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FEATURE-BASED NON-MANIFOLD MODELLING SYSTEM FOR INTEGRATION OF CAD AND CAE SYSTEMS FOR INJECTION MOULDING PRODUCTS

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ABSTRACT

A feature-based non-manifold geometric modelling system has been developed to provide an integrated environment for design and analysis of injection moulding products. In this system, the geometric models for CAD and CAE systems are represented by a non-manifold boundary representation and are merged into a single geometric model, from which the suitable form of geometric model for design and analysis can be extracted. In our system, a part model containing geometric and feature data is first created using the feature modelling shell. Then, the abstract model for analysis is extracted using the feature mapping shell. Finally, two or three node meshes for injection moulding simulation systems are automatically generated on the abstract model. By introducing the Boolean operations based on a non-manifold representation, the feature deletion and interaction problem of the feature-based design system has clearly been solved. The sheet modelling capabilities were also developed for easy modelling of thin plastic parts.

KEYWORDS : injection moulding, non-manifold geometric modelling, feature-based design, feature mapping.

INTRODUCTION

(1) Background and Objective

Traditional design and manufacturing process for plastic injection moulding parts is performed based on the expert's several years of experience, and its long-term trial-and-error causes an increase in costs. In order to reduce costs, there have been various trials to develop a specialized CAD system for plastic part and mould design [1, 2, 3], and to develop a CAE system to simulate the injection moulding process to find defects before the manufacturing stage [4, 5, 6, 7]. Traditional design and manufacturing processes can be supported by the CAD and CAE systems as shown in Fig. 1. At the initial design stage, the specialized CAD system can help designers. The process simulation with the CAE system verifies the initial design result. The mechanical capabilities and defects of a plastic part are predicted through the simulation process. If the simulation results do not satisfy the functional requirements, the design process is repeated by feeding back the simulation results. The re-design process is repeated until the functional requirements are satisfied.

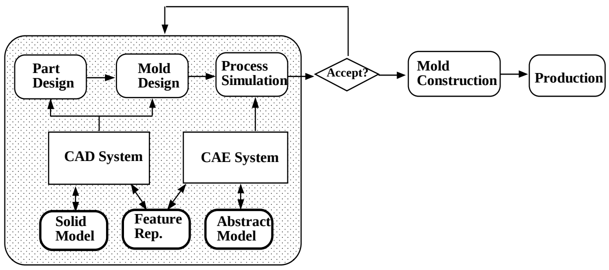


Fig. 1 Design process using traditional CAD and CAE systems for plastic injection moulding.

The geometric models necessary for the initial design stage are solid models containing feature representations such as ribs and bosses, whereas the models needed for the simulation process are shell meshes made from a sheet model composed of medial surfaces and wireframes that are contractions of the solid. Since the current CAD systems only deal with solid models, and the abstract model is generated in the CAE system using a pre-processor, the designer must create two types of models at the same time to design and verify a plastic product. Therefore, if two geometric models for design and simulation are created in one CAD system at the same time, the CAD and CAE systems can be integrated, and concurrent engineering methodology can be realized more readily.

We developed a feature-based CAD system based on a non-manifold geometric modeller as shown in Fig. 2 to produce the two models. In this system, the geometric models for CAD and CAE systems are represented with a unified data structure and stored in a part model. The solid model for design, or the abstract model for analysis, can be extracted from this part model directly. Since the part model also contains the removed faces, during feature-based modelling, the feature deletion and the feature interaction checking were easily implemented.

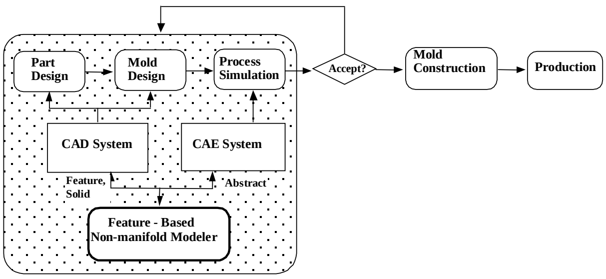


Fig. 2 Integration of CAD and CAE systems by introducing unified geometric modeling.

(2) Related Work

Huh and Kim [1] developed a knowledge-based CAD system to support the initial design of injection moulding products. This system contains two components: the one is an expert system for the optimal design of ribs and gates, the so-called RIBBER and GATEWAY, and the other is a three-dimensional geometric modelling system to represent design result in solid models. In order to develop the expert system, they gathered empirical equations and knowledge for design of ribs and bosses, and extracted the rules for the knowledge-based modules. Ishii et al. [2] proposed a system based on the design compatibility analysis methodology, in which product design is examined to determine how well it meets customers' requirements and the constraints on mould production and the injection moulding process. Gadh et al. [8] emphasized the role of the systems based on experts' knowledge to judge the mouldability for products as an alternative to numerical analysis systems. They also mention the representation and extraction of features for knowledge-based expert systems.

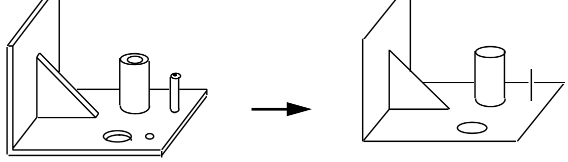
he injection moulding process is composed of a series of filling, packing and cooling processes. There has been considerable research to predict defects and optimal injection moulding conditions [4, 5, 6]. As a result, there have appeared various commercial CAE systems: MOLDFLOW developed by Austin et al. [9], and C-FLOW developed by Wang et al. through the Cornell Injection Moulding Program [4, 7]. These systems focus on the filling simulation, but recently packing and cooling process simulation modules have been included. MOLDFLOW includes not only MF/FLOW but also MF/COOL and MF/WARP.

DESIGN OF AN INTEGRATED CAD/CAE SYSTEM FOR INJECTION MOULDING

(1) Functional Requirement

As described above, an integrated CAD/CAE system for the design of plastic injection moulding parts should have the following functionality in order to support feature and solid models as well as abstract models for CAE systems for injection moulding process simulation and structural analysis.

- Create thin-walled parts easily. The objects dealt with in this paper are thin-walled plastic parts, especially outer panels for electronics devices. They have large surfaces as well as thin and constant thickness walls. Therefore, powerful modelling capabilities for thin-walled parts should be provided in the system [10].
- Provide design-with-feature capabilities [11]. When a plastic part is designed, first the main shape is determined and then the size and location of sub-features, such as ribs and bosses, to satisfy functional requirements are determined [1]. Thus, the three-dimensional CAD system for plastic parts must allow initial design and re-design with features, and represent the design result with a solid model.
- Provide geometric models for analysis efficiently. While a part is designed, the injection moulding process simulation is performed to find the problems in advance, and the result is fed back to modify the initial design. Shell meshes on the medial surface of a part should be derived easily in order to run the simulation packages. In order to generate shell meshes, at first, the main shape of a part is converted to a sheet model of medial surface, and then sub-features are converted to sheets or wireframes depending on mesh size. The geometric model composed of sheets and wireframes, on which meshes are generated, is called an abstract model. An example of an abstract model is shown in Fig. 3.



(a) Solid model (b) Abstract model

Fig. 3 Example of abstract model for analysis of injection moulding.

(2) Possible CAD/CAE Integration Methods

When we construct an integrated CAD/CAE system for an injection moulding product, satisfying functional requirements, based on current research achievements the possible combinations of integration methods can be classified into three groups according to model types to be stored in the database of the system for the design result:

- Store only the solid model
- Store solid model and feature information
- Store solid model, feature information, and abstract model for analysis simultaneously

If one wants to obtain an abstract model for analysis from the design database, a conversion or extraction process is required, according to storage method, as shown in Fig. 4. Now we investigate the abstract model generation process for each method, and compare each of these to show the advantages and disadvantages of CAD/CAE integration.

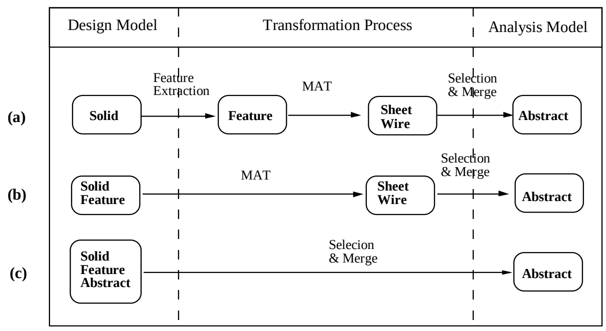


Fig. 4 Extraction of the abstract model for analysis from the design model.

In the first method, which stores only the solid model, an abstract model for analysis must be generated from the solid model to obtain shell meshes for the CAE system. In order to get an abstract model, sub-features such as ribs, bosses, or holes must be extracted from the solid model and transformed into sheets or wires according to the given mesh size, and then the medial surface of the main shape is generated through medial axis transformation (MAT) [12]. The abstract model is completed by combining sheets or wires for sub-features and a sheet of medial surface for the main feature. This process requires considerable computing time and it must be repeated for the whole body whenever any partial modification is performed, if the design is performed in parallel with the analysis in a concurrent engineering environment. Moreover, since the design result does not contain feature information in this method, the designer must change the shape of the solid model using the solid modelling system directly when modification is necessary.

In the second method, the design for plastic parts is performed on a feature-based modelling system and the solid model and feature information for the design are stored in the database. When the abstract model is required for analysis, the medial axis transformation is applied to the sub and main features, respectively, to produce a sheet or a wire according to the mesh size. Then the final abstract model for analysis is obtained by combining sheets and wires extracted from the features. Comparing with the first method, storing only solid models, this method utilizes feature information in the database so that feature extraction can be omitted. However, this method still has a time-consuming process when MAT is performed for each sub-feature whenever an abstract model is required during the design process.

In the third method, the database stores not only solid models and feature information, but also the abstract models for the features at the design stage. As shown in Fig. 4(c), the solid model and abstract model for each feature are generated during the feature-based design, and the analysis model can be extracted directly from the database according to the mesh size. In this method, a design change is propagated to the analysis model instantly so that an abstract model can be extracted directly for analysis.

(3) Design for Integrated CAD/CAE System

Of the three CAD/CAE integration methods, the third method alone satisfies the requirements for a concurrent engineering environment. In order to build an integrated CAD/CAE system based on the third method, we determined the system specification as follows:

- Provide the feature-based modelling capabilities and the feature conversion capabilities from design features to analysis features, which are the abstract model for shell mesh generation. As illustrated in the system functional requirement, the CAD system for injection moulding products should be able to support feature-based design. Moreover, since the analysis features for CAE systems can be easily obtained from the design feature information, feature mapping from design to analysis features is more efficient than feature extraction of the analysis features from a solid model.
- Use non-manifold representation for the geometric modelling system. The non-manifold B-rep can represent not only solid objects but also wireframe, sheet, and cellular objects, along with a mixture of these, in a single data structure [13, 14, 15]. Thus, solid models, for design, as well as abstract models, for analysis, can be represented in a single modelling environment. Moreover, when the user models thin-walled plastic parts, they can create a

sheet model for the inner or the outer wall, and then offset it to generate a thin-walled solid with a given constant thickness. In addition, since a non-manifold B-rep supports cellular models in which the hidden faces of features deleted with the Boolean operations can be stored, any feature can be cancelled immediately independent of the generation sequence, and feature interaction can be easily detected [15, 16].

- Use the part model in which the solid and abstract models for all features are merged into a non-manifold model. Not only a solid model but also an abstract model for each feature is inserted into the part model so all the geometric information for design and analysis can be contained in a single part model. By adopting this method, design change propagates to the analysis model immediately and the abstract model, for analysis, can be obtained by simple filtering from the geometric model for the part if analysis is necessary during design.
- Use the object-oriented programming technique. Since a feature-based modelling system uses redefined features, it is difficult to enlarge the feature library when the user needs to define a new feature. To solve this problem, we adopted the currently widely used object-oriented programming technique so that the user can add a new feature to the feature library without changing the existing system code.

The integrated CAD/CAE system that was implemented according to the above design strategy consists of the following five sub-systems as shown in Fig. 5:

- User interface
- Feature modelling shell
- Feature mapping shell
- Non-manifold geometric modelling system
- Product database

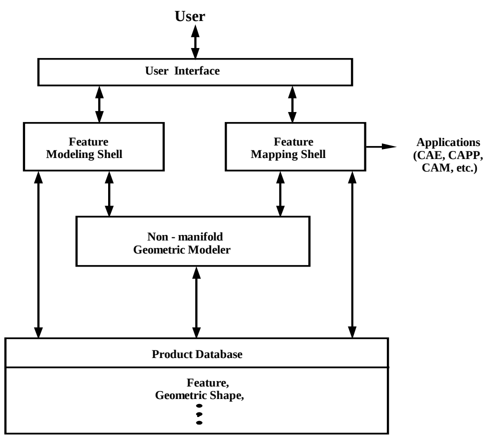


Fig. 5 Architecture of the integrated CAD/CAE system.

Of these sub-systems, we briefly explain three main sub-systems: the feature modelling shell, the feature mapping shell, and the non-manifold geometric modelling system.

The feature modelling shell creates, deletes and modifies features and maintains the hierarchical relationship among features. This module sends messages to create or delete geometric models for features to the non-manifold geometric modeller.

The feature mapping shell converts features for design to features for other application areas, such as CAE, CAM, CAPP, etc. In this paper, the only commercial package for mould flow simulation, C-FLOW, is developed. Development of feature mapping modules for other applications remains for future work.

A non-manifold geometric modelling system, called AnySHAPE [14], receives messages of creation, deletion, query from the feature modelling or mapping shells, and performs corresponding modelling operations. Especially, this modeller manages the merged-set models for parts, which are generated by merging solid models and abstract models for all features. In this system, the capabilities for sheet modelling and transformation into solids are provided for simple modelling of thin-walled parts.

The design and analysis process with this system is as follows. First, the user creates the solid model for the main shape of the part. They can use not only traditional solid modelling functions but also the sheet modelling capabilities to accelerate thin-walled part modelling. After generation of a solid model, the user prepares a sheet model for the medial surface of the part through an automated MAT procedure or manual work. They can use a sheet model before transfor- mation into a solid. Secondly, the user transfers to the feature modelling shell and registers the solid and sheet models for the main shape of the part as a base feature, and then creates sub-features sequentially to complete the whole part. Finally, the user goes to the feature mapping shell. In this module, the abstract model for analysis is extracted and two or three node meshes are automatically generated on this abstract model. These meshes are used as a geometric input for the C-FLOW.

FEATURE MODELLING SYSTEM

(1) Representation of Features

The part model contains data for the features and geometric information. Features are connected to each other with a graph structure in which features have a parent-child relationship. The base feature for the main shape of the part is the starting node of the graph.