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RESEARCH ON FUNCTION SURFACE RECONSTITUTION TECHNOLOGY IN THE GROWTH DESIGN PROCESS

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ABSTRACT

The growth design is a new top-down design method for mechanical product conceptual design based on the decomposition and reconstruction of function surface. The reconstitution of function surface, determining the number, the style and the relationship of function surface are the key of conceptual structure in the process of growth design. It is the constraint of the manufacturability of the part structure. Due to the lack of the related knowledge, it is the barrier to improve the efficiency of the growth design. The position relationship, the joint mode and manufacturability of function surface are analyzed comprehensively in this paper. According to the actual technical knowledge, the methodology of determining the position relationship and joint mode concurrently is proposed. So manufacture technical knowledge is introduced into the product conceptual design stage. It can improve the efficiency of growth design process, and feasibility is proved by specific case.

Keywords: *Function Surface, Growth Design, Concept Design, Design Theory*

1. INTRODUCTION

The growth design [1] is a new top-down design method for mechanical product conceptual design based on the decomposition and reconstruction [2] of Function Surfaces (FS) [3, 4]. Supported by the Generalized Positioning Principle (GPP) [5], FS is used as the media between the function and structure in the process of the mapping from the function to structure. The design model of "Function-FS-Structure" [6, 7] is proposed in order to avoid the uncertainty of the mapping in the growth design process.

In the process of growth design based on the decomposition and reconstitution of function surface, the reconstitution of function surface, determining number, the style and the relationship of function surface are the key of conceptual structures. They are the constraint of the manufacturability of the structures.

Due to the lack of related knowledge and support technology, the designer has to determine the type and the quantity of FSs based on experience, and it reduces the efficiency of the growth design. So it is necessary to research the reconstruction method and relationship of FSs in the process of the growth design. It can make the reconstruction more reasonable and improve the efficiency of the growth design.

2. FUNCTION SURFACE

The Concept of Function Surface. Surfaces are basic elements of mechanical parts, and according to correlative statistics, most of them are planes, cylinders, cones, spheres, involutes or helicoids on the parts' surfaces. The function of the product is carried out by the mating of parts. And the mating relationship of parts is implemented by the contact of correlated parts' surfaces.

Under the different functions, part surfaces can be classified into FSs and Auxiliary Surfaces (ASs). FS is the surface which can perform the primary function of the part, and the AS is not closely associated with the product's primary function. For example, the cam shown in Fig. 1, it can be considered that it's primary function can be performed by the profile surface and the cylinder only. Other surfaces, such as the plane, have little relationship with the cam function although they are also important components of the cam. So the profile surface and the cylinder can be considered as FSs, and other surfaces are ASs.

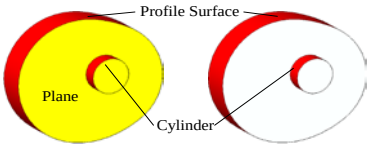

Fig. 1 The Function Surface Of A Cam

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According to the different Generalized Positioning functions, FSs can be classified into two types, Generating-Position Surface (GPS) and Make Generating-Position Surface (MGPS) [8]. GPS locates the part itself just like the cylinder shown in Fig. 1, and the profile surface 1 is a MGPS which locates the other parts.

The Decomposition and Reconstruction of FSs. In the process of the growth design, the decomposition and reconstruction of FSs can be described as shown in Fig. 2.

Firstly, the Executing Pattern and the MGPSs for the Executing Pattern are generated from the product prototype. Then, according to the need for power transmission and design constraint, the MGPSs are decomposed and the first class Transmission Pattern with its MGPSs or the Static Structure Pattern with its MGPSs are generated. MGPSs are properly divided until all function requirements are met, and the Drive Pattern or the last class Static Structure Pattern is generated. Finally, the Function Pattern chain is created with an Executing Pattern as a start point and a Drive Pattern or a Static Structure Pattern as the end. The product conceptual model which is made up of all Function Pattern chains is founded at last. The Function Surfaces and Function Patterns of the product conceptual model are called conceptual part [7].

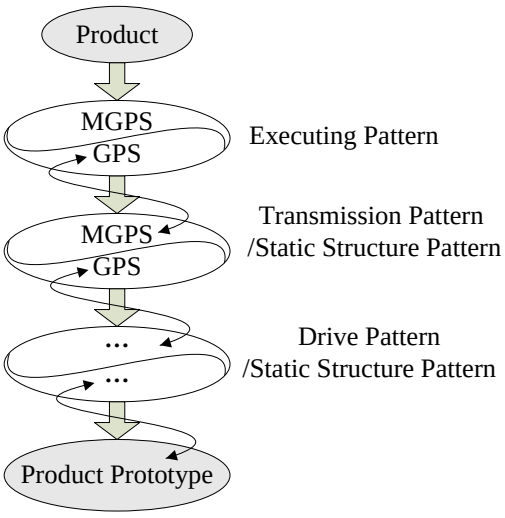

Fig. 2 The Decomposition And Reconstruction Process Of Fss

3. THE POSITION RELATIONSHIP AMONG FSS

It can be seen in the process of the growth design, and conceptual structure is generated by the reconstruction of FSs which is the process to determine the positional relationship among FSs. It means that the form of conceptual structure is determined by the positional relationship of FSs directly.

There are two kinds of relationships between FSs. One kind of relationship exists between the surfaces which belong to the same part, and the other exists among the FSs which belong to different parts.

FSs' Relationship within the Same Part. FSs without relative motion can be regarded as the same part's surfaces in theory when FSs' decomposition is complete. It is necessary to divide FSs into different parts according to the complexity of technology and manufacturing. That is, the number, the type and the spatial relationship should be determined in the same part.

Surfaces' relative spatial location is the main relationship within the same part, and it can be divided into parallel relationship, intersectant relationship and coaxial relationship.

Parallel relationship includes the parallelism between two planes, the parallelism between a plane and a straight line, the parallelism between two straight lines and so on, such as a plane parallel to the plane belong to the same cuboid, a plane parallel to an axis of the cylinder surface, and an axis parallel to another axis of the different cylinder surfaces.

Intersectant relationship includes the intersection between two surfaces, the intersection between a surface and a line, the intersection between two lines and so on. The intersection of extension lines or extension surfaces is included too. Coaxial relationship means cylinder surfaces or conical surfaces sharing the same axes. Such as there is only one axis for the internal cylinder surface and external cylinder surface of a bearing.

According to the different spatial relationships between surfaces, the location parameters can be defined. Such as D is the distance between two parallel surfaces, T is the radius difference of two coaxial cylinder surfaces, and A is the angle between two intersection lines or surface normal, shown in Fig. 3.

In fact, there are other relative positions, such as the skew axis of two cylinder surfaces. But it is difficult to define the spatial location parameter which can be used in design process. So the relationship can be determined indirectly by the

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relative spatial location of others surface. In addition, even if the location parameters can be determined accurately between surfaces within the same part, it is not necessary to identify all the relationships between any two surfaces. Because they can be determined indirectly using the relationship between others surface.

Two surfaces which should be determined their spatial location relationship necessarily are called Related Surface.

The conceptual structure could be determined when the spatial relationship and the location parameter are determined. It is called conceptual structure because it represents the location function only, and it is not the real close physical structure. So it is necessary to add ASs to the conceptual structure to make a real part.

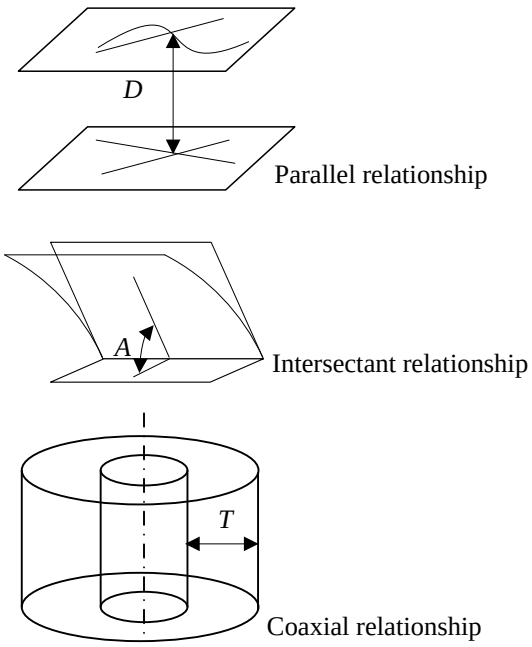

Fig. 3 Surfaces' Relative Spatial Location

FSs' Relationship between Two Parts. Different relationship within the same part, the relationship between two parts is the mating relation. Mating relationship can be divided into the following.

Fit relationship refers to the low-level motion pair between the same type surfaces, which allow a surface moves along the other surface or rotates around the other surface normal in any direction. According to the type of fit relationship, it can be divided into the fit between surfaces, position alignment, the tangent between contact surfaces, and the point and the surface contact. According to the type of contact surfaces, it can be divided into plane kinematic pair, cylinder surface kinematic pair, and cone surface kinematic pair and so on.

Connection relationship is enhanced fit relationship due to the force from the connector. It is used to amend and supplement fit relationship. According to the different of connectors, it can be divided into thread connection, key connection, pin connection, and interference fit connection, etc.

Movement relationship expresses relative motion one part along the other part without constant physical contact, and there are three basic forms including relative static, relative motion and associated motion.

From the perspective of GPP, the mating relationship among parts is the generalized positioning relationship among FSs. It is stored in relationship network in the process of the growth design.

The Joint Mode among FSs. It is necessary to determine the joint mode among FSs and ASs for the design from functional structure to entity structure after the relative spatial location is determined.

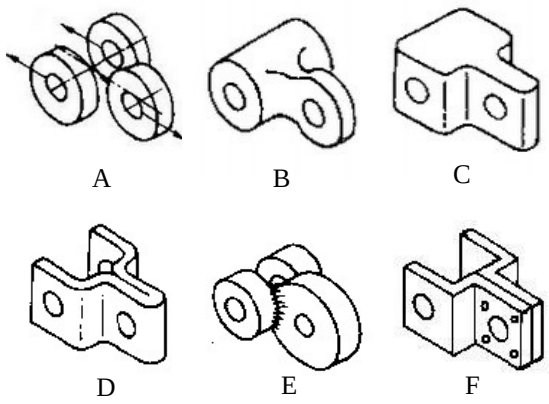

Fig. 4 Different Structure By Different Manufacturing Mode

The joint mode of FSs within the same part is restricted by the manufacture method of the part. Different part structures can be achieved by different manufacture mode. For example, there are three FSs shown in Fig 4(A), the part 4(B), 4(C) and 4(D), which should be made by casting, forging, and stamping respectively.

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The connection of parts can be divided into static connection and dynamic connection. The need of using dynamic connection or static connection is determined by the machine movement requirements. In this paper, the reconstruction of FSs without relative motion is the main study object. So the case of static connection is studied only.

There is no relative motion among static connection parts. So it can be manufactured as one large and complex part. But it is advantageous to machining, repairing and transporting by dividing the complex part into several small and simple parts which can be assembled as a component. Static connection includes welding, bonding, bolt connection and so on. The different static connection mode makes different part structure. For example, there are the different parts shown in Fig. 4(E) and 4(F) by welding and bolt connection.

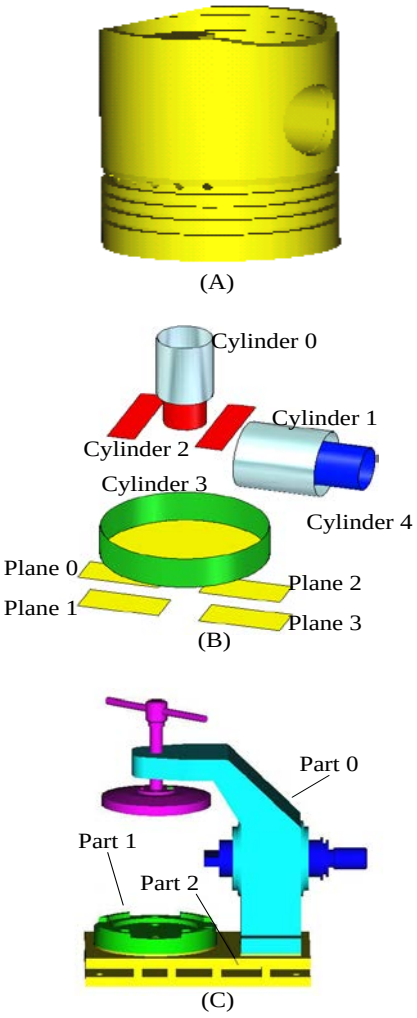

Fig. 5 The Fixture And Its Fss For A Piston

Therefore, it is necessary to introduce manufacturing modes and processes into the conceptual design stage as design constraints. It is useful to determine the spatial relationship and the connection mode of FSs.

The Method to Determine the Functional Relationship. As a systematic integration method, Concurrent Engineering manages production design and its related processes concurrently. It tries to consider all factors in the process of the product life-cycle from concept design stage to product retirement stage. Based on the concurrent engineering ideas, the FSs' relationship and the parts' manufacturing methods are combined in the process to determine the relationship of FSs by choosing different manufacturing methods.

Each manufacturing method has its structure design rules. So the spatial relationship and the connection mode among FSs can be determined by choosing appropriate manufacturing method for conceptual structure to meet the design guideline.

On the other hand, the existing product structure, especially the standard part, should be used as an important reference in the process of the conceptual product design. So product instances base and structure design rules base should be built as an assistance to identify FSs relationship, and they are used in growth design process. The FSs relationship table is built and stored in the design parameters database, and the structure of the entire product can be determined finally.

4. CASE STUDY

For example, a fixture, for the piston shown in Fig. 5(A), is used to bore the piston pin hole. According to the generalized positioning requirements of the piston, FSs of the fixture can be extracted and the function prototype of the fixture can be built. Based on the GPP, the combination of the fixture FSs, shown in the Fig. 5(B), can be obtained by decomposing the FSs repeatedly.

In Fig. 5(B), there is no relative motion among the cylinder0, cylinder 1, cylinder 3, plane 0, plane 1, plane 2 and plane 3 in the working process. So, these FSs can be designed as one part theoretically. And according to the structure design rules, the part can be manufactured by casting.

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But, it can be found that there are too many FSs within the same part to manufacture by further analysis. On the other hand, there is mating relationship between the part and other parts, such as the assembly between cylinder 0 and cylinder 2, the assembly between cylinder 1 and cylinder 4 and so on. It means that the post-machining is necessary for the complex part. So, these FSs can be divided into two parts.

Therefore, all FSs can be divided into different parts, and the relationship among these FSs can be achieved as showing in table 1. In the table, P stands for parallel relationship, and I stands for intersectant relationship. Values of D and A can be calculated according to the structure sizes of the piston.

Tabele 1 The Relationship Of FSS

Concepte Part	**Part 0**		**Part 1**	**Part 2**
Related Surface ID	Plane 2	Plane 2	Plane 1	Plane 1
	Cylinder 0	Cylinder 1	Plane 3	Cylinder 3
Position Relationship	P	I	P	I
Parameter	D	A	D	A
Manufacture mode	Casting	Casting	Casting	Casting

Part 0 and part 1 are welded together. Part 1 and Part 2 are connected with bolt. Parts joint mode table can be established as showing in table 2.

Tabele 2 The Joint Mode Of Parts

Related Part ID		Joint Mode
Part 0	Part 1	welding
Part 1	Part 2	Bolt

The entire relationship table can be established according to the analysis of other function surface and conceptual structure using the same method. Integrating function surface relationship net data, the design results can be obtained finally, as shown in Fig. 5(C).

5. CONCLUSION

The method to determine the spatial relationship of FSs and the joint mode of parts concurrently is proposed in this paper. The feasibility of the method is verified by specific case. Using the method, manufacture technical knowledge is introduced into the product conceptual design stage. The manufacture mode and joint mode of parts can be determined to design parts structure. So, the rationality of mechanical product structure is improved, and it builds the foundation for the follow-up successful manufacturing. The design efficiency of growth design method is improved.

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