ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 1992
Seria: MECHANIKA z. 109 Nr kol. 1171

International Conference on
COMPUTER INTEGRATED MANUFACTURING
Internationale Konferenz über
RECHNERINTEGRIERTE FERTIGUNGSSYSTEME
Zakopane, March 24-27 1992

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MODULAR ASSEMBLY TECHNOLOGY

Summary. Basic principles of modular technology of assembling of different products are considered in this paper. This technology is built at the account of technological modules, sets and complexes. Technological modules have a corresponding design equipment. The paper is provided with an example of developing the technology of flexible assembling.

The technological assembly process (TAP) in flexible manufacturing is being setup in connection with elaborating the product and its component design for technological effectiveness and developing the manufacturing equipment and appliences (MEA). Technological and structural design system must be fully compatible. In addition to the general principles of TAP building in a flexible computer-aided manufacturing such as sequence of assembly operations, production efficiency within the shortest dimension line, concentration of operations, combination of transfers, stability of the base scheme, orientation, joining and fixing, intensification of assembly modes, simplicity of MEA design, etc. one must take into account the factors connected with the process adaptation to continuously changing objects assembled as well. Group technological processes are the best to meet these requirements.

Working out an optimal version is the most difficult event in designing TAP. This may be done only when using mathematical models and computing devices. These models are based on the formal description of [1,2] unit structure by base image graphs which are represented by Boolean matrices. The general character of movements available in the assembly process is described by an equation set that implies transfers needed and their connections by means of logical operations. The disadvantage of this method lies in the fact that occasional changes of unit or ele ment structure as well as changes of MEA features are impossible. Besides, this method becomes more sophisticated, however, it implements all conditions necessary for obtaining optimal version of TAP with simultaneous correction of the product and MEA design. This is possible in a dialogue projecting of flexible technological processes.

TAP flexibility is provided by its multipurposeness, i.e. the ability to provide computer-aided assembling of products of a certain type which may be technically and economically approved. This concerns the optimal number of products assembled. Therefore flexibility, as the basic feature of the assembly system in the whole, should be considered at the technological, designing and algorithm levels and be provided by technological and design modules, control program and be calculated by corresponding adaptability coefficients. Technological flexibility implies the ability to rearrange separate transfers of the assembly operations (AO) while changing the object assembled or assembly conditions. This is reached by a certain structure which is estimated by stable ties and combination of separate transfers and evaluated by their quantity. Technological flexibility is implemented by the adaptability of MEA design and technically approved availability to alter it. Flexibility is influenced by structural-technological properties of units assembled, components, their positioning, combination and MEA set-up, assembly modes. The idea of stipulating the assembly process of any product at the present technical base is to be considered as erroneons one and such that does not yield high efficiency of the assembly system functioning in the whole.

In a modern machine-building industry the most characteristic engineering solutions of formation of flexible assembly systems are as follows:

- autonomous block-modular structures of functionally completed assemblies;
- universal structures of the assembly centre type;
- structures using industrial robots;
- special developments in up-to-date advanced structural-technological solutions.

The first three types of MEA are batch-manufactured and on the basis of their technological properties TAP is being designed according to the principle "from equipment to operation structure". With the regard to such an equipment the nomenclature of products assembled is selected and the group technological process is developed. The last type of MEA is the most prospective. It is the most sophisticated type and requires scientific approach to modern achievements in the field of computer-aided assembling and development of the newest methods of assembling and new technologies. Only in this case the elaborating the product design for manufacturing effectiveness should be tightly connected with TAP designing and MEA developing.

The characteristic features of TAP are the identity of processing routes or operation set that provides high assembling efficiency of a group of products, unity of technological bases of all nomenclature products, implementability of MEA, continuous functioning of the assembly system under its optimal loading.

The development of TAP can be considerably facilitated by using principles of modular technology which is based on the process representation by a number of various technological modules (TM) and by formation of modular sets (MS) and modular complexes (MC). TMs imply simple assembly movements that run at the separate stages of the assembly operation such as feeding components into the assembly area, directing components, joining, fixing, controlling, replacing units and subunits. Several TMs from MS, i.e. combination of movements having a certain assigment, for instance, setting a check ring, bearing pressing-in, etc. A number of functionally combined MSs from MC. Such MC may be computer-aided component directing MC, basic surface feeding and fixing MC. Each module has its corresponding equipment zone. Thus, a component replacement TM requires a certain design of the respective replacement mechanism, i.e. corresponding design module (DM). According to this approach flexible assembly technology is tightly connected with MEA design. Then, the interrelation of modules is described by

$$MS_k = \bigwedge_i^n (TM_{ki} \wedge DM_{ki}),$$

and in general

$$MC^* = \bigwedge_i^n (MS_{ki} \wedge MC_{ki}) = \bigwedge_i^n \left[\bigwedge_i^m (TM_{ki} \wedge DM_{ki}) \right].$$

Investigations carried out has shown that the number of TMs is limited. This predicts high prospects for typization and unification of TAP and MEA. This approach also presupposes TAP subdivision into operations, transfers and passes as well as frames and actions in the respect of program control.

By the analysis of main types of couplings in the assembling one can note that they are based on the following motions: linear, rotation, helicl and curve ones, i.e. nine initial TMs (for a coordinate system) and their respective design TMs are obtainable.

Replacement and rotation motions are described by diagonal matrix

$$M_{\ell,\alpha} = \begin{vmatrix} \ell_1 & \ell_{1,2} & \ell_{1,3} & \ell_1\alpha_1 & \ell_1\alpha_2 & \ell_1\alpha_3 \\ & & & \ell_2\alpha_1 & \ell_2\alpha_2 & \ell_2\alpha_3 \\ & & & \ell_3\alpha_1 & \ell_3\alpha_3 & \ell_3\alpha_3 \\ & & & \alpha_1 & \alpha_{1,2} & \alpha_{1,3} \\ & & & & \alpha_2 & \alpha_{2,3} \\ & & & & & \alpha_3 \end{vmatrix} = \begin{vmatrix} M_\ell & M_{\ell\alpha} \\ & M_\alpha \end{vmatrix},$$

where ℓ_i is linear assembly motions relative to one, two, three axis; α_i is rotation motions relative to the same axes; M_ℓ, M_α, $M_{\ell\alpha}$ are matrices of linear, rotation and combined motions. Similarly one can describe helical and curve motions and a matrix which is common for the available assembly motions.

Hence, elementary TMs are presented by a block matrix

$$TM_i = \begin{vmatrix} TM_\ell & TM_{\ell,\alpha} & TM_{\ell,\alpha,\beta} & TM_{\ell,\alpha,\beta,\gamma} \\ & TM_\alpha & TM_{\alpha,\beta} & TM_{\alpha,\beta,\gamma} \\ & & TM_\beta & TM_{\beta,\gamma} \\ & & & TM_\gamma \end{vmatrix},$$

where TM_i is a technological module that performs linear motion (ℓ), rotation (α), helical (β) and curve (γ) motions being of 10 various types. One should also differenciate basic and auxiliary TMs in analogy to the assembly transfers.

MS is a functional block of TMs which are combined according to the content of the assembly transfers. Thus, for a bearing pressing-in MS, bearing gripping, feeding, directing, joining and fixing TMs are designed. Evidently, based on the product design they will be performed in a pre-determined combination, i.e. in a sequence or simultaneously with certain emerging limitations. Limitations will be dependant on the product design and MEA design as well. By changing these designs one may reach the maximum flexibility of the assembly system. MEA developed according to this point of view will possess much broader technological capabilities than the standard one. Design implementtion of TM, i.e. DM, will also predict the functions coinciding available. For instance, TM that feeds and directs bearing simultaneously, etc.

MC consists of functionally completed MSs, but in addition to this it may be built by the other principle, for example, a unit or subunit assembly MC. It means that one assembly operation can comprize one or more MCs which depend on the TAP complexity. Evidently, MC performance is similar to that of MS, i.e. structurally pre-determined sequence or simultaneousness are preserved. Hence, building of particular MC, MS and TM depends upon the design of the products assembled.

Designing modular TAP presupposes implementation of modular product structure and, in the first place, correct formation of units, sub-units, components that are being assembled at minimum number of assembling movements, have permanent base components, type structure and assembly method, similar instrument facilities and, consequently, rearrangeable MEA. Group rout is being developed based upon a sophisticated product or typical technological solution. Among the competitive versions ofoperations sequence the most optimal one is chosen by the criteria accepted. Necessary calculations of the assembly accuracy and reability, especially modelling results are used. The technological assembly scheme with TM mapping is of a great importance. MSs that are formed should have similar or multiple performance time, which is obtainable by selectings variety of TMs. When it is possible TMs coincide. When increasing TMs concentration TAP becomes more complicated but productivity rises. Optimal concentration of TMs in MS and MC is determined by the process structure and given conditions. One can built typical assembly structures among which the best one is defined for a technological prime-cost. The approach to the formation of typical rearrangement structures is similar.

An example of designing modular technology may be flexible assembling of a spark plug (Fig. 1a.) which consists of 8 components and may be of different sizes. The technological scheme of the assembling (Fig. 1 b) implies the implementation of 5 MSs and 39 TMs (Table 1). The said above TMs from 8 types: feeding components, directing components, joining control, transportation, heating, rolling, rearranging. Totally 1-3 MCs are built (depending on the process structure). The spark plug components have basic surfaces of the same configuration that enables to rearrange MEA in a comparatively simple way by regulating and changing some elements. TMs may be universal for feeding one type components, their orientation, joining, control. With this approach 39 TMs may be reduced to 12 that simplifies MEA design. (Fig. 1 b). The optimal version of a flexible TAP will include

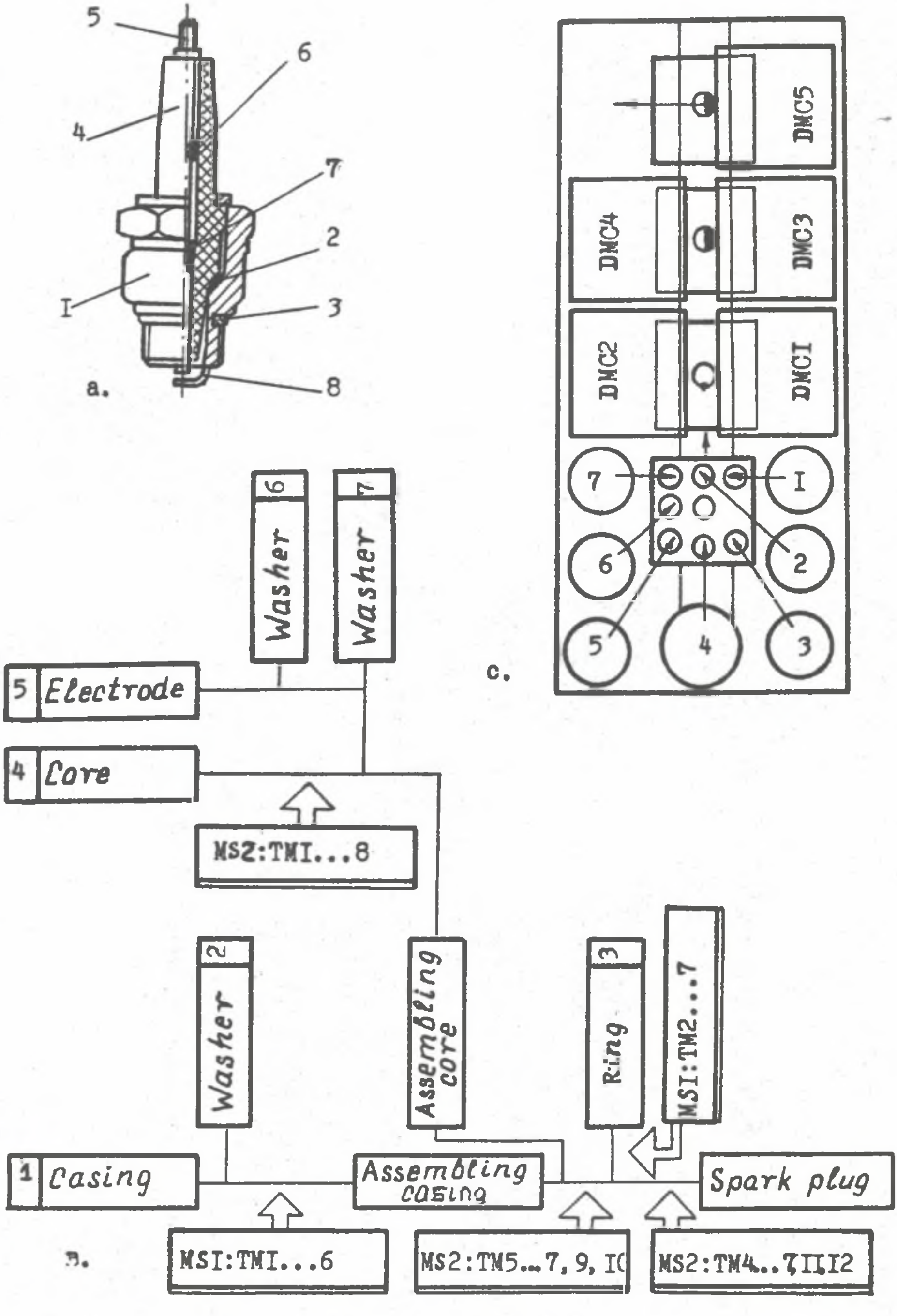

Fig.1. General View of Automobile Spark Plug (a).Technological Scheme of Assembling with the Sequence of MCs, MSs and TMs (b). Assembling Equipment Setup (c).

TABLE 1

Sequence of TMs, MSs, MCs in assembling the spark plug

Rec. No	Technological Modules	Content	Modules Coincide	Design Module
1.	MC 1	Assembling the unit of a casing and a core	MC 1	
1.	MS 1	Assembling the casing	MS 1	DMC 1
1.1	TM 1.1	Feeding the casing 1	TM 1	DM 1
1.2	TM 1.2	Feeding the washer 2	TM 2	DM 2
1.3	TM 1.3	Directing the casing 1	TM 1	
1.4	TM 1.4	Directing the washer 2	TM 2	
1.5	TM 1.5	Joining the washer & casing	TM 3	DM 3
1.6	TM 1.6	Control	TM 4	DM 4
1.7	TM 1.7	Transportation of the unit	TM 5	DM 5
1.8	TM 1.8	Rearranging	TM 6	DM 6
2.	MS 2	Assembling the core	MS 1	DMC 2
2.1	TM 2.1	Feeding the core 4	TM 1	
2.2	TM 2.2	Feeding the washer 6	TM 2	
2.3	TM 2.3	Feeding the washer 7	TM 3	
2.4	TM 2.4	Feeding the pin 5	TM 8	DM 8
2.5	TM 2.5	Directing the core 4	TM 3	
2.6	TM 2.6	Directing the washer 6	TM 2	
2.7	TM 2.7	Directing the washer 7	TM 2	
2.8	TM 2.8	Directing the pin 5	TM 3	
2.9	TM 2.9	Joining the washer with pin 5	TM 4	
2.10	TM 2.10	Joining the washer7 with pin5	TM 4	
2.11	TM 2.11	Joining the pin 5 with core 4	TM 8	
2.12	TM 2.12	Control	TM 5	
2.13	TM 2.13	Transportation	TM 6	
2.14	TM 2.14	Rearranging	TM 7	
3.	MS 3	Assembling the ring with unit	MS 1	DMC 3
3.1	TM 3.1	Feedinh the ring 3	TM 2	
3.2	TM 3.2	Directing the ring 3	TM 2	
3.3	TM 3.3	Joining the ring 3 with unit	TM 4	
3.4	TM 3.4	Control	TM 5	
3.5	TM 3.5	Transportation	TM 6	
3.6	TM 3.6	Rearranging	TM 7	
II	MC 2	Assembling the spark plug unit	MC 2	DMC 4
4.	MS 4	Fixing casing with core	MS 2	
4.1	TM 4.1	Heating	TM 9	DM 9
4.2	TM 4.2	Pressing-around	TM 10	DM 10
4.3	TM 4.3	Control	TM 5	
4.4	TM 4.4	Transportation	TM 6	
4.5	TM 4.5	Rearranging	TM 7	
5.	MS 5	Formation of a side electrode8	MS 2	DMC 5
5.1	TM 5.1	Angle orientation of the spark	TM II	DM II
5.2	TM 5.2	Bending the electrode	TM 12	DM 12
5.3	TM 5.3	Refining the electrode	TM 4	
5.4	TM 5.4	Control	TM 5	
5.5	TM 5.5	Transportation	TM 6	
5.6	TM 5.6	Rearranging	TM 7	

3 operations: three subassemblings and one general assembling. The assembly equipment setup is shown in Fig.1 c. Besides, subassembling together with assembling can be performed on the same equipment that, in general, is advantageous in comparison with TAP of the spark plug assembling at the Smit-Industries Corporation, Great Britain.

Conclusions. Modular technology of flexible assembly permits to considerably simplify TAP designing and MEA design, in particular. TMs are described by matrices and due to the fact that some functions coincide their general number is limited. Each TM is implemented by corresponding typical design modules. Modular technology has the advantages of individual, typical and group processes, adding flexibility.

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MODUŁOWA TECHNOLOGIA MONTAŻU

Streszczenie

W artykule podano podstawowe zalety technologii modulowej montażu różnych produktów. Ta technologia jest tworzona przez moduł technologiczny. Moduł technologiczny jest wyposażony we współpracujące urządzenia konstrukcyjne. W artykule przedstawiono przykład rozwoju technologii elastycznego montażu.

Wpłynęło do redakcji w marcu 1992r. Recenzent: Jan Darlewski