A Assembly Modeling Method Based on Assembly Feature Graph-Tree

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Abstract: Assembly model plays an important role between conceptual design and detail design. Method of assembly modeling has been discussed in this paper. A novel model, in which a structural Graph-Tree has been constituted by assembly feature as a basic unit, is presented. Furthermore, a notation system has been presented for representation of the model. Based on the proposal feature mapping arithmetic, the assembly model is been built easily. Mapping between functions and structures has been realized easily and the instance of closed loop in constrain resolve has been avoided successfully. Finally, the integration of conceptual design and detail design has been well realized.

Key-Words: Assembly model, Feature Graph-Tree Symbol, CAD

1 Introduction

The product design is a mapping and optimization process from abstract concept information to concrete structure information. In the design process, to establish a unified information model is conducive to the realization of the integration of product concept design and detailed design, as well as the integration of design process and design history. Assembly model throughout the design process plays the role of link, which inherit and reflect the functional requirements in the upstream of the concept design, but also represent a design rational information in the downstream of the detailed design. As a result, to research the assembly model and its modeling method for improving the efficiency of product design and reduce the design fault is of great significance.

The rest of this article is organized as follows. In section 2, the related works are reviewed. In section 3, the assembly feature graph-tree model is presented. In section 4, the notation representation of assembly feature graph-tree model is given. In section 5, the modeling method based assembly feature graph-tree model is presented. Finally, a prototype system is given to validate the proposed approach.

2 Literature Review

In the research fields of the product assembly modeling, the Part-of Graphs model which was presented by M. Mantyla [5] and the mixed assembly model based on Virtual Link was presented by K. Lee[4][3] had been appeared. But these methods had cut apart the completion of product design process in varying degrees, so they couldn't effectively exchange the information from the information model of the upstream concept design and information model of the downstream detailed design. In order to support the whole process of product design, a hierarchical unit assembly model has been addressed by Yuan Bo [10], which applied the hierarchical structure to represent the functional structure. The four concept model based on the design process has been brought up by Tan JR etc. And the mapping algorithm from the assembly sketch model to the assembly drawing model has been present[8]. In the above-mentioned models, part level is the lowest level of models. The research for feature is begin from the machine forming feature, which are mainly used in part modeling, process planning, and CAM etc. Further, some attempts to implement the information integration during the design process have been done. For example, feature extracting from the geometry entities and feature mapping between the design and other engineering application[2]. The feature-based assembly model is present by Shah and Rogers[7], which distinguished the representation of the assembly and that of the assembly relationships. Connection features used to represent the physical relationship between the geometry entities[6]. Brunetti and Golob introduced a feature-based parametric model, which incorporated a feature-based representation scheme for capturing product semantics handled in the conceptual design phase[1]. Ma. et. al present a associative assembly
design feature, which represent associations between the parts in the assembly[9]. The assembly feature models mentioned above do not fit in some situations. For example, when solving the assembly model constraint problem, the closed-loop problem as a whole to solve has not been resolved. On the other hand, a unified information model hasn’t been built for information exchange between upstream and downstream information models. On the other hand, and taking into account the exchange of information between the upstream and downstream information model, not yet a unified information structure information can be achieved, and whole resolve of closed loop can be avoid. The information linkage between concept design and detailed design has been established.

On the ground of above research, a new assembly mode which is expressed by assembly feature graph-tree has been brought up in this paper. by which mapping from function information to structure information can be achieved, and whole resolve of closed loop can be avoid. The information linkage between concept design and detailed design has been established.

### 3 Assembly Feature Graph-Tree Model

#### 3.1 Assembly Feature

The assembly feature is defined by Holland[9] as a specific assembly-related information media. The assembly feature mentioned in the article is geometry feature face-pairs restricted by specific assembly constrain. The assembly feature has follow properties: 1) Assembly features are emerging in pairs; 2) The definite movement and location relation certainly exist among the assembly features. 3) The movement and location relation is related to the specific functional features. The common geometry feature faces which composed the assembly features are shown as follows: plane, cylindrical surface, round hole surface, convex spherical surface, concave spherical surface, curved surface, inverse curved surface etc. Assembly constrain which composed the assembly feature are shown as follows: mate, mate-offset, align, align-offset, coaxial, coaxial-offset, tangent, tangent-offset etc. The geometry features and assembly constrains are shown as Table 1.

<table>
<thead>
<tr>
<th>Geometry feature</th>
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<th>Convex spherical surface</th>
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There is a definite mapping relation between assembly feature and functional feature of parts, for example, the assembly feature corresponding to rotation around axis is composed of cylinder surface and round hole surface constrained by Coaxial, which marked with column<coaxial>hole. The
assembly feature corresponding to Inter-axis positioning is composed of plane and plane constrained by Mate, which is marked with: plane=mate>plane. There are definite restriction connections between geometry features constituting assembly feature, for example, the normal of the two feature faces are contrary, the surface equations of the two feature faces are equivalent, there has existed definite relation in the relative motion between each other.

3.2 The Assembly Feature Graph-Tree Model

The assembly model of product can sustain product design from concept design to detailed design, and can transmit design parameters, assembly levels and assembly information of various assembly bodies completely and correctly. The most information of assembly bodies has been expressed through the form of tree and graph in the assembly model based on feature graph-tree. The level relation of assembly model is expressed by tree, and the connection between the various components of assembly model in the same structure level is expressed by graph, namely assembly relation. As the assembly feature of the products most directly reflects the functional features in the concept design and the structure feature in the detailed design, the product assembly model expressed by the assembly feature graph-tree can achieve the mapping between function and structure effectively, and can solve the closed loop problem in constrain satisfaction solving. The assembly model can be divided four levels, that is, 1) assembly level, 2) sub-assembly level, 3) part level, and 4) feature level. Concrete model structure is shown in Figure 1. The assembly level is on the top of the structural, which has included the abundant and abstract information. The sub-assembly level is under the assembly level, which is the results of product’s decomposing according to function and structure, and it reflects functional division and modularization. The part level is the results of sub-assembly’s further decomposing, which reflects structure division. The basic units of this level are independent in physical structure and processing. The feature level is in the bottom of the tree, which mainly reflects concrete realization form of function. The connection relation between features reflects the connection relation between nodes in the upper level. The assembly feature graph finally formed is a single dual semantic network graph. The nodes of the graph are the leaf-nodes of the tree, each leaf-node only has one root-node, leaf-nodes can share one root-node. The nodes of the graph are the geometric features (GF) located in parts. Geometry features and constrain relations between them constitute the assembly feature (AF). Assembly feature embodies the function feature of product, that is to say, the space position relations of geometry feature and motion ways affected by constrain can be determined by the assembly feature.

4 The Notation Representation of Assembly Feature Graph-Tree (AFGT) Model

The model expressed by assembly feature can be shown with the four tuples:<A, SA, P, F >:

(1) Assembly level: A denote assembly, which is a set of symbols and each symbol correspond to the assembly;
(2) Sub-assembly level is two tuples: <SA, CSA> SA denote sub-assembly that contain all information correspond to sub-assembly. CSA denote constrain between sub-assemblies.
(3) Part level is two tuples: <P, CP > P denote part, which is the set of symbol about the parts. CP denote constrain between parts;
(4) Feature level is also two tuples: <F, CF> F denote features, which is a feature symbol sets. F contains AF and GF. AF denotes assembly features, GF denotes geometry features, except AF. CF denote constrains between Fs, which contains CFinP and CFbetweenP.

And so, A={AF, GF, CFinP} The final assembly model has composed of AF, other GF and CFinP of geometry feature. CFinP is feature constrain inside the parts which is independent in physical structure. This constrain is merely geometry structure constrain. Assembly features and other geometry features have constituted the structure feature of parts. The constrain relation between features is a kind of geometry constrain relation. Through the coordinate transformation, the coordinate system of one feature can be introduced from the coordinate system of another feature. The factors determining geometry relations between feature and feature are assembly relations between parts and process design and structure design of parts. So, parts design on the one hand, has inherited the information of assembly design, on the other hand, has increased information of process design and structure design. As a result, the top-down design has been achieved. If there is interference between information of assembly design and process design or structure design, it will be necessary to revise
assembly design again, even to adjust function design and rational solution.

\( CFinP \) is denoted by \( \Psi \), which has expressed relative position relations between geometry features inside the parts. \( CFbetweenP \) is denoted by \( \Omega \), which has expressed assembly constrain relations between parts.

\[
\Omega = \{ \text{mate}, \text{mate-offset}, \text{align}, \text{align-offset}, \text{coaxial}, \text{coaxial-offset}, \text{tangent}, \text{tangent-offset} \}
\]

So the assembly part shown in Figure 2 can be expressed as follows:

\[
A = ( GF_1P_1 \cup GF_1P_4 ) \cup ( GF_2P_1 \cup GF_2P_4 ) \cup ( GF_3P_1 \cup GF_3P_4 )
\]

In it, \( A \) -Assembly

- \( GF_nP_m \)-number N geometry feature of \( P_m \)
- \( AF_n \)-number N assembly feature
- \( \Omega_n \)-number N constrain of \( CFbetweenP \)
- \( U \)-Combination of assembly features

\( \) -Matching preferred level can be represented by brackets at all levels.

Among them, there are \( GF_iP_1, GF_jP_1, GF_kP_1 \) and other geometry feature on \( P_i \), relation between geometry features belong to the design of parts structure.

5 The Modeling Methods Based on Feature Graph-Tree Assembly Model

5.1 Basic feature operation

In the process of assembly feature modeling, there are three types of basic feature operations, the corresponding arithmetic is as follows:

(1) Assembly feature mapping: according to assembly constrain relations, the mapping operation from assembly feature to geometry structure feature can construct geometry feature pairs with the assembly constrain. For example, the mapping to assembly feature of plane <mate> plane is generating directed plane pairs with same geometry property on the assembly feature plane, the plane pairs have opposite normal direction. The same geometry property has same plane equation, same size and same outline shape.
(2) Feature merging: Merging features with similar processing property into one part body. This is based on the merging principle that each features can finish processing by different working procedures on one part.

(3) Feature dismantling: Feature dismantling is dismantling the features that can’t be merged from the assembly body, and constituting them into a independent part entity, or reforming new part entity with emerging other features.

4.2 Methods of constructing model

On the ground of feature constrain mapping algorithm, assembly feature can be drawn from broad mechanism concept model put forward by literature [8]. Through the assembly features modeling tools to build assembly feature model. The mapping from product concept model to concrete part structure model can be achieved. The detailed steps are as follows:

(1) Constructing broad structure model by function decomposing.
(2) Extracting the movement relations from the broad structure model;
(3) Mapping the movement relations into assembly feature, establishing the assembly feature sets.
(4) Constructing assembly features successively, mapping the assembly feature into two geometry feature planes with opposite normal direction according to feature mapping algorithm. Constructing the solid model based on geometry feature planes until traversing all assembly features in the set.
(5) Dismantling and merging the solid model and constructing form in depended part solid model finally.

The modeling process of Roller-shaft assembly is shown in Fig. 3. The assembly has one rotating movement around axis, two plane<mate>plane and one thread connection assembly features. The mapping process from assembly feature to structure feature is shown in this figure:

(a) Constructing assembly feature face rotating around axis, which is cylinder surface with parametric functions.
(b) To implement mapping operation on the assembly feature face, change it into two geometry feature faces with same equation of curved surface, opposite normal direction. (c)(d) Along two curved surfaces as boundary surfaces respectively, to construct solid model with normal direction pointing out of body, and the curved surface which normal direction is far away from central construct a cylinder.. Another surface need constructing new surrounding surface to finish the solid construction. The surface equation is determined according to the specific broad structure model. In the example, the roller is expressed by cylinder, and also it could be other shapes such as a cam or a connecting rod etc.

(e) Mapping shaft shoulder positioning into plane<mate> plane assembly feature. To construct the solid model of shaft shoulder by the mapping operation like (b) on the end face of the roller.
(f) Because the other end face of the roller is free, a cylinder feature is built on the end of shaft, which has isolated the end face of the hoop and the shaft.
(g)To construct the assembly feature of round nut and the thread of the end of shaft by the connection between the round nut and the thread of the end of shaft.
(h) To construct the round nut and the thread of the end of shaft. According to the mating relation between the end face of the round nut and the end face of the shaft, attach the round nut and the end of shaft to the shaft.
(i) By feature emerging operation, merging the features with similar processing property to form the body of the shaft.
(j) By feature dismantling operation, to construct the solid model of the roller.
(k) By feature dismantling operation, to construct the solid model of the round nut.
(l) The assembly model of the roller-shaft.
(m) The dismantling diagram of the roller-shaft.
The assembly model constructing by assembly feature graph-tree is a information model that can connect concept design and detailed design. Main manifestations are as follows, assembly feature can directly inherit functional information is realized by assembly feature; meanwhile, assembly feature has transmitted the information to part model in the process of detailed design. In assembly design, the parts in assembly can be modified mutually by assembly model, the dimensions modified are transmitted to each related part. The self adaptability of parameter design has been realized.

6 Example

The prototype system DFA(G-T)S based on MDT2.0 has been exploited by applying Object ARX. By constructing assembly feature, assembly feature mapping, assembly feature dismantling and assembly feature merging, the mapping from assembly feature to structure feature has been realized. Integration of assembly design, concept design and detailed design from top to down has been realized. This system has been used in assembly modeling of switch machine for railway, which has improved design efficiency and success rate of assembly modeling.

7 Conclusion

The technique of assembly modeling is important in whole design information modeling. By the methods based on the assembly feature graph-tree, assembly model is expressed by assembly feature. The method can support the combination of design from top to down and design from down to top in the process of product design, and can realize the integration of concept design, structure design and detailed design. Meanwhile, by constructing feature model regarding assembly feature as unit body,, the algorithm of constrain transmitting solution has been simplified, the overall parameters design method has been realized.

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Fig. 3 The process of assembly feature modeling

References: