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Abstract

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MECHANICS

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ON THE QUESTION OF OPTIMIZING THE SYNTHESIS OF TECHNOLOGICAL AUTOMATIC MACHINES

At the present stage of technological development, the process of creating automatic machines is characterized by a multiplicity of variants both in the methods and paths of solution and in the resulting solutions themselves, covering questions of the choice, first, of schemes and, second, of the constructive realization of the latter, i.e., the choice of the principle and parameters of the corresponding mechanisms and devices ⁽¹⁾.

It is not possible to analyze “manually” all these discrete variants; therefore at present, in most cases, one is limited to examining a comparatively small number of variants, which by no means always ensures the highest techno-economic efficiency of the design-and-engineering solutions ultimately obtained. From what has been said follows the task of formalizing and mechanizing (including with the aid of computers) design processes aimed at obtaining optimal variants of automatic machines.

The consideration of the problem of synthesizing an optimal variant—in particular, of such a widespread and at the same time promising type of equipment as automatic machines for assembling a product consisting of a base component (part) and several smaller components (parts) attached to it—may be represented (of course, to a certain degree conditionally) in the form of two successive stages (Table 1). In this case, the decisions made at the second stage are, to a certain extent, a consequence and development of the decisions made at the first stage. Decision making at the second stage is multistep in nature ⁽⁸⁾.

In the formulas for actual productivity (see Table 1) the following notation is adopted: $I^{(i)}$ is the number of parallel streams (cyclic output); $[k^{(i)}]$ is the mathematical expectation of the value of the product-quality coefficient, $0 < k^{(i)} \leq 1$; $\sum_j t_p^{(ij)}$ is the total time of nonoverlapped actual working operations; $\sum_j t_1^{(ij)}$ and $\sum_j t_2^{(ij)}$ are the total cyclic time losses for nonoverlapped cyclic auxiliary operations, considered respectively at the first and second stages; $\sum_j t_1^{(ij)}$ and $\sum_j t_2^{(ij)}$ are the total noncyclic time losses associated with mechanisms and devices used to carry out the cyclic operations, considered respectively at the first

and second stages; $\sum_j t_3^{(ij)}$ is the total noncyclic time loss for technical maintenance; $\sum_j t_4^{(ij)}$ is the total amount of time of noncyclic losses caused by the nonconformity of the initial assembly components; $\eta^{(i)}$ is the mobility coefficient, evaluating the adaptability of the machine to readjustment and, accordingly, reflecting productivity losses in connection with changes in product sizes, etc., $0 < \eta < 1$. All noncyclic losses are referred to one conforming product.

Table 1

	1st stage	2nd stage
Developed and constructively realizable graphical schemes of automatic machines Factors determining the scheme of the automatic machine	Conceptual The principle of the technological process, sequence of operations, conditions of concentration and differentiation, character of aggregation; number and kinds of motions required for carrying out the given technological process, etc.	Structural The degree and principles of “machinization” for obtaining, transferring, transforming, and using interrelated main and auxiliary material flows, energy flows, and information flows
Elementary technological operations considered	Actually working operations; auxiliary cyclic operations, defined mainly in the conceptual scheme (transportation of the base part, etc.)	Cyclic auxiliary operations not directly connected with the conceptual scheme (loading–unloading, control, etc.); noncyclic auxiliary operations

	1st stage	2nd stage
Method of describing graphical schemes of automatic machines Operators used Correspondence to the groups of operations considered	Operators ⁽²⁻⁶⁾ “Nonlogical” (arithmetic) “Nonlogical” operators: actually working operations <i>P</i> ; auxiliary operations connected with change of position (including orientation) in space <i>B</i> ; auxiliary operations connected with the implementation (realization) of control	Operators ⁽²⁻⁶⁾ “Nonlogical” (arithmetic) and logical Logical operators for operations of control: correctness (including accuracy) of the position of assembly components <i>n</i> ; geometrical parameters of assembly components <i>e</i> ; nongeometrical parameters of assembly components ; condition of mechanisms and devices of automatic machines, operating modes, etc. These operations are divided into: a) recognition of the correspondence of the actual situation to the specified one; b) formation and transmission of control, which may be active and passive

	1st stage	2nd stage
Conditions used	Nonverified (corresponding to “unconditional” control); pseudoconjunction corresponding to successive execution of operations (●); pseudodisjunction corresponding to parallel execution of operations (∨)	Nonverified and verified (corresponding to conditional control), taking the value 0 or 1. Verified conditions: selecting, switching on and switching off (maximum and minimum). The order of triggering and the combination, in each situation, of operators is determined by a system of corresponding verified condition arrows arranged according to definite rules
Formulas of automatic machines describing the action of mechanisms and devices corresponding to the indicated operations (or groups of operations) Flows reflected in the schemes and formulas of automatic machines	Operator (“nonlogical”) Main material (transportation of the base part) and energy	Logical Main material, auxiliary material (transportation of attached parts, etc.), energy, flows of central and local information
Actual productivity of the i -th variant of the automatic machine (7-9)	$Q_{\phi 1}^{(i)} = I^{(i)} [\eta_1^{(i)}] \left(\sum_j t_p^{(ij)} + \sum_j t_1^{(ij)} I_{\phi 1}^{(i)} \left[\sum_j t_1^{(ij)} \right]^{-1} \left(\sum_j t_p^{(ij)} + \sum_j t_1^{(ij)} + \sum_j t_1^{(ij)} + \sum_j t_2^{(ij)} + \sum_j t_2^{(ij)} \right) \right)$	$Q_{\phi 2}^{(i)} = I_{\phi 2}^{(i)} \left[\sum_j t_1^{(ij)} \right]^{-1} \left(\sum_j t_p^{(ij)} + \sum_j t_1^{(ij)} + \sum_j t_1^{(ij)} + \sum_j t_2^{(ij)} + \sum_j t_2^{(ij)} \right)$
Specific (per unit time) total labor costs characterizing the i -th variant of the automatic machine (8)	$C_1^{(i)} = \sum_{k=1}^K m_{\alpha}^{(k)} (c_{\alpha} + c_{\alpha} + c_{\alpha})$	$C_2^{(i)} = C_1^{(i)} + \sum_{r=1}^R \sum_{l=1}^L m_{\beta}^{(l)} (c_{\beta} + c_{\beta} + c_{\beta})$
Optimization criterion: technological cost of the product	$\bar{C}_{1 \min} \approx C_1^{(i)} / Q_{\phi 1}^{(i)}$	$\bar{C}_{2 \min} \approx C_2^{(i)} / Q_{\phi 2}^{(i)}$

(continued)

	1st stage	2nd stage
Variable characteristics of the solutions	Degree of concentration and differentiation; number of positions and flows; nature of aggregation and layout; number and types of motions, etc.; modes of carrying out operations (within the range of optimal values); in doing so, analytical and non-analytical dependencies are taken into account between individual time components of the process, etc.	Principles of automation of each of the operations (centralized or decentralized, digital or analog control, etc.); level of automation of the machine as a whole
Types of mechanisms and devices corresponding to particular operations (or groups of operations) of the given functional purpose, used for the constructive realization of the schematic solutions	Power units (drilling, thread-cutting, pressing, riveting, etc.), heads, associated heads, rotary and linear indexing tables, cantilever and loading devices, technological and transport rotors, etc.	Hoppers with gripping-and-orienting devices, magazines, trays, piece and batch-feed separators, various elements of control systems, control and blocking systems (sensors, blocks for comparison and storage, in particular for rejects, etc.), lubricating devices, etc.

The specific (per unit time) total labor costs characterize, from the standpoint of simultaneous and current expenditures of past labor, as well as expenditures of living labor, the α -th variant of the type (or size) of a mechanism or device used for the constructive realization of the principal scheme, or the β -th variant of the type (or size) of a mechanism or device used for the constructive realization of the structural scheme. Here $m^{(k)}$ is the number of identical specimens of each type (or size); K is the number of types (or sizes) of mechanisms or devices used for the constructive realization of the principal scheme; L is the number of types (or sizes) of mechanisms or devices used at each of the R steps in the constructive realization of the structural scheme.

Writing the assembly process by means of the operators indicated in Table 1, we obtain the initial operator formula of the automatic machine, characterized

by a minimal degree of concentration and differentiation and by the execution of all operations in one position.

Since a change in the degree of concentration and differentiation, the number of positions, the nature of aggregation, etc., is accompanied by quite definite changes in the operator formulas, then, with the aid of the appropriate rules borrowed from the theory of finite automata ⁽¹⁰⁾, and also rules taking into account the specificity of the given technological process and of the given type of automatic machines, algorithms may be obtained for transforming the initial operator formula into “derived” operator formulas.

In addition, algorithms may be obtained for “building up” operator formulas to the corresponding logical formulas by expanding the latter through the addition to them of logical operators and the corresponding conditions to be checked, as well as by the addition of additional chains of “non-logical” operators corresponding to auxiliary transport flows. In this case, on the basis of each operator formula, several logical formulas may be obtained, differing from one another both in the number and nature of the combination of operators (i.e., in the principle of automation of one operation or another) and in their “completeness” (i.e., in the level of automation).

The initial data concerning the technological process, as well as the technical-and-economic data concerning the types of mechanisms and devices used, should expediently be represented in the form of linear equalities-inequalities convenient for use in formalized synthesis.

Since each technological operation (or group of operations) corresponds to a standard mechanism (or device) by means of which a given operation is performed, and also in view of the mutually one-to-one correspondence within each triad of formulas—operational formulas, productivity formulas, and specific total labor costs—considered at the first stage, optimization of the synthesis of the first stage of designing an automatic machine can be carried out by using, in addition to the indicated methods of finite-automata theory, enumeration methods, including accelerated enumeration.

Corresponding to changes in the principles and level of automation, definite changes are also undergone by the mutually one-to-one-corresponding formulas within each triad considered at the second stage: logical formulas, productivity formulas, and specific total labor costs.

Optimization of the synthesis of the second stage of design is carried out by means of dynamic programming methods ^(8,11) and methods for solving shortest-path problems or problems of a flow of minimum (maximum) cost ^(12,13).

The use of a digital computer in this case makes it possible to survey a very wide range of variants of the schemes of automatic machines and their structural implementations, and of the corresponding triads of formulas of the first and second stages. At the same time, over a wide range, a large number of non-random parameters (for example, mobility indices) and random parameters (for

example, quality indices of the initial components, etc.) are taken into account.

The development, within machine mechanics as a science, of problems of algorithmizing the synthesis of the set of mechanisms and devices forming an automatic machine as a whole; the use of the theory of operations research for purposes of optimal design; the creation of standard technological processes and a unified methodology for designing automatic machines on the basis of standard elements; and the use of digital computers will make it possible, with sufficient effectiveness, to solve the problems of comprehensive mechanization and automation.

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