# A online retrieving method for product functional and structural information based FGT model

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*Abstract:* - In reusable design, the reusability of product information model is a key criterion for design efficiency. In order to improve the reusability for product information model, a online retrieving method of product functional and structural information has been discussed, based on the feature graph-tree model. In the model, a structural Graph-Tree has been constituted by assembly feature as a basic unit. 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, reusable design, CAD

## 1 Introduction

The acquiring technology is the vital method to improve the reusability of the reusable artifact design information. Through the abstract and formal acquiring method, the functional common characters of design information have been extracted. On the other hand, the standardization for design information is also a main goal. The acquiring method is not limit to the artifact feature information, but also include the artifact functional information, the customer requirement information and the design rationale information through the extend artifact structural information model.

The acquiring method for artifact information can be divided two kinds: 1) Offline method. This method mainly aims at the object which had been built before acquired. Because reusability is not been considered in the modeling process, the model has not the reusable character. 2) Online method. The online method standardizes the artifact design information strictly according to the reusable requirements in the artifact design information modeling process.

The artifact functional and structural information is the most important component which constitute the reusable artifact design information model. Functional and structural information on the one hand reflects the design requirement information, on the other hand, is also a behavior which reflects the design rationale information in artifact structure. And so, functional and structural information is a key link which connect design requirement and artifact structure.

From the view of the reusable artifact design model, assembly model is a kind of information model which can express the functional and structural information of artifact. Although the assembly model was initially used to express a set of components which relationship has been recognized through a series of assembly operations generated, but later assembly model can not only describe the spatial location and assembly relationships in all parts of the product, but also support and express the product design information in multiple levels of abstraction (functional, global geometry and physical geometry more information). In top-down design approach, assembly model include three kinds of information. First, the product functional description, it is the user's initial request for the product, but also the ultimate goal of product design. Product design process is the progressive realization process in which the functionality has changed to parts entity. Second, the assembly feature information, which is to define the relationship between the assembly components. Third, part entity information, which is combined entity information of the various parts and components in assembly, such as point, line, surface, precision etc. geometric information, material, color and other physical characteristics.

The product design is a mapping and optimization process from abstract concept information to concrete structure information. From a view of reusable design, artifact design is the process in which the reusable design information can been retrieved.

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.

This paper proposed a representation model for product functional and structural information based on Feature Graph-Tree Model. The Function FGT(FFGT) Model mainly record the functional information. The Assembly FGT(AFGT) Model load the structural information. The mapping from the functional view to the structural view has been realized. Based on the FGT Model, the retrieving of functional and structural information has been completed. The functional and structural information of product can support the reusable design, as a part of the design resource model.

The rest of this article is organized as follows. In section 2, the related works are reviewed. In section 3, assembly feature has been proposed. In section 4, the function feature graph-tree model is given. In section 5, the assembly feature graph-tree model is presented. In section 6, the notation representation of assembly feature graph-tree model is given. In section 7, 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 recent years, the study for the early product conceptual design has been attracted more and more interests. Albano and Suh based on "functional independence" and "the minimum amount of information" two axioms, discussed the function of coupling in concept design. Kusiak, Wang and Larson discussed the functional decomposition and the expression in the mechanical design

They decomposed the mechanical design problem into three categories: product decomposition, problem decomposition and process decomposition. And the formalized representation of decomposition has been given by using the application of constraints - parameter correlation matrix. The above models have not referred to the transition from a functional model to the product structure model.

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 model can be built in order to achieve the integration between top-down design and bottom-up design.

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

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.

| Geometry feature | Plane | Cylindrical Surface | Round hole Surface | Convex spherical surface | Concave spherical surface | Curved surface | Inverse curved surface |
|---|---|---|---|---|---|---|---|
| Plane | Mate, mate-offset , align, align-offset | Tangent, tangent-offset | Align, align-offset | Tangent, tangent-offset | | Tangent, tangent-offset | Tangent, tangent-offset |
| Cylindrical Surface | Tangent, tangent-offset | Tangent, tangent-offset, Coaxial, coaxial-offset | Tangent, tangent-offset, Coaxial, coaxial-offset | Tangent, tangent-offset, align, align-offset | align, align-offset | Tangent, tangent-offset | Tangent, tangent-offset |
| Round hole Surface | align, align-offset | Tangent, tangent-offset, Coaxial, coaxial-offset | Coaxial, coaxial-offset | Tangent, tangent-offset, Coaxial, coaxial-offset | align, align-offset | Tangent, tangent-offset | Tangent, tangent-offset |
| Convex spherical surface | Tangent, tangent-offset | Tangent, tangent-offset, align, align-offset | Tangent, tangent-offset, Coaxial, coaxial-offset | Tangent, tangent-offset, | Tangent, Mate, mate-offset, align, align-offset | Tangent, tangent-offset | Tangent, tangent-offset |
| Concave spherical surface | | align, align-offset | align, align-offset | Tangent, Mate, mate-offset, align, align-offset | align, align-offset | Tangent, tangent-offset | Tangent, tangent-offset |
| Curved surface | Tangent, tangent-offset | Tangent, tangent-offset | Tangent, tangent-offset | Tangent, tangent-offset | Tangent, tangent-offset | Tangent, tangent-offset | Tangent, tangent-offset, mate, mate-offset |
| Inverse curved surface | Tangent, tangent-offset | Tangent, tangent-offset | Tangent, tangent-offset | Tangent, tangent-offset | Tangent, tangent-offset | Tangent, tangent-offset, mate, mate-offset | Tangent, tangent-offset |

Table 1 The geometry features and assembly constrains between them:

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.

# 4 Function Feature Graph-Tree Model

## 4.1 Representation for the design functional information

The functional information of artifact can be two kinds methods described. 1) The description methods similar to the natural language, which mainly describe the purpose of a mechanism action. For example, the function of a axis is to transfer torque. 2) The mathematical description methods of function, which describe function as a transform from input to output. The transformation including change, coupling, conduction and storage, etc. The object of transformation including energy flow, material flow and signal flow.

Function modeling in the product concept design phase is mainly reflected in the following areas:

Design problems can be modularized and standardized by the function modeling, so that design problems can be convert into a series of sub-problems that easy to solve.

Design information will be abstract in the functional level of description by the function modeling, making the concept design of product more focused on meeting the functional requirements;

The functional modeling of a general functional requirements will be progressively refined, specific, thereby the relations between the various sub-functions can be established.

The functional model will provide the basis for follow-up reasoning and analysis, such as behavior simulation, design evaluation, decision-making, modification, etc. ;

The functional model as an important reference for the downstream design, will provide a basis for feature-oriented product design process.

The overall function of mechanical products will be completed jointly by the different parts or some specific geometric features, showing that the product functions have the hierarchy. In general, function model can be divided into four levels, a total function, sub-function, function unit and geometric features. We call the sub-function at the bottom of the function layer as the function unit. The granularity of sub-function decomposition depends on whether sub-function can satisfy the rational solution. If a sub-function implementation can be found the certain physical action rational and the corresponding physical structure, then this sub-function can be used as a function unit, otherwise continue to decompose.

Therefore, the proposed functional features are used to represent the function unit. The function features are composed by the assembly features which perform functional behavior between parts and the constraint relationship. The function features both express the abstract functional behavior information, and relate to the concrete implantation features. The specific description of function features is as follows:

*FF ={AF,CbetweenAF}*

In: *FF*——Function Feature；

*AF*——Assembly Feature；

*CbetweenAF*——The constraint between assembly features.

The definition of assembly feature has been given in the previous section. The assembly features which constituted the function features have a defined constraint, which including the orientation constraint, the order constraint and the logic constraint etc. The constraint between assembly features can be formalized as follows:

*CbetweenAF ={CId, CType, CEquation, CRelation, AF1, AF2}*

In: *CId*——ID of constraint

*CType*——Type of constraint, It has three kinds: 1) The orientation constraint, represent by O, mainly express the orientation constraint relationship between assembly features. It is a fully parameterized constraint equation. 2) The order constraint, represent by S, indicate the assembly sequence between assembly features.3) The logic constraint, represent by L, denote the logical constraints, and, or, not, integration, etc..

*CEquation*——Constraint Equation of constraint.

*CRelation*——representation of the order or logic constraint. When expressing the order relationship, you can indicate the order of assembly features using the sequence number. When expressing the logic relationship, you can indicate the logic constraint relationship between assembly features using the predefined signs.

*AF1, AF2*——Assembly features .

The function feature can be organized as a graph with nodes representing assembly features and edges representing constraints between assembly features. A example of function feature is shown in Fig.1.

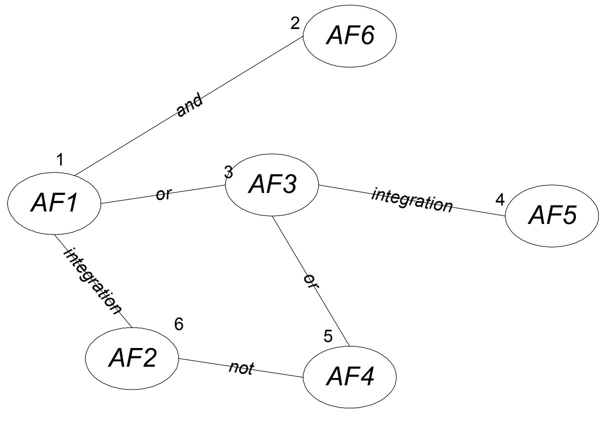



Fig. 1. The graph of function feature

### 4.2 The function feature graph-tree model

During the product conceptual design, the product function structure is step by step set up through the total function decomposition into sub-functions, then sub-function divided into function units. The overall function of a system is composed by sub-functions through the logic relationship between them.

In the reusable product design resource model, the product information model is divided into four levels, namely: product level, component level, part layer, and feature level. Therefore, the same function information model is divided into four levels. In four levels, product is in the top of the model, which represents the overall function of the product by the abstract ambiguous functional concepts. The function model in part level is a subdivision of the overall function. The principle of decomposition is based on functional classification and gradually narrow the scope of the principle functions. The information units in part level are function features and constraint between them. Feature level is composed of the assembly features and constraint between them.

As a result, the product function information model can be expressed by the function feature graph-tree model. The following shows the formal description of the model.

*FM* ——product level

FM——the overall function model ,

*FM={SF, CbetweenSF}* ——part level

*SF*——sub-function

*CbetweenSF*——constraint between sub-functions, including the logic constraints and the order constraints.

*SF={FF, CbetweenFF}* ——part level

FF——function feature

*CbetweenFF*——constraint between function features. Part of the constraint relations are inherited from the component level.

*FF ={AF, CbetweenAF}* ——feature level

*AF*——assembly feature

*CbetweenAF*——constraint between function features. Part of the constraint relations are inherited from the part level and the component level.

The established function feature graph-tree model diagram is shown in Fig. 2.

### 4.3 The modeling method of function feature graph-tree model

The modeling method of function feature graph-tree model is a online retrieving method. Basic algorithm is as follows:

step1: From the market requirements, analyzing the function requirements of the product, describing the function information with a general language;

step2：Subdividing the overall function according to the principle of functional classification, as well as to gradually narrow the scope of the function concept. In process, the independence of function should be ensure, and constraints relationship between the sub-functions should be established.

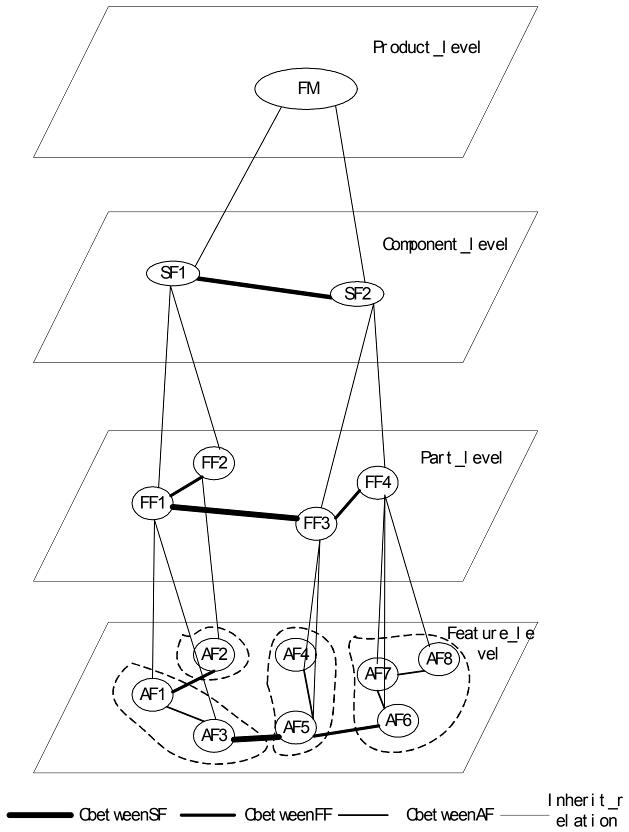



Fig. 2. The function feature graph-tree model

step3 ： According to the sub-functions, the corresponding function features can be retrieved from the database of function features.

Step4：Assembly features and the corresponding constraint between them can be obtained from the function features;

Step5：From the bottom, along the hierarchy of the function features graph-tree model, to establish the function feature model.

## 5 Assembly Feature Graph-Tree Model

### 5.1 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 Fig. 3. 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.

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

The model is 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 *F*s, which contains *CFinP* and *CFbetweenP.*

Among them: *A={SA,CSA}, SA={P,CP}, P={GF, CFinP}, CSA={CP}={CFbetweenP}, AF={GF, CFbetweenP }.*

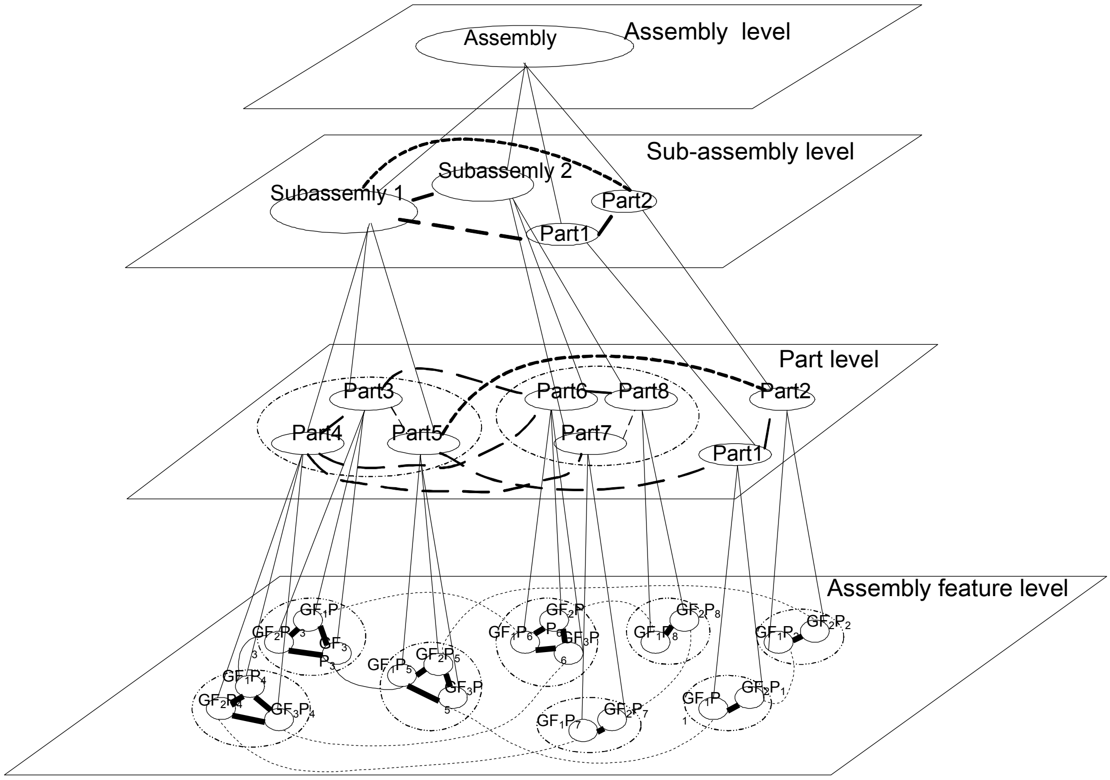
And so, *A={AF, GF, CFinP}*

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.

$$\Omega = \{ mate,\ mate\text{-}offset,\ align,\ align\text{-}offset,\ coaxial,\ coaxial\text{-}offset,\ tangent,\ tangent\text{-}offset \} \quad (1)$$

So the assembly part shown in Fig.4. can be expressed as follows:




Physical constrain Assembly constrain

Fig. 3. The structure figure of the assembly feature graph-tree model

$$A= \left( \left( GF_1P_3\ \Omega_1\ GF_1P_1 \right) \square \left( GF_2P_1\ \Omega_2\ GF_3P_4 \right) \right) \square \left( \left( GF_1P_2\ \Omega_3\ GF_2P_3 \right) \square \left( GF_2P_2\ \Omega_4\ GF_3P_3 \right) \right) =( AF_1 \square AF_2 \square AF_3 \square AF_4) \quad (2)$$

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*

$\square$-Combination of assembly features

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

Among them, there are $GF_1P_1$, $GF_2P_1$, $GF_3P_1$ and other geometry feature on $P_1$, relation between geometry features belong to the design of parts structure.

# 6 The Modeling Methods Based on Feature Graph-Tree Assembly Model

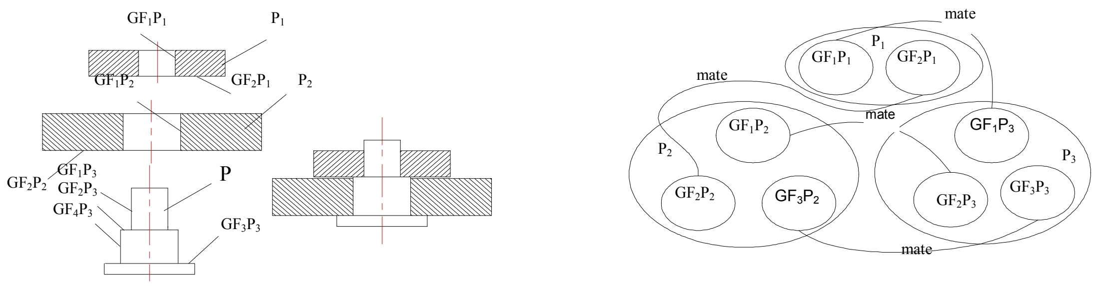
## 6.1 Basic feature operation

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.




(a) (b)

Fig.4 The figure of the assembly feature in a assembly

**6.2 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. 5. 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.

# 7 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.

# 8 Conclusion

The modeling techniques for functional and structural information plays an important role in the product reusable design. Through the feature graph-tree modeling method, functional model and structural model is represent with the assembly features. 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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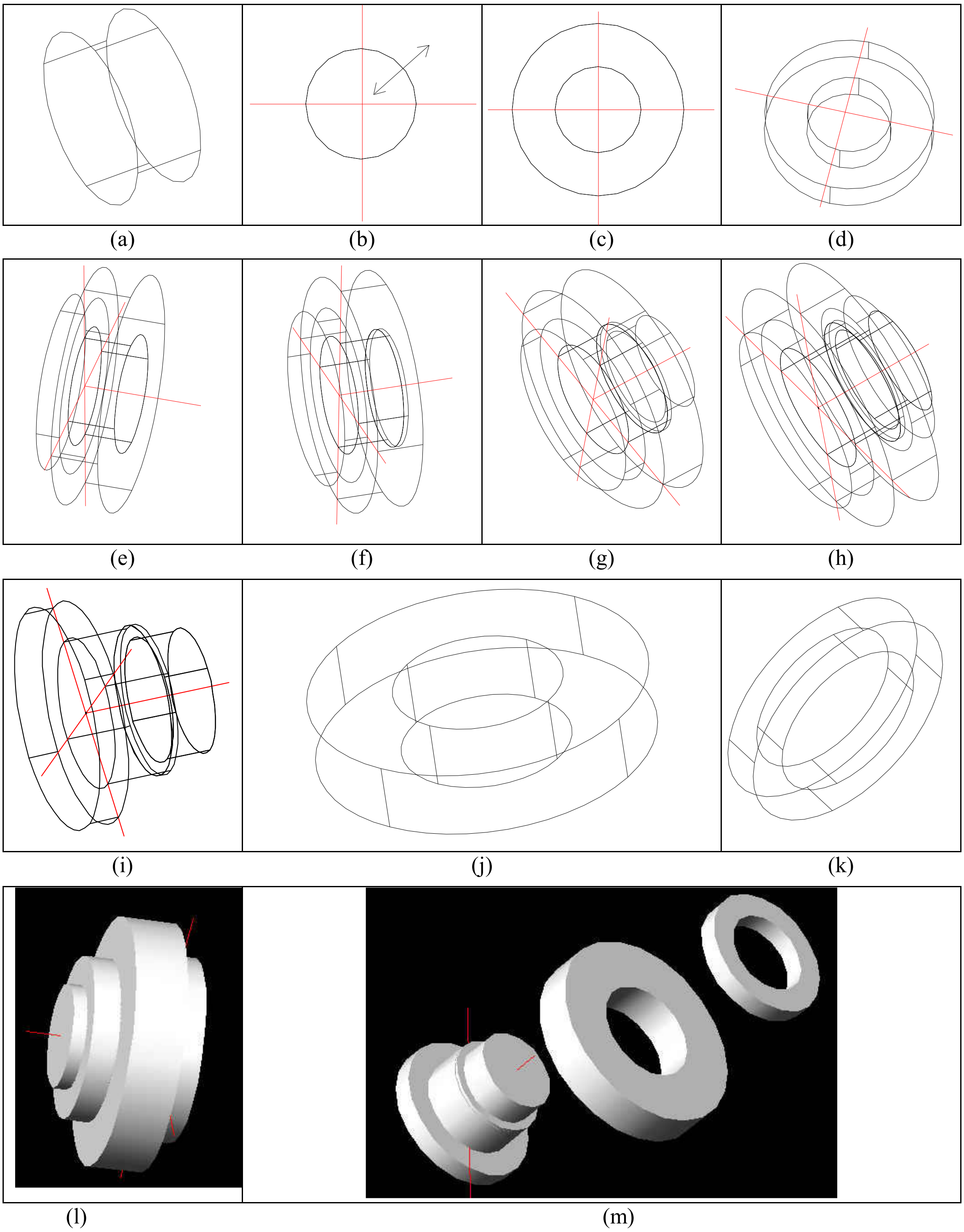


Fig.5 The process of assembly feature modeling