Development of Technology for Automated Construction of FMS Based on Distributed Frame Hierarchy

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***Abstract*— The date paper is dedicated development of computer design technology of FMS on the base of distributed frame-hierarchy. The method supported suppleness of knowledge representation and does knowledge processing more efficiency, what in corresponding to frame form, from the hierarchical objects are created a set of volume primitives and formed a complex object of it by means of theory-set operations. Overall, the research results contribute to the development of new approaches in the application of flexible manufacturing systems and automated technologies and the optimization of existing systems. This makes higher-level control and automation processes possible through the application of technological innovations.**

Keywords*— *Flexible manufacturing system, automated construction, knowledge base, frame hierarchy, CAD systems, structural element , functional element

I. Introduction

By now, CAD has reached a high degree of system maturity. They can actually cover almost the entire life cycle of the designed product: from conception to production, including elements of modeling, trial operation of components, units and subsystems in the form of virtual images, which leads to a significant reduction in development costs and implementation times for manufactured products. And this, in turn, requires improvements in design automation systems, the creation of various applications for many areas of production [1,7], including in the field of flexible manufacturing system (FMS).

In connection with the development of work on automated design, many researchers touch upon the issue of dismembering parts into individual elements. However, in this case, in the known works insufficient attention is paid to the issues of definitions, terminology and systematization of part elements [2,11].

In order to eliminate these reasons, it is proposed to develop and implement automated design technology from standard elements. The development of such technology is a complex and multifaceted task, the solution of which is impossible without the typification and unification of design elements. Typification and unification, grouping of structural elements according to similar characteristics, and creation of unified knowledge bases make it possible to form a wide variety of structures from a minimum set of standard elements.

II. The Main Stages of Automated Design from Standard Elements

The proposed technology defines the content and sequence of operations in automated design from standard elements.

The technology under consideration defines the following main stages:

– definition of constituent and structural elements of designed objects;

– selection of standard elements from them;

– formation of models of standard elements in the geometric modeling system;

– development and creation of a knowledge base of standard elements;

– design of parts and assemblies of the structure from standard elements.

Standard elements can be of varying degrees of detail. The degree of detail of elements is determined by the designer depending on the purposes and methods of their further use based on the simplicity of the standard element, a certain semantic content, relative universality and ease of description of its topology in the language of description of graphic information.

Since the result of automated design is a graphic image, and this is obtained by applying the method of generating an object from known geometric primitives and design elements, it would be advisable to replace the concept of a "standard element" with a constructive element (CE).

In addition, the concept of a "functional element" (FE) is also used. Each FE has a fixed geometric shape and has a stable set of design and technological features.

Examples of functional elements are a neck, flange, boss, fillet, shaft end, stiffener, wall, rod, groove, chamfer, keyway, center hole, shoulder, countersink, louver, etc.

It should be noted that each FE has a very specific geometric shape and therefore is part of the geometric description of the synthesized part. Functional elements are carriers of the features of the synthesized part.

It follows from the above that in automated design, SE and FE act as the main carriers of information about the designed object in the modeled design processes. Thus, from the information point of view, CE should be represented by a set of data necessary and sufficient for the implementation of these processes.

In general, the design system should have the following knowledge about CE [3,8]:

- the function it performs;
- its role in the structure of the structure;
- the relationship of CE in the designed structure;
- the location in space of the designed structure;
- the geometric shape of CE;
- CE graphics for displaying the design results.

Thus, CE for an automated system is a fairly complex engineering and mathematical concept and is a form of representing knowledge about the subject area in design processes.

Of great practical interest is the application of the above technologies in the automated design of flexible manufacturing systems (FMS). An important stage in the design of FMS is the task of selecting and analyzing their structure, since the successful solution of problems at the following stages is largely determined by the correctness of the choice of the structure of the FMS and their elements. In this case, analysis is understood as the process of decomposing the object under study and its properties into components in order to more fully identify the characteristics of the object depending on the conditions of its functioning at the initial stage [4,10]. When analyzing structures, the following tasks are solved: description of the composition of the FMS and construction of its structural diagram, construction of a generalized structural model of the FMS, determination of the main elements of the FMS, etc.

III. CREATING A KNOWLEDGE BASE FMS.

The above allows us to conclude that the FMS is a complex technical system and its automated design requires a special approach. In this sense, in order to apply the described design technology, a general structural diagram of the FMS is developed (Fig. 1). The hierarchical structural diagram states that the FMS as design objects consist of groups of CE, which represents the smallest part of the object and can work with an application program. Such CE can be called a logical and structural unit. Therefore, it should be noted that the process of designing the FMS is a consistent, step-by-step specification of a technical product, in particular its shape, implemented according to a hierarchical scheme.

In this regard, at each stage there is some objective uncertainty of geometric shapes, the assessment of which can be performed on the basis of a measure of the amount of information, the same for all types of models of the development object. Since, the organized design process is

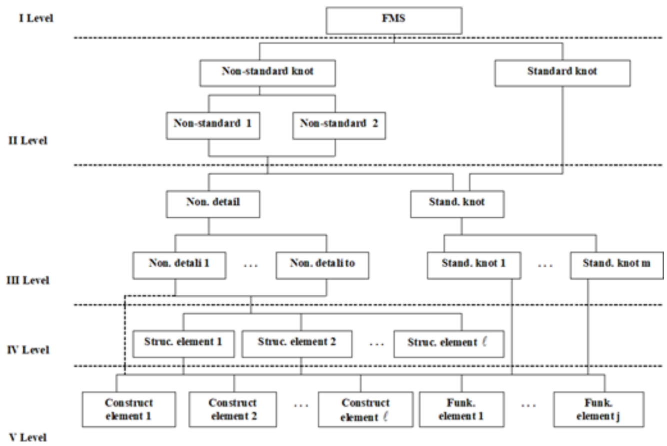

Fig. 1. Hierarchical structure diagram FMS

associated with a consistent decrease in the uncertainty of the geometric shapes of the object.

In this regard, the formation of models of structural elements is an important step in the proposed technology. CE models are modules for designing more complex elements of the FMS using a set of automated design tools.

The main technological requirement for models of typical elements is parameterization and standardization of access to them. Parameterization will allow storing CE with subsequent use with any specified standard sizes, and standardization of access will automate the assembly process from CE with an unlimited growth in the complexity of the formed models of objects from "typical" elements, which are also complex objects.

Fulfillment of all requirements imposed on CE and the successful solution of the automated design problem are implemented by using artificial intelligence methods. The use of artificial intelligence methods (knowledge representation, formal logical reasoning, etc.) gives CAD developers a fundamentally new formalization apparatus that allows for a more complete use of the practical experience of designers, handling and taking into account the uncertainties of the subject area, developing flexible, situational management of the design process and adaptive human-machine interaction.

Analysis of design solutions, carried out using logical inference, allows the user to receive advisory information containing a description of the nature and sequence of actions to finalize the project. The basis for organizing knowledge for the tasks of analyzing design solutions is a set of frames, i.e. procedural knowledge. Each frame is associated with a rule that characterizes the conditions of its activation and represents a logical combination of properties that were not implemented at the design stage. Using a sequence of frame procedures, it is possible to study the current situation in more detail [5,9].

Taking into account the above and the structural diagram of the FMS (Fig. 1), a frame network of FMS elements is further developed. Since the lower level of the structural diagram of the FMS includes structural and functional elements of parts and units, from the beginning of the forming frame models of these primitives in the following forms:

$$\{CE_1, (x_{11}, a_{11}),\ldots,(x_{1\kappa 1}, a_{1\kappa 1})\}$$
$$\{CE_2, (x_{21}, a_{21}), \ldots,(x_{2\kappa 2}, a_{2\kappa 2})\}$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.$$
$$\{CE_n, (x_{n1}, a_{n1}),\ldots,(x_{nkn}, a_{nkn})\}$$
$$\{FE_1, (y_{11}, b_{11}),\ldots,(y_{1\ell_1}, b_{1\ell_1})\}$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..$$
$$\{FE_m, (y_{m1}, b_{m1}),\ldots, (y_{m\ell_n}, b_{m\ell_n})\}$$

where CEi and FEj are the frame name, (xij, aij) and (yij, bij) are slots.

As a result, a set of frames of structural and functional elements is formed

$$CE=\{CE_1, CE_2,\ldots,CE_n\}$$
$$FE=\{FE_1, FE_2, \ldots, FE_m\}.$$

At the next stage, frames of structural elements (SE) are formed from frames of structural and functional elements. If structural element 1 (SE1) is formed by combining structural elements CE_1 and CE_2, as well as functional elements FE_1, then frame SE1 will be in the following form:

$$\{SE_1, (CE_1, value), (CE_2, value), (FE_1, value)\}$$

Thus, a set of frames of structural elements will be constructed

$$SE=\{SE_1, SE_2, \ldots, SEn\}$$

Analysis shows that the structural model of parts included in the FMS is obtained by synthesizing constructive, functional and structural elements. In this case, the structural element is considered the basic element. This applies to both standard and non-standard parts. Since the structural models of standard parts are known in advance, non-standard parts (NSP) are considered in this case. In general, the model of parts can be written as follows

$$NSP=\{SE, CE, FE\}.$$

If the structural model of parts is obtained only by synthesizing structural elements, then the frames of parts are formed in the following form:

$$\{NSP_1, (SE_1, value), \ldots, (SE_i, value)\}$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$\{NSP_m, (SE1, value), \ldots, (SE_j, value)\}$$

In the case of obtaining a structural model of non-standard parts from structural, constructive and functional elements, the frames of non-standard parts are formed from a set of these elements:

$$\{NSP_i, (SE_1, value), \ldots, (SE_n, value), (CE_1, value),\ldots, (CE_m, value), (FE_1, value),\ldots, (FE_k, value)\}$$

The above method can be used to form multiple frames for non-standard and standard parts (SD):

$$NSP=\{NSP_1, NSP_2,\ldots,NSP_k\}$$
$$SD=\{SD_1, SD_2,\ldots,SD_m\}$$

Based on the frames of standard and non-standard parts, frames of standard and non-standard assemblies are defined. The slots of the frame of the assembly model, containing the list of parts included in the assembly, have inheritance pointers to the frames of the part models

$$\{NSAi, (NSP1, value),\ldots,(NSPn, value), (SD1, value),\ldots,(SDk, value)\}$$
$$\text{or } \{SAi, (SD1, value),\ldots, (SDn, value)\}.$$

The resulting standard and non-standard assemblies are specified as sets given below:

$$NSA=\{NSA_1,\ldots,NSA_\ell\}.$$
$$SA=\{SA_1,\ldots,SAn\}.$$

As a result, after defining the structural model of standard and non-standard assemblies, as well as using the models of parts, a structural model of the FMS is obtained, the frames of which are specified in the following general form:

$$\{FMS,(SA_1, value),\ldots,(SA_n, value), (NSA_1, value),\ldots,(NSA_m, value), (NSP_i, value), (SD_i, value)\}$$

The conducted research shows that the hierarchical structure of the frame consists of terminal nodes of slots and non-terminal nodes containing specific data and information related to the conceptual object that the frame describes, as well as data required for the inference procedures. The terminal represents and describes the object, its specific features, as well as information about the relationships between objects, about the way the frame is used, about the next action or about the action that needs to be performed. Different frames of one system describe one object from different angles.

A hierarchy built on the basis of "inheritance" provides an effective way to simplify the presentation of knowledge and reduce the amount of information that needs to be remembered for each specific node. This makes it possible to significantly speed up the knowledge processing process, as well as to extract information using general queries.

Based on this, it can be noted that the multi-stage division of the FMS into structural units allows for the full use of all unified design procedures not only at the stage of forming the image of the part, but also at the stage of creating a database from graphic primitives [6]. For this purpose, a procedure for forming graphic models of structural and functional elements is provided, which allows creating an object-oriented graphic database. Consequently, it can be noted that the representation of hierarchical objects in the form of frames leads to the creation of a basic set of volumetric primitives and a complex object is formed from them by means of set-theoretic operations of union, intersection and difference. This means that one of the main design tasks is the conceptual construction of a complex device from simple elements. Therefore, the general technology of FMS synthesis is as follows. Using predicates and implications, various physical laws and patterns of construction of the corresponding technical elements, as well as application conditions, are formalized. The laws of element connection are described. Synthesis is carried out in the process of logical inference, and one or all possible schemes for a given knowledge base can be obtained.

Knowledge about the construction of parts, units, structures of the FMS, about the fundamental physical laws underlying the construction of technical devices, etc. are expressed by implications

$B(x) \rightarrow A(x)$ (if B, then A),

where B(x) is a logical formula that is a premise; A(x) is a logical formula that is a consequence; x is a vector of variables, constants.

Implications ensure the modularity of knowledge and can be interpreted as products.

If X_1 and X_2 and X_3 and ... and X_n THEN $Y_\ell = \bigcup_{i=1}^{n} X_i$

Considering the above, two groups of rules are included in the knowledge bases for the synthesis of FMS elements. The first group of rules, in accordance with the structural diagram and the frame network, is formed to obtain a structural model of the FMS elements, based on the lower level of the hierarchy. Such rules are divided into four types. The first include products, using which structural elements are organized:

P1: If X_1=CE_1 and X_2=CE2 and … and X_ℓ=$CE\ell$ THEN

$$SE_i = \bigcup_{j=1}^{\ell} KЭ_j$$

The second type of rules is used to form a model of parts included in the structure of the FMS:

P2: If X_1=SE_1 and X_2=SE_2 and … and X_n =SE_n THEN

$$DET_i = \bigcup_{j=1}^{n} SE_j$$

The structure of the model of the FMS unit reflects the composition of the parts included in it and this is described by the following rule:

P3: If X_1=DET_1 and X_2=DET_2 and … and X_k =DET_k THEN

$$SU_i = \bigcup_{j=1}^{k} DET_j$$

The last type of production using the model of parts and units of the FMS is used to obtain a structural model of the FMS itself:

P4: If X_1=SU_1 and X_2=SU_2 and … and X_m=SU_m THEN

$$FMS = \bigcup_{j=1}^{m} SU_j$$

It should be noted that in the specified designs of each developed product, one functional element of the FMS refers to it and is stored in the production knowledge base of the intelligent design system of the FMS. Thus, the formed production system has the following drawback. Elements that are obtained by transforming another element, as well as similar elements with different overall dimensions are determined by separate products. And this reduces the efficiency of using the system. Therefore, it is necessary to minimize the number of products, each product corresponds to separate groups of elements. This means that the minimum number of products P1 should be equal to the number of different structural elements. This means that each structural element is included in the knowledge base of its corresponding products.

Therefore, it can be noted that the minimum number of products P2 is equal to the number of non-standard parts, the minimum number of products P3 is equal to the number of non-standard units, and the minimum number of products P4 is equal to one, and this determines the structural model of the FMS.

The second group of rules is designed to analyze the metric correctness of the part and to check the correctness of the functional elements. The meaning of the latter is that parts containing such functional elements as a chamfer, chamfer, transverse groove cannot be located in the middle part of the part.

IV. Conclusion

The proposed technology increases the level of FMS CAD and, based on the knowledge base, expands the capabilities and intelligence of the developed system.

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