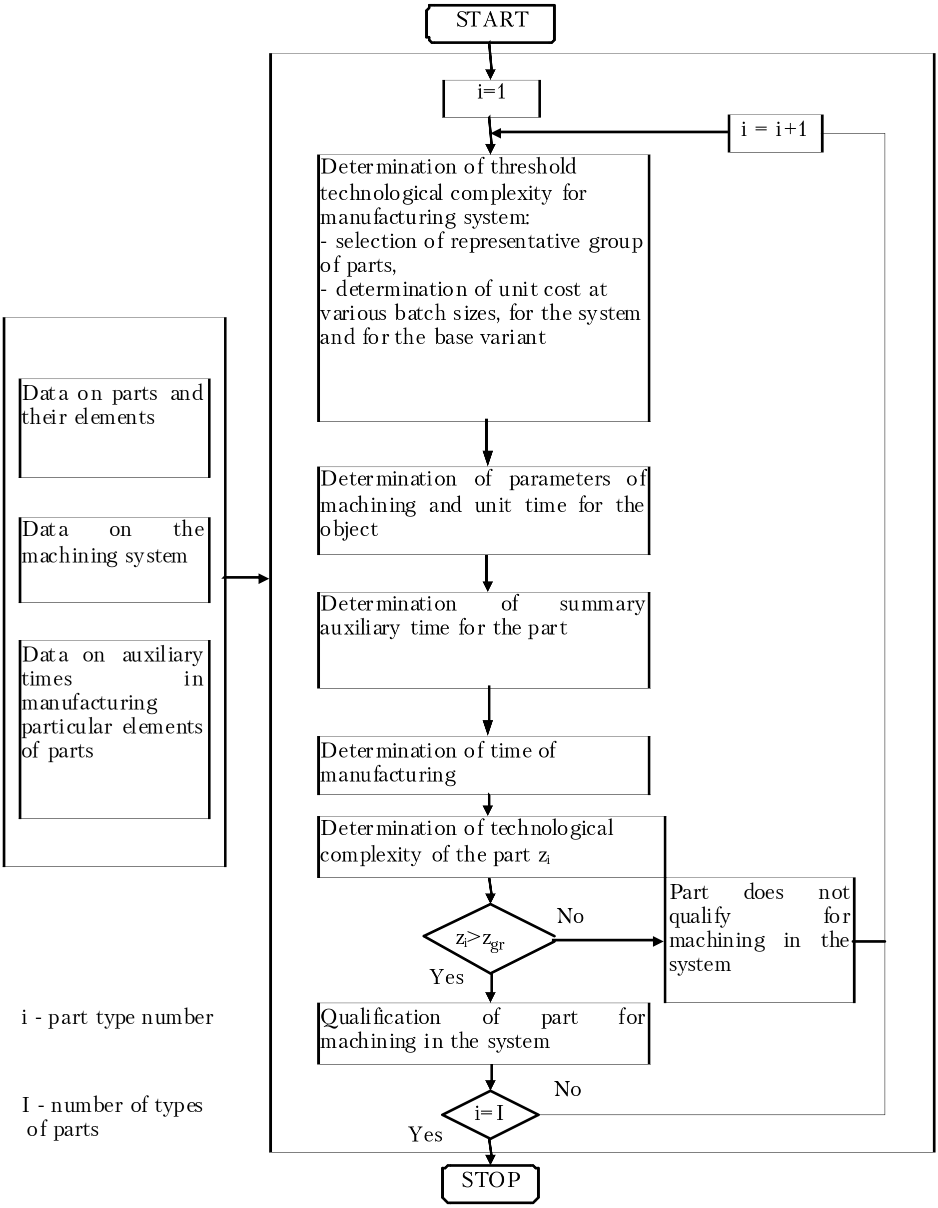

Figure 1. **Algorithm for determination of feasibility of part machining in a system**

$$K = f(RO,,Z,P,N,O),\ T = f(RO,,Z,P,N,O). \qquad (6)$$

Parameters *RO* and *O* are the qualitative parameters – discrete values, and therefore the above functions – for the analysed set of parts (ZP_n), and also for the set (*RO*) – are determined by the set of their possible realizations.

The cost of machining (*K*), for the analysed groups of machine tools (RO_m) and parts (ZP_n), can be written as follows:

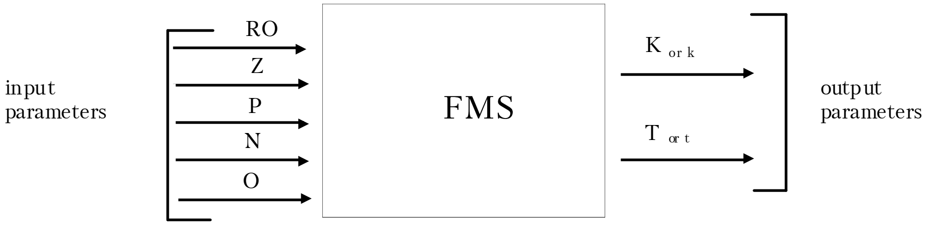

Figure 2. **Model of the process of machining of parts in FMS: *k* – unit cost of part machining spent on processing of a unit of information, *t* – unit time of machining necessary for processing of a unit of information**

$$
\begin{aligned}
&K(ZP_1) = f(Z_1, P_1, N_1)\Big|_{RO_1}^{O=const}\\
&K(ZP_2) = f(Z_2, P_2, N_2)\Big|_{RO_1}^{O=const}\\
&\ldots\\
&K(ZP_n) = f(Z_n, P_n, N_n)\Big|_{RO_1}^{O=const}\\
&K(ZP_1) = f(Z_1, P_1, N_1)\Big|_{RO_2}^{O=const}\\
&K(ZP_2) = f(Z_2, P_2, N_2)\Big|_{RO_2}^{O=const}\\
&\ldots\\
&K(ZP_n) = f(Z_n, P_n, N_n)\Big|_{RO_2}^{O=const}\\
&\ldots\\
&K(ZP_1) = f(Z_1, P_1, N_1)\Big|_{RO_m}^{O=const}\\
&K(ZP_2) = f(Z_2, P_2, N_2)\Big|_{RO_m}^{O=const}\\
&\ldots\\
&K(ZP_n) = f(Z_n, P_n, N_n)\Big|_{RO_m}^{O=const}
\end{aligned}
\qquad (7)
$$

where: n – number of types of parts machined in the machine tool subsystem;

m – number of variants of machine tool subsystem.

The cost of machining for the base set of machine tools (RO) is calculated from the relations:

$$
\begin{aligned}
&K_b(ZP_1) = f(Z_1, P_1, N_1)\Big|_{RO_b}^{O=const}\\
&K_b(ZP_2) = f(Z_2, P_2, N_2)\Big|_{RO_b}^{O=const}\\
&\ldots\\
&K_b(ZP_n) = f(Z_n, P_n, N_n)\Big|_{RO_b}^{O=const}
\end{aligned}
\qquad (8)
$$

The time of machining (T) in the case of the analysed groups of machine tools (RO_m) and groups of parts (ZP) is calculated from the relations:

$$
\begin{aligned}
&T(ZP_1)=f(Z_1,P_1,N_1)\Big|_{RO_1}^{O=const}\\
&T(ZP_2)=f(Z_2,P_2,N_2)\Big|_{RO_1}^{O=const}\\
&\ldots\\
&T(ZP_n)=f(Z_n,P_n,N_n)\Big|_{RO_1}^{O=const}\\
&T(ZP_1)=f(Z_1,P_1,N_1)\Big|_{RO_2}^{O=const}\\
&T(ZP_2)=f(Z_2,P_2,N_2)\Big|_{RO_2}^{O=const}\\
&\ldots\\
&T(ZP_n)=f(Z_n,P_n,N_n)\Big|_{RO_2}^{O=const}\\
&\ldots\\
&T(ZP_1)=f(Z_1,P_1,N_1)\Big|_{RO_m}^{O=const}\\
&T(ZP_2)=f(Z_2,P_2,N_2)\Big|_{RO_m}^{O=const}\\
&\ldots\\
&T(ZP_n)=f(Z_n,P_n,N_n)\Big|_{RO_m}^{O=const}
\end{aligned}
\qquad (9)
$$

The time of machining for the base set of machine tools is determined from the relations:

$$
\begin{aligned}
&T_b(ZP_1)=f(Z_1,P_1,N_1)\Big|_{RO_b}^{O=const}\\
&T_b(ZP_2)=f(Z_2,P_2,N_2)\Big|_{RO_b}^{O=const}\\
&\ldots\\
&T_b(ZP_n)=f(Z_n,P_n,N_n)\Big|_{RO_b}^{O=const}
\end{aligned}
\qquad (10)
$$

The best process for the group of parts is the process realized on machine tool group $RO_{i=b}$ which ensures better effects than in the case of technological processes conducted on the other groups of machine tools:

$$K_{i\neq b}-K_{i=b}=\Delta K>O,\quad T_{i\neq b}-T_{i=b}=\Delta T>O. \qquad (11)$$

At the same time, the process should be realized at values of Z, P, N that ensure the following: $K_{i=b}\to(K_{i=b})_{min}$ and $T_{i=b}\to(T_{i=b})_{min}$.

Parameters (Z, P, N) meeting conditions (11) determine rational utilisation of the chosen group of machine tools.

Functions (11) should be built on the basis of specific data for the company, as even similar data (O): organisation, economic and technical from various companies do not provide grounds for the statement that the results of production will be the same — identical values of the input variables do not yield identical effects of the process of machining (Bocewicz, Banaszak, 2013).

The cost and time of machining are calculated for the following conditions:

$$K_{ij} = f(P,N)\left| \begin{array}{c} O = const \\ RO_i \\ Z_j \\ P = P_{\min} - P_{\max} \\ N = N_{\min} - P_{\max} \end{array} \right. \quad (12)$$

$$T_{ij} = f(P,N)\left| \begin{array}{c} O = const \\ RO_i \\ Z_j \\ P = P_{\min} - P_{\max} \\ N = N_{\min} - P_{\max} \end{array} \right. \quad (13)$$

where: i — machine tool group number;

j — number of the successive type of parts;

P_{min}–P_{max} — range of variation of the production program;

N_{min}–N_{max} — range of variation of the batch of parts.

The determination of rational use of machine tools that are mutually replaceable technologically (in the case of FMS and base production) is reduced to the analysis of a set of input data meeting the relations (14):

$$\Delta K = K_b - K_{ESP} > 0,\ \Delta T = T_b - T_{ESP} > 0 \quad (14)$$

Parameters (Z, P, N) at which the condition $\Delta K>0$ and $\Delta T>0$ is fulfilled determine the rational application of FMS.

After the determination of rational application of the analysed FMS we can, in the case of the kind of parts under consideration, with known production program and batch size, and after calculating their complexity, determine the feasibility of their machining without the need of developing the technological process.

Optimisation of application of FMS in the production of parts. The minimum cost (K_{min}) and time (T_{min}) of machining permits the achievement of the maximum effect of machining.

If

$$K_i = f(Z,P,N)\left| \begin{array}{c} O = const \\ RO_i \end{array} \right., \quad (15)$$

then the values of input parameters Z, P, N fulfilling the system of equations:

$$\frac{\partial K}{\partial Z} = 0,\ \frac{\partial K}{\partial P} = 0,\ \frac{\partial K}{\partial N} = 0 \quad (16)$$

determine the realization of the process of machining on machine tool RO_i, guaranteeing K_{imin}, and are thus also the optimum relative to the cost of application of the FMS.

If

$$T_1 = f(Z,P,N)\Big|_{RO_i}^{O=const}, \tag{17}$$

then the values of input parameters (Z, P, N) fulfilling the system of equations:

$$\frac{\partial T}{\partial Z}=0,\ \frac{\partial T}{\partial T}=0,\ \frac{\partial T}{\partial N}=0 \tag{18}$$

determine the realization of the process of machining in the FMS, and guarantee the achievement of T_{imin}.

The values of the variables determining the compromise realizations between K_{imin} and T_{imin} define the best (optimal under given conditions) application of the system.

Analytical solution of the above systems of equations is very labour-consuming. Often such a solution is not necessary as in a given company there are actual parts with specific technological complexity. The production program results from the needs of production (demand), and thus it is a value that the design engineer received as a constant.

The only value that may change is batch size. The methodology of determination of the pathways of machining and the structure of the machine tool subsystem (and thus also of their retooling) is built in such a way that in the case of a patch with size determined in accordance with the needs of production (e.g. assembly), it optimises the time of retooling and thus also the cost and time of machining.

As follows from the above, the effectiveness of a flexible manufacturing system is largely determined by suitable choice of parts to be machined in the system.

Conclusions. A method was developed that permits the determination of feasibility of parts machining in a FMS without developing the technological process (the technological complexity of the part is determined and compared with its threshold value). On the basis of an algorithm a computer program was developed that works together with a database on the parts machined. Although the method is a simple one, it permits the achievement of fairly accurate results (more accurate than in the case of methods used for the selection of parts for CNC machine tools – as it takes into account more factors determining the technological complexity of the part).

According to the method developed, the determination of the technological complexity of the part permits the determination of rational application of FMS in terms of costs and time of machining.

Analysis of rational application of FMS leads to the following conclusions:

– machining of small batches of parts with low technological complexity in FMS is effective only in the case of a large production program;

– parts with high technological complexity can be effectively machined in FMS even at a small production program.

On the basis of a given technological complexity it is possible to determine the size of batches of parts at which their machining in the system is economically justified.

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