System for Computer Aided Cavity Layout Design for Diecasting Dies

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ABSTRACT
Diecasting is one of the forming methods which is used for producing large number of components with good surface finish by injecting cast alloys in a metal mould under high pressure. Design of a diecasting die requires human expertise and is normally performed by trial and error method, which leads to monetary and time loss. Automation at initial die design stage will result in higher productivity besides reducing production lead time. Decision about number of cavities, layout pattern and placement of cavities in diecasting is critical for die design and manufacturing. This paper presents research work related to system for computer aided cavity layout design for diecasting dies. Proposed system consists of three modules namely determination of number of cavities, selection of layout pattern and placement of cavities in the die-base. It enables die designers to generate cavity layout design automatically from CAD (Computer Aided Design) file of the part with little information provided manually. Optimal number of cavities is determined by considering economic, technical, geometrical and time limitations followed by selection of layout pattern. Thereafter, cavities are placed in the die-base. The developed system depends upon database of diecasting machines and materials along with a knowledgebase of die design. This system has been tried on a number of diecasting parts and results have been found to be on the lines of those obtained from industry. Proposed system is more comprehensive than those available presently and is a step forward in the direction of design-manufacturing integration for diecasting.

KEYWORDS
Diecasting, Die Design, Multi Cavity Dies, Layout Patterns, Layout Design

INTRODUCTION

Die casting is a versatile process for producing metal parts by forcing molten metal under high pressure into reusable steel molds. These molds, called dies, can be designed to produce complex shapes with a high degree of accuracy and repeatability. Parts can be sharply defined, with smooth or textured surfaces, and are suitable for a wide variety of attractive and serviceable finishes [NADCA 2010].

The quality of parts produced by diecasting is essentially determined by the die. A diecasting die consists of two mould halves known as *core* and *cavity*. That part of die which remains stationary is called cavity half (or cover die) and the other half which is movable, is called core half (or ejector die). Two mould halves are assembled and poured with molten metal at high pressure. After solidification, these mould halves are separated and cast component is automatically ejected with the help of ejection mechanism. The direction in which core half moves is known as parting direction. Undercut feature is that region of the part which is not accessible from the parting direction or negative parting direction. Side core(s) are usually employed if a part has undercut feature(s). Figure 1 shows die casting process with basic terminology.

Diecasting die design is a complex and time consuming process that requires vast technical know-how and experience of a die designer. Determining number of cavities and its layout, gating system design, die-base design, parting design, setting shrinkage, core & cavity creation, ejection design, cooling design, side core design, and standard component design etc. are the tasks identified in diecasting die design [Fuh et al. 2002]. These tasks can be divided into two stages namely initial or conceptual die design and detail die design. At the conceptual stage of the die design, selection of type of mould configuration, determining number of cavities and its layout are the major tasks which also influence other tasks of die design.

A single cavity die is normally designed for a fairly large component. However, it is always more economical to design multi-cavity die so that more number of components can be produced in a single diecasting process cycle. At the initial stage of the die design a decision must be made to either have a single cavity or a multi-cavity die. Using a multi-cavity die will reduce cost of the product besides increasing productivity. Reinbacker [1980] suggested that on a per cavity cost basis, two cavities provide little saving, eight cavities cost 25% less and 64 cavities have an associated cost reduction of 60%.

For designing cavity layout of a diecasting die, designer must first determine the number of cavities. Deciding number of cavities depend upon several factors related to time and cost in addition to manufacturing and geometric limitations. This requires much attention of the diecasting expert and is also time consuming. Once the number of cavities has been determined, these have to be placed in the die base as ingeniously as possible in a particular pattern which requires good knowledge of die design. These decisions, together, are also crucial for deciding other downstream activities related to die design and manufacturing.

Cavity layout design therefore needs to be automated for achieving the objectives of design-manufacturing integration of diecasting process. Present research is motivated by the fact that an automated system for cavity layout design would be a step in the direction of design-manufacturing integration of diecasting and would ultimately result in reduced lead time and cost. Such a system would help the designer to determine optimal number of cavities and arranging these cavities with usual clearances in a very short time. A few attempts have been made by researchers in the past [Hu et al. 2002, Low et al. 2003] for cavity layout design, but most of these are limited to the use of case based approach and pre-loaded database. Use of generative approach for design of cavity layout has been given little attention.

In the present work a knowledge based system for computer aided cavity layout design for multi-cavity dies has been proposed which requires very less time and attention of the expert. The system takes geometrical information from CAD model of the part, while some other information is input interactively. It is able to determine number of cavities and placement of cavities in the die-base by using diecasting die design knowledge. This system is more comprehensive than previously known systems as it determines number of cavities by considering economical, technical, geometrical and time aspects. Possible solution of layout pattern and arrangement of cavities has also been provided in the proposed system by making use of die design knowledge.

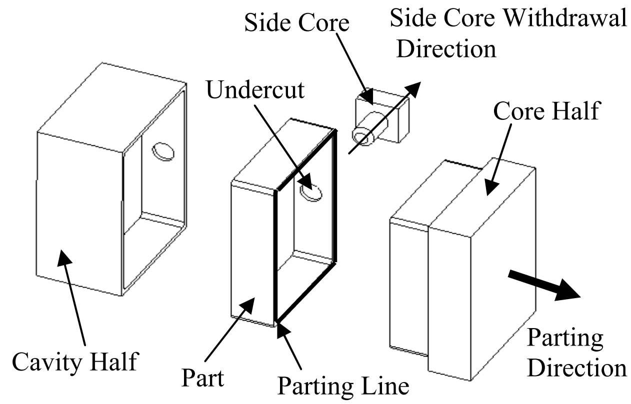

Figure 1. Diecasting Process Terminology.

Next section of this paper discusses related research and objectives of present study. Subsequent sections deal with three modules of the system i.e. determination of number of cavities, selection of layout pattern and layout design. This is followed by sections which discuss system architecture, implementation and results and, conclusions drawn from this research work.

RELATED RESEARCH

Most of the research in die design of diecasting is focused on parting line and parting surface determination only, while little attention has been given to identify optimal number of cavities and cavity layout design.

This section deals with review of previous research attempts made on determination of number of cavities and cavity layout design for diecasting die design. Some research papers published on the mould design of injection moulding have also been included due to strong similarity between both the processes.

Hu and Masood [2002] developed an Intelligent Cavity Layout Design System (ICLDS) for multiple cavity injection mould that assists mould designers in cavity layout design at early stages. This knowledge based system makes use of case-based and rule-based reasoning to arrive at layout solution. The system graphically shows the possible design of cavity layout based on the input taken from the user. It takes number of cavities as input from the user and is not able to extract the information from product model.

Low and Lee [2003] proposed a methodology of cavity layout design for plastic injection mould in which only standard cavity layouts are used. When only standard layouts are used, their layout configuration can be easily stored in a database for fast retrieval to be used in the mould design. However, undercut features and non-standard configurations have not been considered.

Ye et al. [2000] presented an algorithm for initial design of injection moulds. First of all it determines parting line for a part, followed by calculation of required number of cavities. The cavity layout is generated based on information of layout pattern and orientation of each cavity, which is taken from the user. The mould base is loaded automatically to accommodate the layout. However, this system does not consider exact details for clearance and selection of layout pattern is manual.

Ravi et al. [1994] developed a software package for providing intelligent assistance in several tasks involved in the design of diecasting dies. These typically include material selection, parting line location, gating calculations and die layout. Number of cavities is determined based on selected machine and alternate layouts are displayed to the user. However, this system can only handle axis-symmetric components. Further, only circular type layout pattern has been considered.

Fuh et al. [2002] developed a prototype system for diecasting die design which is structured by several functional modules as specific add-on application of Unigraphics (UG). These modules include data initialization, cavity layout and gating system design etc. However, the number of cavities has been determined based on selected machine only besides pattern selection for cavity layout requires human expertise.

Chan et al. [2003] developed an interactive knowledge-based injection mould design system called IKB-MOULD, which uses experience and knowledge of product design and mould manufacturing. It is a CAD system, which provides an interactive environment to assist designers in the rapid completion of mould design. Number of cavities is determined by using empirical relations only. The system does not consider geometrical constraints while calculating number of cavities. Balanced cavity layout patterns are only considered and also lacks in level of automation.

Woon and Lee [2004] proposed a system that enables the die designer to design a diecasting die beginning with CAD file of the part. It uses a methodology that combines feature-based and constraint-based modeling, in a parametric system along with geometrical and topological information extraction technique from a B-rep model together in the die design system. However, selection of number of cavities and cavity layout is not automatic and requires human expertise.

Wu et al. [2007] developed a system that helps to realize automatic generation of gating system by applying parametric design. Design module of the system deals with data initialization and cavity layout design. The number of cavities to be used is suggested on the basis of empirical relationship only. The system does not consider geometric constraints and cost factors for calculating number of cavities. Also, orientation of individual cavities is based on the expertise of the designer.

Dewhurst and Blum [1989] presented a methodology for cost estimation of die-cast parts by considering processing time and manufacturing cost. It derived an expression for optimum number of cavities considering cost factor only. However, it does not consider cavity layout design or platen size determination tasks.

Recent work on cost estimation of die-cast parts presented by Madan et al. [2006] determines number of cavities by considering factors like available manufacturing resources, diecasting machine constraints along-with limitations due to part geometric features. They used a knowledge base of die casting process to determine part cost in the environment of manufacturing resources. However, the system does not report any possible solution for arrangement of pattern layout and cavity layout design.

Research Gaps and Objectives of Present Work

Overview of past research indicates that number of cavities have been determined by considering one of the factors only i.e. diecasting machine or part manufacturing cost or delivery date. Also, geometric detail of the part which is quite important has not been considered. No such system has been reported that considers comprehensive factors of machine selected, allowable production cost, delivery date and part geometrical constraints for selection of number of cavities. Selection of layout pattern had been totally based on user selection and is limited to symmetric type layout pattern only. In actual practice, arrangement of cavities in the die base requires clearances to accommodate gating system and side-pulls which have not been taken into account in the earlier systems. Most of the systems take information from the user and lack in level of automation.

Present work is an attempt to bridge these research gaps by developing a system for computer aided design of cavity layout for a diecasting die. Proposed system consists of three modules and depends upon the knowledge base of diecasting die design. It takes geometric information of the part from its CAD file and makes use of diecasting machine and cast alloy database, while some other information is input by the user. First module of the system determines number of cavities in a comprehensive manner as it considers technical, economical, time and geometrical limitations together. It presents optimal but feasible number of cavities as output as it takes into account undercut features of the part. Second module of the system determines layout pattern of the die based on the number of cavities. It takes into account circular, series and symmetric type of patterns and uses a knowledgebase of die design. Once the layout pattern has been selected, third module of the system arranges and places the individual cavities by selecting a suitable die base. Selection of die base takes into account the clearances required to accommodate gating system and side pulls and is based on the die design knowledgebase. Different alternatives of die layout are considered and most suitable die-base is selected.

DETERMINATION OF NUMBER OF CAVITIES

The number of cavities in a die is affected by several factors, such as delivery requirements, allowable production cost, capacity of the selected machine and part geometric shape. First two factors are dependent on the dynamic market conditions, and the designer must review the delivery and cost issues based on the latest information available. Machine parameters like clamping (locking) force, maximum flow rate and machine size restrict the number of cavities which can be used on a diecasting machine. The part shape (or number of side-pulls) also affects maximum number of cavities that can be arranged in mould base and their orientation. Therefore selected number of cavities must be economically acceptable, technically permissible and geometrically feasible besides fulfilling time constraints. Following paragraphs describe the procedure to find number of cavities based on criteria of delivery date, cost, machine parameters and part geometry.

Delivery Date [N_{del}]

The number of cavities must ensure that the order can be fulfilled within the available time period. Minimum number of cavities for meeting delivery date can be determined using the relationship given by Menges et al. [2001].

Proposed system calculates cycle time for both processes i.e. die casting process and trimming process with the help of material database and part feature data. Cycle time calculations for each stage of diecasting process and trimming process have already been given by Boothroyd et al. [1994].

Part Manufacturing Cost [N_{cost}]

The optimum number of cavities to be used in a diecasting die for a part can be determined by first calculating most economical number of cavities and then analyzing the physical constraints of the equipment to ensure whether the economical number of cavities is practical. Dewhurst and Blum [1989] and Madan et al. [2006] proposed a formula to calculate optimum number of cavities based on economical criteria, which has been used in the system.

Machine Parameters [N_{mac}]

The capacity of a diecasting machine also puts a limit on the maximum number of cavities. This is because of the reason that number of cavities is dependent on diecasting machine constraints like clamping (locking) force, maximum flow rate and machine size. Following paragraphs discuss determination of number of cavities based on machine constraints, while resultant number of cavities is taken as per the following relationship.

[N_{mac}]= ***Minimum of*** (N_{cf}, N_{fr} and N_{ms})

Clamping force [N_{cf}]. The force applied by the machine is required to hold the die halves together and must therefore exceed the pushing force generated within the die [Herman 1996]. Maximum number of cavities has been calculated using procedure laid down by Boothroyd et al. [1994].

Maximum flow rate [N_{fr}]. Flow rate represents power of the shot system of the die casting machine. Flow rate means volume of molten metal that is pushed into the cavity per second by the shot system. The flow rate required by a die should not be more than the machine capacity [Herman 1996]. Based on this principle, maximum number of cavities has been determined in the system.

Machine size [N_{ms}]. The distance between tie bars of the machine decides the maximum size of the die that can be used. When choosing the number of cavities, one should assure that all cavity inserts be contained within the die and that adequate margins be provided. Assuming that the cavities are arranged in a rectangular array in the die, the maximum number of cavities is found by procedure laid down by Fuh *et al.* [2002].

Part Geometric Features [N_{geo}]

Maximum number of cavities is not only limited by the machine constraints itself but also depends upon the number of side-pulls (or side-cores) and their location. This factor has also been considered in the proposed system. Maximum number of cavities applicable to a given design is found by applying well practiced rules being followed in the industry. For example, parts having four number of undercuts are limited to single-cavity die, while cavities with undercut on three sides are limited to two-cavity dies etc.

Selection of Number of Cavities

First module of the proposed system functions for determination of number of cavities. This module takes part CAD file as input and extracts part geometric information such as projected area, volume, wall thickness, and longest part depth and envelope size. Some other details like lot size, delivery date, undercut details and material are taken from the user interactively.

Figure 2 shows information flow diagram for determining number of cavities based on delivery date, economical, technical and geometrical aspects. Diecasting machine is selected from the machine database and information about cast alloy is taken from the material database. Representative material and machine database used in developed system are shown in table 1 and table 2 respectively.

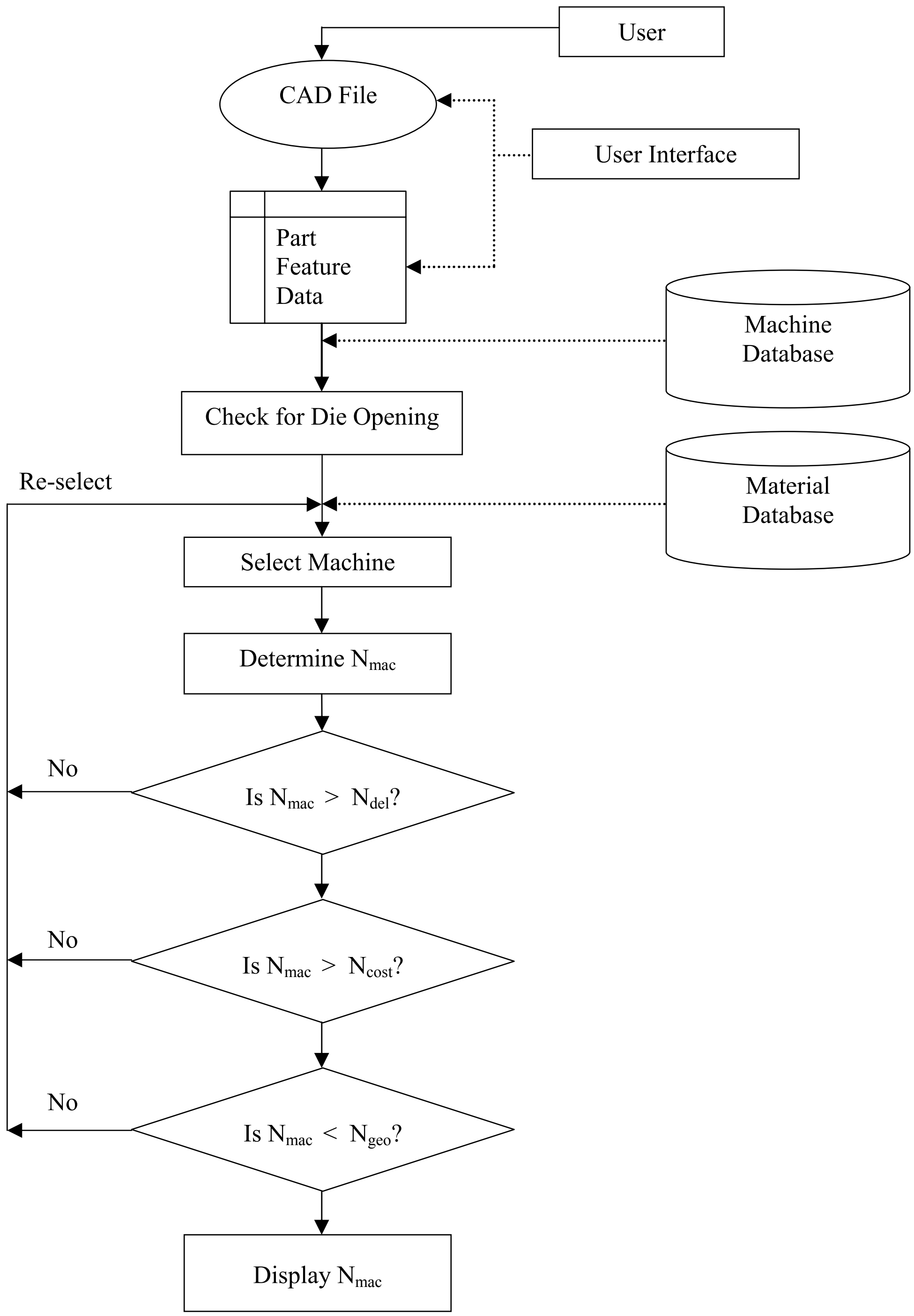

Figure 2. Information Flow Diagram for Determination of Number of Cavities for Multi-cavity Die.

Table 1. Representative Cast Alloy Material Database [15]

Alloy	Specific Gravity	Cost $/kg	Injection temp. ^{0}C	Liquidus temp ^{0}C	Die temp ^{0}C	Ejection temp ^{0}C	Cooling Factor β	Cavity Pressure (MN/m^2)
Zinc	6.6	1.78	440	387	175	300	0.4	21
Aluminum	2.7	1.65	635	585	220	385	0.47	48
Zinc Aluminum Alloy	6.3	1.78	460	432	215	340	0.42	35
Copper	8.5	6.6	948	927	315	500	0.63	40
Magnesium	1.8	2.93	655	610	275	430	0.31	48

Table 2. Representative Machine Database [15]

Clamping Force (kN)	Shot Size (cm^3)	Dry Cycle time (s)	Clamp Stroke (cm)	Platen Size Length (cm)	Platen Size Width (cm)	Diecasting Process Operating rate ($/h)	Trimming Process Operating Rate ($/h)
900	305	2.2	24.4	48	64	66	26
1800	672	2.8	36	86	90	73	29
3500	1176	3.9	38	100	108	81	32
6000	1932	5.8	46	100	120	94	38
10000	5397	8.6	76	160	160	116	46
15000	11256	10.2	81	210	240	132	53
25000	11634	19.9	109	240	240	196	78
30000	13110	23.3	119	240	240	218	87

Longest part depth is first checked against die opening size or clamp stroke by using rule proposed by Blum [1989]. This is done to ensure that selected machine is technically permissible. Selected machine is then used to determine number of cavities (N_{mac}) by using different machine parameters like clamping force, maximum flow rate and machine size. If the selected number of cavities (N_{mac}) is technically permissible, economically acceptable and also meets the time limitations, N_{mac} is selected as the number of cavities; else next machine from machine database with higher capacity is selected to check its suitability. Number of cavities so determined is also evaluated against geometric limitations to determine acceptable number of cavities for a part. Detail of each step of this module has already been discussed in this section. Number of cavities is thus determined in a very short time by seeking little interaction from the user. Next step is to find layout pattern, which has been discussed in the following section.

SELECTION OF CAVITY LAYOUT PATTERN

This section presents methodology used for selection of cavity layout pattern. Once the number of cavities has been decided, the next step is to select cavity layout pattern. Design of cavity layout is totally dependent on the selected layout pattern. This module of the system makes use of diecasting die design knowledge to select cavity layout pattern. However, it is left to the user to either go along the suggested layout pattern or to input any other layout pattern. Proposed system uses well laid down industrial practice to arrive at suitable layout pattern. For example, if a single cavity mould is being designed, then the cavity is typically located in the centre of the mould base.

For multi-cavity moulds, there are essentially two fundamental types of cavity layout patterns. These are classified as geometrically balanced pattern and non-geometrically balanced pattern [Fuh et al. 2004]. Geometrically balanced pattern are widely used in diecasting industries due to no need of gate and runner size correction and to achieve proper filling of cavities.

Primarily, circular and symmetric patterns are frequently used in diecasting industries. The advantage associated with these patterns is equal flow length to all cavities without gate or runner size correction. Equal flow length ensures proper filling of all cavities. Use of circular pattern is limited to less number of cavities as compared to symmetric pattern. Number of cavities in circular pattern depends upon part geometry and part size.

For an odd number of cavities, circular pattern is selected. For even number of cavities, series pattern is selected except those cases when even number is a power series of number 2 (such as 2, 4, 8, 16...etc), in which case symmetrical pattern is selected. Some of these layout patterns have been shown in figure 3.

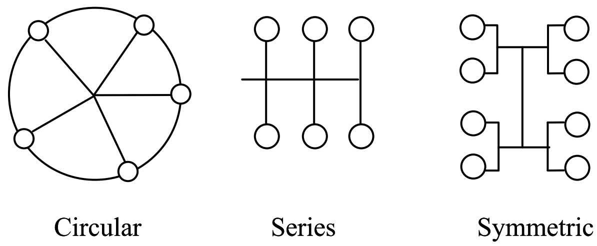

Figure 3. Cavity layout patterns.

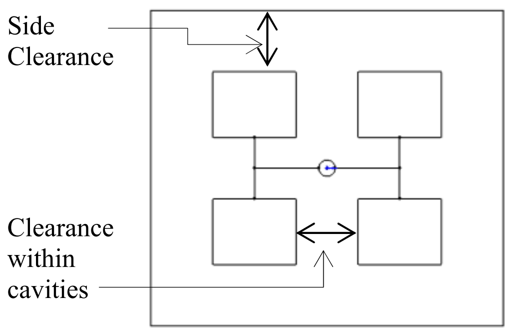

Figure 4. Arrangement of clearances in die-base

ORIENTATION AND PLACEMENT OF CAVITIES

After number of cavities and layout pattern has been decided, the next step is to orient and position the cavities in the die. This section presents the procedure for orientation and placement of cavities in die base. For proper orientation and placement of cavities in the die base various factors like number and position of undercuts, and position of gate is important. This module of the proposed system therefore makes use of die design knowledge to make a decision on this critical aspect. For example, number of undercuts and their location puts a restriction on the orientation of cavities. Side of the cavity, which contains undercut feature, should be placed along outer edge of the die base plate.

Once orientation of individual cavities has been finalized, the next step is to provide clearance to accommodate feed system (biscuit, runner and overflow wells) and side-pulls mechanism. A database of clearances has been developed after consulting die casting industries, available literature [Boothyard et al. 1994] and interviewing die designers and die makers. This contains minimum value of clearances required between adjacent cavities, between the die base edge and the cavity, clearance for feed system and side-pull mechanism etc. Arrangement of clearances in the die has been shown with the help of figure 4.

A fixed clearance in length or width is also added to facilitate biscuit and overflow wells, which in turn is dependent upon shot volume. These clearances are incorporated in the proposed system to achieve automated cavity layout design.

SYSTEM FOR CAVITY LAYOUT DESIGN

System for computer aided design for cavity layout design takes geometrical information of the part from CAD file, while other required information is taken from the user interactively. First module of the system calculates the number of cavities that is economically acceptable, technically permissible, and geometrically feasible and also meets the time limitations. Detailed methodology to determine number of cavities has already been described in this paper. Second module of the system selects layout pattern based upon number of cavities. Third module of the system positions cavities in the die and displays it graphically. This information is used to determine size of die base along with possible alternatives. Cavity layout with minimum size of die base is selected. Finally, system displays the cavity layout design selected by the system as an output. Information flow diagram of the proposed system has been given in figure 5. Next section of this paper deals with system implementation and results.

SYSTEM IMPLEMENTATION AND RESULTS

System for computer aided cavity layout design for diecasting die has been implemented using MATLAB 7 environment. The geometrical information of the part such as projected area, volume, envelope size, wall thickness and longest part depth are extracted from CAD file of the part which was modeled in SolidWorks 2010 environment.

Developed system has been tested on a number of parts including parts with undercut features. Two such example parts are shown in the figure 6 and figure 7. Information of number of undercut features and their location is entered by the user. Also user has to input data related to delivery date i.e. lot size, total production time along with the material.

Number of cavities determined by the system for example part 1 shown in figure 6 is four and the layout pattern selected is symmetric. Four rectangular blocks show the position of cavities in the die base. Size of single rectangular block is equal to the envelop size of part that is 160 mm x 120 mm, while size of the die base determined by the system is 465 mm x 585 mm. Output from the system is in terms of design of cavity layout as shown in figure 8.

Number of cavities determined by the system for example part shown in figure 7 is five and layout pattern selected is circular. Cavity layout pattern for this example part is shown in figure 9. The envelope size of the part is 110 mm x 110 mm, while die base size is 760 mm x 760 mm. The system arranges the cavities along a circle at points calculated by 360/number of cavities.

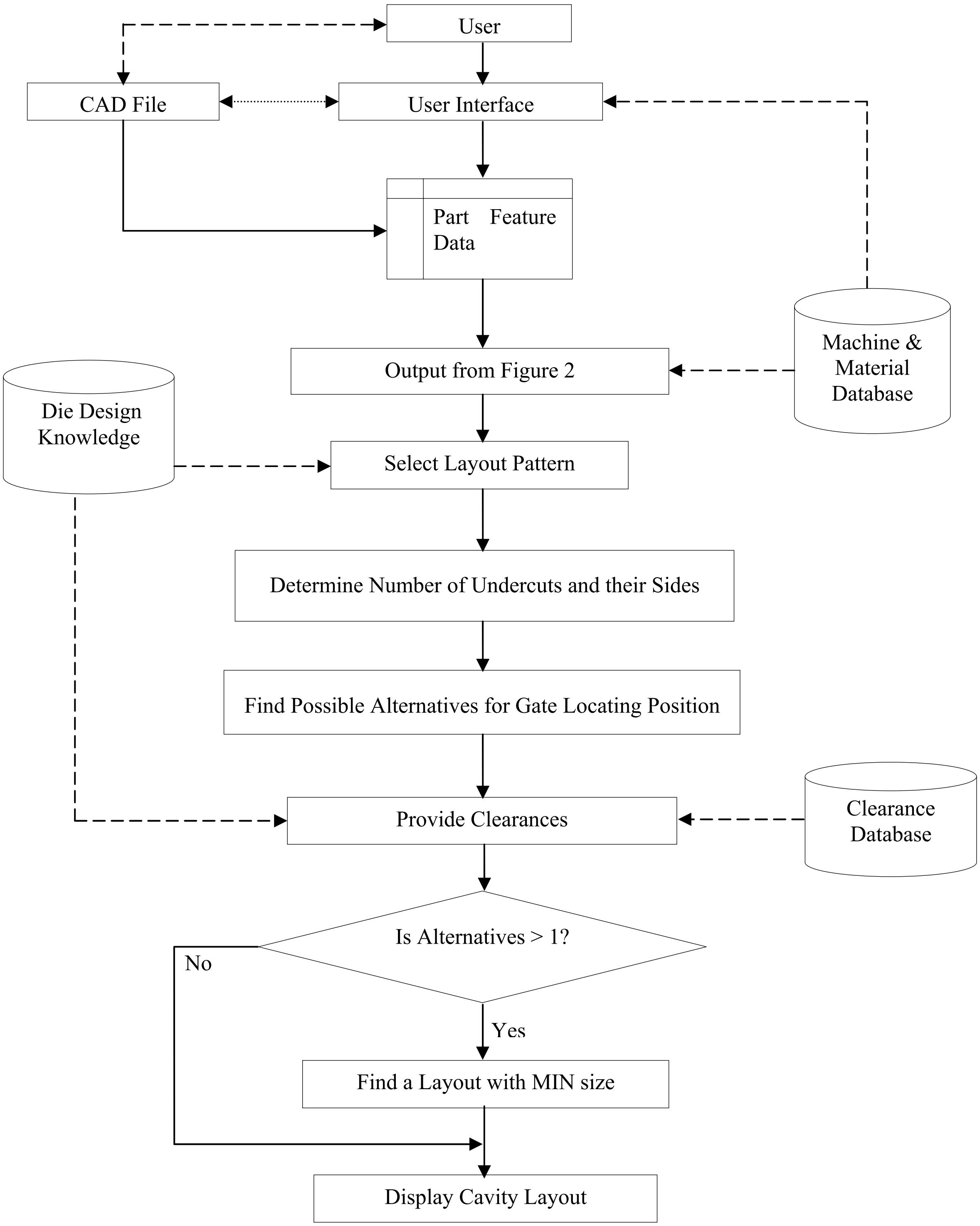

Figure 5. Information Flow Diagram for Automatic Cavity Layout Design of Multi-cavity Die.

In each of the example parts number of cavities determined by the system are sufficient to meet the delivery time. Although more number of cavities could have been geometrically possible for these example parts, same is not explored with an intention to make proper use of manufacturing resources namely the die casting machines.

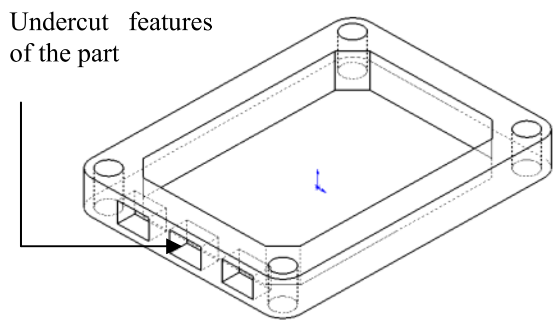

Figure 6. Example Part 1 with Undercut Feature.

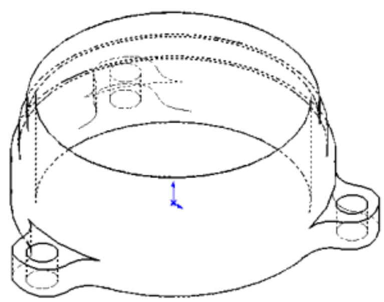

Figure 7. Example Part 2 without Undercut Feature.

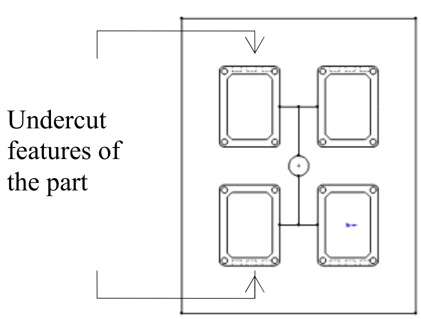

Figure 8. Cavity Layout Design for Example Part 1.

CONCLUSIONS

System for computer aided cavity layout design for diecasting has been developed, which is a major step towards design-manufacturing integration for this process. Proper selection of cavity layout at die design stage is the biggest problem faced by diecasting industries. This system would be very useful for diecasting industries as it would help in reducing lot of human expertise and effort for selection of cavity layout.

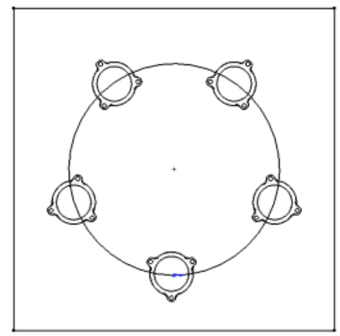

Figure 9. Cavity Layout Design for Example Part 2.

Proposed system is capable to calculate number of cavities by considering delivery date, production cost, machine constraints and part geometric limitations. System presented in this paper also determines layout pattern using standardized layout pattern for better geometrical balancing. Finally orientation and placement of cavities is determined keeping in view the clearances and geometric aspects such as number and location of undercuts. It displays graphical arrangements of cavities as output.

Proposed system is very user-friendly and makes use of machine database, material database and die design knowledgebase to determine cavity layout for a diecasting die. It is assumed that the parting direction is already known to the user. Identification of undercut features and their location in an automated manner would make the system more useful and increase the level of automation. Use of non-standard cavity layout patterns and placement of feeding system would further improve the system. Computer filling analysis is needed to ensure proper filling of all cavities and this aspect can also be integrated with the system. Improvements in the system are being attempted in this direction to make it more useful.

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