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THE INTEGRATION OF CAD/CAM/CAE BASED ON MULTI MODEL TECHNOLOGY IN THE DEVELOPMENT OF CYLINDER HEAD

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ABSTRACT−The integration of CAD/CAM/CAE in product development is the key to realize concurrent engineering. Generally, different systems are employed in product development departments. These different systems create a lot of troubles such as difficulty in communication, misunderstanding and so on. A new approach to integrate CAD/CAM/CAE in one system based on CATIA for the end-to-end process in cylinder head development is presented. Multi Model Technology (MMT) is used to create consistent and associated CAD models for the end-to-end process in cylinder head development. The concept and method to create and organize multi models are discussed. A typical four-layer structure of MMT for mechanical products is defined. The multi level structure of the cylinder head models based on MMT is provided. The CAD models of cylinder head created based on MMT can be used as the consistent model. All models in the downstream of cylinder head development such as structure analysis, CFD, sand core design, casting simulation and so on are associated with the CAD models. Practice shows the approach in this paper enables the development process to be carried concurrently and can obviously shorten time to the market, reduce product cost and improve product quality.

KEY WORDS : Integration, CAD/CAM/CAE, Modeling, Cylinder head

1. INTRODUCTION

The competition environment has been changed greatly in recent years with the increasing globalization of the automotive market and the requirements for the higher quality, lower price and more personalization. These changes include (Doeller, 1999; Pfohl, 1998):

(1) Reducing product life cycle;
(2) Increasing complexity of product;
(3) Personalizing and diversifying;
(4) Raising quality standards;
(5) Lowering product cost;
(6) Shortening market time.

In order to face such challenges, all automotive manufacturers are seeking new technology and method to shorten development time, reduce concentration of manufacturing, fully use outside resources, and integrate and cooperate with their global suppliers.

Traditionally, cylinder head development involves design department, analysis department, foundry and machine factories and so on. There are different systems used in different departments, and even in the same department there are different systems. Different systems cause a lot of troubles such as difficulty in communication, lack of consistent product models and so on (ISO, 1994). Thus, it is a great challenge to integrate all activities in one system in entire product development process because of the limit of capabilities of software and hardware. The great progress in CAD/CAM/CAE system, high performance workstation and network technology in recent years makes it possible now (Bokulish, 1999). A new product modeling technology, Multi Model Technology (MMT) is discussed in this paper. Based on MMT, a new approach to integrate CAD/CAM/CAE based on CATIA in cylinder head development is presented.

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2. MULTI MODEL TECHNOLOGY

2.1. Concept of MMT

Until now, product modeling has meant the creation of the product model only at design level in automotive industry. It only concerns better geometry description so that it can perfect and integrate product geometry information and function information. In fact, product is a system especially the complicated product such as cylinder head. The product development process needs not only design level modeling which is down-up implemented, but also system level modeling which is up-down for organization and management. Therefore, in order to describe product model and manage the process better, product development process should consist of two levels of modeling. One is system level modeling for supporting higher-level organization and management; the other is design level modeling for supporting lower level model realization (such as 3D CAD modeling).

2.1.1. System modeling technology

System modeling technology is the analysis and design methodology used to deal with complicated systems. It has been with us for more than 40 years. System modeling technology is widely applied in information engineering and software engineering. It has experienced four stages from traditional system analysis and design methodology, Structure Analysis and Structure Design methodology (SA/SD), and information modeling methodology, to modern Object-oriented Technology.

2.1.2. Object-oriented technology

Object-oriented Technology (OT) emerged in the late 1980s and was applied in object-oriented programming language at the beginning. Because an object consists of not only function but also information, OT has all advantages of other methodologies. When developing a system or a product, the system or product should be divided into some relatively stable units according to the thought of OT. These smaller units are objects. This basic concept and method of OT can be used in product system modeling.

OT uses three kinds of model to describe a completed system: object model, dynamic model and function model. The object model describes the static structure of a system including objects and their relations, the properties and operations of objects. The dynamic model describes the instant and behavior control characteristics, it describes the changes in system lifetime and is related to time and changes. The function model describes the data changes in the system.

2.1.3. Concept of MMT

OT considers object model as the most important model in its three models, then dynamic model, and function model. To analyze the three models, we find that the object model that describes the static structure of a system is just the model needed to support system level management in product development process. The modeling process of the product in design level modeling technology is just the dynamic model related to time and changes. The changes of every model of object in modeling process are just the function model. These mean that as a system, a products completed model can be and should be described with the three kinds of models. The traditional product modeling technologies such as solid modeling and feature modeling only describe the dynamic model and function model. Because there is no object model, it does not support system level modeling and management. So, it is necessary to combine the traditional modeling technology with OT in product modeling process.

Multi-model modeling technology is a new product modeling technology that combines OT with feature-based modeling technology. It employs OT to create the object model of a product and process-oriented feature-based modeling technology to build the model of object. In this way, it can concurrently support system level modeling and design level modeling. Because the object model consists of multi models, it is called multi-model modeling technology.

2.2. Multi Model Structure

2.2.1. Typical multi model structure of powertrain product

The object model of a product describes the static structure of the product that is relatively stable. Because of the layers of abstract, the static structure of object model is a layered structure that consists of multi models. Each object maps a detailed model in product development process. So, we call it Multi-Model Structure (MMS). MMS must be created by all members of the team before design level modeling with the essential concepts and methods of OT such as abstract, encapsulation and associativity and so on. MMS depends on the structure and the manufacturing of the product. Only the typical parts in powertrain system, which is machined after casting, are discussed in this paper.

To determine MMS, first the objects in object model should be defined, second the layer which each object belongs to should be defined, *i.e.* the classification of objects.

The physical structure of the product and the abstract and encapsulation of the product determine the number of objects in MMS. The more complexity of the product and smaller units of abstract and encapsulation, the more amounts of the objects there will be in MMS. More amount of objects in MMS means that more users working concurrently, smaller size of each model of object, and more time costing to update the product model if any object is modified. How many objects the object model should consist of must be defined according to the physical structure of the products, the software and hardware resources, and human resources available in the team and development cycle.

After the definition of objects, the objects should be classified, one class belongs to one layer, and the objects in the same layer have the same characteristics of behavior and common relation among objects. Therefore, the manufacturing process determines the amount of layers

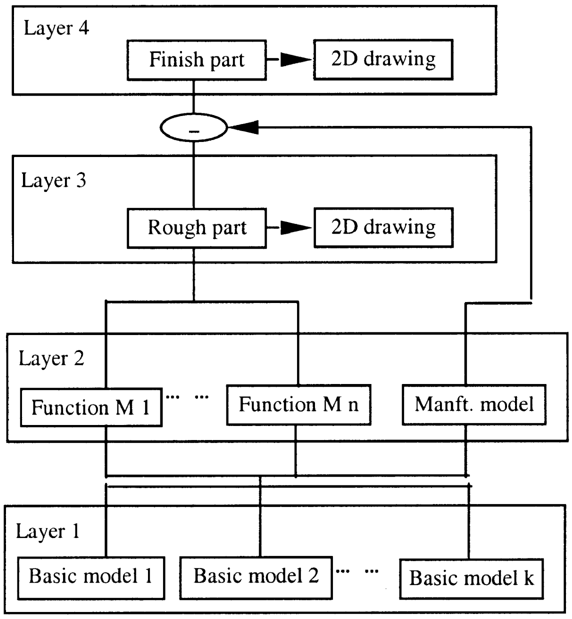

Figure 1. The layered multi model structure.

of MMS. The more layers, the more difficulty in managing the modeling process, and the fewer layers, the less clarity of the product structure.

Typical powertrain products such as cylinder head, cylinder body and transmission body are generally machined after casting. For this kind of product, the MMS is given in Figure 1. There are four layers in Figure 1. The first layer is basic model layer. Basic model layer consists of the basic elements and basic geometries. The second layer is function model layer. Every model object has concrete function of the product in function model layer. The objects of the second layer inherit, enrich and modify the model structure of objects in the first layer. The third layer is rough part model layer. It consists of rough part model and rough part 2D drawing. The objects in lower layers are imported into the third layer and then compute to get the rough part model. The 2D drawing is directly from 3D CAD model. The forth level is finish part model layer. It consists of finish part model and finish part 2D drawing. It is the result of rough part model subtracts machining model.

To optimize the product development process and realize concurrent engineering, product modeling includes not only product itself but also casting tools, sand cores and sand core tools related to product development. Therefore, the MMSs of casting tools, sand cores and sand core tools are also required to define. The MMS for casting tools, sand cores and sand core tools also consists of four layers too. The meanings of the first layer and the second layer are the same as those in product MMS, and some of the objects are also the same as the objects in product MMS (in this way, tool modeling and sand core modeling can use the product resources and then are built concurrently with product modeling). The third layer is the part model layer. Models in this layer are part models of tools assembly or sand cores assembly. The fourth layer is the assembly model layer of tools or sand cores.

2.2.2. Associativity of multi-models

Associativity is an approach to connect different objects. The objects in MMS are connected by associativity and transfer information via associativity among them. Associativity is a mechanism of connection between different related objects. Models in different views can share the master CAD model data via this mechanism. Associativity is related to the software and hardware platforms, and the realization method and strategy of MMT. Associativity includes several aspects in product development process such as the associativity between rough part and finish part, associativity between 3D CAD model and 2D drawing. All associativities should be fulfilled in system level modeling.

(1) Associativity between layers.

In MMS, the lower layer models are imported into and positioned in higher layers, and then are modified by function operation and computation. The associativity between layers is fulfilled by the CATIA Solide/Import function (IBM/Dassault System, 1997). When the model in lower layers is modified, the update function can be used to update the related models layer by layer according to the MMS. The product structure can be fast modified automatically in this way. And the consistency of the product models can also be fulfilled.

(2) Associativity between models in the same layer.

The models in the same layer have their own clear boundary. So no direct associativity between them from the view of model structure. But there is position associativity between models in the same layer. It depends on the realization methods.

(3) Associativity between the current model and the imported model.

The current model can be achieved from the computation of imported models and function operations on imported models such as Union, Subtract, Thickness (add or reduce materials from the model), Draft, Fillet, Chamfer and so on. These create the associativity between the current model and the imported model.

(4) Associativity between the basic model and basic sketch.

The basic sketches are used to build the models of objects in basic model layer. When the basic sketches are modified, the related models in basic model layers should update automatically. The intelligent sketch creator Sketcher and Update function realize this associativity.

(5) Associativity between 3D CAD model and 2D drawing.

The 2D drawing is direct from 3D CAD model with the CATIA function of AUXVIEW2.

(6) Associativity between CAD, CAM, CAE models of product, rough part, tools and sand core.

All models are based on one product 3D master CAD model and managed with the same CATIA database.

The above associativities are the basis of CE and integrated product development process.

2.2.3. MMS of cylinder head

The physical structure of the cylinder head consists of intake manifold (inlet), exhaust manifold (outlet), combustion chamber, water jacket, oil jacket etc. They not only make up the structure and the functions of the cylinder head but also play an important role in down stream application in product development process. For example, water jacket CAD model can be used to build sand core model of water jacket, casting tool model of the cylinder head and CFD analysis for cooling system and so on. Therefore, they are indispensable function model objects in multi-model structure. Usually the finish part of cylinder head, which can be assembled on the engine, is machined by NC machine from rough part, which is made by casting. Therefore, the multi-model structure should consist of finish part model layer, rough part model layer and so on, and consist of finish part model, rough part model and machining model etc. In short, the multi-model structure of cylinder head is shown in Figure 2.

There are four layers in the multi-model structure of cylinder head. The basic model layer includes models of inlet (ELK), outlet (ALK), chain box extremity-basic element (KKG), basic model for elements not corresponding to a slice (EGK), basic model for elements corresponding to a slice (MGK), parting parts (TL), Foundry tool parting parts (GT) and Finishing parts (FHK). These models are the basic models for the modeling of cylinder head, casting tool and sand cores. The function model layer includes models of inlet & outlet and combustion chamber (EBA), water jacket (WM), oil jacket (OR) and machining operation (BM). The function models are created based on the imported model from the basic model layer. All function operations in product modeling such as operations of thickness, draft, fillet, chamfer and transfer are completed in this layer. These function operations create models with concrete functions of the cylinder head such as water jacket model. The rough part layer includes rough part model (ZK-RT) and its 2D drawing. The finish part model layer includs finish part model (ZK-FT) and its 2D drawing.

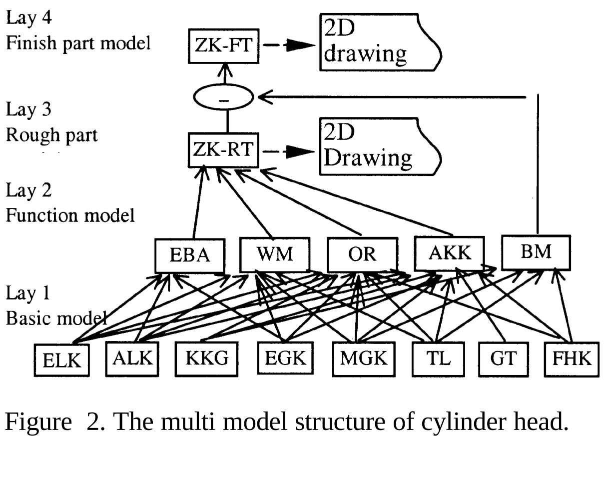

Figure 2. The multi model structure of cylinder head.

3. INTEGRATION OF CAD/CAM/CAE IN CYLINDER HEAD DEVELOPMENT PROCESS

3.1. Integration of Modeling based on MMT

Cylinder head development includes not only product itself but also rough part, casting tool, sand cores and sand core tools. Traditionally, their models are created in different departments with different CAD systems. There is no consistent CAD model and no data sharing for the whole product development process. Finish part, rough part and tools have to be modeled serially.

In our research, CATIA is selected as the core CAD/CAM/CAE system to cover main activities in the entire product development process. In this way, finish part modeling, rough part modeling, casting tool modeling, sand core modeling and sand core tool modeling are

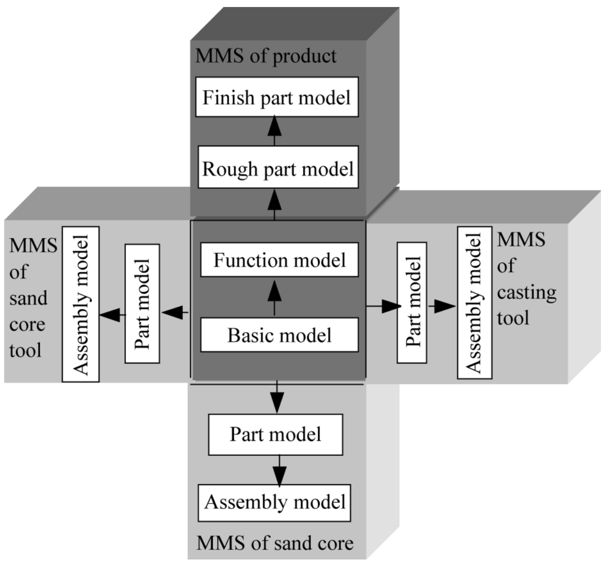

Figure 3. Integrated modeling based on multi model technology.

within the same CAD environment. With the help of MMT and its associativities, all modeling activities in the process can be integrated and share data with the product master CAD model as shown in Figure 3. In Figure 3, basic models and function models make up the common base for MMSs of product, casting tools sand cores and sand core tools. Models in basic model layer and function model layer are shared by product, casting tools, sand cores and sand core tools. If any model in product basic model layer and product function model layer is modified, casting model, sand core model and sand core tool model can be updated quickly and automatically by updating related models layer by layer. At the same time the consistency among product, casting tools, sand core and sand core tools can be kept. Evidently, the integration of modeling activities, the concurrent engineering and data sharing in product development process can accelerate development process, reduce product development cost and improve product quality.

3.2. Integration of CAD/CAE based on MMT

It needs several times of modifications and optimization of the product structure in product development process. MMT can not only make it easy to modify and optimize the product structure but also make it easy to update CAE model to keep associativity between CAD model and CAE model at all times after modifying and optimizing as showed in Figure 4. Because all models in MMS are created with feature-based technology, it is easy to get CAE-oriented CAD model by feature suppression or feature deletion. And then the CAE-oriented CAD model can be meshed within CATIA with integrated CATIA FE functions. If product is modified, it is easy to update the FEM model at any time with the help of the associativity mechanism between CAD model and CAE model. This is a significant benefit for product development process since the analysis engineers can use the correct CAD model to create CAE model and give correct suggestion to the design engineers at early stage.

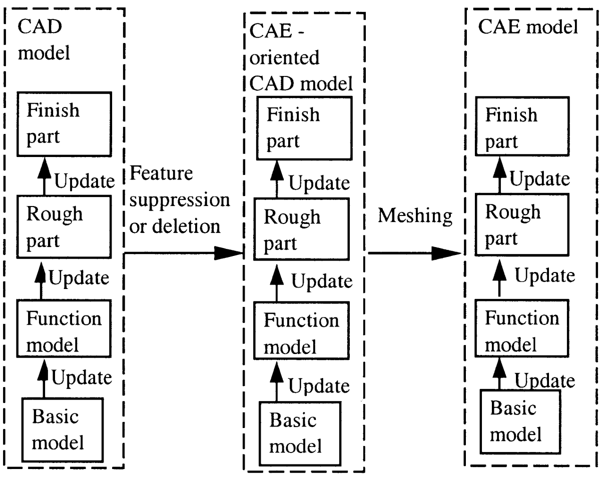

Figure 4. The integration of CAD/CAE in multi model technology.

3.3. Integration of CAD/CAM/CAE in Cylinder Head Development Process

With MMT as the core, CATIA as the core CAD/CAM/CAE system covering the entire product development process, and advanced Client/Server network structure as the hardware platform, the integration of CAD/CAM/CAE in cylinder head development process can be realized. Figure 5 is the integration frame. The characteristics are as follows.

(1) Consistent product model.

All CAD/CAM/CAE activities are based on one consistent product CAD model that is product master CAD model. The models in basic model layer and function model layer in product MMS can be used not only in rough part and finish part modeling but also in FEM, manufacturing and modeling of casting tools, sand cores, and sand core tools. This data sharing mechanism avoids a lot of duplicated work in FEM, manufacturing and tool development.

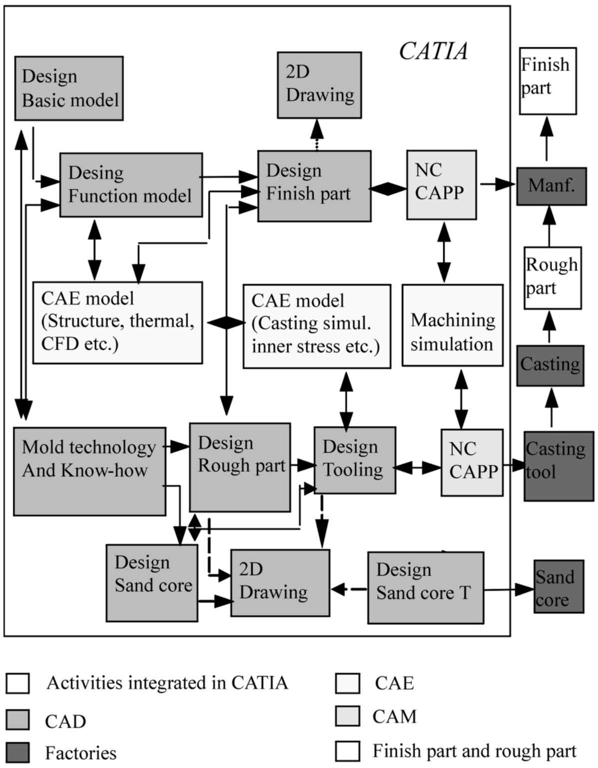

Figure 5. Integration frame of CAD/CAM/CAE in cylinder head development process.

(2) Concurrent engineering.

Product is abstracted and encapsulated into several objects with object-oriented technology in MMT. This allows different users to work on different objects concurrently.

(3) Single advanced software platform.

CATIA covers main activities and all departments involved in product development process. The amount of data exchange is reduced to the lowest. All involved engineers concurrently work on the same environment and the same master 3D CAD model. It is easy for the engineers to understand, high in working efficiency and economical in resources.

(4) Associativity.

The associativity of MMT is a mechanism that sets up a connection between different models. 2D drawing is created directly from CAD database. The modification and optimization of one model can be expanded to the related models automatically and quickly with this mechanism.

(5) Supporting rapid prototype technology and digital mock-up technology.

The 3D CAD model can be used directly in rapid prototype of finish part, rough part, casting tools, and sand core tools. 3D CAD models can also be directly used in engine digital mock-up, or even in whole vehicle digital mock-up. So physical prototype can be digitalized, the development cost and time can be significantly reduced.

(6) Optimization of enterprise resources and product development management.

The enterprise resources can be optimized and reused since the models of the objects in MMS can be used in series product development. Therefore, the development time for the series product can be significantly shortened.

4. CONCLUSION

The approach mentioned in this paper has been applied in one type of cylinder head. Practice shows it can obviously shorten time to the market, reduce development cost and improve product quality in cylinder head development. For example, traditionally it takes about 4 months to mesh a cylinder head, however, with the approach in this paper it takes only about 15 days. In addition, the approach can be extended to other complicated powertrain product development such as cylinder body and gearbox case.

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