Evaluation of the types of multiproduct manufacturing of machine components and some aspects of their design

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Abstract. Type of production, evaluated at the initial stage of production design, determines the basic principles of its organization, mode of operation and specialization. It is particularly relevant to determine the type of production adequate to the given production procedure. Modern technical approaches used to determine it poorly reflect multiproduct nature of such production. The suggested method of determining the coefficient of seriation in multiproduct manufacturing allows evaluating its type, but requires information not always available at the initial stage of the project development. Applying the method of the design based on the reduced program facilitates decreasing its tasks dimensions. Choosing a base component on the basis of quantitative evaluations of the resemblance between components allows reasonably decreasing dimensions of task for designing production sites of multiproduct manufacturing. For this purpose formalized device was developed. On the basis of quantitative evaluation of the resemblance, characteristics of the reduced production program, and labour intensity hours in particular, can be determined. Automation is facilitated due to the formalized objective transformation of multiproduct programs of manufacturing for the sites being designed in the program of base components manufacturing, equal to the set programs on labour intensity hours. Thus, the quality of the design increases and the schedule of the project reduces.

1 Conventional description of the type of production

The type of production is the classification of the production, distinguished by the assortment width, periodicity, stability and the volume of output. Three types of production are distinguished in machine building industry: mass, batch and job production (all-Union State Standard (GOST) 14.004-83).

When designing production systems, the type of production determines the underlying principles of its organization, employed working procedures (continuous flow process, variable continuous flow and batch process) and specialization of the system being designed [1], [2]. In particular, it is recommended [2]:
- In mass production – to use subject-specific assembly lines;

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- In batch production – to organize workshops, specializing on definite component parts, and production sites, to use multiproduct assembly lines;
- In job production – to organize production sites with technological specialization.

The above-noted significantly decreases the dimension of the task of production engineering; specifies it, allows transferring from conceptual engineering to technical project development at the least cost of time and resources [3].

It is particularly relevant to determine the type of production adequate to the given production procedure. However, modern technical approaches (for instance, [4]), which are used to determine this procedure, poorly reflect multiproduct nature of such production, thus increasing the probability of getting erroneous estimate.

Coefficient of seriation (Кз.о) is considered to be the main characteristics of the type of production. It is determined in compliance with all-Union State Standard (GOST) 3.1121-84 by the formula:

$$\hat{E}_{\c{C}.0} = \frac{\hat{\imath}}{\DJ},$$ (1)

where *O* – number of different technological functions performed in a production system within a month; *P* – number of employees within a production system.

Depending on the value of Кз.о the following types of production are determined (table 1).

Table 1. Types of machine building production according to the value of the coefficient of operation fastening (in compliance with all-Union State Standard (GOST) 3.1121-84)

Value of the coefficient of seriation ($K_{3.0}$)	Types of production
1	Mass production
$1 < \hat{E}_{\c{C}.0} \leq 10$	Large batch production
$10 < \hat{E}_{\c{C}.0} \leq 20$	Medium batch production
$20 < \hat{E}_{\c{C}.0} \leq 40$	Small-batch production
$\hat{E}_{\c{C}.0} < 40$	Job production

The value of Кз.о in the type of production (1) can be determined only for an existing production system. It is rather difficult to apply this characteristic at the early stage of production systems engineering.

To determine the type of production approximately, the ratio of output of the components with the same name and weight is used (table 2).

Table 2. Data for determining the type of production approximately [4]

Types of production	Output of the components with the same name produced within a year, pieces		
	Weigh of parts, kg		
	More than 100	10…100	Less than 10
Job production	>5	<10	<100
Small-batch production	5…100	10…200	100…500
Medium batch production	100…30	200…500	500…5000
Large batch production	30…1000	500…5000	5000…50000
Mass production	>1000	>5000	>50000

Modern scale of the types of production is highly differential [5], and range of values of Кз.о according to the types of production, is determined rather conventionally.

Traditionally, when programming multiproduct manufacturing, the type of production is determined separately for each of the items it contains, for components in particular. On the whole, the type of production is not usually determined, as a result, the components of mass and, for example, small batch production are manufactured at one and the same department. The existing definition of Кз.о does not take into account multi-product nature of the modern machine building production. It is hardly possible to use $K_{3.0}$ as a characteristic useful for solving tasks of designing production systems on the basis of the existing technical approach.

2 Defining types of multi-product manufacturing

Let the components of *I* name be produced in the production system. Labour intensity hours for the components T_p output is determined by the formula

$$T_p = \sum_{i=1}^{i=I} N_i \cdot T_i,$$ (2)

where N_i – annual production volume of the component i; T_p – value of labour intensity hours per single piece of the component i production.

$$T_i \approx n_i \cdot t_{ødi}, i = 1,...,I$$ (3)

where n_i – number of technologic operations, connected with changing forms and dimensions of the component i billet; $t_{ødi}$ – average value of time per piece performance of the stated operations.

The stated operations, involved into any of *I* single technological processes, implemented into the production system, are considered differently. This rather strong assumption allows for a certain increase in the expected use of the production resources of the production system being designed; however, it seems reasonable, as the purpose of the initial stages of the design process is to get the project parameters that will eventually facilitate guaranteed performance of the design assignment.

Number of the operations, performed while manufacturing parts in compliance with the preset production program (O):

$$O = \sum_{i=1}^{i=I} n_i,$$ (4)

where n_i – number of different operations, performed in i single technological process.

If the designed production system functions at the preset regime, the number of workplaces in it is (*P*):

$$P \approx \frac{\sum_{i=1}^{i=I} N_i \cdot T_i}{\hat{O}},$$ (5)

where $\hat{O}$ – factual annual production time of the equipment of the production system being designed [4]. The value of *P* approximately determines the number of critical workers in the system being designed. Taking into account (4), (5) formula (1) is modified into:

$$K_{\zeta,0} = \frac{\hat{O} \cdot \sum\limits_{i=1}^{i=I} n_i}{\sum\limits_{i=1}^{I} N_i \cdot T_i}, \tag{6}$$

In contrast to (1), formula (6) allows formally determining the value of Кз.о for the conditions of multi-product manufacturing and evaluating its corresponding type, but it does not simplify calculations necessary for it and requires information not always available at the initial stages of the project development.

The use of the reduced production program [1], [2] is a frequently applied method of decreasing the dimensions of the design tasks, examined later as exemplified by designing a site for manufacturing components.

The method under discussion is used for designing multi-product manufacturing site, often of small batch and middle batch types, and restricted technological information about the product. Formation of the reduced production program is started with selection of the components, which are projected to be manufactured at this designed site. They are base components.

In the existing literature [1]-[3], [6, 7] and others, the term «base component» is not defined, and the recommendations on such selection are insufficient. A base component is usually selected just on the basis of visual comparison of constructions and some technological characteristics of the components to be manufactured on the production site.

Base component is one of the components of the prescribed nomenclature for the production site being designed. Construction of the base component and technological process of its manufacture fully reflect both structural and engineering solutions which are characteristic for all the components of the same nomenclature and corresponding process (unit and batch ones). According to the results of the pair-wise comparison of I processes of manufacturing the components of the given nomenclature $\{D_i\}, D_i = 1,...,I$ the matrix of evaluation of the resemblance between the components is developed [8]:

$$
\begin{array}{c|c}
 & D_1 D_2 ... D_I \\
\hline
D_1 & 1 ... \; S_{1,2} S_{1,I} \\
\hline
 & \text{....} \\
\hline
\cdots & \\
D_1 & S_{I,1} S_{I,2} \; ... \; 1 \\
\end{array}
\tag{7}
$$

where $S_{i,j}$ evaluation of the resemblance between the components D_i and D_j; $i,j=1,...,I$. Here

$$S_i = \frac{2m}{a+b}, \tag{8}$$

where a,b – number of technological operations in the process of the components manufacturing D_i and D_j [9].

Component D_p is a base component of the nomenclature if

$$\exists D_p \in \{D_i\}, \sum_{j=1}^{i=1} S_{p,j} = \max. \tag{9}$$

Technological process of a base component manufacturing must be developed up to the stage of the unit process with technical rate setting, per unit labour time cost accounting, total labour intensity and machining content calculation [6]. Thus, name (D_p),annual production volume (N_p), labour intensity hours (T_p) are determined for the base component.

Reduced program is a program of a base component manufacturing equal by labour intensity to the program of producing the components of the given nomenclature on the production site being designed. The reduced program allows transferring from multi-product program to the base component (single unit) production. The design made on the basis of the reduced program is especially efficient if preliminary selection of the components to be manufactured and formation of technologically similar groups are performed. [10, 11, 12]. In this case, base components, reduced programs and types of productions are determined for each group individually. The value of Кз.о for the group of technologically similar components can be evaluated by the formula:

$$K_{Ç0} = \frac{\hat{O} \cdot n_p}{\left(N_p\right)_{np} \cdot T_p},\tag{10}$$

where n_p – number of operations in the fixed-route technological process of the base component manufacturing; T_p – labour intensity of the base component manufacturing; $\left(N_p\right)_{np}$ – reduced program of the base component manufacturing, equal by labour intensity to the program of producing the components of the given nomenclature.

If the values of labour intensity $\{T_i\}$ of manufacturing the components of the given nomenclature $\{D_i\}$ are as usual unknown, they can be approximately determined by the formula:

$$T_i = \frac{2mt_i}{S_{p,i}} - \frac{t_i}{t_p}T_p,\tag{11}$$

where t_p, t_i – average value of per unit labour time cost accounting for operations of manufacturing a base component and any (i) part of the given nomenclature; m– number of similar operations in the process of a base component manufacturing and (i)part of the given nomenclature; $S_{p,i}$ – evaluation of technical resemblance between the components D_p and D_i, $i \neq p$. Ratio (11) is correct if

$$mt_i > \frac{T_p \cdot S_{p,i}}{2}.\tag{12}$$

The conditions for the reduction of a production program:

$$\left(N_i\right)_{\bar{i}\partial} \cdot T_p = T_i \cdot N_i,\tag{13}$$

where N_i – initially given output volume of i component of the nomenclature; T_i – labour intensity of manufacturing i component of the given nomenclature.

The volume of the components manufacturing on the designed production site $\left(N_p\right)_{np}$, reduced to the base component D_p:

$$\left(N_p\right)_{\bar{i}\dot{o}} = N_p + \sum_{i=1}^{i=l} \frac{T_i \cdot N_i}{T_p}, \tag{14}$$

where N_p – initial production volume of the component recognized as base component. The number of workplaces in the designed production system can be determined similarly (5):

$$P \approx \frac{\left(N_p\right)_{\bar{i}\dot{o}} \cdot \sum\limits_{i=1}^{i=l} T_i}{\acute{O}}. \tag{15}$$

Value *P* is the most important parameter of the designed production site.

The described technical approach for evaluating the type of multiproduct production, determining the reduced manufacturing programs and the number of workplaces at the designed production site was tested on the results of designing object-closed sites of small batch production of step-shaped shaft, disks, gear wheels and in using technologically similar processes. The results prove sustainability of implementing this approach when factually designing production sites.

The advantage of this approach is its standardized nature, allowing for automation in perspective, thus turning it into powerful tool of increasing the effectiveness of designing a production.

3 Conclusions

- Conventional technical approaches, used to determine the type of the designed production, poorly reflect multiproduct nature of such production, thus increasing the probability of getting erroneous estimate.
- Selection of base components on the basis of quantitative evaluation of technological resemblance allows for a decrease in the dimension of the tasks of designing production sites of multi-product manufacturing of machine components.
- The developed formalized approach allows objectively determining the number of workplaces, which is the most important quantitative parameter of the project, at the initial stage of designing a multi-product production site.

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