Chapter 4

Core, Cavity and Side-Core Design for a Multi-Cavity Die-Casting Die

In the die-design process, design of core, cavity and side-core is a non-trivial task, which requires much attention and time of the die designer. This is because of the reason that design of core, cavity and side-core should take care of the existing practices and rules being followed by the industry. Generating CAD models of the core, cavity and side-core is also a major requirement not only for their computer-aided assembly with other components of the die but for their manufacturing too. Both the activities of design and CAD model generation of core, cavity and side-core become even more complex in case of a multi-cavity die, use of which is very common in the die-casting industry. In this chapter a system for core, cavity and side-core design for a multi-cavity die-casting die is presented that takes care of design and CAD model generation of core, cavity and side-core with minimal user interaction at some of the steps.

The design of core, cavity and side-core is instantiated with the information, such as cavity design, number of cavities, cavity layout and die-base size, which information is derived from the system for cavity layout design for a multi-cavity die-casting die that has been already presented in Chapter 3.

To generate CAD models of the core, cavity and side-core, two approaches, namely Euler-based approach (EBA) and Boolean-based approach (BBA) are most commonly used [45]. In EBA, Euler operation is used which is inherently efficient to generate surfaces of the core, cavity and side-core. However, this method can generate
ambiguous results, when two or more than two undercuts overlap [55]. In BBA, the core, cavity and side-core are generated using Boolean regularized difference operation (BRDO) between the part model and bounding box. Subsequently, the bounding box is separated along the parting surface to get CAD models of core and cavity. The system for core, cavity and side-core design for a multi-cavity die-casting die presented in this chapter uses BRDO method to generate CAD models of core, cavity and side-core. The steps of BRDO method are briefly explained in the following paragraphs.

![Diagram](image)

(a) Part model with bounding box | (b) Generate parting surface
---|---

(c) Resultant solid after Boolean operation | (d) Generated core and cavity

Fig. 4.1: Instances of the steps to generate core and cavity
Step 1: Bounding box of the part model is generated. The bounding box is a solid box with usual clearances to accommodate other mechanisms of the die, such as side-core, and cooling system. A snapshot of the bounding box of a part is shown in Figure 4.1 (a).

Step 2: The parting surfaces is generated at a suitable location, an instance of which is shown in Figure 4.1(b).

Step 3: The part model is subtracted from the bounding box using BRDO method. An instance of subtraction of the part model from the bounding box is shown in Figure 4.1(c).

Step 4: The bounding box is split into two halves along the parting surface to generate core and cavity. An instance of splitting of the bounding box is shown in Figure 4.1(d).

The proposed system for core, cavity and side-core design for a multi-cavity die-casting die consists of five modules, which are mentioned below. Subsequent sections of this chapter explain each of the five steps.

i. Parting line selection,

ii. Shut-off surface creation,

iii. Core and cavity generation for a single-cavity,

iv. Side-core design, and

v. Multi-cavity core and cavity generation.

The organization of this chapter is discussed. Section 4.1 presents the parting line selection module, which helps the user to select parting line interactively using a part CAD model. Section 4.2 discusses the shut-off surface creation module; a shut-off
surface separates an undercut surface from the core or cavity surface in case of a through feature. Section 4.3 discusses the core and cavity generation for a single-cavity module. Section 4.4 discusses the side-core design module, which helps to generate side-core for a single-cavity. Section 4.5 discusses the multi-cavity core and cavity generation module, which helps to generate CAD models of core, cavity and side-core for multi-cavity die. Section 4.6 discusses the system implementation and results. Lastly, section 4.7 discusses conclusions drawn from the research work presented in this chapter.

4.1 Parting Line Selection

Parting line selection module is used for selection of a parting line for a given part interactively by using SolidWorks software. The designer needs to select edges of the parting line one by one on the part model. If selected edges form a closed loop, the system shows the message “parting line created successfully” else the message of “wrong loop selection” is displayed. A snapshot of the GUI for parting line selection module is shown in Figure 4.2. The algorithm for selection of parting line is shown in part 1 of Figure 4.3.

![Fig. 4.2: A snapshot of the GUI for parting line selection module](image-url)
User interface

Load solid part model

Part feature data

Default parting direction Y/Y axis

Select edges to create parting line

Do selected edges form a closed loop?

Yes

Display created parting line

No

Wrong loop selection

Re-select

Is through undercut > 0?

No

Yes

Select inside edges of through undercut

Wrong loop selection

Re-select

Do selected edges form a closed loop?

Yes

Display created patch surfaces

Create inside and outside shut-off surfaces

X
Fig. 4.3: Information flow diagram of the system for core, cavity and side-core design for a multi-cavity die-casting die
4.2 Shut-Off Surface Creation

Undercut(s) may be present in some of the die-cast parts. Those regions of the part, which form the undercut(s) cannot be realized by either core or cavity and need special tooling, which is known as the side-core. Sometimes, the undercut feature may be a through hole. This creates a through passage from the undercut region to either the core or the cavity region. The undercut(s) therefore need to be separated from the regions to be covered by core and cavity. This is done by creating a surface or a patch at the interface of the undercut region with core or cavity. This surface creation is done by using fill surface command, wherein the user is prompted to select inner edges of undercut feature. The purpose of creating this patch is to facilitate formation of shut-off surfaces. A shut-off surface is nothing but a surface formed by stitching all the core side surfaces (core shut-off surface) and cavity side surfaces (cavity shut-off surface) of the part.

Fig. 4.4: A snapshot of the GUI of shut-off surface creation module
The *Mould Tool* which is an application of *SolidWorks* software is used for the purpose of creating shut-off surfaces. The algorithm for shut-off surface creation is shown in part 2 of Figure 4.3. A snapshot of core and cavity shut-off surfaces of a part model having undercuts on two sides is shown in Figure 4.4.

### 4.3 Core and Cavity Generation for a Single-Cavity

*Core and cavity generation for a single-cavity* module is used for generation of core and cavity for a single-cavity die. The single core and cavity so generated are utilized in later modules to generate multi-cavity core and cavity. The sequence of steps followed in this module is as follows:

- Create a plane at highest point of the parting line.
- Draw a rectangular sketch on this plane, whose size equals maximum projected dimensions of the die-cast part.
- This rectangular sketch is offset by applicable clearances.
- Parting surface is created by extruding the parting line beyond this rectangular sketch.
- This rectangular sketch is extruded in bi-direction to create solid box called bounding box around part model.
- The bounding box is divided into core and cavity halves by taking parting surface as the dividing surface using *Tooling Split* function of *SolidWorks* API. The *Tooling Split* function subtracts the part model from the bounding box and also keeps a copy of part model.
- Core and cavity shut-off surfaces are used to separate core and cavity halves to get core, cavity for a single-cavity.
All the steps described above are automated in the developed system and the user only needs to click a button named *core and cavity for single-cavity* to generate the core and cavity blocks. The algorithm pertaining to this module is shown in part 3 of the Figure 4.3. The output from this module is used as an input to the next module of the system, namely the side-core design module.

### 4.4 Side-Core Design

This module of the developed *system for core, cavity and side-core design* is used for generating side-core(s) for a single-cavity. The direction of side-core removal is the same as that selected by the user interactively in the part model. The steps used in this module are mentioned below.

- A plane parallel to the parting direction is created on that side of the die-cast part where an undercut is present.
- The user needs to select the outer edges of the undercut feature and the undercut withdrawal direction. These selected edges form a closed loop to form a sketch, which is selected for the next step.
- The selected sketch is extruded up to the plane, which was created in the first step of this module.
- To generate side-cores, split feature of *SolidWorks* is used to create multiple bodies from a single body.

Figure 4.5 shows a part model having two undercuts. The first undercut is cylindrical in shape having ‘Plus X’ withdrawal direction, and the second undercut is hexagonal shaped having ‘Plus Z’ withdrawal direction. For the cylindrical shaped undercut, the generated side-core is shown in Figure 4.5. The procedure followed to generate side-core for the second undercut is described. The user only needs to select
the side-core direction (shown as ‘Plus Z’ in Figure 4.5) and ‘sketch2’ shown on the part model itself (shown in construction history as well) to generate the side-core.

Fig. 4.5: A snapshot of the GUI of side-core design

4.5 Multi-Cavity Core and Cavity Generation

The multi-cavity core and cavity generation module of the developed system for core, cavity and side-core design for a multi-cavity die-casting die, which is used to generate core, cavity and side-core for a multi-cavity die, is discussed in following paragraphs.

4.5.1 Relationship between single-cavity and multi-cavity

As already discussed in Chapter 1, in a single-cavity die only one part is produced in a die-casting processing cycle. A multi-cavity die is used to produce a number of parts in a single die-casting processing cycle. A multi-cavity die has a
number of identical impressions, which are generally arranged in a particular layout pattern. The layout pattern in which the cavities are arranged has already been discussed in Chapter 3. The identical impressions, also known as cavities are connected with a gating system, which is used to feed all the cavities. For generating a multi-cavity die, details of a single-cavity are first figured out, which are then utilized for design of the multi-cavity in a definite relationship. The relationship between a single-cavity and multi-cavity is outlined in the following points.

- Parting surface, which is the surface that divides the cavity into core and cavity halves remains the same in a single-cavity as well as in a multi-cavity die.
- The undercut features, which are recognized for a single-cavity, are also applicable for the multi-cavity.
- The individual cavities in a multi-cavity die are placed in the die-base in such a way that there is sufficient clearance distance between any two adjacent cavities.
- In both single-cavity and multi-cavity dies, the clearance distance between a cavity and edges of the die-base remain the same.
- Same shrinkage rate and draft allowance rules are applicable in both the single-cavity and multi-cavity dies.

4.5.2 Generation of multi-cavity die

This module of the developed system for core, cavity and side-core design for a multi-cavity die-casting die provides final output in the form of CAD model of the core and cavity for a multi-cavity die. The core and cavity CAD models can be directly used for process planning and manufacturing of the die. The steps followed in this module to generate multi-cavity core and cavity are mentioned below.
• The output of the previous module, *core and cavity generation for a single-cavity* is taken as input.

• Single core-half and cavity-half are patterned as per previously determined number of cavities in the selected layout pattern (see Chapter 3).

• The complete arrangement of above mentioned core-halves and cavity-halves is enclosed inside a bounding box with applicable clearances on all six sides (+/-X, +/-Y, +/-Z direction).

• The bounding box is then split along parting surface into two halves.

• Boolean operation is performed to subtract all patterned core-halves from upper half of the bounding box to form a super-core.

• Similarly, all cavity-halves are subtracted from lower half of the bounding box to get a resulting solid.

• Subsequently, all the side-cores are also subtracted from the resulting solid to form a super-cavity. Super-core and super-cavity are the final core and cavity halves for the multi-cavity die.

One example of multi-cavity core, cavity and side-core is shown in an exploded view in Figure 4.8.

### 4.6 System Implementation and Results

An automated *system for core, cavity and side-core design for a multi-cavity die-casting die* for die-casting is developed using API of *SolidWorks* [13] with Windows XP operating system. An application programming interface (API) is a particular set of rules and specifications that any CAD system can follow to communicate with the design of a component. It serves as an interface between different software programs and facilitates their interaction, similar to the way the user
interface facilitates interaction between humans and computers [81]. The system uses object orientated programming approach used with Microsoft Visual Basic.NET (VB.NET) language [93].

The geometrical information of the part such as projected area, wall thickness, longest part depth, number of undercuts and their location is the only information to be provided by the user. Furthermore, the user has to provide data related to delivery date, lot size and total production time along-with the part material. Developed system is tested on a number of parts. To demonstrate the capabilities of the developed system, results obtained from the system for four die-cast parts are being presented in the following case studies.

*Case study: Part 1*

The die-cast part taken in this case study is an example part, which is shown in Figure 4.6. This part is having the characteristics of: Zinc alloy material, two undercut features in the selected parting direction and envelope size of 180 mm x 90 mm x 40 mm (Length x Breadth x Height).

![Fig. 4.6: Case study part 1](image-url)
Fig. 4.7: The cavity layout design for case study part 1

Fig. 4.8: Multi-cavity core and cavity along-with side-cores for case study part 1
Results generated by the system for core, cavity and side-core design for a multi-cavity die-casting die for this case study part are presented in Figure 4.7. The system generated a cavity layout arrangement in which the undercuts were on outer sides. The number of cavities determined by the system in this case study is four and the layout pattern is symmetric with central feeding system. Four is the maximum possible number of cavities when a die-casting part is having undercuts on two sides. The envelope size for a single cavity in this case is 218 mm x 128 mm x 120 mm, whereas size of the die base is 519 mm x 519 mm x 120 mm. The die layout generated in this case study is also satisfying the condition of minimum die-base size requirements. The standard die-base size selected by the system is 546 mm x 546 mm x 140 mm. CAD models of super-core, super-cavity and side-cores generated by the system in this case are presented in Figure 4.8 in an exploded view.

Case study: Part 2

The die-cast part taken in this case study is an example part, which is shown in Figure 4.9. This part is having the characteristics of: ZA alloy material, one undercut features in the selected parting direction and envelope size of 138.97 mm x 119.26 mm x 72 mm (Length x Breadth x Height).

Fig. 4.9: Case study part 2
Fig. 4.10: The cavity layout design for case study part 2

Fig. 4.11: Multi-cavity core and cavity along-with side-cores for case study part 2
Results generated by the system for core, cavity and side-core design for a multi-cavity die-casting die for this case study are presented in Figure 4.10. The system generates a cavity layout arrangement in which the undercuts are lying on outer and opposite sides. The number of cavities determined by the system in this case study is six and the selected layout pattern is series with central feeding system. Envelope size for single cavity in this case is 176.97 mm x 157.26 mm x 152 mm, while size of the die base is 716.91 mm x 471.52 mm x 152 mm. The die layout generated in this case study is also satisfying the condition of minimum die-base size requirements. The standard die-base size selected by the system is 796 mm x 496 mm x 170 mm. The CAD models of super-core, super-cavity and side-cores generated by the system in this case study are presented in Figure 4.11 in an exploded view.

Case study: Part 3 (Cylinder Head Cover)

The die-cast part taken in this case study is of an automotive part named cylinder head cover, which is shown in Figure 4.12. This part is having the characteristics of: aluminium alloy material, no undercut features in the selected parting direction and envelope size of 82.8 mm x 65.3 mm x 15 mm (Length x Breadth x Height).
Fig. 4.13: The cavity layout design for cylinder head cover

Fig. 4.14: Multi-cavity core and cavity for cylinder head cover
Results generated by the system for core, cavity and side-core design for a multi-cavity die-casting die for this case study part are presented in Figure 4.13. The number of cavities determined by the system in this case study is four and the selected layout pattern is series with bottom feeding system. The envelope size for a single cavity in this case is 120.8 mm x 103.3 mm x 95 mm, whereas size of the die base is 490.6 mm x 355.6 mm x 95 mm. The die layout generated in this case study is also satisfying the condition of minimum die-base size requirements. The standard die-base size selected by the system is 496 mm x 396 mm x 115 mm. The CAD models of super-core, and super-cavity generated by the system in this case are presented in Figure 4.14 in an exploded view.

Case study: Part 4 (Clutch Centre)

The die-cast part taken in this case study is of an automotive part named clutch centre, which is shown in Figure 4.15. This part is having the characteristics of: aluminium alloy material, no undercut features in the selected parting direction and envelope size of 67.8 mm x 67.8 mm x 50 mm (Length x Breadth x Height).
Fig. 4.16: The cavity layout design for clutch centre

Fig. 4.17: Multi-cavity core and cavity for clutch centre
Results generated by the system for core, cavity and side-core design for a multi-cavity die-casting die for this case study part are presented in Figure 4.16. The number of cavities determined by the system in this case study is five and the selected layout pattern is half-circular with bottom feeding system. The envelope size for a single cavity in this case is 105.8 mm x 105.8 mm x 130 mm, whereas size of the die base is 585.6 mm x 576.7 mm x 130 mm. The die layout generated in this case study is also satisfying the condition of minimum die-base size requirements. The standard die-base size selected by the system was 596 mm x 596 mm x 150 mm. CAD models of super-core and super-cavity generated by the system in this case are presented in Figure 4.17 in an exploded view.

Discussion: The present system depends upon a knowledge-base, which is developed with the help of available literature and guidelines provided by the industry experts. Opinions of the industrial experts were taken to verify results. Furthermore, enough flexibility has been provided in the system that enables the user to alter suggested decisions interactively, which makes the system quite useful under practical situations.

4.7 Conclusions

A system for core, cavity and side-core design for a multi-cavity die-casting die has been presented which can be used for design of a multi-cavity die-casting die. It uses CAD model of the part (as a SolidWorks part file) along-with user interaction to generate CAD files of core, cavity and side-cores for a multi-cavity die-casting die in a semi-automated fashion. The API toolkit of SolidWorks along-with VB.NET programming is used to develop this system. The proposed system is an effort to integrate die-casting die-design application into an existing CAD software.
The developed system is able to perform several die-design steps in very less time with some interaction from the user. The system for core, cavity and side-core design for a multi-cavity die-casting die generates CAD models of core, cavity and side-core for a multi-cavity die. Use of databases of alloys, machines, clearances and standard die-bases, along-with die-casting die-design rules makes this system least dependent on the die-design expert; the system alongside reduces lead time for producing a die-cast part. CAD files of different die components, such as core, cavity and side-core, which are generated by the system, can subsequently be used for their computer-aided manufacturing. The computer-aided manufacturing of the die components is however not in the scope of this thesis. The proposed system can therefore be used as an add-on application of SolidWorks which can be further extended to other CAD packages like CATIA, Pro/E and NX.

Since SolidWorks is proprietary software, some of the data extraction from CAD file of the part is not feasible, which was therefore taken as an input from the user. The identification of undercut features and their location and determination of parting direction [18-21, 24-27] in an automated manner would increase the level of automation and make the system more useful.

Following paragraphs summarize some of the major advantages of the developed system. An overview of the comparison between the developed system and the existing mould tool applications is provided in Table 4.1.

- The developed system works as an add-on application for design of core, cavity and side-core for multi-cavity die-casting die for an existing CAD software, which in this case is SolidWorks. Such an application is much desirable by the
die-casting industry since available mould design applications of CAD software do not provide such functionalities especially suitable for die-casting.

- The generation of core, cavity blocks for single-cavity die require a number of activities to be carried out with manual interaction. The time spent in this activity usually varies from 15 to 30 minutes, which depends upon the complexities of the die-cast part. In the developed system, the core and cavity generation for a single-cavity die is semi-automated and can be completed in 2-3 minutes.

- The time taken for generation of side-core usually varies from 15 to 30 minutes depending upon the number of side-cores requires. This function is also semi-automated in the developed system, and the time taken to generate a side-core using the proposed system is around 5 minute, which is a significant saving of time.

- Multi-cavity dies are quite common in the industry, but most of the existing systems do not provides direct facility to generate their core, cavity and side-core. A number of activities need to be performed by the designer using his/her experience to generate CAD model of core, cavity and side-core. The developed system is capable to generate CAD model of core, cavity and side-cores for multi-cavity dies in very less time in a semi-automated manner.
Table 4.1: Comparison of developed system for core, cavity and side-core design application with an existing mould tool design application

<table>
<thead>
<tr>
<th>Modules</th>
<th>Existing mould tool design application</th>
<th>Developed system for core, cavity and side-core design</th>
<th>How developed system is better?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parting line selection</td>
<td>a) Input parting direction</td>
<td>a) Parting direction is by default +Y/-Y</td>
<td>No difference</td>
</tr>
<tr>
<td></td>
<td>b) Select edges to create parting line</td>
<td>b) Select edges to create parting line</td>
<td></td>
</tr>
<tr>
<td>Shut-off surface creation</td>
<td>a) Select edges to create shut-off surfaces</td>
<td>a) Select edges to create shut-off surfaces</td>
<td>No difference</td>
</tr>
</tbody>
</table>
| Core, cavity generation for a single-cavity | a) Parting surface creation | Fully automatic (completed in 2-3 minute) | • Reduce human expertise  
                                | b) Core and cavity generation using Tooling Split command of mould tool application, which requires number of inputs from the user | |  
|         | c) Time Taken: 15 ~ 30 Minutes | |  
| Side-core design | a) The side-core design requires a number of activities to be carried out, such as selection of the side on which the side-core is needed, shape of the side-core, side-core withdrawal direction, and length of side-core | a) Side-core creation requires only two activities to be carried out by the designer, i.e., selection of the sketch to define side-core shape, and side-core withdrawal direction. | • Reduce human expertise  
|         | b) Time Taken: 15 ~ 30 Minutes | b) Time Taken: 5 Minutes |  
| Multi-cavity core and cavity generation | a) Creation of core and cavity for a multi-cavity die involves a number of activities to be carried out that requires knowledge and experience of a die-designer. | Fully automatic (completed in 2-3 minute) | • Reduce human expertise  
|         | b) Time Taken: 30 ~ 60 Minutes | |  

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