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Using Features as the Knowledge Carrier for Cross Company Collaboration and Change Management

– A design methodology for compressing lead-time from plastic part design to mold making

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Abstract – This paper presents a methodology in which the knowledge of design intents and change requests is communicated unambiguously cross collaboration partners through features. The domain of application is focused on the plastic part design for enabling effective collaboration between the product design and plastic mold making. The methodology takes the feature-based design approach and allows design features and knowledge to be reused in plastic injection mold design. It shortens the mold design lead-time, reduces mold design efforts, and enables unambiguous and fast design change management between product and mold designers. These contribute to the reduction of product development cycle time.

Keywords: **Product design, Feature-based, Knowledge management, Mold design, and Design change management**

1. Introduction

Market pressures demand better, cheaper, and faster introduction of products. In many of these products, plastic parts are used for casing and supporting structures. The capability to design and make the plastics parts faster and cheaper has become a key competitive factor for these manufacturers.

Since 1990's, many efforts have been made to reduce the mold making time as an effective means to shorten the product development cycle time. Concurrent Engineering (CE) methodologies [1, 2, 3] have been developed to involve mold designers early in the product design process. This allows mold makers to be involved before and duration the product design process to ensure that the plastic parts designed can be molded cost-effectively and efficiently. Additionally, CE has also been applied in the mold design process to enable more than one mold designers to work on one mold concurrently, achieving more than 50% reduction in mold design time [20].

Often applied together with the CE methodologies is the Design for Manufacturing and Assembly (DFMA) methods [4, 5]. The benefits of DFMA are well-documented [6]. Central to the various benefits is that DFMA considers manufacturability and ease of assembly of the parts at the design stage for the purpose of avoiding the costly design changes when faults are found during manufacturing and assembly. Applying the DFMA principles to the plastic part design means that design features that can cause problems in molding need to be identified and avoided at the design stage. During the design, design options should be evaluated and optimally selected based on cost and time of making the part through the plastic injection processes.

While the CE and DFMA methodologies optimize plastic part design, efforts have been made to develop specialized CAD tools to expedite mold design [7, 8, 9]. To date, most major CAD systems have modules specializing in plastic injection mold design. Examples include Pro/Mold from PTC [www.ptc.com], MoldWizard from EDS [www.eds.com], and MoldWorks from CIMQuest [www.cimquest-inc.com]. These tools allow mold designers to directly utilize and reference the three-dimensional (3D) solid part model in mold design. The resulted 3D models of the mold design can also be used directly for NC program generation.

Further research has also been made to establish a CE based environment in mold design. Lee tried to establish a CE based methodology and knowledge base for injection mold design [10]. Wang reported a simulation-based methodology in the design of plastic part, mold making, and setting up plastic injection process control parameters [11]. All these have contributed to the shortening of mold making time.

To date, all these research efforts have been focused on either product design or mold design. As a result, much design knowledge and information is lost while the product part model is passed to the mold designer. Collaboration tools and methodologies are needed to seamlessly integrate the product design process with that of molding, avoiding unnecessary work and improving the overall product development lifecycle efficiency.

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The work of this paper is devoted to the development of a feature-based knowledge management methodology. This methodology considers the product design and mold design as an integrated process with disregard for organizational boundaries. The developed methodology is for use by product designers in 3D plastic part design modeling. An interface is extended to the mold designer to realize a structured data exchange. The methodology enables the mold designer to directly utilize product design features in the mold design to achieve reduction in mold design time and efforts. Moreover, it provides a means for unambiguous and fast design change management between product and mold designers. This minimizes time delays and wastage arising from design changes that is inevitable and increasing due to compressed design time and increased product complexity.

2. Product and Mold Design Processes

Product design is arguably one of the most complex tasks. It involves a series of processes by multi-disciplines teams (Fig. 1). Among them, the design modeling effort is centered at engineering design. In the mechanical aspect, engineering design takes inputs from the industrial design (ID) that provides the product's functional features, shape, surface texture and color in a surface model. Mechanical designers reference and utilize the model from ID to create assembly and component design models that incorporate the ID design with features for assembly, mechanism, and other manufacturing and functional needs. With 3D CAD systems, designed plastic parts are modeled in every detail and represented in a solid model (Fig. 2). For plastic parts, the models are transferred to the mold designer to carry out mold design.

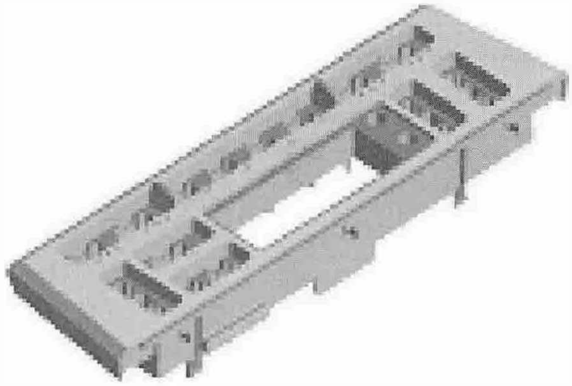

Fig. 2. An example design model.

Mold design process [12, 13, 18] consists of a sequence of activities, conceiving and designing a mold in a step-by-step manner. Shown in Fig. 1 under the Mold Design are the major activities and their sequence in a typical mold design process. Here,

- Cavity layout decides the size, the number and the layout pattern of the plastic part in a mold, and hence determines the overall size and structure of the mold insert;
- Moldbase design defines the type, size and position of the moldbase;
- Core & cavity generation requires the creation of parting line, and then uses the parting line to split the insert into core, cavity and sub-inserts; and
- Undercut mechanism design is only processed when undercut areas exist in the plastic part feature. The undercut area may exist in core side or cavity side.

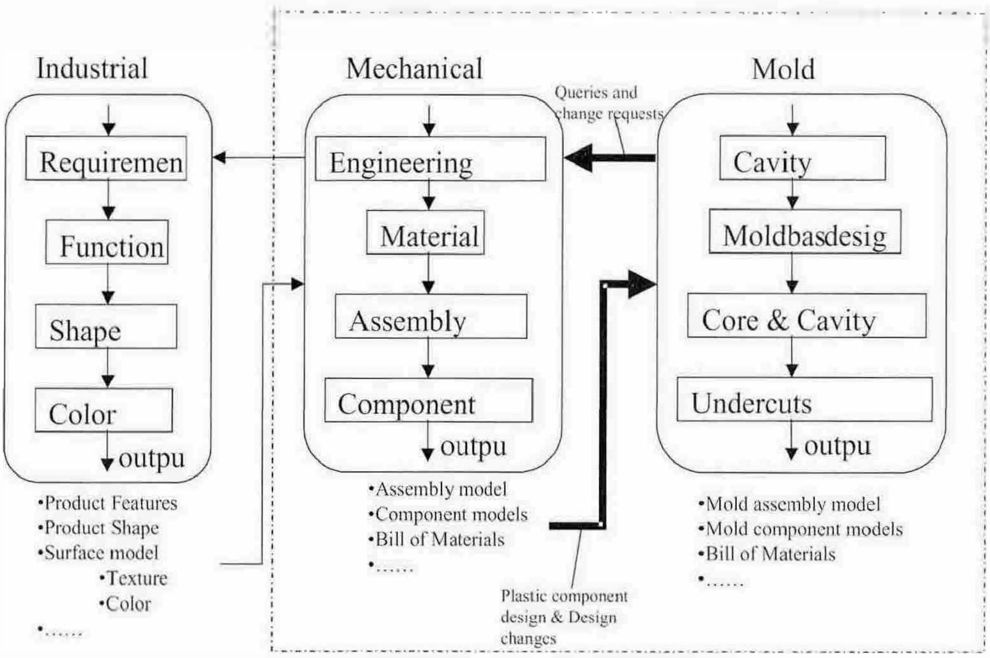

Fig. 1. Industrial, mechanical and mold design.

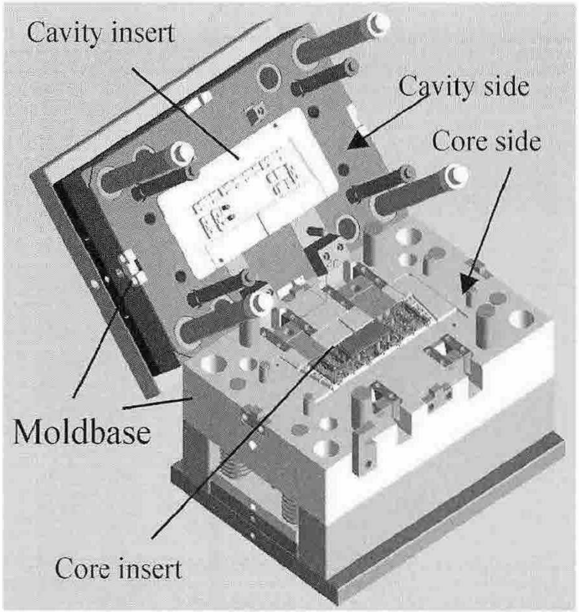

Fig. 3. A plastic mold design.

Other major mold design processes include feed system design (gate, runner and spruce), cooling system design (the dimension, type and position of the cooling channels), and ejector system design (ejector pins and plates). Fig. 3 shows a completed 3D-mold design model.

Poor integration between plastic part and mold design can result in producing functionally good, but un-moldable or moldable but high cost plastic component design. It is highly recommended that, prior to mold design, the mold designer is to investigate the design model to clarify design intents and details with the product designer. He or she would also feedback to the product designer on suggestions for moldability and ease of mold making. These feedbacks help to optimize plastic component design for faster and cheaper manufacturing of the components through plastic injection. In fact, the involvement and on-going feedback of mold designers in the product design process, rather than waiting till the parts are released, has made great contributions in shortening product development lead-time.

The feedback mechanism has a serious weakness. It only works from the mold designer to the product designer. The designed component model is "thrown over the wall" to the mold designer in a complete solid model. The mold designer must work out the parting lines and fill up the holes in the solid model in order to create the core and cavity models. This can be a tedious and frustrating effort due to the complexity and geometric modeling errors that often exist in the component model.

Further more, the "thrown over the wall" method generates ambiguity and major re-work when design changes occur. The mold designer needs to examine the changed design model from the product designer to find out the details of the changes. Any misunderstanding or negligence of some changes can result in losses in time, man-hours, and materials. In addition, the mold designer has to re-generate the core and cavity in accommodating most of the changes. These cause delays in mold making, and result in prolonged product development cycle time.

3. Knowledge Management for Collaborative product design

3.1. Knowledge transformation from product to mold design

The widely practiced product design method described in section 2 results in a complete solid model of a plastic part. Few design features are retained

To capture the design knowledge, the design features need to be retained as feature models. For plastic parts, the design features typically include the main body, protrusions (boss), depressions (cut-through), holes, and ribs (undercuts). On the other hand, a mold design is also consisted of mold features. The most common mold features are the core, cavity, sliders, gate/runner, etc.

The purpose of the mold is to form a void volume with the shape of the product part. This indicates that each product feature must have a corresponding mold feature. The correspondence of features establishes the relationship between design features and mold features. The capturing and modeling of the product features, the mold features, and their relationships would provide a knowledge model for passing the intents of product features to the mold design process (Fig. 4). This requires a knowledge management methodology.

3.2. A Feature-based Knowledge Management Methodology

The importance of Knowledge Management (KM) technology has been well recognized in research and application in the past decade. The power of knowledge is seen as a essential resource for preserving valuable heritage, learning new things, solving problems, creating core competences, and initiating new situations for

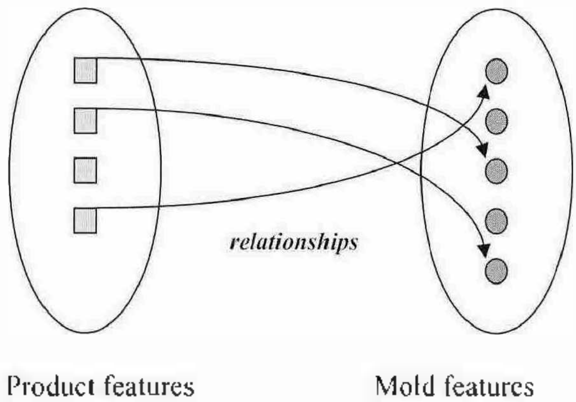

Fig. 4. Knowledge transformation from product to mold.

both individual and organizations now and in the future [15]. KM systems generally comprise a set of interrelated computer-based elements that retrieve, processes, store and distribute information to support activities intra- or inter-enterprises. This support is provided through improved methods and processes for decision-making and control within an organization, as well as the provision for accurate and current information [16, 17]. Looking into mechanisms to process the information and knowledge for decision-making, Hitcks *et al.* [19] proposed a framework under which knowledge is defined by information elements that are in turn described by either numeric or alphabetical data. This framework can help an organization to capture and reuse information and knowledge for better decision-making.

For collaboration between product and mold designers at the system level, however, the transition of design features to mold features also need to be captured and managed in addition to the capture and re-use of the features. For this purpose, we propose a knowledge management framework as shown in Fig. 5. Here, information provides the product and mold features, respectively. The attributes of features, e.g. material, color, and tolerance are represented as a unified data model. The relationships between the product and mold features, together with the change requests for each of the features, provide the knowledge elements that carry the product design intents and instructions from the product designer to the mold designer. A collaboration agent takes advantage of the feature representation, feature relationship and the change requests structure to enable unambiguous communication during the product and mold design.

Today's major CAD systems are good for creating feature-based modeling and defining the feature attributes for inheritance usage. The work of this paper has therefore been focused on the development of a methodology for product feature definition and the knowledge that represents product to mold feature mapping.

3.3. Definition of features and feature relationships

Corresponding to the knowledge framework shown in Fig. 5, let's define that the plastic product parts can be represented by a feature set PF = {PF1, PF2, ..., PFn}. These design features include the main body, protrusions (boss), depressions (cut-through), holes, and ribs (undercuts). They should be naturally generated by the product designer along with maturity of the part design model. In the process, design modeling in a 3D parametic CAD system environment is basically a combination of feature-creation and Boolean operations. Fig. 6 illustrates a summary of the possible feature creation scenarios. Here, the main body (PF1) is obtained by using the ID surface to cut, or generate, a solid body (Fig. 1). Because the plastic injection process requires a unified thickness of the plastic part [12, 13], the shell of the part can be obtained by substracting an off-set body [PF1'] of the PF1 from the PF1. The off-set value equals the thickness of the part. A boss is created by two steps:

- Step 1: a body with the boss's outter shape (PF2) is unioned to PF1; and
- Step 2: the PF2 is substracted by its off-set body PF2'.

Again, the off-set value equals to the thickness of the boss. Similarly, a depression can be created in the same manner as the boss by the union of PF3 and substraction of PF3 with its off-set PF3'. Taking the same approach, a rib can be obtained by the union of a rib body (PF4), and a hole can be created by the substraction of a body (PF4') that resembles the shape of the hole. Hence, we have PF = {PF1, PF1', PF2, PF2', PF3, PF3', PF4, PF4'} (Table 1).

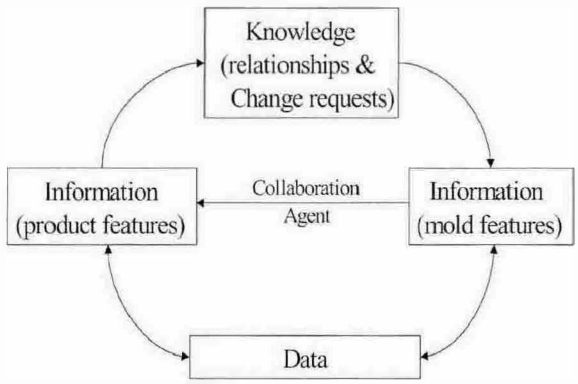

Fig. 5. KM framework for collaborative product design.

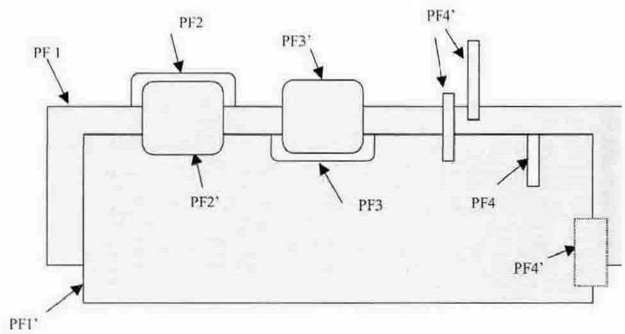

Fig. 6. The 8 basic Part Features (PFx) for modeling a plastic part.

Table 1. The definition of PFi

PF1	Profile solid, based on ID design	PF1'	Internal solid, reduced off-set of PF1
PF2	Boss (Protrusion) solid	PF2'	Reduced off-set solid of PF2
PF3	Depression or Cut-through solid	PF3'	Reduced off-set solid of PF3
PF4	Solid inserts	PF4'	Subtracted solid

Table 2. The relationship between product and mold features through PFi

Product / Mold	Main Shell	Boss	Depressions	Indents/Holes Minor Details/ +ve Ribs/Boss	
				Hole/ Undercut	Ribs
Cavity	+PF1	-PF2'	+PF3	-PF4'	
Core	-PF1'	+PF2	-PF3'	-PF4'	+PF4

In the plastic injection molds, the solids of the plastic part model become the void volumes of the mold either on the core or cavity side [12, 13]. As such, the corresponding mold features (MF) of the part features (PFi) can be defined as MF = {MF1, MF1', MF2, MF2', MF3, MF3', MF4, MF4'} where MFi corresponds to PFi.

The correspondence of MFi to PFi establishes the relationships between the part features and the mold features (Table 2). These relationships provide the base to model the information integration between the product design and mold design. In practice, when all part features are provided, the mold designer can use the features in a reverse manner to generate the mold features. This enables the mold designer to significantly reduce the mold design time and effort by directly using the part design features in its mold design.

3.4. Mold design using the design features

The core of the methodology is to design a mold using the product features received from the product designer. The following is an illustrated case showing how the methodology works.

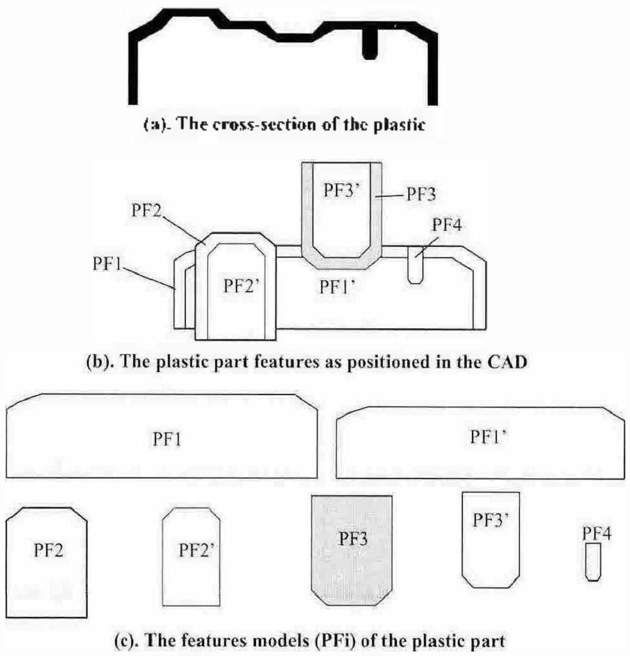

Fig. 7. The plastic part and its feature models.

Let's assume that a plastic part as showne in Fig. 7(a) is designed and the features that are used to create the part model are kept in feature models (Fig. 7(b) and (c)).

For illustration purpose, let's design the plastic injection mold's cavity and core inserts using the plastic part features (Fig. 7(b)) provided by the product designer. Fig. 8 illustrates the steps of creating the cavity insert. Firstly, a solid model MF1 is created as the cavity insert base. As defined in Table 1, PF1 is the outer shape of the plastic part. When a boolean operation:

$$MF1 \cup (-PF1)=CA1$$

is carried out to subtract PF1 from MF1, we obtain the CA1. The other plastic part features (Fig. 7) that make part of the outer profile of the cavity are PF2 and PF3', respectively. The final cavity insert can be obtained by

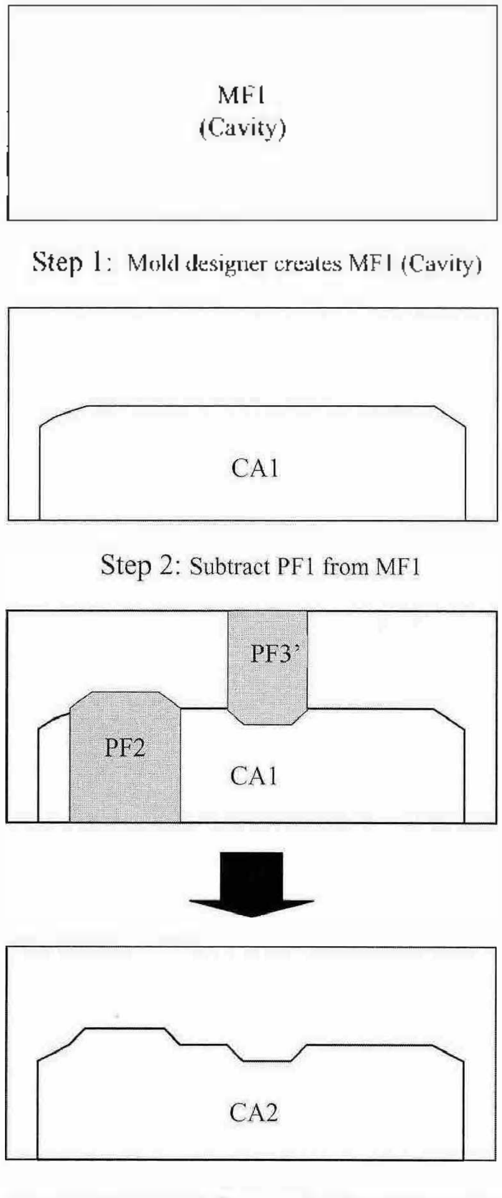

Fig. 8. Illustration of cavity design method

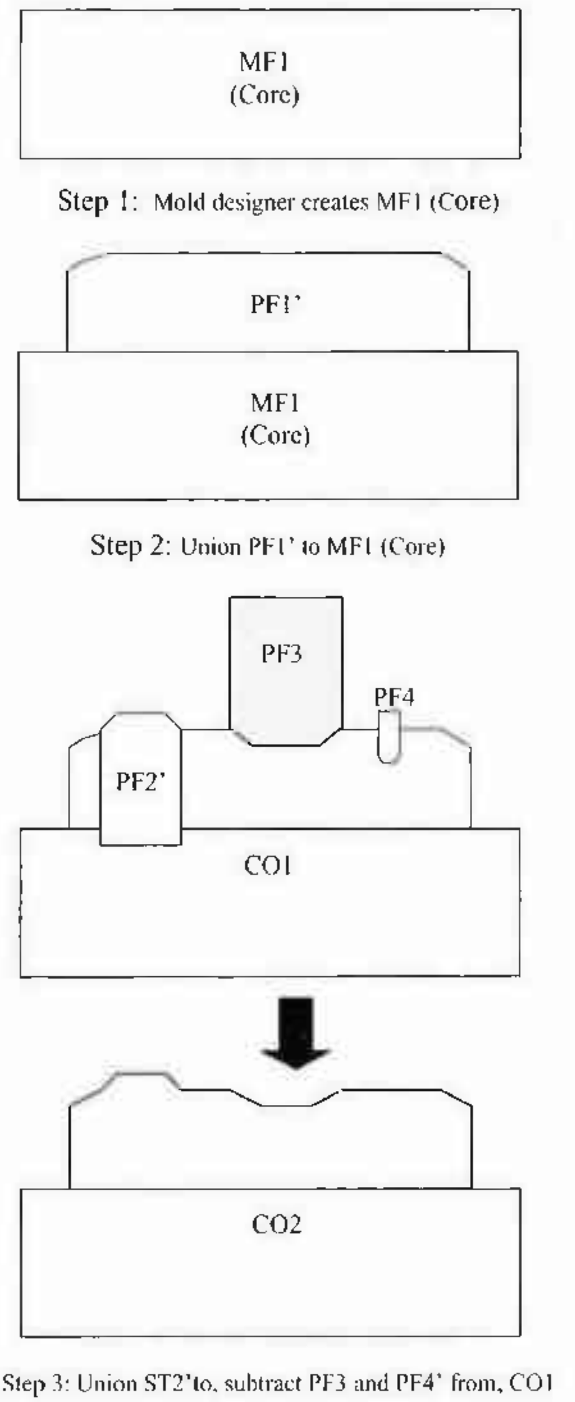

Fig. 9. Illustration of core design method.

subtracting PF2 from, and union of PF3' to, the CA1, i.e.,

$$CA1 \cup (-PF2) \cup PF3' = CA2$$

As illustrated in Fig. 9, a core insert design starts with the creation of a core insert base MF1 (Core). When the created base is unioned with the inner shape of the plastic part, PF1', i.e.,

$$MF1 \cup PF1' = CO1$$

the core insert's base profile, CO1, is obtained.

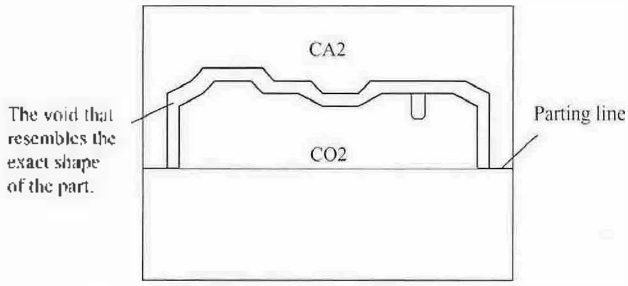

Fig. 10. Positioning CA2 and CO2 to form the complete mold insert.

In the example part shown in Fig. 7, the features that determine the rest of the shape of the core insert are PF2', PF3, and PF4, respectively. The PF2' is to be unioned to CO1 to form the inner protrusion (PF2). The PF3 needs to be subtracted to have the outer profile of the depression. The rib (PF4) must become a hole in the core insert of the mold. In summary, the above requires the following Boolean operations:

$$CO1 \cup PF2' \cup (-PF3) \cup (-PF4') = CO2$$

where the CO2 is the desired core insert.

The complete mold insert is obtained when both the cavity and core inserts are positioned along the parting line as shown in Fig. 10.

3.5. Bill of features for design change management

As product design is a creative activity and the lifecycle of product development time is greatly compressed, design changes are inevitable. Each time a design change is made in a plastic part, the mold design has to be changed accordingly even while the mold is being designed and made. Dictated by the conventional mold design process described in Section 2 above, the product designer will send the mold designer a new version of the product part model when changes are made. The mold designer would, in most cases, have to re-start the mold design process from the beginning and make necessary changes in the mold design model.

The product features, mold features, and their relationships provide a base to drastically improve the design change management. We can let the product features act as the carrier to communicate product design intents to mold designers. A effective means to realization such a purpose is to define design change requests in the form of a bill of features (BOF). An example of the BOF is given in Table 3.

Here, the part has a code, and is consisted of a number of part features of different types. Each type of features may have one to many instances (series no.). A design change request can be either New (a new feature to the design model), Delete (the feature is to be removed from the design model), or Replace (to replace the previous version of the feature). The BOF,

Table 3. Bill of features

No.	Part Model Code	Part Feature Type	Series No.	Change Request Code
1	AT08	PF1	003	New
2	AT08	PF2	035	Delete
3	AT08	PF2	014	Replace
...	...	...	...	...

coupled with the features in B-Rep solid models, result in an unambiguous method to express the design changes from the product designer to the mold designer. In this way, the mold designer, upon receiving a new file from the product designer, will be able to check the BOF for changes. When a change is requested, the mold designer can, in most cases, update only the mold features that correspond to the affected product features rather than having to re-visiting all the mold design process at each of the changes. This effectively localizes and minimizes the impact of design changes.

Design changes have become more often due to compressed design time and increased product complexity. From the reception of the part design to the delivery of the mold, a mold maker can typically receive over 10 design changes from the product designers. The unambiguous change specifications and communication, plus the localization of design change in the mold making process, provide effective means for significant reduction of lead-time and costs.

4. Conclusion

A methodology for collaboration between product and mold design is presented. A KM system framework together with its related feature and knowledge definition method is proposed. The core approach is to utilize product features the carrier for design intents and change requests in order to realize unambiguous communication between collaboration partners.

Using this methodology, the product designers can create and retain the product part features along with the progress of the design modeling. The product part feature models, together with the corresponding BOF, are transmitted to the mold designer. The mold designer can directly utilize the product part features in the creation of mold features. This can avoid the often-tedious tasks of generating parting surfaces for obtaining Core and Cavity by the conventional approach. Since the BOF carries the change requests related to each of the features, the mold designer is able to update, in most cases, only the corresponding changes of the mold features. The coupling of change request specification with each product part feature also removes ambiguities in the communication of design changes from the product designer to the mold designer, minimizing human errors and related materials wastage in the mold making process.

This methodology has been implemented in a product development chain consisting of a product design team specializing in designing consumer electronic products and a plastic injection mold maker. The first 4 mold design cases using the methodology were monitored and measured against those of similar molds done previously. The results have shown a consistently over 25% reduction in mold making lead-time due to saving in mold design modeling and localization of mold design changes when design changes take place. All the 4 cases had more than 15 design changes during the course of the mold design and making. The benefits of this methodology in lead-time reduction increase along with the increase of the number of design changes.

This methodology can be further enhanced for broader applications in information and knowledge capturing, representation, and re-use. The product part features captured can become the design knowledge for re-use in a new design. The method of representation and unambiguous communication is the base for realizing a collaborative environment in a product lifecycle management solution.

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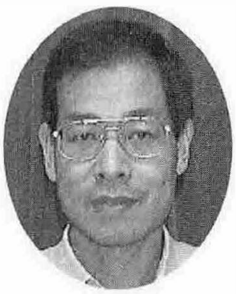
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