

## Technology of WAVE and Feature Cutter volume of manufacturing

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**Abstract.** A forward and automatic method for in-process model generation is proposed and integrated with three-dimensional computer aided process planning (CAPP) system. The method based on feature cutter volume of manufacturing drives the in-process model to evolve from blank to part, which is coincident with the manufacturing process and ideology of process design. At the same time, technology of What-if Alternative Value Engineering (WAVE) is implanted in the generation to establish the relationship of in-process models, which supports function of the automatic update for models. The paper introduces a theory of the solution to demonstrate the connection between manufacture feature and feature cutter volume, and detailedly presents the technological process in applying the WAVE technology. Examples are completed in a commercial CAPP system to illustrate the feasibility of this approach.

### 1 Introduction

With the development of three-dimension computer aided design (3D CAD) technology in the design field and manufacturing industry, the pattern of computer aided process planning (CAPP) have already changed fundamentally, process information based on 3D digital model ensure the consistency and accuracy in the process of product digital manufacturing. Model-based Definition (MBD) technology is the main method to express the 3D digital Model, which integrates the information of the design product, such as the geometrical data, the dimensional tolerance, the machining datum, etc [1-2]. The way taking the integration of 3D digital model as the only basis for the manufacturing process, changes the traditional description method, which is relied mainly on digital quantity (digital model) while analogy quantity (the process information based on 2D sketch) subsidiary. The MBD model solves the problems taken by 2D CAPP pattern, such as tediously data input, dependent data between design and manufacturing.

The 3D digital model provides a good foundation for information and intelligence of process planning. In the design of process, the 3D in-process model, carrier of process information, is the key point to realize digitalization for 3D CAPP system. It is very

significant to research how to build in-process model efficiently [3].

### 2 The overall scheme of building in-process model

#### 2.1 The concept related with in-process model and idea of current solution

In the machining process of parts, the working procedure accords to the planned process route. After the end of every process, an intermediate state workpiece will be formatted, as a foundation for the next process. These intermediate state workpiece models are referred to as in-process model. In the full three-dimensional digital process planning, the three-dimensional process model as a carrier of the process information, eventually guides the parts' formatting [4].

At present, according to the direction of evolution, the methods of building in-process model basically have the following two kinds of solution.

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2.1.1 Reverse generating method, evaluating from the part design model to blank model.

A typical scheme is Teamcenter, a process planning Software published by Siemens PLM Software. The main idea takes advantage of function of WAVE (What-if Alternative Value Engineering) in CAD. At first, part design model is copied to every part component in every process, and then the synchronous modelling technology, which based on the structure of B-Rep, is used to modify corresponding features, such as remove, move, offset, etc. These operations will be automatically associated with the follow-up in-process model. Finally, blank model and intermediate state model are generated.

2.1.2 Forward generating method, evolution from blank design model to part design model.

This method is based on the designed blank model, taking advantage of function of Boolean operation in CAD. The idea is coincident with the manufacturing process and ideology of process design. Actually, there are some studies about this method. This paper discusses the generation method of in-process model based on technology of WAVE and delta-volume of manufacturing feature. The new modelling method combines manufacturing feature and UG/Wave function, and has strong operability and flexibility in engineering applications.

2.2 In-process model automatically generate scheme analysis

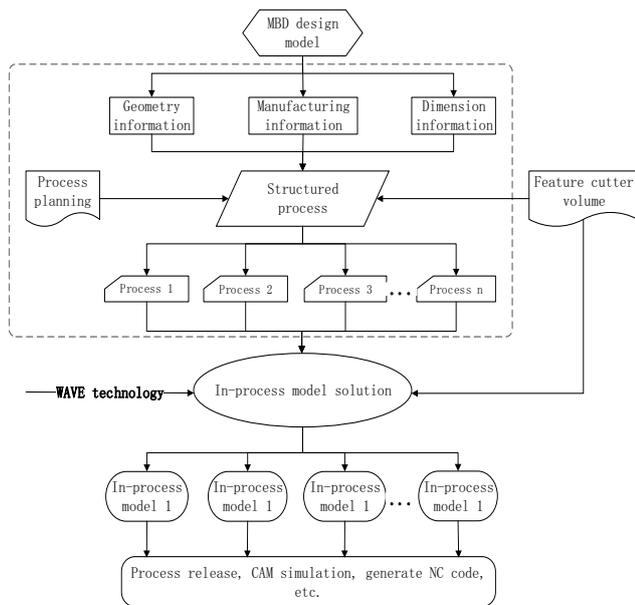


Figure 1. the overall scheme of building in-process model

Since the In-process models express the intermediate state of mechanical processing and are

taken as a carrier of the digital information in the whole process planning system, the generation is the core content of the whole system. As shown in Fig. 1, the solution takes the planning of information as input, combines with a certain technology and outputs the in-process model corresponding the process routine to realize the whole process planning system. As mentioned above, this paper is based on the structured process of manufacturing information, combined with technology of WAVE and delta-volume of manufacturing feature, effectively to generate the in-process model supporting WAVE technology.

3 Theory of solving in- process model

3.1 Process model to solve technical related concepts

3.1.1 Manufacture feature

Manufacture feature is a set of reflecting process constraints and a collection of feature information, which having the certain machining shape[5].In-process of identifying the feature on the part design model based on the manufacturing process, the procedure groups the surfaces which has a certain process semantics and meet a certain process constraints on the part design model. To extract and calculate these surfaces data, the system can get the attribute parameter about manufacturing feature. So manufacturing feature is the basic unit for researching the integration system of CAD/CAM/CAPP.

3.1.2 Feature Cutter volume

In parts of machining process, one process corresponds to at least one manufacturing feature. Feature Cutter refers to volume which would be removed from the workpiece to form some kind of manufacturing features. The volume having consistent structure on geometry is designed a kind of model which can be derived by parameters. Then procedure can instantiate feature cutter volume with parameter extracted from manufacturing feature.

3.1.3The WAVE technology

The WAVE (what-if the Alternative Value Engineering) technology is lunched by UG (Unigraphics NX), to implement the technology of modelling between related components[6], which can design a new part based on geometry information and spatial location of the existing part, it is different from parameterized modelling technology, which only have the link between the features within a single par. WAVE technology can establish connection between different parts about geometry information so that

subsequent components can be automatically updated when the parent components modify.

The in-process models generated by WAVE technology are inheritance relations, so the child process model can be automatically updated with the change of the parent process model.

### 3.2 The technical principle analysis about generating in-process model

In-process model can describes parts machining process, the mathematical expressions as shown below:

$$ProModel_{n_i} = PartBlank - \sum_{i=1}^{n_i} \sum_{k=1}^{m_k} FC_{ij} \quad (1)$$

$ProModel_{n_i}$  is a process model generated after the  $i$ -th process,  $PartBlank$  is the blank model,  $n_i$  is the number of the total machining process,  $m_k$  is the total number of steps in the  $i$ -th process  $i$ ,  $FC_{ij}$  is the feature cutter volume of the  $j$ -th step in the  $i$ -th process.

As in (1), the relationship of in-process model between the  $k$ -th process and the  $k-1$ (th) process is shown below:

$$Pr oModel_k = \begin{cases} ProModel_{k-1} - \sum_{j=1}^{m_k} FC_{kj} & (2 \leq k \leq n_i) \\ PartBlank & (k=1) \end{cases} \quad (2)$$

On the condition of blank model existing, the in-process model corresponding process  $k$  is generated through Boolean operation between the model of process  $k-1$  and collection of feature cutter volumes instantiated by the current process. As you can see, the solving process corresponds with mechanical processing, it is a forward method evolving from the blank to the workpiece. As shown in Fig. 2, there are two steps in the process  $k$ : truning outer diameter ( $\Delta_{k1}$ ) and drill hole ( $\Delta_{k2}$ ), so the feature cutter volume collection can be expressed as follow..

$$\sum_{j=1}^{m_k} FC_{kj} = \Delta_{k1} + \Delta_{k2} \quad (3)$$

In-process models of next process are built with the method of Boolean Difference.As shown in Fig. 2.

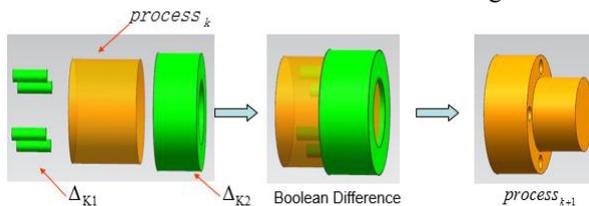


Figure 2. Feature Cutter and In-process Model

### 3.3 Solution of in-process model

Boolean subtract is operated to minus the feature cutter from the linked in-process models. At the same time, since linkage has been established among

in-process models with WAVE technology, the Boolean operations will automatically update in the subsequent in-process model. Automatic process modelling technology according to the above principle to simulate machining results, each working step removal feature cutter can be divided into the following five steps:

Step 1: To parse process route and content, getting information of manufacturing feature properties and machining allowance.

Step 2: To match the feature cutter volumes, depending on the type of manufacturing feature in the library of feature cutter volumes automatically matching the corresponding feature cutter.

Step 3: To calculation the size and position of feature cutter, depending manufacturing feature shape properties and machining allowance information to get drive size, according to positioning properties to place feature cutter.

Step 4: To instantiate feature cutter volumes, instantiating the volume with the dimension information getting from the Step 3.

Step 5: To subtract the feature volume from workpiece, placing the feature cutter volume at the position pointed in the step 3, then subtracting the instantiated feature cutter volume from the workpiece model to get the current in-process model.

The corresponding features will be added in every feature step by repeating the steps mentioned above. And the features in current step will be inherited by the child in-process model automatically because of the associative linkage.

## 4 Key technologies for generation of in-process model

The principle in the process model generation from the blank or in-process model removal volume of cutting body unceasingly, getting the in-process model corresponding to the model.

### 4.1 To instantiate feature cutter

The effect of feature cutter volume is similarity with the tool in manufacturing working on the workpiece in cutting, having both the geometric constraints and space requirements.

$$FeatureCut = MID + Size + Location \quad (4)$$

The instantiation of feature cutter is depending on the type of manufacturing feature (MID), size and location constraints to quickly build a block with processing significance. For different manufacturing feature, specific methods of constructing are different, but the three elements as follows are same. Based on the different complexity feature cutter, there are four different building methods:

(a) Simple manufacturing feature, such as face, outer cylinder, simple hole, etc., can be directly parameter drive to establish feature cutter.

(b) The more complex features, but has certain modelling rules, such as slotting, relief groove, the

ladder hole, etc., to create according to the CAD user defined feature (UDF).

(c) With complex cross section, irregular features, such as irregular groove, the method is to extract the sketch section, by operations such as tensile to instantiate the object.

(d) The complex surface characteristics, such as b-spline curved surface, the method is to copy the design surface, with synchronous modelling to create feature cutter.

As shown in Fig. 3, a U-shaped groove with the concrete process of feature cutter volume, which belongs to the complex features, has the stable geometrical structure. The cutter volume can be rapidly initiated by the UDF technology to build the in-process model.

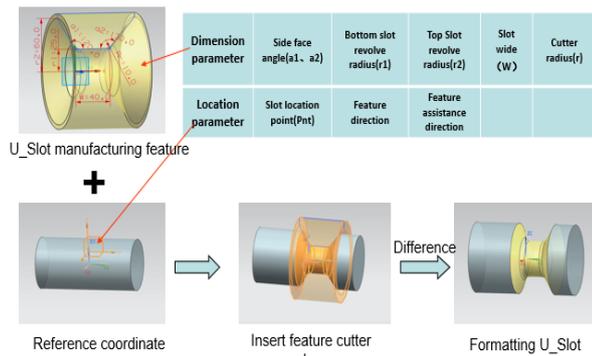


Figure 3. U-shaped groove Cutter instantiation

4.2 WAVE technology of correlation process

Using UG/WAVE technology to establish the incidence relation between in-process models, to make the follow-up in-process model can automatically inherit the early manufacturing feature. In the method of forward direction generation of in-process model, the common practice is constantly on the replication of last step in-process model, on the basis of the model adding manufacturing feature, getting this process corresponding in-process model. To establish incidence relation between the in-process models the biggest advantage is that can automatically update the manufacturing features. Practical application is likely to appear a new complex features or need to timely change process model, so the follow-up process model can automatically change, to improve the adaptability and flexibility of the system.

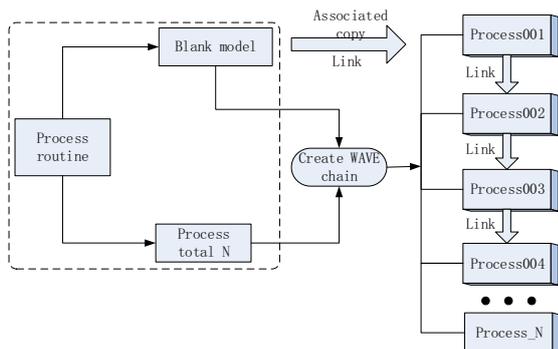


Figure 4. Associative Linked Components

Fig. 4 shows that before adding manufacturing feature cutter volume, according to the total working procedure, N associative components are created in turn by WAVE Associative Linker. The blank model is added into the created components. Then the feature cutter volumes inserted into corresponding components to build the in-process models.

5 Instance of process model generation

Based on the manufacture features and the key technology of building process model, this approach has been programmed on the VS2010platform and NX re-development interface technology(NXOPEN), successfully illustrates the feasibility of the in-process model forward generation in the 3D CAPP system (KMCAPP-M). The paper takes a process of a part as an example to show the result of method discussed. Fig.5(c) shows interface of the part's manufacture process route. The in-process models are generated according to the given process routes as shown in Fig.6.

In practical engineering, we may have to adjust the size or shape of blank, or get some problems with unconventional manufacturing characteristics, such as some free-form surface, then we hope to complete the design of in-process model by means of manually adding manufacturing characteristics. However, the Manual method wastes time and increases the cost of process. It is contrary to the purpose of the system design. The process model generation method supporting WAVE technology can realize the function of automatically updating process model. After one process finished inserting new manufacturing features, the subsequent step model will be automatically inserted with the new manufacturing characteristics. Thais obviously improves the efficiency of the process model generation. As shown in Fig. 7, the blank added two different groove features, the following process model updates the features automatically.

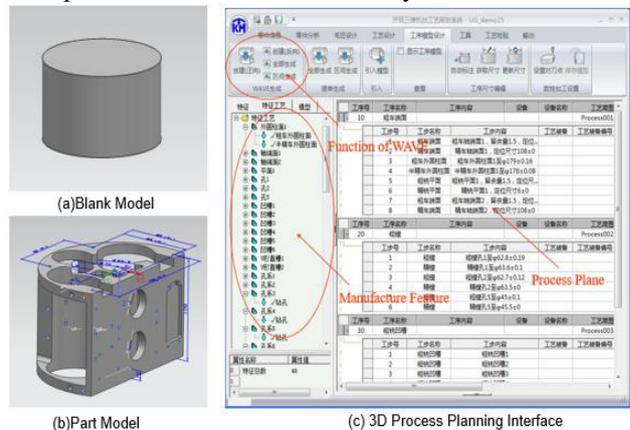


Figure 5. Designed model and Process planning.

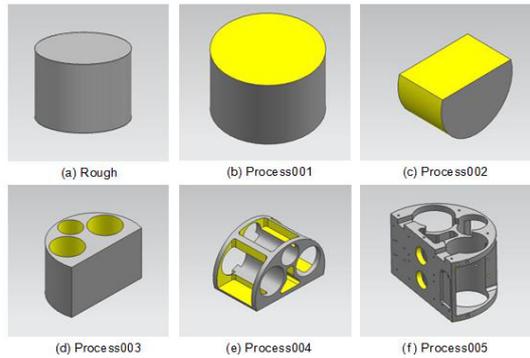


Figure 6. Generated Process Model.

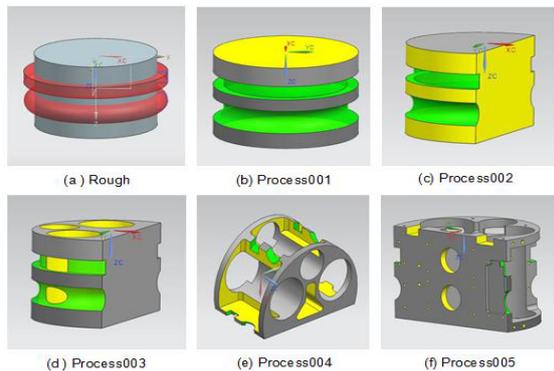


Figure 7. Updated the Process

## 6 Summary

This paper demonstrates a new method for in-process model generation, building relationships between the process models by means of WAVE technology, instantiating of manufacturing features cutting body and matching for the manufacture process according to the process information from the structured manufacture process. As result, in-process models are formatted according to the process route automatically.

Process model generation method described in this paper was verified successfully on KM3DCAPP-M system, a commercial CAPP system, but the process model currently produced has not added necessary dimension and manufacturing information, so it needs to further improve.

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