Generation of Optimum Parting Lines for Metal Cast Parts

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ABSTRACT

The quality and cost of parts developed using metal casting is directly impacted by the tooling comprising of the pattern halves, core boxes, loose pieces. The tooling cost is largely determined by the type of the parting line (planar, stepped or profile)of the pattern and cores. An un-optimized parting line could lead to a larger number of cores which would lead to cost escalation. The automatic or semi-automatic identification of parting line from CAD models requires identifying undercuts comprising of curved surfaces, blends and their inter-relationships based on parameters such as curvature and visibility. A methodology for automatic suggestion of a non-planar (stepped or profile) parting line on an as-machined CAD model for metal cast parts has been proposed. The broad steps involve a stepwise update of the CAD model. The steps include identification of cavity cores, identification of external undercut cores, and their suppression, followed by silhouette generation. The methodology is applied in three principal directions and the parting lines in each direction are quantitatively evaluated to generate the optimum parting line. The methodology has been developed within a CAD system and a case study based on a real life part suggests that the approach generates robust and optimum profile parting lines.

1 Introduction

CAD systems are extensively used for designing patterns, core boxes, mould cavity. However, there is little knowledge base within CAD systems to support higher levels of automation. Most foundries and young patternmakers recreate or remodel the pattern and core-box models leading to time overruns and dimensional errors which ultimately impact the quality of casting. Following are some of the limitations of the current approaches[1]:

- Insignificant re-use of product information available within the CAD model by foundries and patternmakers.
- Lack of integrated system to capture standards (e.g. ISO 8062, [2]), good castability and mouldability practices[3].
- Greater human skill and experience requirement at different stages of casting design.
- Computing approaches are not leveraging digital trends of distributed architecture.

There is a need for a system that can bring together the knowledge and experience of expert pattern makers within the CAD systems for pattern and core box design in metal casting.

An important element of such a system is the ability to suggest optimized parting line for the pattern and core boxes. A parting line affects and is affected by part orientation, design of pattern and cores, number of cavities in the mould, location of feeders, and channels for gating, cooling and venting. An incorrect parting line negatively impacts quality and manufacturing cost.

Published literature [1-3] since 1990s highlights approaches taken regarding generation of parting lines along with considerations for mouldability. Most of the work is related to design, manufacturing integration of die-casting die design process for the injection moulding process.A major limitation of the approaches has been that the edge loops in the CAD model, are used to determine the parting line. If there are no edge loops then determination of parting line is difficult [4]. The same depth of published research is lacking in metal casting domain for the sand casting or permanent mould processes. Parts designed for metal casting have several unique characteristics: wide variations in part dimensions, higher thickness variations, complex shaped cavities, core handling requirements, multiple process options with each process having different capabilities and having its own impact on part weight, economic considerations for metal fluidity and heat transfer.

Parting lines can be planar(or flat) and non-planar which includes stepped or profile as shown in Fig 1[5].

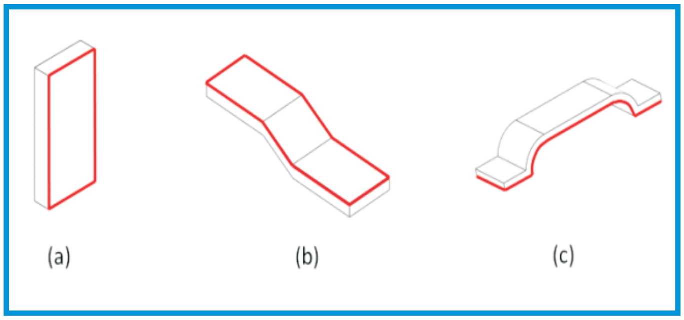

Fig 1: Parting Line types (a) Planar, (b) Stepped, (c) Profile

This paper presents an approach for generation of non-planar parting line (stepped, profile) for parts manufactured using metal casting process. The generated parting line can be analysed and optimized based on quantitative parameters. This is part of a tooling system which is designed as an add-in to a commercial CAD system[6].

2 Terminology

2.1 As-machined part model: This is the functionally designed part modelled by the OEM product design team.

2.2 As-cast part model: This is the modified as-machined part model based on considerations for castability and mouldability.

2.3 Manifold model: The algorithms described are developed to ensure that manifold solid models are generated at each step based on the API interfaces (Applications Programmable Interface) provided by the CAD system[6]. A manifold solid model as defined by[7] is one that satisfies the Euler-Poincare Law:

$$F-E+V-L= 2(B-G) \quad \text{.................. Eq. 1}$$

Where: F, E, V represent the face, edge and vertices; B represents the Bodies; L represents the inner loops; G represents the Genus.

2.4 Undercut: Any recess in a part which prevents its removal from the mould cavity is called an undercut. For a parting direction $\vec{P}$, with a face normal $\vec{N}$, the face is an undercut face if following conditions are satisfied for the dot product,

a. Face is located below parting line (drag face)

and $0 < \vec{P}\cdot\vec{N} \leq 1$ Eq. 2

b. Face is located above parting line (cope face)

and $-1 \leq \vec{P}\cdot\vec{N} < 0$ Eq. 3

Undercuts could be internal or external:

- **Internal undercuts** are due to faces of the cavities in the part, and are manufactured using cavity cores.
- **External undercuts**, are due to arrangement of faces on the exterior of the part such that they inhibit the removal of the pattern from the mould.They are typically manufactured by providing external cores.

2.5 Occluded region: A region of the part which is not visible when viewed in a given direction is called an occluded region in that direction. The undercuts are categorised based on their visibility in both the parting direction and the flipped direction. Refer to Fig.2.

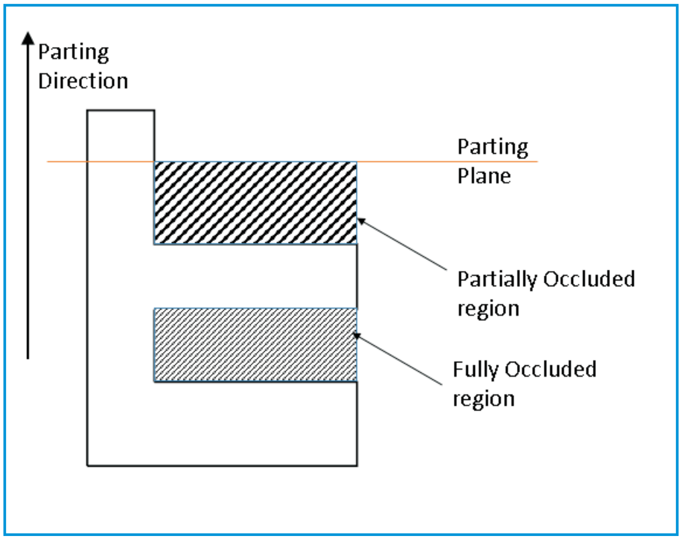

Fig 2: Types of Occluded Regions

- **Fully occluded region:** These are the faces that are occluded by the part faces when viewed in the parting and flipped direction.
- **Partially occluded region:** These are the faces that are occluded by the part on one side and the parting plane on the other side. They are the consequence of the parting location chosen for a given parting direction.

2.6 Silhouette: A silhouette curve is created where the face curvature on the model instantaneously changes from positive to negative when viewed in the parting direction.The red line in the Fig.3 is the silhouette for the parting direction shown.

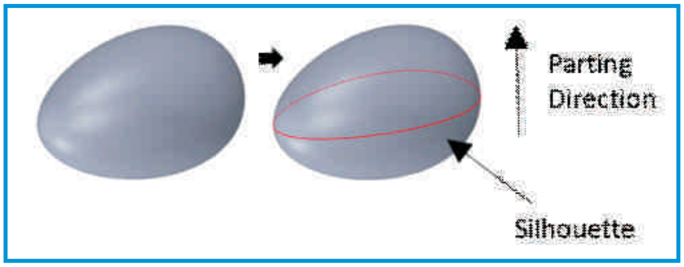

Fig 3: Silhouette and Parting Direction

2.7 Parameters for Evaluating Parting Line: Parting Line is evaluated on following three key parameters[8]: Undercuts, Draw Distance, and Flatness.

- **Undercuts:**

Quantitatively, optimum parting line (for the pattern) can be chosen by minimising the number and volume of external cores. Alternatively, a dimensionless factor for undercuts can be defined as:

$$P_U = \frac{1}{1+N_C}\left(1 - \frac{\sum_i V(C_i)}{V(D)}\right) \qquad Eq.4$$

Where, N_C = number of cored undercuts, $V(C_i)$ = volume of core i, $V(D)$ = volume of component.

- **Draw Distance:**

The draw distance is also critical since it drives the mould box dimensions and amount of draft allowance. The dimensionless factor for draw distance is defined as:

$$P_D = \frac{0.5 d_{min}}{\max_i(d_i)} \qquad Eq.5$$

Where, d_i = distance of withdrawal of mould segment (cope side or drag side), d_{mn} = smallest overall dimension of part.

- **Flatness:**

Flatness is an important parameter when comparing planar and non-planar parting lines. It is defined as the ratio of the total projected length of the parting line in the parting direction to the actual length of the parting line. For a planar parting line, flatness will be 1.

$$P_F = \frac{\sum_i(|\bar{e}_i| \sin\theta_i)}{\sum_i(|\bar{e}_i|)} \qquad Eq.6$$

Where, $\bar{e}_i$=edge *i* of parting line, θ_i = angle between $\bar{e}_i$ and parting direction

3 Key Steps in Algorithm for generation of Non-Planar Parting Line for Pattern

The algorithm is based on a step-wise update of the as-machined part based on castability and mouldability considerations. The algorithm is applied to a manifold part as a case study as shown in Fig. 4.

For a given part orientation and a parting direction the following are the key steps in the algorithm:

1. Identification and Suppression of Machined holes:

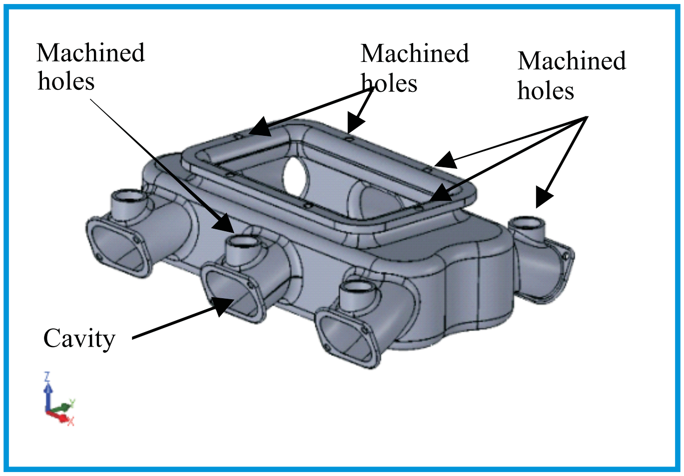

Fig 4: As-machined Manifold model

1.1 The system automatically recognizes and suppresses machined hole chains based on user defined tooling information. The volume of the as-cast part along with volume to be machined is computed. Refer to Fig.5

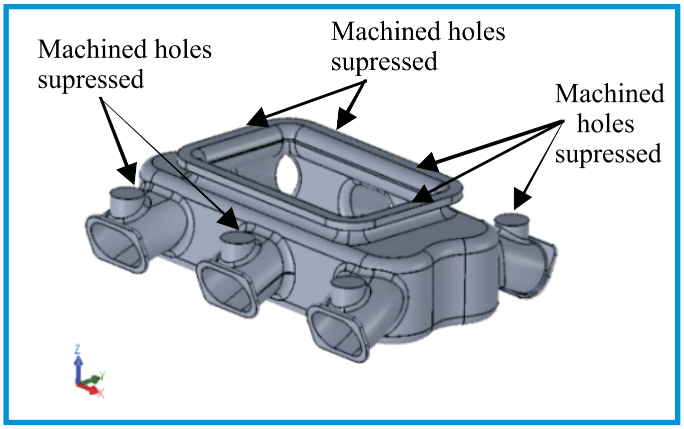

Fig 5: Part with machined holes suppressed

2. Identification and Suppression of Cavity regions:

2.1 Generation of cavity core volume and suppression:Castings such as pumps, valves, manifolds, housings have complex shaped cavities which are manufactured using cores. The ends faces (or openings) of the cavity core need to be provided as input and the system then computes the cavity core volume and also suppresses the same. The volume of the cavity core along with the updated as-cast part is computed.

2.2 Addition of core prints: These are extensions to the core volume provided due to mouldability considerations for core stability. The dimensions of core prints are determined based on buoyancy calculations. Refer to Fig. 6. .Core prints are important in determining location of parting line in the case where the core opening is in a direction normal to the parting direction.

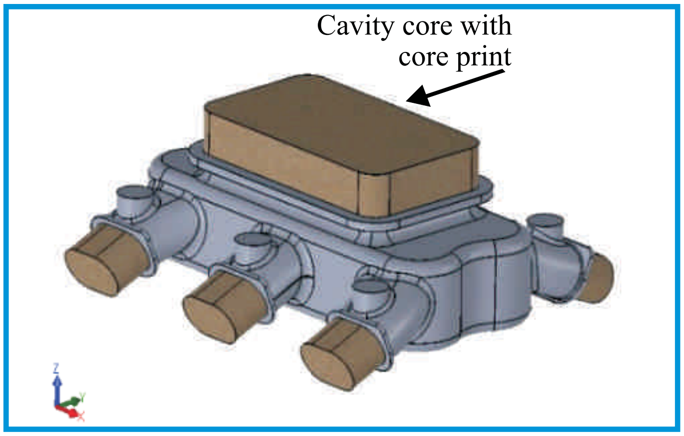

Fig 6: Part with cavity core and core prints

3. Curvature based splitting of faces:

3.1 For as-cast model faces having curvature in parting direction, silhouette curve in parting direction is identified and the faces are split.

4. Identification and Suppression of Fully occluded regions:

4.1 Identification of Fully occluded regions: There are regions within a part model which are self-occluding. Refer to Fig 2. The faces that constitute such a region are identified using ray firing techniques. It should be noted that a complete face or part of a face may form part of a fully occluded region. Vertical faces (w.r. to parting direction) that are connecting and adjacent to complementary fully occluded regions are included as part of the fully occluded region.

4.2 Generation of external undercut core volumes: For each fully occluded regions, a closed outline is generated and an extruded or swept or revolved volume is created called the external undercut volume.

4.3 Addition of core prints: The core print extension directions are determined by analysing the two non-parting directions to identify supporting faces for the core prints in the mould. The dimensions of the core print are based on buoyancy and mouldability considerations related to proper support for the core. Fig 7 shows the output of steps 4.1, 4.2, 4.3.

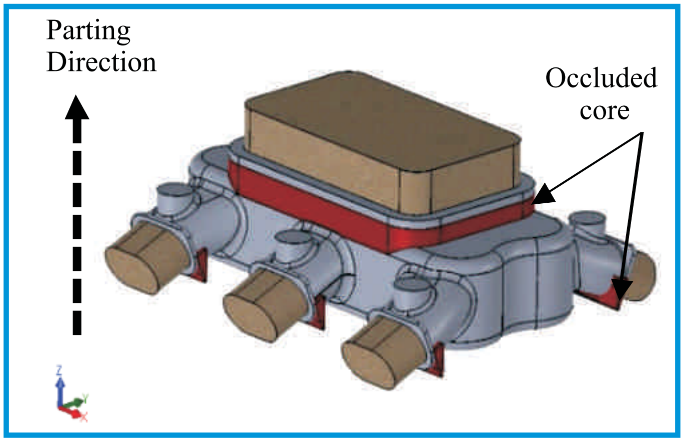

Fig 7: Part with fully occluded core volumes, core print in given parting direction

4.4 ***Suppression of external undercut volume***: The external undercut volumes are merged with the updated as-cast part of the previous steps.

5. Identification of silhouette which represents the initial parting line:

5.1 The as-cast part silhouette is generated based on the parting direction. This is the initial parting line. The generated silhouette is a closed curve that could be planar or non-planar depending on the as-cast part geometry. The silhouette is generated as a 3D sketch within the CAD system. The generation of the silhouette curve has to be such that it does not introduce any additional undercuts.

6. Modification of initial parting line to maximise flatness

6.1 The silhouette curves on vertical faces are moved along the vertical faces in order to maximise flatness and also to locate parting at core centres.

7. Comparing and analysing the parting line for multiple parting directions based on key quantitative criteria:

7.1 The above steps are repeated for the three principal directions. The steps can also be executed for any additional direction.

7.2 The parting line is then analysed based on key parameters such as: Undercut volume, draw distance, parting line length thereby providing an optimized parting line.

8 Additionally, rules for part orientation can be defined which include general practices followed in the foundries such as: heavier part will be in the drag, blind cores should be oriented such that air blow hole defect is minimized.

4 Case Study

The algorithm, described in Section 3, is applied to a real life manifold part. The three principal directions are taken as potential parting directions. The resulting parting line is shown for each of the three directions in Figures 8, 9, 10.

It can be seen that the X, Y parting directions result in a planar parting line and the Z parting direction results in a non-planar (profile) parting line.

The parting lines are evaluated as per parameters specified in Table1.

Table 1:Comparison of Parting Line in X,Y,Z directions

Parameter	Parting Direction		
	X	Y	Z
Undercut *(Eq 1)*	-0.062	0.0153	0.134
Flatness *(Eq. 2)*	1	1	0.814
Draw Distance *(Eq 3)*	0.264	0.314	0.391
Draw Distance *(mm)*	127	106.72	85.6
Number of undercut Cores	2	4	7
Net Undercut Core volume *(mm3)*	4,32,042.06	3,35,537.21	67,569.27
Length of Parting Line *(mm)*	656.72	686.67	2,707.6

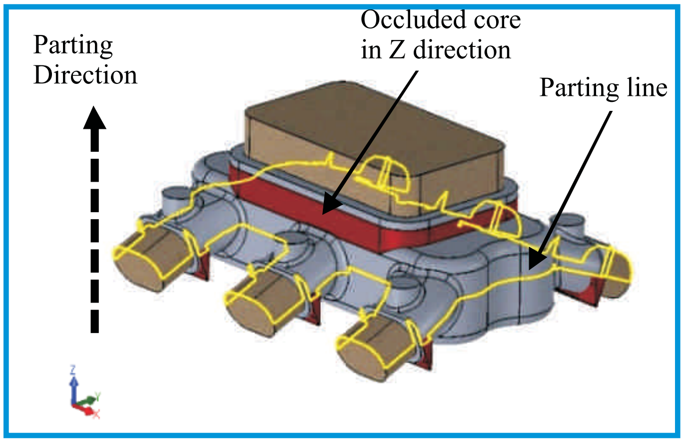

Fig 8: Parting line for Z parting direction

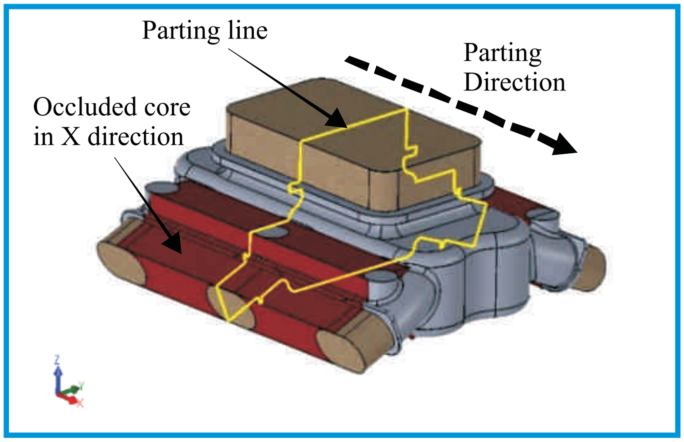

Fig 9: Parting line for X parting direction

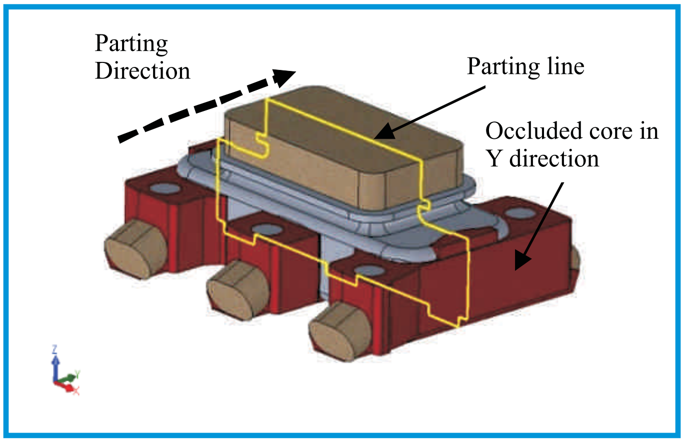

Fig 10: Parting line for Y parting direction

The Z parting direction and the corresponding non-planar parting line generates the least undercut volumes and draw distance. The same has been confirmed by trials with production facilities.

5 Conclusions

An innovative algorithm that generates a non-planar (stepped or profile) parting line for patterns for sand casting and dies for gravity die casting processes has been outlined. The parting line is generated for multiple directions and parameters such as undercut volumes, flatness, and draw distance can be compared for each direction. An optimum parting line which satisfies the quality and cost criteria is thereby generated.

A provisional patent has been filed (PCT/IN2015/000041 dated 22/01/2015) for the technology.

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