AUTOMATIC DETERMINATION OF PARTING LINE AND NUMBER OF CAVITIES IN DIE CASTING DIE

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Abstract— Mold cavity and core are important working parts of mold directly affecting product casting. Design process of mold cavity and core for a casting part includes three related tasks namely, determining parting direction, parting line and parting surface. Further the number of cavities in a single die-casting dies in another important aspect of die design. Determination the design entities have important role in die structure design. In the present work, MATLAB is used to determine the parting line and direction along with parting surface. An automatic system is developed that accepts a machine and product data as input and give result as number of cavities in die casting die.

Keywords: Die-casting, Parting line, Parting direction, GUI, Multi Cavity Dies, STL file

I. INTRODUCTION

Die-casting is a versatile process for producing engineered metal parts by forcing molten metal under high pressure into reusable steel molds to produce complex shapes with a high degree of accuracy and repeatability. The main stages in producing a die casting product using a die casting machine include (a) Clamping (b) Pouring of Molten Metal (c) Cavity Filling (d) Solidification (e) Ejection and Trimming [1].The standard process is to prepare and use a CAD model of the part for designing and making the CAD model of the die [2]. The manufacturing data is generated form the CAD model of the die. However, all the parameters for a die-casting die are decided by a die-casting expert using his expertise with no or sometimes very little automation. Moreover, the design process is iterative in nature and consumes much of the time of die-casting expert. Therefore die design is a gap in design manufacturing integration of die-casting process. The system would take 3-D model of the part as input, recognize features of the part model and determine different aspects of die such as, parting direction, parting surface, gate runner design, cavity layout [2].The principal parameters taken into account are: shape and size of the part, material of the part, type and capacity of the machine, lot size, and tolerances required. Based on the above parameters, features like: design of cavity, number of cavities, gating and runner system, parting design, cooling design etc. are determined [1].

Parting Line [4].

Fig 2 illustrates the key entities in a parting system. For a given design, the moulded product is formed between the core and cavity inserts, and ejected after the core and cavity inserts are opened. The pull direction along which the core and cavity inserts are opened is called the parting direction (PD). PD+ is the moving direction of the cavity insert, while PD- represents the moving direction of the core insert.

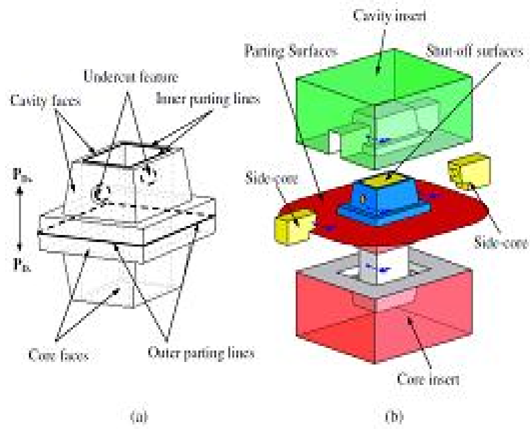

Fig 2: Dominations in Parting Line [3]

Multi Cavity Die Casting Dies

At the initial stage of the die design, a decision must be made to select, types of die which may be either a single cavity die or a multi-cavity die [4]. Multi-cavity dies introduce a cost reduction of in the form of labor cost and high production rate. Thus the design of number of cavities in should make a balance between the high productivity and setup and running cost. Fig 3 shows the steps for arrangement of cavities in a typical mold.

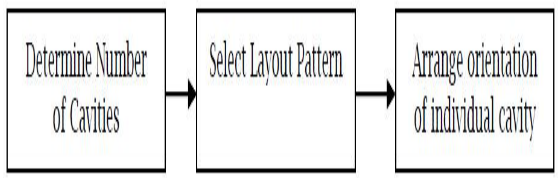

Fig 3: Automatic cavity layout design [4]

Once the number of possible cavities determined, the data can be used to design the arrangement of

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cavities throughout the die mold i.e. the cavity layout and orientation of cavities in a die.

II. LITERATURE REVIEW

Key researchers work related to parting line determination and multi-cavity design being discussed in the preceding section. Khardekar and McMains [2] presented a methodology to compute near flat parting line passing through vertical facets of a tessellated CAD model. Madan et al. [3] used feature recognition for determination of parting direction and parting line for die casting parts. Singh et al. [5] proposed a system to select optimum parting line out of present candidate parting lines. Kumar et al. [6] proposed a method for recognition of parting surface of the moulded parts. Chakraborty and Reddy [7] proposed a system in which selection of best parting direction and parting surfaces was based on minimum number of undercuts, flatness of parting surface and draw depth. Kumar et al. [8] demonstrated that using multi-cavity die will reduce labor cost and increase the production efficiency. Hu and Masood [9] developed an Intelligent Cavity Layout Design System (ICLDS) for multiple cavity injection mold that assist mold designers in cavity layout design at its concept stage. Dewhurst and Blum [10] presented a methodology for cost estimation of die-cast parts considering processing time and manufacturing cost.

III. AUTOMATIC PARTING LINE DETERMINATION

As per literature, expert view or manual selection is needed to identify the optimum parting line. Besides this, the calculation of number of cavities is done manually. In this section, the parting line is determined for a 3D model designed in solid works (CAD software) with the help of MATLAB program. The system takes STL CAD file as input. The direction, in which the projected area of the part is maximum, is selected as parting direction.

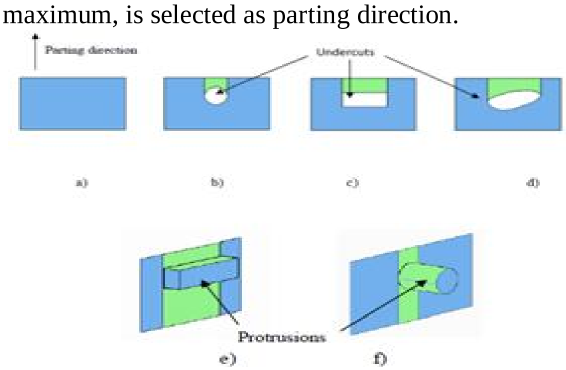

Fig 4: Parting line regions (in blue colour) for vertical surfaces with a) no undercut, b) circular undercut, c) Rectangular undercut, d) irregular undercut, e) rectangular protrusion and f) circular protrusion.

Parting Line determination

Parting line determination starts with common edges between core and cavity moulded facets. Parting line regions are selected one by one and parting line is determined for each based upon undercut position and shape. Vertical surfaces with their parting line region that are shown in Fig 4. Parting lines for these surfaces are shown in Fig 7 by bold lines. Parting line for vertical surface with circular and rectangular undercut is shown in Fig 5b & 5c Parting line for vertical surface with irregular shaped undercut is shown in Fig 5d. The profile of the undercut is divided by parting line into core and cavity moulded halves. Fig 5e shows a vertical surface with rectangular protrusion. Parting line for vertical surface with circular protrusion is shown in Fig 5f.

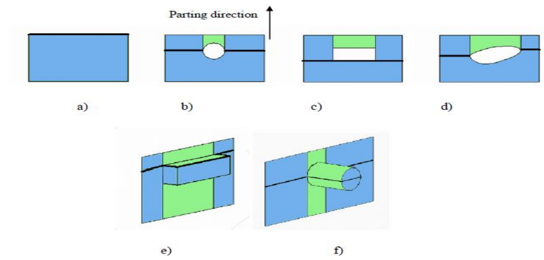

Fig 5: Parting line (bold black line) for different vertical surface with a) no undercut, b) circular undercut, c) rectangular undercut, d) irregular undercut, e) rectangular protrusion and f) circular protrusion.

Algorithm Steps:

Step1: Design the part model in any 3D CAD software.

Step2: Store this 3D CAD model as STL file(in ASCII).

Step3: Run Matlab code in Matlab software and call the STL
file to be checked against the matlab code, designed to determine parting line.

IV. AUTOMATIC NUMBER OF CAVITIES DETERMINATION

In the present study an effort is being made to automate the caculation of number of cavities a die can sustain easily satisfying the different design criteria and using the following production,part, machine, and material databases [7].

Determination of Number of Cavities

A multi-cavity die cetainly will save cost of production but this it will also increse the size of die and size of machine to be used. This will lead to larger investments. But by making a balance between factors affecting number of cavities, optimal number of cavity can be calculated.

1. Criterion for Selecting Number of Cavities [8]

A) Number of cavities based on delivery date [N_{del}]

The number of cavities must ensure that the order can be Based production database, the minimum number of cavities for meeting the delivery date can be determined as.

$$N_{del} = \frac{K_r \times t_{cycle} \times L}{t_m} \quad \ldots(1)$$

Where, K_r=Rejection factor, t_{cycle}=Cycle time of product (sec), L=Lot size, t_m=Time available for production (sec).

B) Number of cavities based on cost [N_{cost}]

The optimum number of cavities to be used in the die casting die can be determined as [8]:

$$N^{m+1}{}_{cost} = \left[\frac{L \times (b_d \times t_m + C_{rt} \times t_{po})}{m(C_d + C_t)} \right] \quad \ldots.(2)$$

Where L=lot Size, b_d=minimum casting machine rate (\$/hr), t_m=Die casting machine cycle time (hr), C_{rt}=Trim press & operator rate (\$/hr), T_{po}=Trimming cycle time (hr), C_d=Cost of single cavity die casting die (\$), C_t= Cost of single trim die (\$), m= multi-cavity die cost exponent (0.7).

C) Number of cavities based on machine parameters [N_{mac}]

The capacity of a die-casting machine is also limited by its parameters. Number of cavities is therefore dependent upon the constraints of the diecasting machine like clamping (locking) force, the maximum flow rate and the machine size.

D) Number of cavities based on the clamping force [N_{cf}]

The force applied by the machine is required to hold the die halves together and must therefore exceed the force generated within the die [8]. Thus, the maximum number of cavities can be calculated as follows:

$$N_{cf} = \frac{F_C}{K \times A_P \times P_M} \quad \ldots(3)$$

Where, F_C=Maximum clamping force (N), A_P=Projected area, its overflow and runner (mm²), P_M=Maximum metal pressure (M Pa), K = Factor of safety against flashing (1.75)

E) Number of cavities based on the maximum flow rate [Nfr]

The maximum number of cavities can be found as follows:

$$N_{fr} = \frac{V_S}{V} \quad \ldots.(4)$$

Where, V_S=Volume of metal pushed into the cavity by shot system (mm³), V=Volume of cavity (mm³). V is (1+2/h) times the Volume of each cavity to accommodate overflow and runner volume. h=Average wall thickness (mm).

F) Number of cavities based on the machine size [Nms]

Assuming that the cavities are arranged in a rectangular array in the die, the maximum number of cavities will be:

$$N_{ms} = (\text{int})\left[\frac{L_{die} - L_{mar}}{L_{ins} + 0.5L_{dis}}\right] \times (\text{int})\left[\frac{W_{die} - L_{mar}}{W_{ins} + 0.5L_{dis}}\right] \quad \ldots.(5)$$

L_{die} and W_{die} are the allowable maximum length and width of the die used (mm), L_{ins} and W_{ins} = length and width of the cavity inserts (mm), L_{mar} = Minimum margin between edges of die and inserts (mm), L_{dis} = Minimum distance between cavity inserts (mm), and int = Mathematic function

V. IMPLEMENTATION AND RESULTS

Determination of Parting Line

Part 1: The presented methodology is tested on some sample parts. Sample part 1 (P1) is shown in Fig 6 with two its different views. The parting direction is input by the user and based on the given parting direction, parting line is selected.

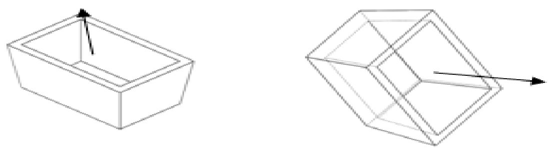

Fig 6: Sample part 1 (P1)

The sample part is designed in the solid works 3D software. The parting line as well the parting direction in 3D CAD software is to be selected by the designer manually. Fig 7 shows a typical solid works window including part P1. Thus according to the methodology the common edge should be selected as the parting line automatically by the proposed system generated in the MATLAB.

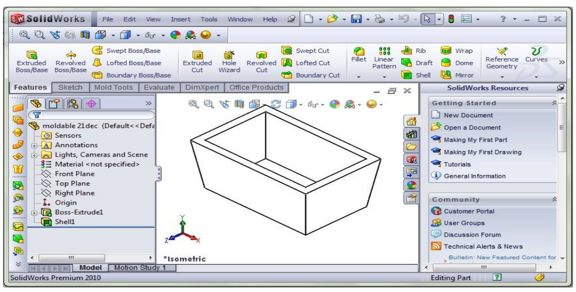

Fig 7: Typical window of solid works containing sample part

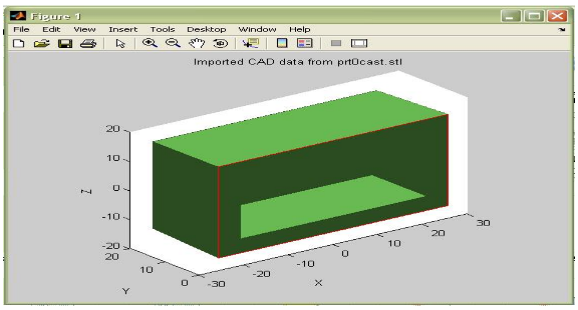

Fig 8: Automatic parting line determined by proposed methdology

Fig 8 shows result window of MATLAB, generated by after implementation of the system on P1. The window generated shows the automatic parting line. The parting line generated is the outer parting line, covering maximum projected area, which is one of the required conditions for good parting line.

Part 2: Fig 9 shows sample part 2 (P2) which is a free form sample model in solid works window. Fig 10 shows the determined parting line in the MATLAB window. It is clearly seen that the largest outer loop covering largest projected area is selected as parting line. In addition, the parting line generated is at the core side of the casting. Thus the system generated can be used to determined the parting line for 3D part models of different configurations.

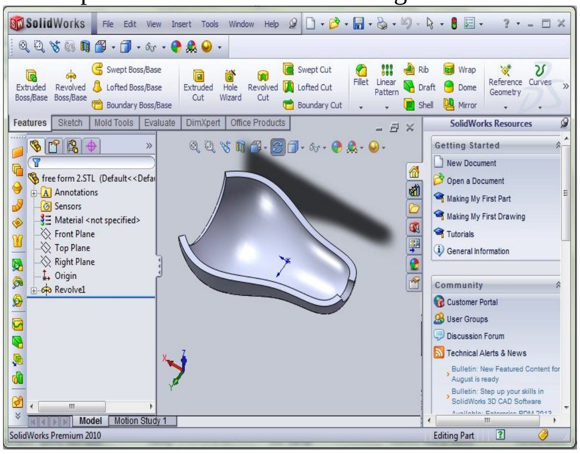

Fig 9: Sample Part 2 (P2)

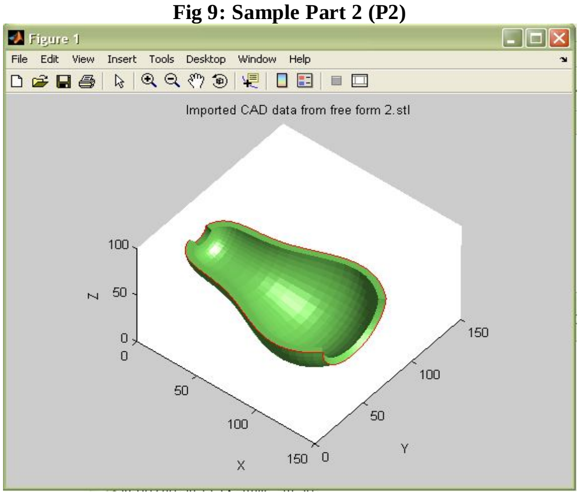

Fig 10: Parting line determined for a free form part model

Determination of Number of Cavities

A system is designed in GUI environment of MATLAB to calculate number of cavities based on technical data like production database. The system is able to determine Number of cavities for various combinations of machine and product data can be calculated using the system. Case 1: Fig 11 shows a GUI window interface of the designed system for demonstration of case1. It is clear from the result that if part number 1 is made of aluminum and generated die is used with machine number 1, the number of optimum cavities for die is 2.

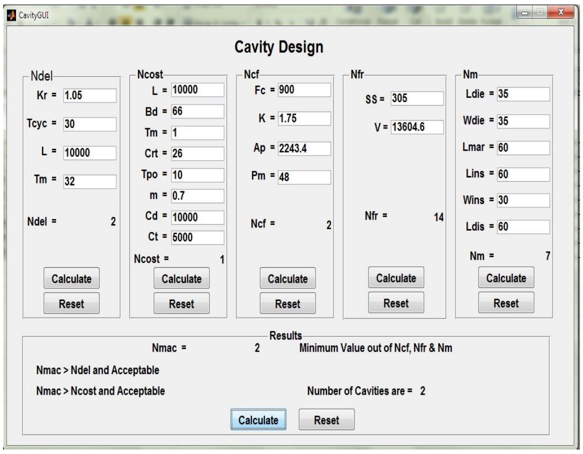

Fig 11: GUI window case 1

Case 2: The part number 2 tested with machine 1 for optimum number of cavities in die. Fig 12 shows a GUI window interface of the designed system for demonstration of case 2. The optimum number of cavities is not achievable with above combination.

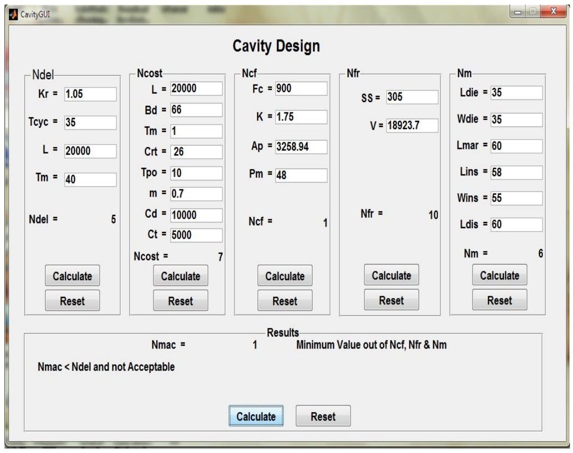

Fig 12: GUI window case 2

Case 3: The part number 2 tested with machine 2 for optimum number of cavities in die. Fig 13 shows a GUI window interface of the designed system for demonstration of case 3. Again, the result is not acceptable by the system.

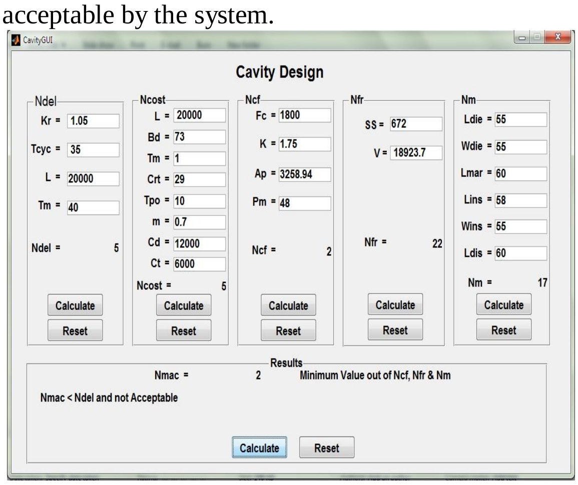

Fig 13: GUI window case 3

Case 4: The part number 2 tested with machine 3 for optimum number of cavities in die. Fig 14 shows a

GUI window interface of the designed system for demonstration of the results obtained for the case 4.

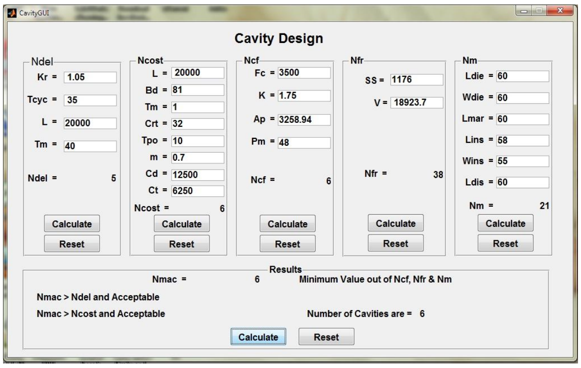

Fig 14: GUI window case 4

The value of N_{mac} is equal to 2, because N_{mac} is least value out of N_{cf}, N_{fr} and N_m (according to methodology). Further analyzing the N_{mac} we find that this value of N_{mac} is greater than N_{del} and N_{cost}. This shows that the number cavities for this particular combination of data is found to be 2 and is acceptable. Finally, the multi-cavity die for part 2 is achievable with machine no. 3. N_{mac} is greater than both N_{cost} and N_{del} and number of optimum cavities are found to be 6. The results summarized in table 1 shows that case 1 and case 4 comes with acceptable number of cavities while case 2 and case 3 shows unacceptable number of cavities.

Table 1: Results for multi cavity dies

	Case 1	Case 2	Case 3	Case 4
Part No.	1	2	2	2
Machine No.	1	1	2	3
N_{del}	2	5	5	5
N_{cost}	1	7	5	6
N_{cf}	2	1	2	6
N_{fr}	14	10	22	38
N_m	7	6	17	21
Number of cavities	2	1	2	6
Result	Acceptable	Not Acceptable	Not Acceptable	Acceptable

CONCLUSIONS

The present paper presents methodology to determine parting line for a die-casting part model in an automated manner. The presented parting methodologies have been implemented on the CAD models prepared on Solid Works platform using a system developed in MATLAB environment the case study shows that, approach developed is good enough to identify the parting line for 3D CAD model having common convex edge loop and surfaces parallel to the parting line.

The optimal number cavities in die-casting die can be determined using standard formulae. But the present approach is an effort towards automating the system. The standard formulae used to develop an automatic system using MATLAB environment. This developed GUI in MATLAB generates the number of cavities required in a die, thereby saving time for designer. The case study shows that system can be applied to various combinations of machine and other technical data to determine the number of cavities for a die-casting part.

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