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USAGE OF ASSEMBLY FEATURES IN ASSEMBLY SEQUENCE GENERATION IN 3D CAD SYSTEM

WYKORZYSTANIE CECH MONTAŻOWYCH DO GENEROWANIA SEKWENCJI MONTAŻOWEJ W SYSTEMIE 3D CAD

Abstract

The paper presents the assembly features of the CAD system – their definitions and mathematical description. Possibilities of applying the assembly features in the assembly sequence generation were also described.

Keywords: *assembly features*, *assembly sequence generation*

Streszczenie

W artykule przedstawiono cechy montażowe systemu CAD – definicje oraz opis matematyczny. Opisano również możliwości wykorzystania cech montażowych do generowania sekwencji montażowej.

Słowa kluczowe: *cechy montażowe*, *generowanie sekwencji montażowej*

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1. Assembly features

Features have broad application in the whole product life cycle with effect from the design phase up to the processing operation planning phase. It is widely considered that the feature-based technology is a basis for integrating CAD systems with other systems that operate in the production preparation environment [1, 2, 4, 7].

One of the first feature definition can be found in Erve 1988 [5], where *feature* was defined as follows: *Technological feature is a specific or characteristic fragment of a workpiece with a certain shape, that is used during processing operation planning or selecting the workpiece settlement variant*. In connection with the development of the application area of feature-based technologies more general definitions have appeared: *The technological feature is a unit of information that is used during the design and process planning phases or during any other engineering activities* [8].

Authors of scientific works concerning the assembly features focus typically on describing the relationship between the components, that is on mates between them by using so called *form features* to describe relations, or on specific part's surface, edge or corner configurations [3, 9, 11]. However, the technological assembly feature provides not only the information about the geometry and relations between the assembly units, but also the information about the assembly process itself.

1.1. Definition of the assembly feature referred to the CAD system

For the sake of many different interpretations of the *assembly feature* notion, own definition has been developed.

The assembly feature in relation to the CAD system is understood as the unit of information about the assembly of the product being designed, which is included both in the model representing the *part* and the *assembly*.

The assembly feature contains information about the connection (mate) – relations between parts – that is complemented with the technological assembly information and other information about part properties that have an influence on the assembly process.

The information about connection of the parts is represented by the set of surfaces named *form features*, being in contact with each other, together with the types of relations between them (*form features*): fit, aligned, against, coplanar.

Part, also known as component or element, is understood as a geometric object of the 3D CAD system, that represents one element – piece of the machine. *Assembly* is understood as a model, which represents the assembly containing at least two parts, including other assemblies.

The assembly features may be divided as follows:

– *Connection features* – features with the form (geometric) information about relationships between the assembly units,
– *Handling features* – features with the information concerning handling (manipulation) of the assembly unit.

From the assembly sequence generation point of view are the *Connection features* significant.

1.2. Features with the form information about dependencies between the assembly units

The idea of assembly features concerning mates is based on characteristic static and dynamic connection of the parts.

For the assembly and disassembly planning the dynamic connections are more important. Therefore, the *connection feature* should contain necessary information that unequivocally describe the connection of the parts, that in turn contain information about:

- geometric and kinematic relation,
- function and structure of the connection,
- position and orientation of the mounted units in relation to the whole product,
- tolerance (fit) required in the connection,
- performed motion of the assembly unit relative to the already assembled units – unit degrees of freedom,
- geometric facilities during the assembly, that is chamfer, fillet, etc.

Assembly features describing the connection between assembly units have been divided, inter alia, into:

- *Simple Connection features* – describing connection between two parts,
- *Composite Connection features* – describing connection between more than two parts.

The above mentioned division stems from the fact that the joining elements named fittings or agents, such as screws, glue, weld or rivet, play a specific role in the structure of the product. They represent the final connection in the chain of parts and their function is to restraint these parts. The assembly features together with the fitting form a unit of information about the assembly of the higher order.

Many of the procedures used to determine the assembly sequences, both exact algorithms and heuristics, apply relational model which describes the product as well as individual parts [10]. The assembly features that describe the connection may also be presented by using the relational model, which illustrates relations between all surfaces of the parts being in contact with each other.

And so, for the analyzed assembly that is represented in the form of the set *P* consisting of *k* parts marked with the *x* symbol, the *i*-th assembly feature describing connection between the assembly units (*Connection feature*) AF_c^i can be written as a set:

$$AF_c^i = \{X^i, G^i, R^i, Z^i, S^i, J^i\} \tag{1}$$

- $X^i = \{x_1, x_5, x_n, ...\}$ – the set of parts between which the connection occurs, *n* – part number,
- $G^i = [F^i, C^i, \rho]$ – the set of ordered triple, where:
  - $F^i = \{f_{11}, f_{12}, f_{17}, f_{32}, f_{nu} ...\}$ – the set of surfaces being in contact, *n* – part number, *u* – surface number in the *n*-th part,
  - $C^i = \{l_{12,32}, l_{nu,mv}\}$ – the set of relations between the surfaces being in contact,
  - ρ is a representation in the following form: $\rho : F^i \times F^i \to C^i$,
- $R^i = \{j_{11}, j_{12}, j_{13}, j_{14} ...\}$ – the set of the occurring types of the geometric relations specified by the j_1^i function in the J^i set of functions,

– $Z^i = \{j_{21}, j_{22}, j_{23}, j_{24}, j_{25}, j_{26}, j_{27}, j_{28}, j_{29}, j_{210}...\}$ – the set of the occurring types of technological relations specified by the j_2^i function in the J^i set of functions,

– $S^i = \{x_1, x_5, x_n, ...\}$ – the set of the joining elements – fittings, $x_n \in P$, n – part number in the assembly. If part x_n belongs to the set of fittings $(x_n \in S)$, it cannot belong to the X^i set, the S^i set can be empty,

– J^i – the set of functions describing the assembly. The domain of the J^i set are $X^i \cup F^i \cup R^i \cup S^i \cup Z^i$ subsets. These functions match to the subsets of parts, surfaces being in contact, relations and fittings their characteristic features,

- j_1^i – the connection structure function – geometrical relation in the form of: $j_1^i : F^i \times F^i \to R^i$, in which the domain is the F^i set, and it matches to the subsets of the fittings their type:
- j_{11} – *against* – relation present between two positive planes with opposite normals (Fig. 1a),
- j_{12} – *coplanar* – relation present between two corresponding planes with identically directed normals (Fig. 1b),
- j_{13} – *fit* – relation present between two collinear cylindrical surfaces with opposite normals (Fig. 1c),
- j_{14} – *aligned* – relation present between two collinear cylindrical surfaces with identically oriented normals (Fig. 1d),

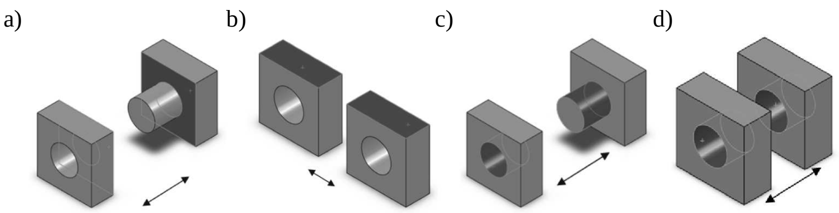

Fig. 1. Relation a) against b) coplanar c) fit d) aligned
Rys. 1. Relacja a) naprzeciw b) współplanarność c) pasowanie d) osiowość

- j_2^i – the technological relations function – methods of persistent connections, mountings present on the surfaces being in contact, in the form of: $j_1^i : F^i \times F^i \to R^i$, in which the domain is the F^i set and it matches to the subsets of the fittings their sort: j_{21} – screwed, j_{22} – riveted, i_{23} – welded, j_{24} – soldered, j_{25} – glued, j_{26} – bonded, j_{27} – keyed, j_{28} – tied up (clipped), j_{29} – pinned, j_{210} – wedged.

In [6] an algorithm for collecting information about the assembly from the CAD 3D model of the product assembly was created and named the AFR algorithm (Assembly Features Recognition). The proposed algorithm was implemented in the form of an add-in integrated with the SolidWorks® CAD system, and named AFRWorks. In addition, in order to prove the thesis of [6] an algorithm for assembly sequence generation was created. The algorithm uses the collected assembly features from the assembly model for one mounting direction.

2. The Assembly Features Recognition Algorithm

As the first stage of the assembly features recognition algorithm the collection of the information about the structure of the product assembly model was assumed. That is:
- information about the parts surfaces being in contact with each other,
- information about the defined mates (constraints),
- information about relations between parts,

on the basis on which the assembly features are being created (*Simple Connection features*).

The second stage of the *AFR algorithm* is recognition of the assembly features named *Composite Connection features*. This stage requires early detection of all fittings of the assembly being analyzed.

The last stage is the assembly features recognition at the part level – *Handling features* in all components of the product being analyzed.

All stages for assembly features collection were described in detail in [6].

3. The assembly sequence generation with the usage of assembly features

Basing on the information included in the *Simple Connection features* the so called *Collision matrix* can be generated. By fulfilling the *collision matrix* it is possible to obtain the image of the model structure during assembly and disassembly process. Creation of such a matrix consists in setting collisions (fittings) present during assembling or disassembling. Collisions are entered into the matrix symbolically in the way that by number "one" the collision of the part shown in a row is marked with the corresponding part in a column (for the specified direction of the Oxyz co-ordinate system). No relation is determined by zero [12]. It is possible to fill the matrix in automatically based on the recognized contacts between parts.

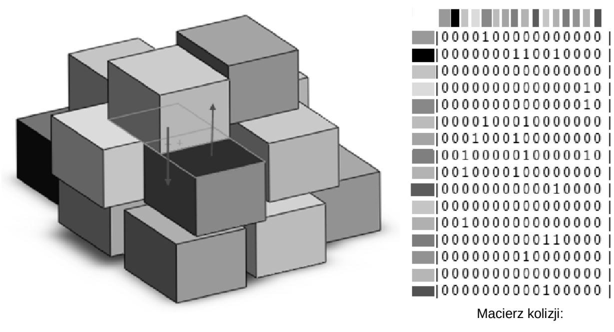

Fig. 2. Example of regular hexahedrons together with the collision matrix for the +Z direction
Rys. 2. Przykład sześcianów wraz z macierzą kolizji dla kierunku +Z

The problem is to be described by using a simple example of regular hexahedron for the mounting direction assumed as +Z. The procedure of the *AFRWorks* add-in enables detection of the existing contacts. "Normal" for each surface of the part shows its direction. By fulfilling the collision matrix for the +Z direction, and solving it consecutively, the possible order for putting the blocks in the stock-pile is achieved. Example of the regular hexahedrons assembly model made in SolidWorks® together with the collision matrix is shown in Fig. 2.

The next step in determining the assembly sequence is to choose the assembly order possible to create and to choose the most profitable assembly order from the User perspective (meaning the priorities/ criteria selected by the User). As a result of the collision matrix solution the sequences are obtained – also such sequences that are "non-executable" in reality, because they do not make allowance for stability analysis, parts gravity, etc.

It is good to imagine that objects are not the regular hexahedrons, but more complicated solids, where assembly has to take place from different directions and at different times. The algorithm would therefore require taking into consideration not only all of the assembly directions, but also the stability of parts.

4. Technical aspects – implementation problems

The proper identification of the surfaces of parts being in contact and information on their mutual orientation are essential for the appropriate collision matrix fulfillment and thereby for the assembly sequence generation.

Detection of contact between the parts depends on if the assembly model was correctly prepared. It is obvious that only those surfaces which indeed are in contact with each other will be detected.

In the detection of contact between the parts, the SolidWorks® API function *ToolsCheckInterference2* was used. The function returns all surfaces of two parts being in contact as an array of *Face2* objects.

In some cases, the developed procedure of identifying the relation type between surfaces, which makes use of this array, unfortunately proved to be ineffective. The implemented SolidWorks® function *ToolsCheckInterference2* turned out to be the problem, as well as the inability to retrieve information about directions of "normals" from the cylindrical surface in a proper manner.

To illustrate the problem of identification of geometric relations the following example was used: a contact between nut and washer.

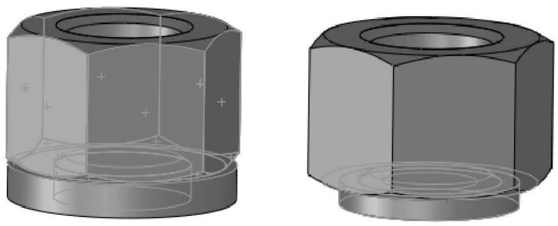

Fig. 3. An example that illustrates the problem of identifying
the adequate geometric (form) relationships
Rys. 3. Przykład obrazujący problem identyfikacji odpowiednich relacji geometrycznych

ToolsCheckInterference2 function, in the case shown in Fig. 3 (left), returns the array of eight flat surfaces and two cylindrical surfaces. This results from the fact that the "front" surface of the washer (in contact with the nut) is in contact with the side surfaces of the nut. In such a case, when the outer diameter of the washer is smaller (Fig. 3 – right) the function will return two flat surfaces – it will not detect the contact with the side surfaces. During the contact between the nut and the washer, there is a relation between the flat surfaces of the opposite type (against) and alignment (aligned) of the two cylindrical surfaces. Computer identification in this case is impossible. The problem is the selection of appropriate surfaces between which the mutual orientation is to be defined and situation in which the proper surface will not be detected every time. When analyzing in detail the example shown in Fig. 3 (left) it can be observed that the cylindrical surface of the nut was not detected, since the actual contact between the washer and the nut is between the cylindrical surface of the washer and the conical surface of the nut, here representing the phasing of the tapped hole. If it is not possible to detect the contact, it is not possible to correctly detect the alignment relation of two objects.

The only solution in this situation is to check whether between the cylindrical surfaces of the nut and the washer respectively, the concentric relationship has not been defined. If so, it is possible to detect the correct alignment relationship. It should be emphasized that the usage of already defined mates is a supporting solution and cannot be the basis for the inference on geometric relations. It is enough that the concentric relation between the nut and the screw and the washer and the screw will be defined.

In this case the model is correct, however, the proper orientation will not be detected here as well. The add-in which implements the algorithm has the additional deduction. The basis for the inference on geometric relations are relations of the surfaces being in contact, while the supporting solution is the analysis of the already defined mates between the assembly parts.

The collection of information about "normal" directions and senses on cylindrical surfaces is also problematic. Correctly operating method of obtaining this sort of information is essential for the proper fulfillment of the collision matrix.

5. Conclusions

Assembly features can be used to assembly sequence generation in the CAD system, but the implementation in the form of a program that communicates with the assembly model is not an easy problem. It was stated that at the present level of development of CAD systems it is possible to generate a sequence of an assembly for a very simple solid models with flat surfaces. It is not possible to generate the correct assembly sequence for models complex in terms of geometry without additional manual fulfillment of the information about the assembly.

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