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RATIONAL SEQUENCE OF DESIGNING ASSEMBLING PROCESSES

The paper proposes a rational procedure of designing assembling processes, which makes it possible to analyze a large number of assembling processes at minimum time and to choose the optimal one.

***Key words**: assembling, product, labor intensity, cost, automated production, computer-aided analysis and synthesis.*

At present assembling processes, including automated processes, are widely used both in mass and batch production [1, 2, 3]. Much attention is paid to rationalization of these processes in order to reduce the number of operations to be performed, to reduce the cost of equipment and tooling as well the cost of operations and the rank of works, to increase productivity and reliability of the equipment. Due to the availability of a large number of various technologies and equipment for automated assembly as well as due to the necessity to take into account many initial parameters, .selection of the assembling process realization variant, that will be the most appropriate in definite situation, is quite a labor consuming procedure [1, 2, 3, 4, 5]. Taking the above-mentioned into account, a rational procedure of designing variants of assembling processes is proposed.

The aim of this work is to develop a procedure that will enable automated design of the processes of assembling modern complex products with a justified selection of the most optimal assembling process from a large number of available variants according to several main criteria.

Introduction

At the first stage of assembling technology design it is necessary to maximally increase manufacturability of the product to be assembled [2, 3]. For this a possibility is considered to use cylindrical, conical and spherical clearance and pressure joints without thermal treatment, rolled and pressure joints (preferably made by cold and spot welding) in its design as well as soldered connections (especially with pre-tinning), screw and pin joints, riveted joints (with rivets that punch holes themselves) and also joints with split C-rings as more adaptable for assembling, especially if automated assembling is required [1].

Easy access to fasteners is checked and ensured for maximally wide application of automated nut-setters and screwdrivers in the assembling processes. With the same purpose fasteners are combined into sets (e.g. a screw or a bolt in the set with a nut and a C-ring) [1].

It is also necessary to make sure that there are axial limiters at the shafts and axes of the product (collars, flanges) in order to provide the possibility of automated precise fitting of mating parts on them (gears, half-couplings, sprockets). It is also necessary for pressed-in and screwed parts to have guiding elements to prevent their radial shift. To fasten covers and flanges, split C-rings are used, if possible, as more suitable for automated installation. [1].

For the components of welded joints the elements of their pre-orientation are required (collars, limiters, contact seat surfaces of appropriate shapes) for precise fitting of these parts in definite positions before welding. The distances between the areas of product components to be welded and their precise elements (seat surfaces, threads) should be maximally increased in order to reduce thermal deformations during the welding process [1].

In order to simplify the design of automated assembling equipment, symmetry of the fasteners should be provided (Fig. 1) [1], which makes it possible to do without their pre-orientation mechanisms. Efforts are made to maximally reduce the number of parts in the product, to simplify their configuration, to provide datum surfaces of base members for realization of standard and accurate schemes of their location during assembling process.

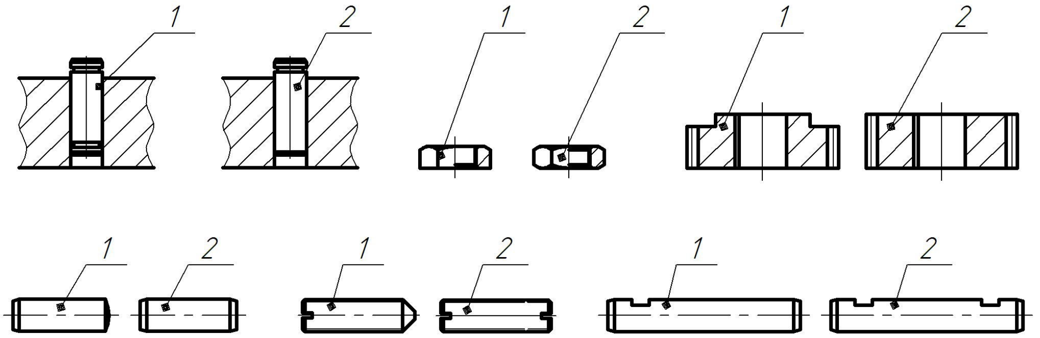

Fig. 1. Examples of increasing adaptability of the parts for assembly by means of providing symmetry relative to the outer contour: 1 – construction non-adaptable for assembly; 2 – adaptable construction

Unified, standard and normalized parts should be used in the product design. It is expedient to compare coefficients of unification – $K_{u.n}$, normalization $K_{n.n}$, and standardization – $K_{s.n}$ of the product to be assembled [6] with corresponding coefficients $K_{u.o}$, $K_{n.o}$, $K_{s.o}$, of the analogous product, that is already produced and the construction of which is considered to be the most rational at the given moment of time:

$$K_{u.n} = \frac{n_u}{N} \leq K_{u.o};\ K_{n.n} = \frac{n_n}{N} \leq K_{n.o};\ K_{s.n} = \frac{n_s}{N} \leq K_{s.o}, \tag{1}$$

where n_u, n_n, n_s – the number of unified, normalized and standardized parts of the product to be assembled; N – total number of parts in it.

A set of design documentation for the product to be assembled (assembly and working drawings, specifications, the product design description and the sequence of its assembly) is developed. Availability of the required projections and cross-sections, accuracy parameters of joints and of the parts mutual location is checked as well as availability of data about forces necessary for pressing-in the parts, torques for tightening the bolts and nuts, tightness of the joints, masses of the product and of its components, accuracy of balancing the rotary parts. Besides, information is collected about the required number of parts to be assembled, the predefined productivity of assembling process, permissible cost of the automated equipment to be used, the terms given for its preparation [3]. The collected information is analyzed in detail.

Then it is expedient to determine organizational form of the assembling process, which could be either stationary or movable (with the application of conveyor) [3]. For stationary assembly the main basic part of the product or of its unit is located stationary in the assembly shop while other units and parts to be connected are supplied to it from different sides. In the case of conveyor assembly this basic part is continuously transferred along the assembly shop (or shops) while other units and components are joined to it. Organizational form is chosen for assembling each unit and for assembling the product as a whole (in certain cases organizational forms of assembling separate units of the product and for assembling the same product as a whole could be different).

The assembling process diagram is developed (Fig. 2), which contains information about the names and sequence of the basic and auxiliary operations to be performed with indication of the product components to be joined at each of the assembly operations.

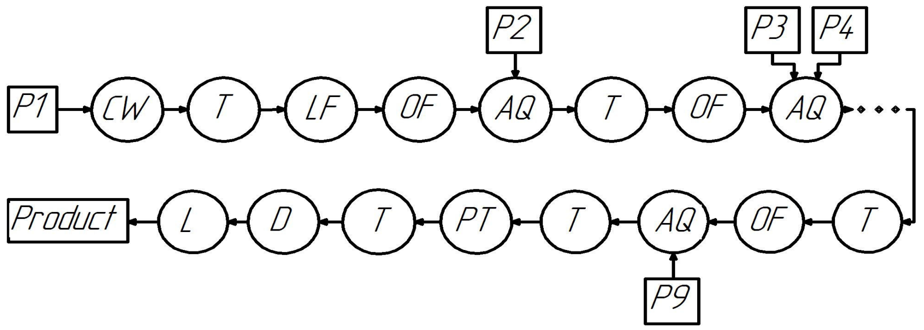

Fig. 2. An example of the assembling process diagram: P1, P2, P3, …, P9 – parts of the product; CW – cleaning and washing; T – transportation; LF – loading into the magazine device and feeding ; OF – orientation and fixing in the working position for assembling; AQ – assembling and its quality control; PT – product testing; D – dying; L – lubrication; N – names of the assembling operations

In accordance with [6], production type, including realization of assembling processes, can be determined by coefficient $k_{a.o}$ of appointing operations, equal to the ratio of the number $n_{o.m}$ of assembling operations to be performed within a month and the number of working places $n_{w.p}$. $n_{o.м}$ is calculated by the formula

$$n_{o.m} = n_{o.m1} \frac{n \cdot n_{w.d.m}}{T_p}, \tag{2}$$

where $n_{o.m1}$ – the number of technological operations for assembling one product (it is determined using the assembling process diagram, Fig. 2); n – the required number of the products to be assembled; T_p – permissible time for assembling n products (in working days); $n_{w.d.m}$ – average number of working days in a month (could be assumed to be 20,83).

Then

$$k_{a.o} = \frac{n_{o.m}}{n_{w.p}} = n_{o.м1} \frac{n \cdot n_{w.d.m}}{T_p n_{w.p}}. \tag{3}$$

If $k_{a.o} < 1$, production is related to mass production type, if $1 \le k_{a.o} \le 10$ – to large-volume production, if $10 < k_{a.o} \le 20$ – to average-volume production, if $20 < k_{a.o} \le 40$ – to small-volume production, if $k_{a.o} > 40$ – to single-piece production [6].

Automation degree is determined for each operation of the designed assembling process (manual, semiautomatic, automatic). Equipment and tooling for its implementation is chosen. Main criteria for such choice are as follows: cost C of the operation, if it is performed manually - C_m, with the use of semiautomatic – C_s and automatic – C_a equipment as well as corresponding labor intensity (per piece time) of performing the operation with a certain degree of automation – $T_{p.m}$, $T_{p.s}$, $T_{p.a}$.

Labor intensity $T_{p.m}$, $T_{p.s}$, $T_{p.a}$. [min] for conditions of large-volume and mass productions are determined by the formula [2]

$$T_{p.p} = (T_m + T_a)\left(1 + \frac{\alpha + \beta}{100}\right) + \frac{T_{p.c}}{n} \quad T_{p.s} = T_m + T_a + \frac{T_{p.c}}{n}; \quad T_{p.a} = T_m + T_a + \frac{T_{p.c}}{n}, \tag{4}$$

where T_m, T_a, $T_{p.c}$ – main, auxiliary and preparatory-concluding time, which for manual operation is determined according to normative documents and depending on its name (if semiautomatic or automatic equipment is used, T_m, T_a are calculated proceeding from productivity and operating mode of the latter); α, β – time losses caused by organizational-technical maintenance and normalized breaks, which are in the range of: $\alpha = 0{,}6 – 8\%$ and $\beta = 2 – 4\%$ depending on the batch production type [2].

For single-piece and batch production $T_{p.m}$ is determined as [2]

$$T_{p.m} = T_m + T_a + \frac{T_{p.c}}{n}, \tag{5}$$

while for calculating $T_{p.s}$, $T_{p.a}$ for the above productions, formulas (4) should be used.

Then for each proposed variant of the product assembling process with the application of manual, semiautomatic or automatic way of performing certain operation it should be checked if the following condition is satisfied:

$$\left(\sum_{i=1}^{m} T_{p.i} - \sum_{i=1}^{k} T_{p.i}\right) n \le T_p \cdot 8 \cdot 60 \cdot n_s, \tag{6}$$

where i – the number of operations in the considered assembling process variant; m – total number of operations in the variant considered; k – number of the process operations that could be performed in parallel (simultaneously) and T_p of which does not exceed T_p of the limiting operation performed in parallel; n_s – the number of working shifts at the enterprise with the duration of 8 hours.

If computer equipment and corresponding standard software products (e.g., Microsoft Excel) are used, it could be checked if condition (6) is satisfied for all possible variants of the product assembling process for manual, semiautomatic or automatic realization of each operation and to select all permissible variants.

For each permissible option the cost is determined, taking [3] into account:

$$C = \sum_{i=1}^{m} \left[T_{p.i}\left(S_{p.i} + C_{m.i}\right)\right] + \sum_{i=1}^{m} \frac{T_{p.c.i}}{n} S_{s.i} + \left[100\left(k_a + k_e\right)C_{eq}\right] / n, \tag{7}$$

where $S_{p.i}$, $S_{s.i}$ – per minute salary of the principal worker and of the setter in performing i-th operation of the variant considered; $C_{m.i}$ – the cost of 1 minute of the assembling equipment work during i-th operation of the variant considered, which is approximately determined according to the norms of the enterprise or by the formula presented in [3]; k_a k_e – coefficients of amortization and exploitation of the assembly tooling ($k_a = 0{,}2 – 0{,}5$, $k_e = 0{,}2$ [3]); C_e – cost of the entire assembling equipment and tooling used for realization of the variant under consideration.

For each permissible variant of the given product assembling process one more condition is checked

$$C_{e.} \le C_{e.p}, \tag{8}$$

where $C_{e.p}$ – permissible cost of the equipment used in the variant under consideration. On the results of checking if condition (8) is satisfied, the list of of the assembling process permissible variants is re-considered. From the variants, that are left, the optimal option is selected – the one for which C is the lowest.

Then routing technology of the optimal assembling process variant is developed taking into account expediency of concentration or differentiation of operations as well as giving more precise information about the names and types of equipment and tooling used in it. While building routing technology, operations with high probability of failures are selected, for which corresponding production reserves should be provided [3].

Datum surfaces and location schemes are chosen. Maximally wide application of the principles of combining datum surfaces and keeping them constant should be provided [3] as well as standard location schemes and universal standard tooling for their implementation. For this, even correction of configuration and size of some components of the product could be used as well as alteration of the elemental composition of the latter.

The final stage of assembling process design is development of its operational technology, where the content of operations and expediency of their concentration is refined once again [3]. At the same stage forces of pressing-in the parts, torques and forces required for tightening the fastening elements are determined. Parameters of the operating modes of the chosen automatic or semiautomatic assembling equipment are calculated, design documentation for manufacturing specialized and special tooling to be used in the developed manufacturing process is elaborated.

Conclusions

1. At the initial stages of the assembling process design it is expedient to provide manufacturability of the product design as well as maximal degree of standardization, normalization and unification of its components.
2. The paper presents a procedure for assembling process parameters computation. It includes determination of the number of assembling operations, known dependencies as well as formulas, proposed by the author, in particular, those for determination of the number of assembling operations, coefficient of their appointment, assembling cost, which are simpler than corresponding known dependencies.
3. Main criteria for choosing the most rational technology of the processes under consideration are labor intensity and cost of assembling the product in the each realization variant as well as the cost of assembling equipment and tooling used. With respect to this, the paper proposes conditions of verification of the designed process variants for their rationality according to the given criteria.
4. Using the procedure, presented in the paper, software could be developed for computer-aided multi-variant synthesis and analysis of highly efficient automated assembling processes.

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