A thesis report on

PARAMETRIC APPROACH TOWARDS AUTOMATED DESIGN OF GATING SYSTEM FOR DIE CASTING PROCESS

Submitted in partial fulfillment of the requirement for

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MASTERS OF ENGINEERING

IN

CAD/CAM & ROBOTICS

Submitted by

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CERTIFICATE

This is to certify that the work done in this thesis report entitled **"PARAMETRIC APPROACH TOWARDS AUTOMATED DESIGN OF GATING SYSTEM FOR DIE CASTING PROCESS"** submitted in partial fulfilment of requirement for the award of the **Master of Engineering Degree in CAD/CAM & ROBOTICS** in the Mechanical Engineering Department, Thapar University, Patiala, is an authentic record of work carried out by me under the guidance of Mr. Kishore Khanna, Assistant Professor, Mechanical Engineering Department, Thapar University, Patiala.

The matter embodied in this report has not been submitted in part or fully to any other university or institute for the award of any degree.

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ABSTRACT

Die-casting is the manufacturing process which is capable of producing near net shape products. Die-casting involves lot of human expertise and knowledge, especially in die design process. The designers use empirical knowledge and use trial and error methods which involved excessive time and often multiple die trials. This makes the die-casting a time consuming and tedious job. The die-casting industry has an imperative need to integrate the design-manufacturing of die-casting process. It helps to shorten the lead time to the market and reduce the cost in die design and manufacturing. The parameters like parting line generation, side core design, cavity layout, gating system design etc. of die-casting die design needs to be automated with the aid of CAD systems. Out of these parameters, CAD of cavity layout and gating system are receiving interest.

This thesis describes the CAD system structured by parameters, cavity system and gating system, of die-casting die design. Cavity design includes the determination of number of cavities and their appropriate layout on the die base. The proposed system calculates optimal number of cavities considering time, economical and technical constraints. The system also provided the feasible cavity layout pattern based on calculated number of cavities. The proposed system for gating system design includes gate design, runner design and overflow design which have their relative importance to maintain the constant flow rate in die-casting process. The system generates different parameters of gating system like gate thickness, gate area, runner selection and their respective area and overflow volume and their length etc.

The system is designed with the aid of MATLAB 7.10.0. Feature library of gating system and die-casting part design has been prepared using Pro-E wildfire 5.0. Developed systems would be useful in achieving the objectives of design-manufacturing integration of die-casting process.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

In the era of liberalisation and globalisation, the demand of new types of products has been increased tremendously. Today, consumers want different kind of products to meet their needs. This trend creates competition among the companies to provide the products to consumers with minimal lead times without comprising on the quality. Companies cannot rely on traditional design process which follows over the wall concept of design. The traditional design process accounts for 75% of total production costs **Chiang,** *et al*. **[1]**. Traditional design departmentalized as the engineers would develop the product design and any working and detail drawings associated within the conceptual design **Giesecke,** *et al*. **[2]**.The design is then passed to other departments within the organization (manufacturing for process and material selection, marketing, purchasing, etc.). If some inadequacy or error is found then the design may be sent back to the design team for rework and revision thus making the design process iterative in nature. These iterations make the traditional design process exceedingly tedious and resource inefficient. This tedious and inefficient nature of the design process leads to increased lead time and cost. Life cycle of a typical product has been illustrated in Fig. 1.1.

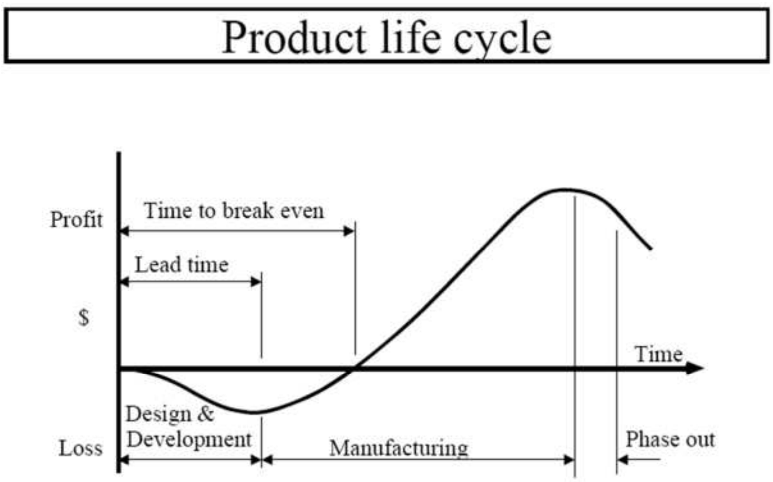

Fig.1.1: The traditional product life cycle Giesecke, [2].

The above mentioned limitations of the traditional design process forces the companies to think different from traditional design process. Introduction of computers in design as well as in the manufacturing processes has changed the picture of manufacturing industries. Designers are now able to design the product on 3D software, analyse it for manufacturing and working and finally generate the machining data for CNC machines for manufacturing of the product. This trend gives birth to the new branch known as CAD/CAM.

CAD/CAM is concerned with engineering functions in both design and manufacturing. CAD is defined as "a process that uses a computer system to assist in the creation, modification, and display of a design**" Giesecke, [2]**.CAM is defined as the effective use of computer technology in manufacturing planning and control **Groover, [3]**.

With the integration of CAD and CAM, the goals of shorter lead times, improved productivity, fewer design errors, better design analysis, greater accuracy in design calculations, standardization of design, reduced data redundancy, scheduling of tools and components, better product planning and control, application in product forecasting etc. can be achieved. Attempts in integration of CAD/CAM have been made by many researchers **Madan,** *et al.* **[4] Sulaiman,** *et al.* **[5]**.The main focus of integration is to take the design specification of the product as it resides in the CAD data base and convert it into process plan for making the product **Groover, [3]**.There are some systems available that are capable of generating manufacturing data from the CAD model.

Die-casting is the manufacturing process which is capable of producing near net shape products. Parts made from die-casting are extensively used in automobiles, aerospace products, electronic equipment, optical and household items among many others. Computer hardware, software and NC machine tools are extensively used in die-casting process. However it has been seen that a lot of human expertise and knowledge is involved at various stages of die-casting process, especially die design process. This makes die-casting die design activity very costly and time consuming. Design-manufacturing integration of die-casting would have great benefits. The following section presents some detail on die-casting process.

1.2 DIE-CASTING PROCESS

Die-casting process is an example of permanent mould casting. In this process molten metal is forced into the die cavity at pressures ranging from 0.7MPa to 700MPa and the product is finally ejected out after solidification of the metal **[6]**. The die-casting process involves the use of a furnace, metal, die-casting machine, and dies. The metal, typically a non-ferrous alloy such as aluminium, zinc or magnesium, is melted in the furnace and then injected into the dies in the die-casting machine. The die-casting method is especially suited for applications where a large quantity of small-to-medium-sized parts is needed with good detail, a fine surface quality, and dimensional consistency. This level of versatility has placed die-casting among the highest volume products made in the metalworking industry **[7]**.

The following paragraphs give a brief idea about stages in die-casting process, die-casting machines and the die-casting die.

Main stages in die-casting process

There are five main stages in die-casting process which are explained as under:

i. Clamping

The first step is the preparation and clamping of the two halves of the die. Each die half is first cleaned from the previous injection and then lubricated to facilitate the ejection of the next part. After lubrication, the two die halves, which are attached inside the die-casting machine, are closed and securely clamped together.

ii. Injection

The molten metal, which is maintained at a particular temperature in the furnace, is transferred into a chamber where it can be injected into the die. The method of transferring the molten metal depends upon the type of die-casting machine, whether a hot chamber or cold chamber machine is being used. The difference in hot chamber or cold chamber machines has been discussed in the next section.

iii. Cooling

The molten metal that is injected into the die will begin to cool and solidify once it enters the die cavity. When the entire cavity is filled and the molten metal solidifies, the final shape of the casting is formed.

iv.Ejection

After the predetermined cooling time has passed, the die halves can be opened and an ejection mechanism can push the casting out of the die cavity. Once the casting is ejected, the die can be closed again for the next injection.

v. Trimming

During cooling, the material in the channels of the die will solidify and would remain attached to the casting. This excess material, along with any flash that has occurred, must be trimmed from the casting either manually via cutting or sawing, or using a trimming press.

Die-casting machines

There are two main types of die-casting machines - hot chamber machines and cold chamber machines

i. Hot chamber machines

These machines are used for alloys with low melting temperatures, such as Zinc, Tin, and Lead. The molten metal is contained in the holding pot which is placed into furnace. The molten metal flows through shot chamber into the goose neck and finally injected through the nozzle into the die with the push of plunger. Figure 1.2 shows the important parts of hot chamber die-casting machine.

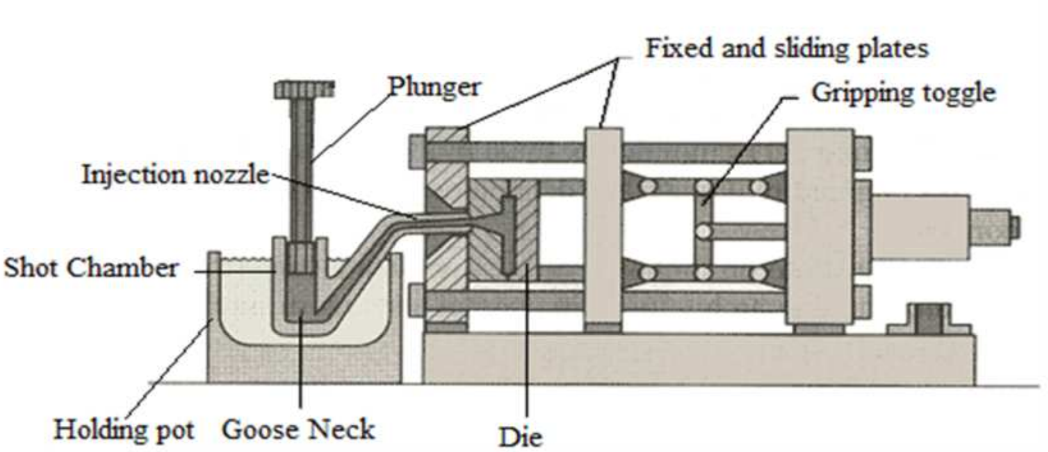

Fig.1.2: Hot chamber die-casting machine [8]

ii. Cold chamber machine

Cold chamber machines are used for alloys with high melting temperatures, such as, Aluminium, Brass, and Magnesium.

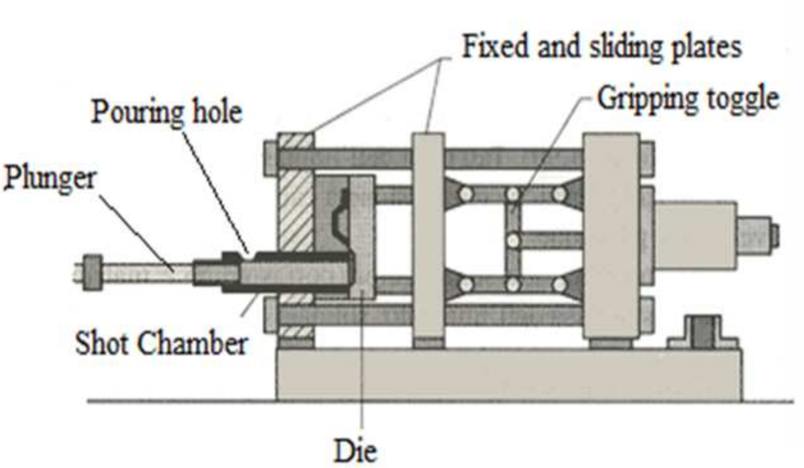

Fig.1.3: Cold chamber die-casting machine [8]

The metal is poured from the ladle into the shot chamber through a pouring hole. The plunger forces the metal through shot chamber into the die. Figure 1.3 shows the important parts of hot chamber die-casting machine.

Die-casting Die

A die-casting die consists of two halves termed as *cavity* (cover die) and *core* (ejector die). The cavity half is fixed and the core half is movable. The core half is moved towards the cavity half to assemble the die. Shot sleeve contains molten metal and works as cylinder in which the plunger is moving to fill the molten metal in the cavity. Molten metal is poured into the space left between the two halves termed as cavity. The molten metal fills the cavity through the gate. Ejectors is used to remove the part after processing. Figure 1.4 shows the various parts of a die.

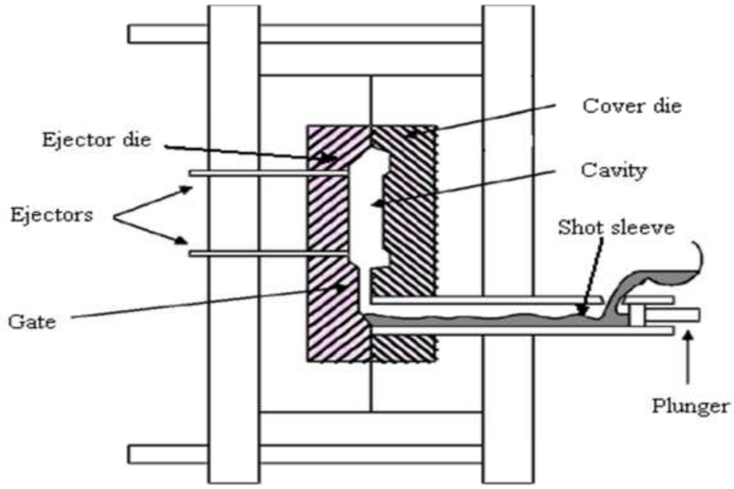

Fig.1.4: Various parts of die Zahi, *et al.* **[9]**

Having discussed the die-casting process the next paragraph discusses the design-manufacturing integration of die-casting process.

1.3 DESIGN-MANUFACTURING INTEGRATION OF DIE-CASTING PROCESS

Die-casting process involves extensive use of CAD tools in part and dies design. The normal process is to prepare a CAD model of the part and use this CAD model for designing and making the CAD model of the die. Designing of die-casting die requires lot of knowledge and expertise on the behalf of the die designer. Design –manufacturing integration can be realized if we develop such a system that is capable of generating die design form the 3-D model of the part itself. The system would take 3-D model of the part as input, recognizes various features of the part model and determine different aspects of die such as, parting direction, parting surface, gate runner design, cavity layout etc.

Figure 1.5 shows the important stages in the die-casting process. Out of these stages die design is the most cumbersome and time consuming. Die design requires optimization of interacting parameters at various steps of the die design process.

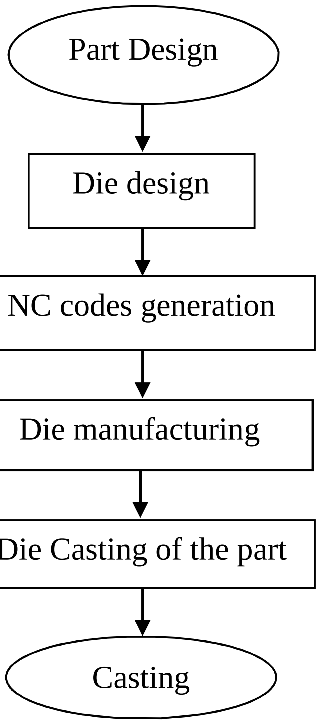

Fig.1.5: Die-casting process flow chart.

The following section throws some light on the die-casting die design process that could be beneficial in understanding the principles of die design process.

1.4 DIE-CASTING DIE DESIGN

Die-casting die design is an intricate process that requires balancing of the conflicting parameters. 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 said parameters the following features like: design of cavity, number of cavities, gating and runner system, parting design, cooling design etc. are determined or calculated. There are no set rules for the designing procedure of a die-casting die but some rules of thumb followed by the industry**. Fuh,** *et al.* **[10]** seven major steps of die-casting die design which are as follows:

- **i.** *Setting shrinkage*. As the molten metal contracts during solidification, the original die-casting part geometry must be scaled by a certain factor to reflect the material shrinkage.
- **ii.** *Determining the cavity number and layout*. Cavity number is the number of cavities to be machined in a die-casting die. It is determined based on the part shape and dimension, machine type, machine size limitation, machine clamping force, machine pumping capacity, etc. Once number of cavities is decided their layout pattern in the die is then decided to reduce the variations in the properties of the castings hence produced.
- **iii.** *Designing the gating system*. The gating system is the feeding system of the die that facilitates the flow of molten metal in the die. Flow paths and filling conditions are analysed at this stage. The type, size and location of the gate, runner and overflow are determined in accordance with the part geometry and cavity layout to achieve proper filling in the die cavity.
- **iv.** *Designing the die-base*. Die base (Die-set) is an assembly of upper and lower die shoes, guide pins and bushings, and punch and die retainers. Once the number of cavities and cavity layout are decided, a suitable die-base is selected to accomplish the proposed layout. The criterion generally used in establishing the overall size of the die-base is that the ejector plate must completely cover or contain all of the cavity area within its bounds.

v. *Parting design*. It refers to determination of parting direction, parting line and parting surface of the die halves. The parting surfaces along the selected parting lines is created and it eventually splits the containing box into two halves, a core block and a cavity block, in which the negative impression of the die-casting part is formed.

vi. *Designing the moving core mechanism*. Components of the die which have motion in a direction other than the main parting direction are called moving cores or side cores. If the die-casting part has any undercut, which will block the die halves from opening, moving cores and angled pins should be designed to facilitate the die opening and the removal of die-casting from the die.

vii. *Designing the cooling system*. The cooling system is an essential feature of a die-casting die, which is composed of a set of waterlines drilled within the dies and inserts that conduct the heat away from the die cavity. The cooling system should be positioned and sized properly so as to achieve rapid and uniform cooling without interfering with the ejection system and moving core mechanism.

Figure 1.6 shows the flow chart for die design process that has been already discussed in above seven points.

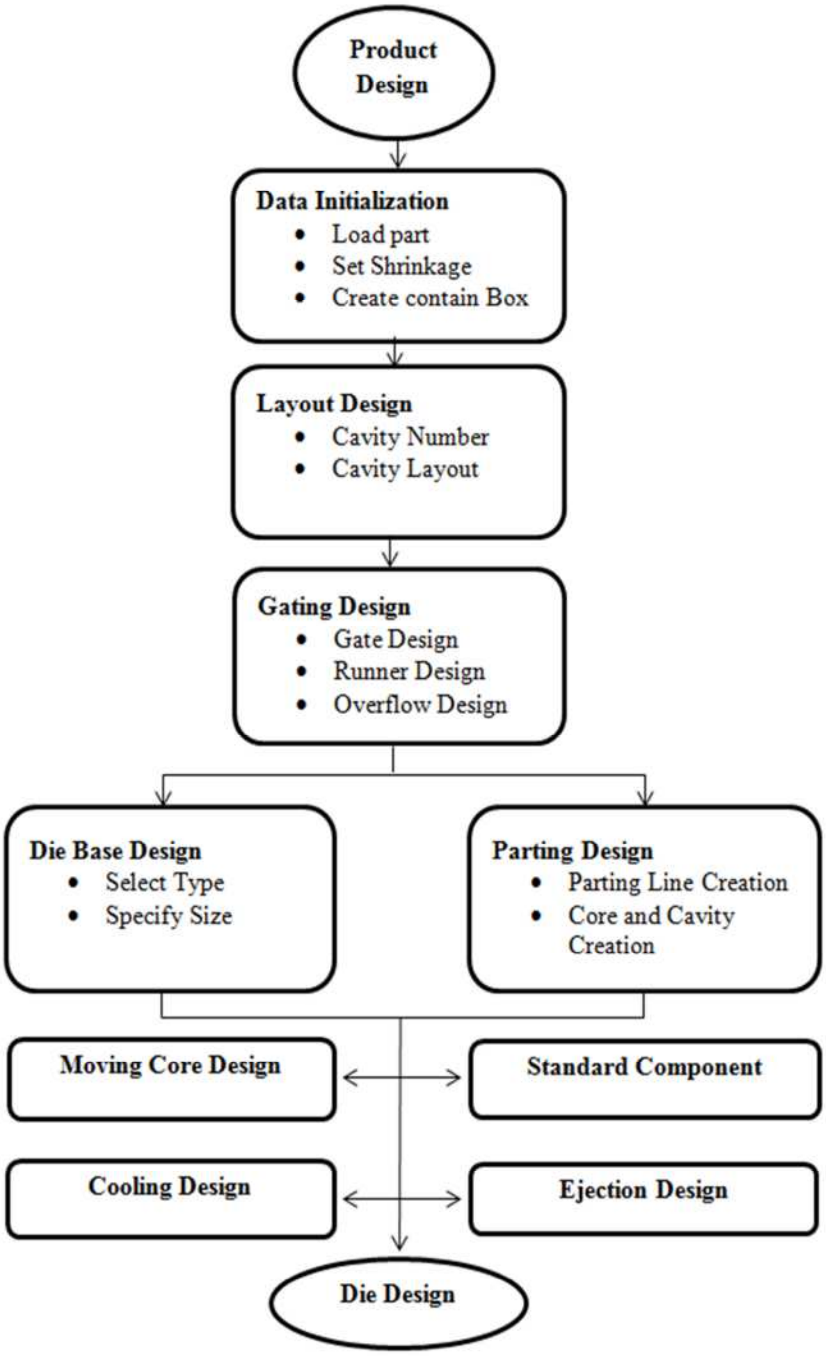

Fig.1.6: Die design process Fuh, *et al.* **[10]**

From the above discussion we conclude that once cavity number and layout decisions have been taken the very next steps are gating system design and parting design. The decisions regarding gating design and parting design further effect the decision of core and cavity generation, side core design, die base design etc.

However the decisions regarding gating design, parting design and side core design are taken by the die-casting expert based on his knowledge and experience. Out of these three parameters, gating system is crucial one, as the quality and soundness of the casting depends on the filling condition which is governed by the gating system. The gating system is placed at the parting line, so the knowledge of parting line is significant. Moreover, the use of side core also plays a significant role in the gating system design. Following section presents an overview of parting line, side core design and gating system.

1.5 CAVITY DESIGN SYSTEM

The impression in which molten metal is being filled is called the cavity. The arrangement of the cavities is called the cavity layout. When a mould contains more than one cavity, it is referred to as a multi-cavity mould. A single-cavity mould is normally designed for fairly large parts such as housings. For smaller part such as gears, it is always more economical to design a multi-cavity mould so that more parts can be produced per moulding cycle. At the early stage of the die design, selection of type of mould configuration, determining numbers of cavities and its layout are the major tasks which also influence other tasks of die design. 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. Figure 1.7 and 1.8 shows a single-cavity mould and a multi-cavity mould respectively.

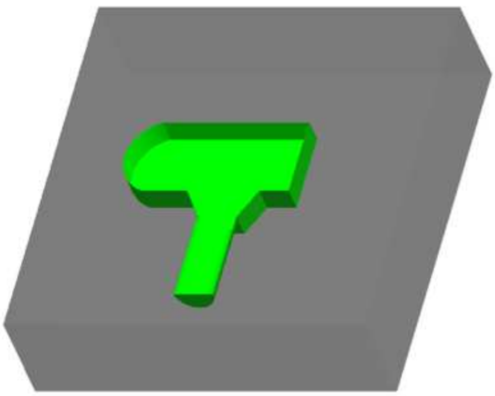

Fig.1.7: Single cavity mould

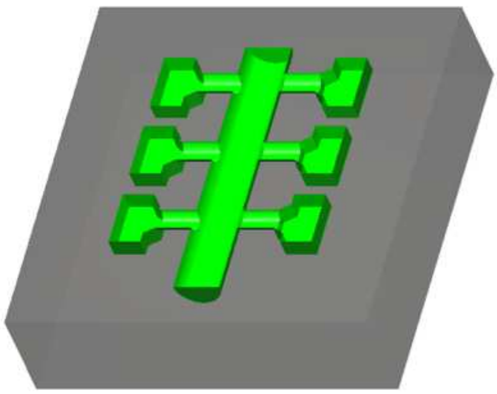

Fig.1.8: Multiple cavity mould

Using a multi-cavity die will reduce labour cost and increase the production efficiency. However, increasing the number of cavities needs a larger die and hence a larger machine, which requires high setup and operating cost. A balance between these two factors is required while selecting appropriate number of cavities. **Low and Lee [11]** 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%. Determination of number of cavities depends on economic and technical aspects.

A multi-cavity mould that produces different products at the same time is known as a family mould. Figure 1.9 depicts the family mould. However, it is not usual to design a mould with different cavities, as the cavities may not all be filled at the same time with molten metal of the same temperature. On the other hand, a multi-cavity mould that produces the same product throughout the moulding cycle can have a balanced layout or an unbalanced layout. A balanced layout is one in which all the cavities are uniformly filled at the same time under the same melt conditions, **Low and Lee [11].** Short moulding can occur if an unbalanced layout is being used, but this can be overcome by modifying the length and cross-section of the runners (passageways for the molten flow from the sprue to the cavity). Since this is not an efficient method, it is avoided where possible. Figure 1.10 shows a short moulding situation due to an unbalanced layout.

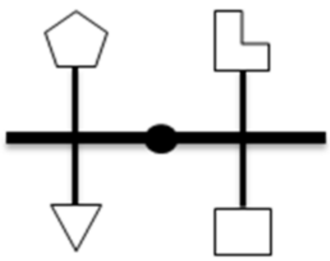

Fig.1.9: Family mould

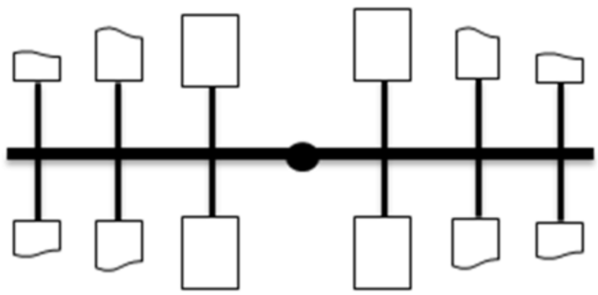

Fig.1.10: Short moulding

If a single cavity mould is being designed, then the cavity is typically located in the centre of the mould base, though gating requirements sometime may necessitate placing the mould cavity off centre. For multi-cavity moulds, there are essentially two fundamental types of cavity layout patterns. These are classified as balanced layout pattern and unbalanced layout pattern.

- **Balanced Layout patterns**: A balanced layout pattern is one in which all the cavities are uniformly filled at the same time under the same melt conditions **Low and Lee [11].** Equal flow length ensures proper filling of all cavities. These types of patterns are widely used in die casting industries due to no need of gate and runner size correction to achieve proper filling of cavities. Symmetric and circular types of patterns fall under this category. These are also known as geometrically balanced and standard cavity layout pattern.
- **Unbalanced layout patterns**: An unbalanced layout pattern is one in which all the cavities aren't uniformly filled at the same time under the same melt conditions **Low and Lee [11].** These types of patterns require gate and runner size correction for proper filling of cavities. They are also known as non-geometrically balanced and series pattern.

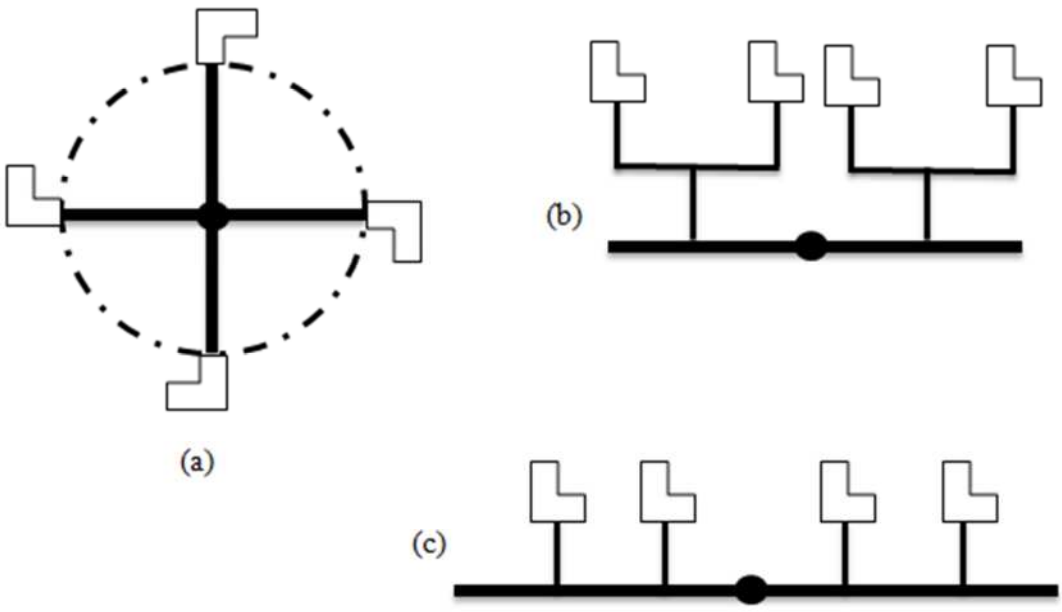

Fig.1.11: Types of cavity layouts

Figure 1.11 shows different types of cavity layout patterns used in die-casting process. Primarily, circular and symmetric patterns are frequently used in die-casting industries. The 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.

The most systematic arrangement of cavities is possible with symmetric pattern as it ensures proper balancing of die base. Series pattern are less preferred due to non-equal flow length to all cavities although they can accommodate more number of cavities as compared to circular pattern.

1.6 GATING SYSTEM

When designing a die casting dies, it is important to ensure that the molten metal fills the die cavity completely, which directly link to the correct design of gating system. Therefore, the design of a gating system is very crucial. The gating system is a series of passages through which the molten metal enters and fills the die cavity Fig.1.12. It is composed of several gating elements as follows:

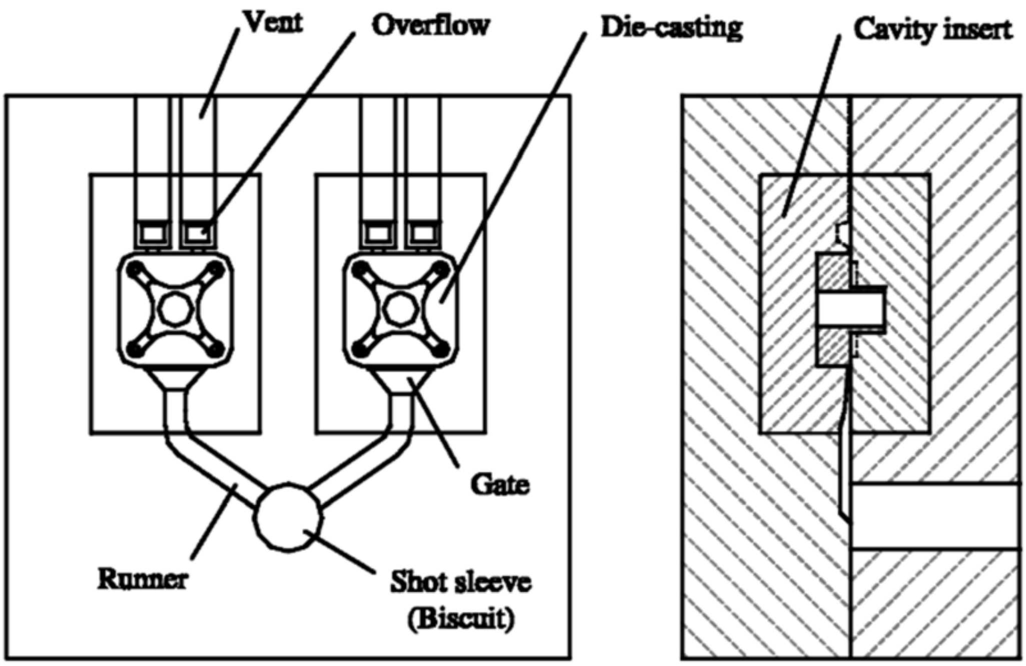

Fig.1.12: Parts of gating system Fuh, ***et al*****. [10]**

- **Shot sleeve (sprue)** - The sprue, usually circular in cross-section, leads molten metal from the pouring basin to the sprue well. The cavity inside the shot sleeve or sprue forms a part of the gating system.
- **Runner** - A runner is a channel located at the parting line to route liquid metal from the sprue or shot sleeve to the gate. It may split into two or more as required

to direct the liquid to various places. The cross-sectional area of runner must be larger than that of gate so as to produce an increase of flow velocity along the flow path. If a cavity has two or more gates, branch-runners are used to connect the gates with the main runner. The area of the main runner should be larger than the sum of the area of all the branch-runners **Woon,** *et al***. [12].**

- **Gate** - As the runner approaches the cavity; it blends into a slit-like opening into the cavity. The slit-like opening is called the gate and the blended portion that links the gate and runner is called the gate runner. The gate and gate-runner have an important function in directing the metal flow so that the cavity is properly filled. Here, the term 'gate' refers to the combination of the gate and gate-runner.
- **Overflow** - This is a chamber usually located at the opposite side of the gate to absorb undesired non-metallic inclusions. Overflow is needed in most aluminium die-casting applications to reduce non-metallic inclusions and air entrapment and help balance the thermal effect during the die filling. In practice, if the 3-D model of die-casting is divided into several segments according to the flow paths, the overflow of each segment will be sized in proportion to the volume of the segment. The flow distance of molten metal also affects the volume of overflow due to the heat loss. The overflow should be enlarged accordingly when the flow distance increases. Generally, the overflow is located at the point the flow reaches last or the point where two flows meet **Woon,** *et al.* **[12]**.

Based on the discussion on cavity system and gating system, the next section deals with the need and motivation for proposed work.

1.7 NEED AND MOTIVATION OF PROPOSED WORK

As discussed earlier, die-casting die design is a tedious, time consuming and costly process involving lot of human effort. Therefore to achieve the objectives of design-manufacturing integration of die-casting, this gap must be filled. Further, parting line determination, gating system design and side core design have been identified as the steps of the die-casting die design process which require lot of human expertise. Presently, CAD systems are extensively used for designing of a die-casting die but these systems rarely provide the requisite knowledgebase for automated die design. The die designer has to take decisions for selecting various parameters for the die design. So there is need for a system that can bring together the knowledge and experience of the die-casting expert. Present procedure of die casting die design seems to be a gap in design-manufacturing integration of die casting. Following are some of the limitations of the present system that need to be addressed.

- Higher design and manufacturing lead times
- Greater human skill and experience requirement at different stages of design
- Little use of the available computing power
- insignificant use of product design data available for the CAD model
- lack of system to capture the experience of die design expert

If such a system is developed which could do the activities of parting line determination, gating system design and side core design automatically by using knowledge and expertise of die casting expert, it would be quite beneficial for the industry. Present study is motivated by this aspect and would greatly bridge the gap between design and manufacturing of die-casting process. The following section gives review of some of the literature survey done on die-casting die design, parting line, cavity system and gating system.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

For the last few decades researchers have been working on design manufacturing integration of die-casting die design process. So, literature available on design manufacturing integration of die-casting die design process was referred. Some of the literature related to plastic injection molding design was also studied because of similarities of the process to die-casting. In the following section literature review has been presented on general topics, related to die casting die design, parting line & gating system design for design-manufacturing integration of die casting process. Research gaps are presented at the end of literature review. Some of the literature surveyed is presented in the following paragraphs.

2.1 LITERATURE REVIEW

Dewhurst and Blum [13] presented a methodology for cost estimation of die-cast parts considering processing time and manufacturing cost. It derived an expression for optimum number of cavities in their research work. However, it does not consider the cavity layout design or platen size determination tasks

Tan, *et al.* **[14]** presented a computer system for automatic determination of parting line and parting surface in a re determined parting direction. The system was successfully implemented on a prismatic part. For the implementation of the system on curved surface part the part must be approximated by planer surfaces. The selection of the parting direction is not automatic.

Chen and Chou [15] defined the levels of visibility being complete and partial. An algorithm was developed for computing augmented visibility map of a non demould able surface and then to find out the direction with the minimum number of under cuts. An algorithm was also developed for computing the volume of the undercuts in a particular direction. Only polyhedron surface was considered for application of the algorithm.

Lui, *et al.* **[16]** presented the concept of die-casting process in five stages instead of traditional three stages. The concept of five stages process retains the familiar first and second stages of traditional process and further breaks down the third stage into two stages and adds a fifth 'residual stage'. The analysis of five stages, which link the metal feed system with the main fluid-power main circuit of the die casting machine gives a mathematical models. However, optimal gate location and selection of types of gates are not considered. Wall thickness calculation is not considered while calculate gate parameters.

Reddy, *et al.* **[17]** It provides system software which provides an intelligent assistance to die designer by integrating various parameters like automatic generation of parting line, shrinkage allowance, draft, gating system. The system also provides die layout options. The requirements for providing draft on the part are given. Gate parameters are determined form the gating data base provided in the software. Only axisymmetric shapes being taken. Only semi-circular and trapezoidal types of runner are incorporated. However, system uses only 2-D part input as only simple shapes are incorporated. The parting line location cannot be determined computationally. Number of cavities determined according to machine capacity (casting area or shot capacity).The least of two is selected as number of cavities.

Sulaiman and Keen [5] performed flow analysis along the runner gate system for a pressure die using a program written in FORTRAN. The analysis was performed to find out the pressure needed during injection of the metal and to note the effect of branch angle of runner gate system. The results were good and give some relation of the branch angle and the die pressure. The system was limited to the simulation of the gating system.

Nee, *et al.* **[18]** proposed a methodology to generate 3D parting lines and parting surfaces for the injection molded parts. An optimal parting direction was considered first. Based on the topological relationship of the surfaces to the optimal parting direction these were classified into three groups. A plane perpendicular to the optimum parting direction was taken to calculate the projected area of an edge loop on it. Then the parting surfaces were determined by extruding the 3D parting lines. The method did not consider application on the free form surfaces.

Wong, *et al.* **[19]** proposed an algorithm for parting line formation based on uneven slicing on the product model. The main function of the algorithm is to locate the parting line in predetermined parting direction. The parting direction is usually selected in the direction of principle axis. The optimum parting line is selected based on parting line selection criteria. The system was implemented on a virtual helmet. The user can also modify the profile of selected parting line. The system cannot take parting direction other than the principle axis.

Fu, *et al.* **[20]** presented the definition, classification and a concept to identify the undercut features for injection mold design system. The Visibility maps (V-maps) were used to find out the draw range and direction of the undercut. A criterion of virtual edges was introduced to deal with blending surfaces. The methodology was limited to the determination of the undercut draw range and direction. Optimum parting direction and parting surface determination were not considered.

Ye, *et al.* **[21]** presented an algorithm for initial design of injection moulds. It first determines the parting line for the part, followed by the calculation of the number of cavities required. The cavity layout is created based on information of the layout pattern and the orientation of each cavity, which is taken from the user. The mould base is loaded automatically to accommodate the layout. The system does not consider the exact details for clearance and selection of layout pattern is manual.

Kim & Kwon [22] describes development of computer aided die design system for die casting which is written in Auto LISP. This system presents several algorithms for automation of die design, especially a runner gate system. The system quantifies practical knowledge and experiences in die design as formulation procedure. System is composed of selection of cast alloy and product design and uses runner gate design. The system applied to simple cap shaped casting. The system has not calculated the overflow parameters. The system do not check for more number of gates.

Choi, *et al.* **[23]** developed a system that dealt with the cast design, die layout design and die generation. The system has sound database for material and shrinkage, gate-runner and overflow, air vent, and cavity block. The application of the system was studied on a cap shaped product and a motor pulley the system was no implemented on parts with undercuts and automatic selection of parting line was not taken into account.

Lin [24] employed FEM and neural network techniques to find the accurate location of injection gate for a die-casting. FEM software was used to analyze the effect of various gate locations on the warping of the casting. Then based on the results learning activity using neural networks and simulation annealing was conducted to form the knowledge base for relation of gate location and wrap of the casting. The system reduces the reliance on human skill to find the location of the injection gate. The optimization of the gate runner system was not considered.

Low and Lee [11] proposed a methodology of cavity layout design system for plastic injection mould such that 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 later in mould design. The system does not consider undercut features and non-standard configurations.

Woon and Lee [12] developed a system for die-casting die design. The system has seven modules that work on the different areas of die design. A parametric designing system is used to create a 3D model using B-rep and to extract the geometric and topological information. The system was implemented in API of solid works 2000 and was written in C++. The system is very helpful in designing a die from scratch or modifying the existing design. The feature library is not sufficient. The system could not perform design of gate and venting system.

Lee and Lin [25] illustrated the process of optimizing the multi cavity injection mold parameters through abductive network approach. Finite element simulation was performed on different runner and gating systems with different volumes, gate diameters, runner diameters and cavities an inputs. Taguchi method was used to get proper data set to train the abductive network. The relationship between input parameters and output parameter (wrap) was established. This relationship was then used to develop the optimal runner gating system model using neural networks. Limited numbers of cavity designs were taken for study. Only circular gate and runners were taken into account. Placement of the gating system was not taken into account. Non identical cavities were not taken into account.

Kumar, *et al.* **[26]** proposed a method to recognize the undercut feature and parting surface using polyhedron face adjency graph. The proposed method was applied on a curved surface part. The proposed method was able to find the most favorable parting surface based on minimum number of undercuts in the chosen direction. A set of parting directions and parting surfaces have to be assumed by the designer. Design of a split cores for partial visible undercuts was decided by the expert.

Madan, *et al.* **[4]** developed a system for automated determination of parting direction and parting line for a die-cast part from part CAD model. The proposed system takes STEP file of the part as input for extracting die-casting features, which consists of protrusion or depression regions of the part. Geometric reasoning is used for feature recognition, which includes nested and interacting features. Parting line is determined based on selected candidate parting direction considering process constraints and priorities.

Wu, *et al*. **[27]** presented a method of gating system design for die-casting. The parametric models of the gating system were created. The pre-construed gating system are retrieved from the database after specifying desired parameters of the casting process, locations are specified and finally joined to the casting by Boolean operations. The system reduces the need of designing the gating system from scratch for a part as the pre constructed gating system can be modified. System application is limited to parts with simple shapes. The database of the gating system needs to be enlarged.

Zahi, *et al*. **[9]** proposed a non-dominated sorting algorithm using runner and molding conditions as design parameters for gate-runner design. The algorithm was implemented on two examples, one with identical cavities and the other was a family mold with different cavity design. Conflicting objectives were tackled by Pareto optimal solution approach. The solution obtained by using this approach is both better and worse at least in one objective. So a weighted sum approach was employed to select the suitable design parameters. The choice of the weighted functions is left to the designer.

Ferencz, *et al.* **[28]** describes the use of different types of runner systems with their limitations in pressure die casting of aluminium. The temperature distribution in the runner system according to their shapes is also presented. The gate cross-section is determined after selection of filling time, filling speed and calculated part weight.

However, the material data base is missing for calculating part weight. Calculation of runner and gate parameters are missing

2.3 RESEARCH GAPS

Most of literature available on gating system design aims at optimizing the gate-runner parameters and properties of molten metal being injected into the die for minimizing the wrap or simulation of flow of molten metal through the gate and runners. A system is thus required that could work on the shortcomings which are written as following:

- Previous cavity systems calculate the number of cavities based on delivery date or technical criteria.
- The economic constraints are not considered in most of the cavity systems.
- Previous systems do not consider clearances to accommodate feed systems, cooling systems.
- Most of the previous gating systems are doing simulation of the gating system.
- Inbuilt feature library is missing. Some systems have feature library but limited.
- Previous gating system do not consider multi-cavities.

CHAPTER 3

PROBLEM FORMULATION

Cavity system should be designed to meet the requirements of the production of the industry. Number of cavities should be appropriate to meet the lot size of the industry and moreover, machine should be available to accommodate the cavity layout. Designing the gating system is an iterative process that can be very time-consuming and costly **Wu,** *et al.* **[27]**. There are a number of factors that must be considered while designing and placing gate and runner system such as: casting geometry, flow path, cavity fill conditions, cavity fill pattern and venting and overflow wells **[6]**. Cross-sectional area of gate is determined in accordance with die-casting thickness, gate velocity, die and metal temperature, etc. Usually, the tangential gate is employed where the segment of a die-casting is shaped like a parallelogram and fan gate is adopted if the segment approximates the shape of a trapezoid. In fact, they are often used together if the die-casting part is complex in shape.

As the design of the cavity system and gating system is an important step in the whole die design, CAD of the gating system is receiving interest. Most of literature available on gating system design aims at optimizing the gate-runner parameters and properties of molten metal being injected into the die for minimizing the wrap or simulation of flow of molten metal through the gate and runner. Some work has been done on the design of gating systems, and software packages such as **CASTFLOWTM [29]** and **MAGMATM [30]** are available in the market. However, most of the previous works focused either on feeder or casting designs only; a comprehensive die-casting design system that covers runner, gating, overflow, die-base, standard components, etc., has not been reported. So, there is a need of system to fill the gaps in design of gating system which are the objectives of the proposed work. In the previous chapter the research gaps are outlined after reviewing the literature available. These research gaps are outlined in the form of objectives of the present work. The objectives and methodology are discussed in the following sections.

3.1 OBJECTIVES

- ✓ Calculate the number of cavities automatically from machine, process and production data.
- ✓ Parametric modeling of gating system for generation of feature library.
- ✓ Automate the generation of gating parameters for single and multi-cavity dies.

3.2 METHODOLOGY

This section presents the proposed methodology for automated determination of number of cavities and gating system design. The methodology is discussed in the following lines.

- ✓ Creation of different data bases like material, machine data bases etc..
- ✓ Collect the knowledge base to determine the number of cavities for die-casting processes.
- ✓ Study of design attributes of the gating system for die-casting processes.
- ✓ Generation of feature library.
- ✓ Development of algorithm for gating system.
- ✓ Coding of defined algorithm using MATLAB in GUI interface.

CHAPTER 4

DESIGN OF AUTOMATED SYSTEM

4.1 CAVITY SYSTEM DESIGN

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 of part from part data base, 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 die-casting die design knowledge. This system is more comprehensive than previously known systems as it determines number of cavities by considering economical, technical 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.

The proposed system has three modules to arrive at automatic cavity design. The system depends upon the knowledge base of die-casting die design. It takes geometric information of part from part data base which is maintained as spread sheet file. Initially, the system determines the number of cavities considering technical, economical and time and presents feasible number of cavities as output. Secondly, it provides a possible solution for layout pattern, which is based on the number of cavities and uses a knowledgebase of layout patterns. Once the layout pattern has been selected, the third module of the system checks the suitable mould base according to selected machine for the selected layout. Selection of mould base takes into account the clearances required to accommodate feeding system, side pulls and is based on the die design knowledge base.

4.2 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 die-casting 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. These criteria are discussed in the following section.

4.2.1 Criteria for determine number of cavities

1. *Number of cavities based on delivery date* $[\boldsymbol{N}_{\boldsymbol{del}}]$

The number of cavities must ensure that the order can be fulfilled within the available time period. Based on time period for die casting, the minimum number of cavities for meeting the delivery date can be determined using the following relation **[17]**.

$$N_{del} = \frac{K_r \times t_c \times L}{t_m} \qquad (4.1)$$

2. *Number of cavities based on cost* $[\boldsymbol{N}_{\boldsymbol{cost}}]$

The optimum number of cavities to be used in the die casting die can be determined for a particular die casting task by first calculating the most economical number of cavities and then analysing the physical constraints of the equipment to ensure that the economical number of cavities is practical. Dewhurst and Blum **[13]** proposed a formula to calculate the economically optimum number of cavities, which is given as follow:

$$N_{cost} = \left[\frac{L \times \left(b_d \times t_m + C_{rt} \times t_{po}\right)}{m \times (C_d + C_t)}\right]^{\frac{1}{m+1}} \qquad (4.2)$$

3. *Number of cavities based on machine parameters* $[\boldsymbol{N}_{\boldsymbol{mac}}]$

The capacity of a die-casting machine is also limited by its parameters. Number of cavities is therefore dependent upon the constraints of the die-casting machine like clamping (locking) force, the maximum flow rate and the machine size and the resultant number of cavities i.e. N_{mac} will be minimum of these values. Following paragraphs discuss determination of number of cavities based on various machine constraints.

➢ *Number of cavities based on the clamping force* $[\boldsymbol{N}_{\boldsymbol{cf}}]$

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:

$$N_{cf} = \frac{F_c}{K \times A_p \times P_M} \tag{4.3}$$

The system takes A_p as 1.75 times the projected area of individual cavity to accommodate overflow and runner area **[8]**.

➢ *Number of cavities based on the maximum flow rate* $[\boldsymbol{N}_{\boldsymbol{fr}}]$

Flow rate represents the power of the shot system of the die casting machine. It describes the 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 exceed the power that the machine can provide **[8]**. Based on this principle, the maximum number of cavities can be determined as follows.

$$N_{fr} = \frac{M_{ss}}{V} \tag{4.4}$$

The system takes V as total volume of each cavity which accommodates overflow and runner and biscuit volume.

➢ *Number of cavities based on the machine size* $[\boldsymbol{N}_{\boldsymbol{ins}}]$

The distance between the 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 will be **[10]**,

$$N_{ins} = int\left[\frac{L_{die} - L_{mar}}{L_{ins} - 0.5\,L_{dis}}\right] \times int\left[\frac{W_{die} - L_{mar}}{W_{ins} - 0.5\,L_{dis}}\right] \qquad (4.5)$$

Therefore, number of cavities based on machine parameters can be taken as:

$$\boldsymbol{N_{mac}} = \textbf{Minimum of } (\boldsymbol{N_{cf}}, \boldsymbol{N_{fr}} \textbf{ and } \boldsymbol{N_{ins}})$$

4.3 PROCEDURE

The system takes the part data such as type of alloy, projected volume, projected area from part data base. Data regarding material characteristics are taken from material data base. Some other details like production time, lot size etc. is taken from production data base. It first checks longest part depth against die opening size or clamp stroke by using simple rule proposed by Blum **[13]**. The machine is selected from the machine data base as per this rule. The rule states that $L_s > 2D + 120$ mm, where L_s is clamp stroke of machine and D is depth of the longest hollow feature in the cavity. This selected machine is then used to determine minimum number of cavities (N_{mac}) which ensure that selected machine is technically permissible. The numbers of cavities as per delivery requirements (N_{del}) and cost requirements (N_{cost}) are calculated. The numbers of cavities based on machine parameters (N_{mac}) are then compared with calculated number of cavities based on delivery date (N_{del}) and cost requirements (N_{cost}). If the selected number of cavities (N_{mac}) is economically acceptable and technically permissible, (N_{mac}) is selected as the required number of cavities, else next machine from machine database with higher capacity is selected to fulfil the condition. All databases are given in annexure-B. Once the number of cavities is selected the next step is select the cavity layout which is discussed in the next section.

The system takes the number of cavities as input from the previous module. Selection of layout pattern is done with assistance from knowledge base to reach appropriate solution. If final numbers of cavities are in odd number, then circular pattern is selected. However, for even number of cavities the series pattern is selected except those cases when even number is a power series of number 2 (such as 2, 4, 8, 16...etc) , when symmetrical pattern is selected.

Once the cavity layout pattern is selected by the user, the next step is to check the capability of machine die base to cast the selected number of cavities with the prescribed layout pattern. If the machine die base is not sufficient to accommodate the selected cavity layout, then the bigger machine with large die base is to be selected from the machine database. Figure 4.1 shows an example of a die base having four cavities along-with usual clearances. The clearance (or margin) between cavities and die base edge is denoted by L_{mar}. This margin is provided to resist distortion due to high injection pressure of melting metal and to accommodate cooling lines. If any side face needs side pull mechanism then margin equal to 2D will be added, where D is the depth of undercut feature. The clearance between adjacent cavities is denoted by L_{dis} and depends upon the projected area of cavities. This clearance is provided to accommodate feed system. The runner diameter depends upon wall thickness of the part. An allowance twice the diameter of runner is generally left on both sides of die base for thermal balancing. These clearances are incorporated in the proposed system to achieve automatic cavity layout design. The flowchart of the cavity system is shown in figure 4.2

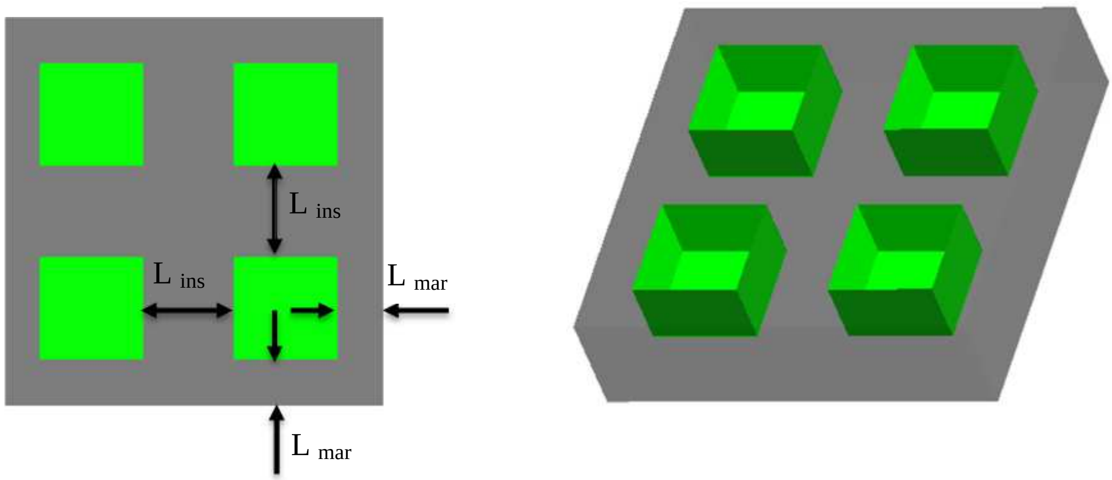

Fig. 4.1: Four cavity layout with clearances

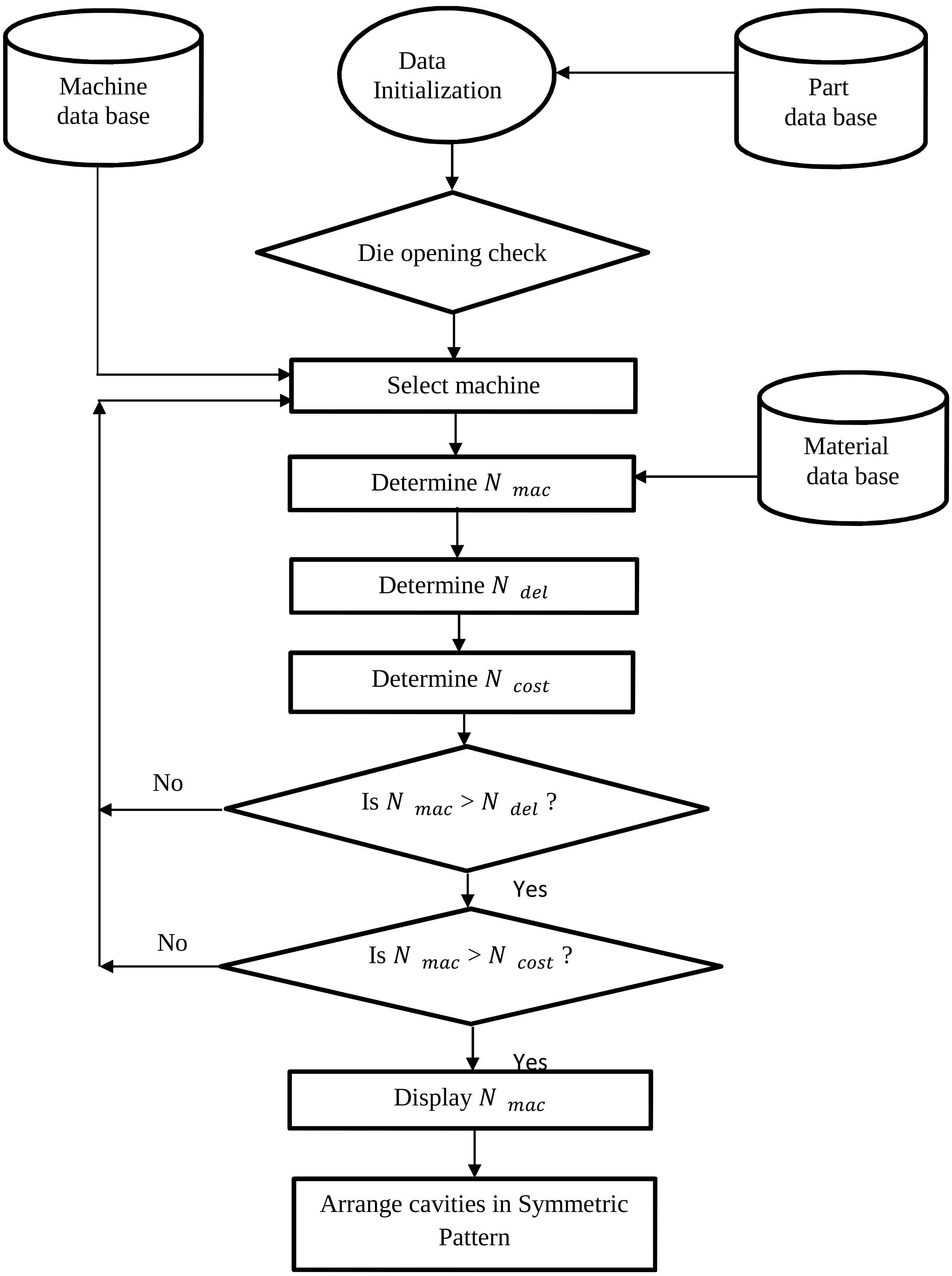

Fig. 4.2: Flowchart for cavity design

4.4 GATING SYSTEM DESIGN

As described in chapter 3, the main function of the gating and runner system is to deliver molten metal passed into all section of the mould cavity in the same time. The proposed system is designed to generate the parameters of gating system. The gating system includes gate, runner and overflow parameters. These divisions of gating system are described one by one in the following sections.

4.5 GATE PARAMETERS

In the system initially part is selected for which gating system is to be calculated. The part data includes wall thickness, projected volume, projected area etc. is input in the form of spread sheet. The easiest way to determine projected volumes and projected area is to use 3D CAD software. This method is fast and accurate. When many gating design scenarios are used, CAD makes the process of calculating volume of the casting fast and efficient. With 3D CAD and a comprehensive spread sheet that calculates in-gates, runners, out-gates, and vents, many gating interactions can be done quickly and efficiently. Figure 4.3 shows fan gate.

The system reads the part data from spread sheet data base. The Gate thickness is calculated from the average wall thickness of the part. The Gate thickness is taken as 80% of the given average wall thickness.

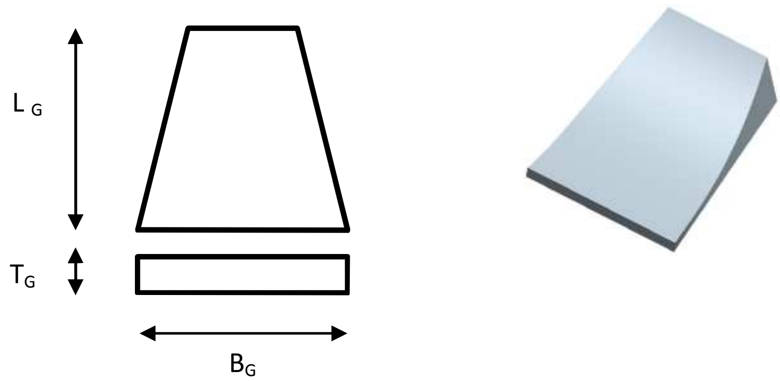

Fig.4.3: Fan gate

Once mechanical properties of cast are input from the material database which is given in the form of spread sheet and filling speed is selected which is taken as constant value of

28m/sec, the gate area is generated. The cross-sectional area of the gate A_g is shown by equation [4.6]

$$A_g = \frac{Q_a}{V_g \times t_g} \qquad (4.6)$$

The filling time of die cavity t_g **[8]** is given by equation [4.7]

$$t_g = k\left(\frac{T_i - T_f + SZ}{T_f - T_d}\right)h \qquad (4.7)$$

The gate length is calculated by dividing the gate area with their thickness. The system, compares the calculated gate breadth with the part length which is provided in part data base. If gate breadth is more than part length, the designer has to put more gates by dividing the calculated gate area into equal number of halves.

The next generated parameter is gate runner length. The gate runner length is taken as 120% of the gate breadth.

4.6 RUNNER PARAMETERS

The runners are the channels through which the molten metal is passed to the gate for cavity filling. The proposed system calculates the runner parameters like runner area, thickness and breadth of different types of runner as selected by the user.

The runner area is calculated by the gate area which is calculated in gate parameters. The runner area is taken as 110% of the gate area. The type of runner is selected by the user as per need. The system displays four types of runners i.e. trapezoidal, rectangular, square and circular. As per the selected type of runner, the system shows the aspect ratio between their breadth and thickness. The aspect ratios are given in the table below:

After calculating runner area the system further calculates the runner breadth and runner thickness according to the selected type of runner. The calculations are discussed below:

4.6.1 Trapezoidal Runner – Figure 4.4 shows the cross-section of trapezoidal runner with their dimensions. The aspect ratio in the following figure is $\frac{B1}{T_R} = \frac{2}{1}$

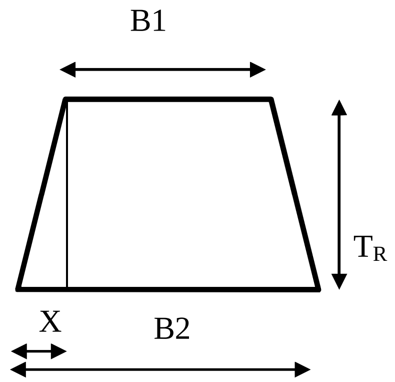

Fig.4.4: Trapezoidal runner

$$\tan 80 = \frac{T_R}{X} \quad (4.8)$$

$$T_R^{\ 2} = \frac{A_R}{2.1111} \quad (4.9)$$

$$B1 = 2 \times T_R^{\ 2} \quad (4.10)$$

$$B2 = 2 \times X + B1 \quad (4.11)$$

4.6.2 Rectangular runner – Figure 4.5 shows cross-section of this runner. The aspect ratio in the following figure is $\frac{B1}{T_R} = \frac{2}{1}$

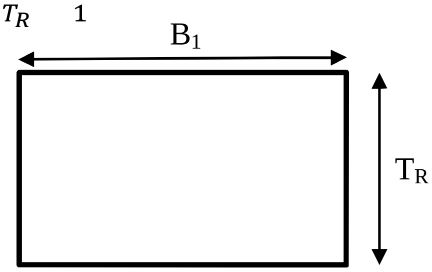

Fig.4.5: Rectangular runner

$$T_R^{\ 2} = \frac{A_R}{2} \quad (4.12)$$

$$B1 = 2 \times T_R^{\ 2} \quad (4.13)$$

4.6.3 Square Runner - Figure 4.6 shows cross-section of this runner. The aspect ratio in the following figure is $\frac{B1}{T_R} = \frac{1}{1}$

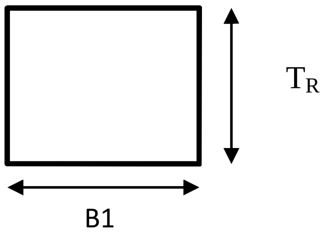

Fig.4.6: Square runner

$$T_R{}^2 = A_R \qquad (4.14)$$

$$T_R{}^2 = B_1 \qquad (4.15)$$

4.6.4 Circular Runner - Figure 4.7 shows cross-section of this runner. The diameter of runner is a complete dimension in itself.

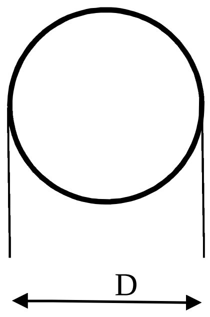

Fig.4.7: Circular runner

$$\frac{A_R}{\pi} = D^2 \qquad (4.17)$$

4.7 OVERFLOW PARAMETERS

Overflow volume is taken from the projected volume of the part which is provided in part data base. It is taken as 20% of the projected volume of the part. The area of the overflow is calculated using 3-D CAD software. The overflow breadth is calculated by dividing volume of overflow with their area.

$$O_B = \frac{O_V}{O_A} \tag{4.18}$$

The thickness of overflow is taken as the gate thickness.

The flow chart for generation of the gating system parameters are shown in figure 4.8

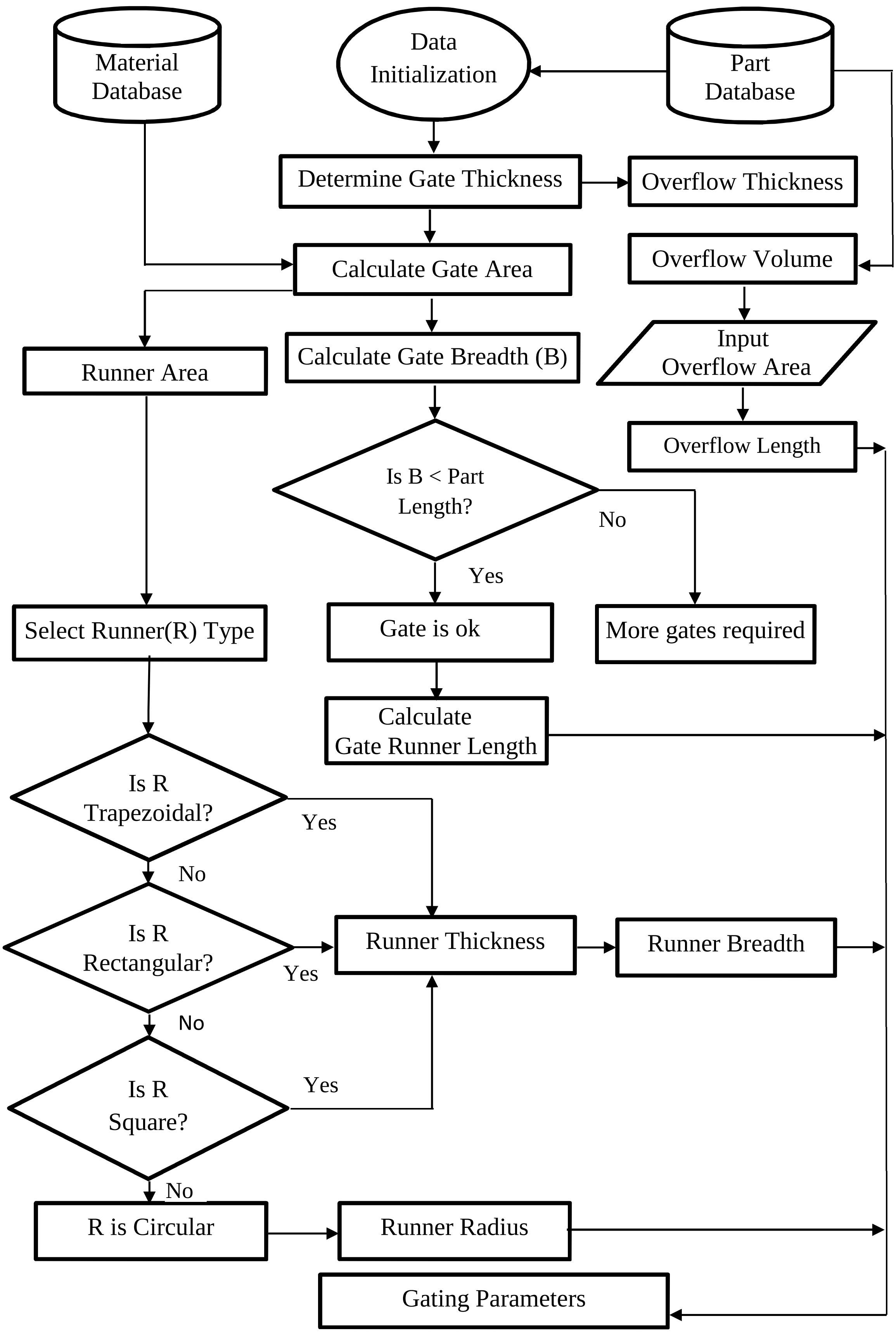

Fig.4.8: Flow chart for gating system

4.8 SYSTEM ARCHITECTURE

Figure 4.9 shows the complete architecture of the system. The system works with the help of die design principles and knowledge base of die designer. The system initially design the cavity system. Further the system generates the gating system parameters which include gate, runner and overflow parameters. The system takes the required data as input from different data bases. Part data provides the various dimensions of the part. Material data gives nature of the alloy on different conditions. Machine data gives information regarding suitable machines. Production data provides the information regarding lot size, delivery date.

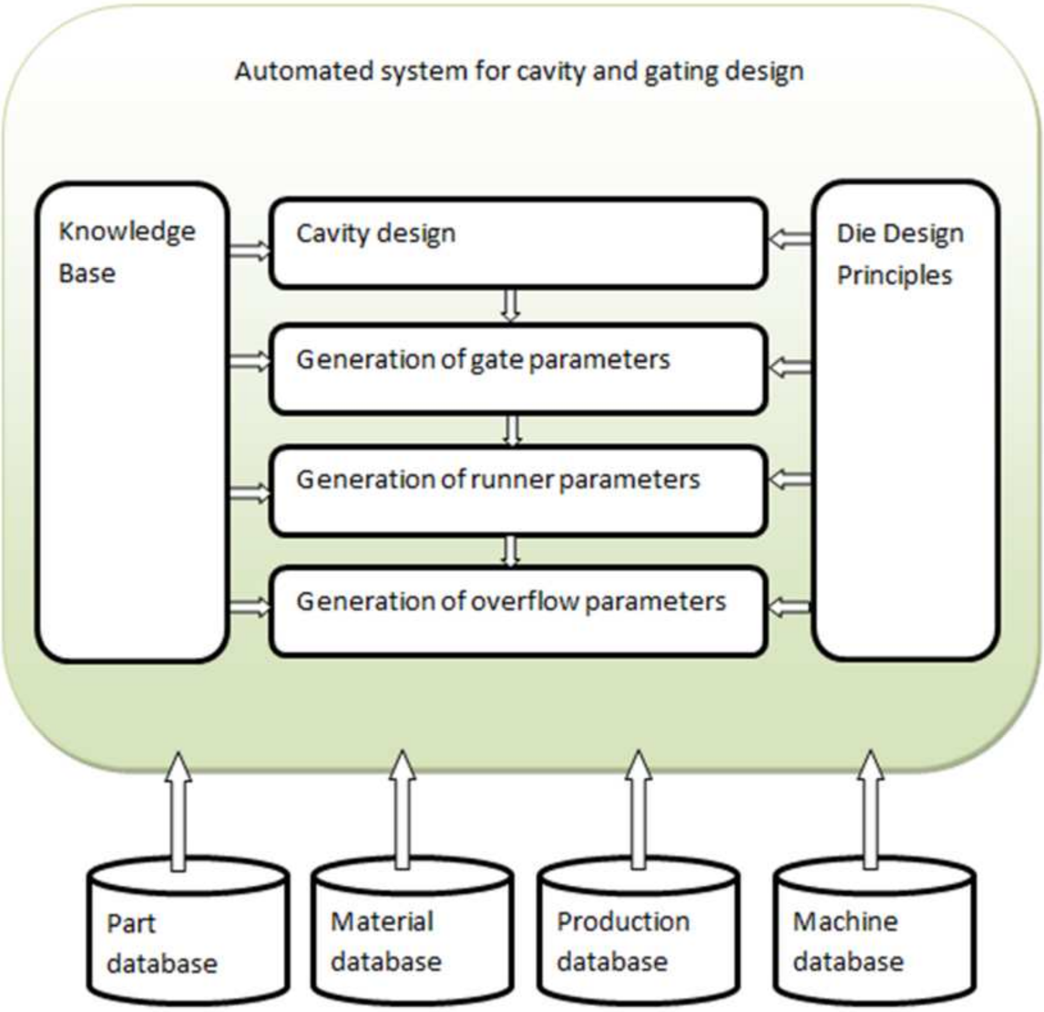

Fig.4.9: System architecture

CHAPTER 5

SYSTEM IMPLEMENTATION

5.1 CAVITY SYSTEM IMPLEMENTATION

GUI interface for cavity design in figure 5.1 and output of the system is shown in figure 5.2. The designed system is applied to the five die-casting parts. The output of the system on all five die-casting parts is shown in table 5.1.

User input the longest hollow dimension of the part to check the clamp stroke of the machine.

The number of cavities are selected from the machine parameters, delivery date and cost parameters.

Cavity layout is selected by the user.

Cavity layout is checked on the selected machine.

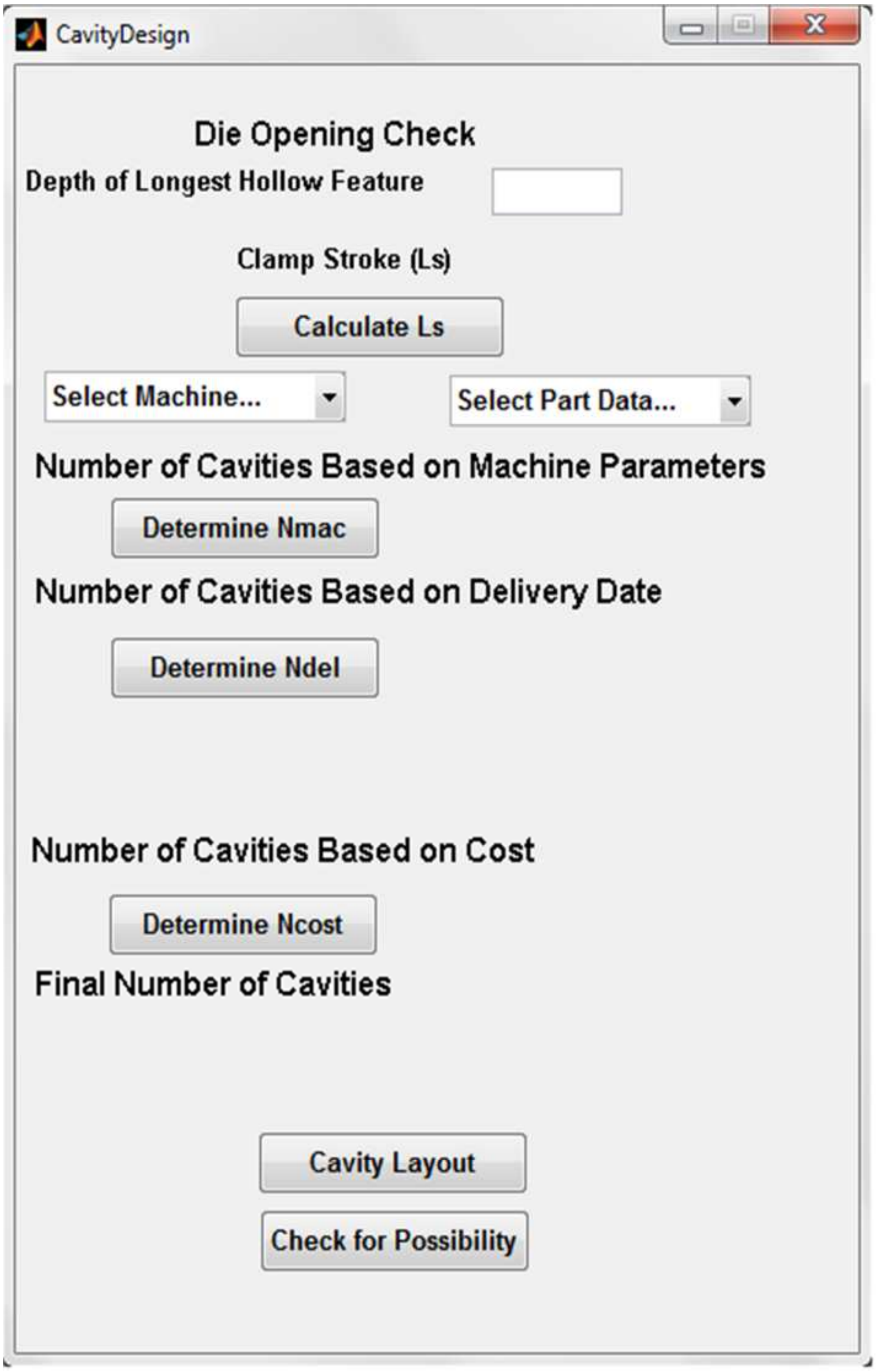

Fig.5.1: GUI interface for cavity design

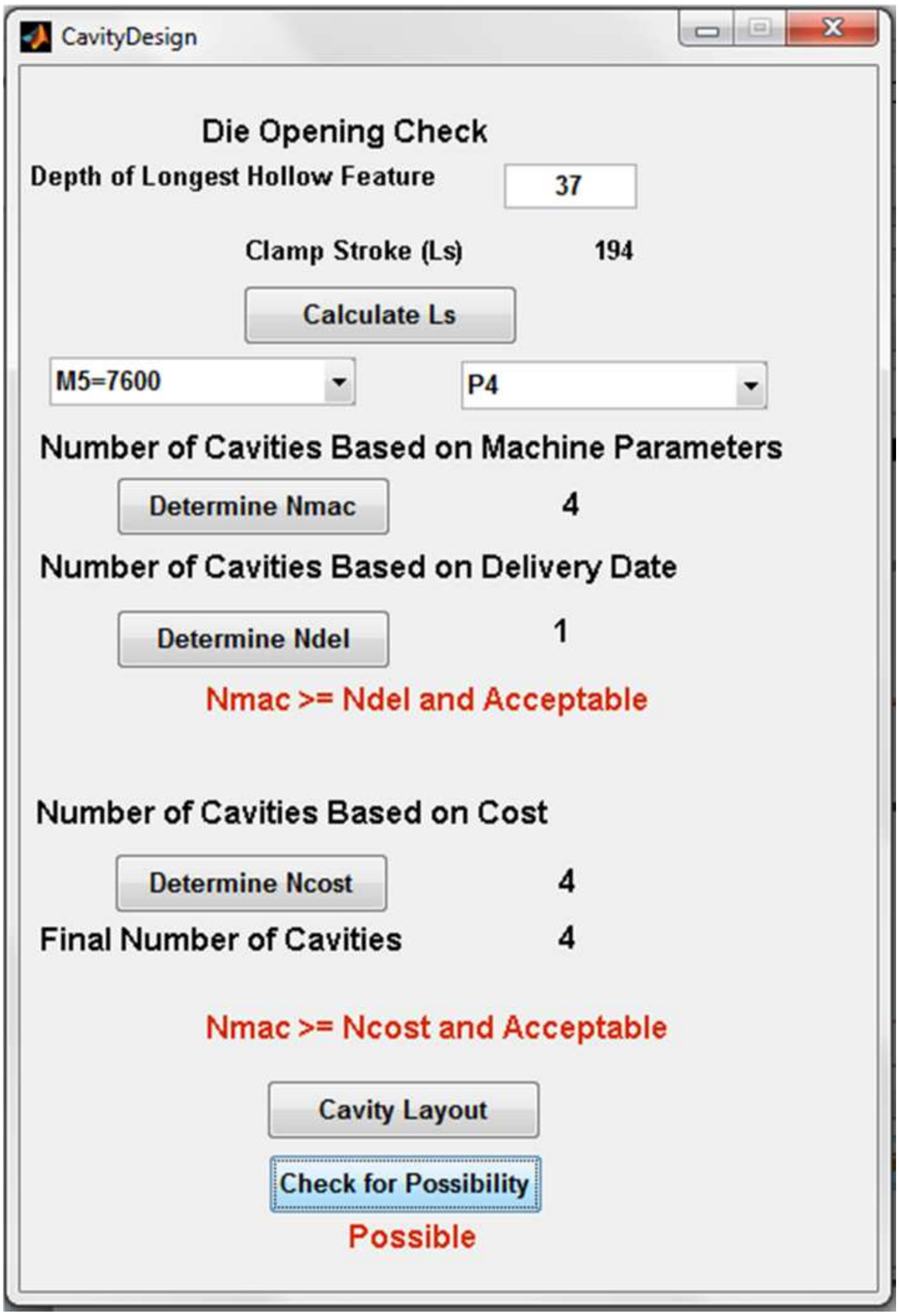

Fig.5.2: Output of GUI interface for cavity design

Table.5.1: Output of cavity system on five die-casting parts

Parts	Selected Machine	N_{mac}			N_{mac} [Min. of N_{cf}, N_{fr} and N_{ms}]	N_{del}	N_{cost}	Final Number of Cavities
		N_{cf}	N_{fr}	N_{ms}				
Part 1	M1	2	14	7	2	2	1	2
Part 2	M3	6	38	21	6	5	1	6
Part 3	M6	4	153	43	4	2	4	4
Part 4	M5	4	29	24	4	1	4	4
Part 5	M7	4	27	65	4	2	4	4

5.2 GATING SYSTEM IMPLEMENTATION

The system is presented in figure 5.3. Figure 5.4 shows the output of the system. The designed system is applied to the five die-casting parts which are shown in the following pages.

User input the part data to generate the gating parameters using the proposed system.

Gate parameters like thickness, area, and breadth and gate runner length are calculated using selected part, material and machine data base.

Runner parameters like area, thickness and breadth are calculated after the selection of type of runner. Runner area is calculated using the gate area.

Overflow parameters like volume are calculated using part data base. Overflow area is input interactively. Overflow length is calculated using its volume and area.

Fig.5.3: GUI interface for gating system

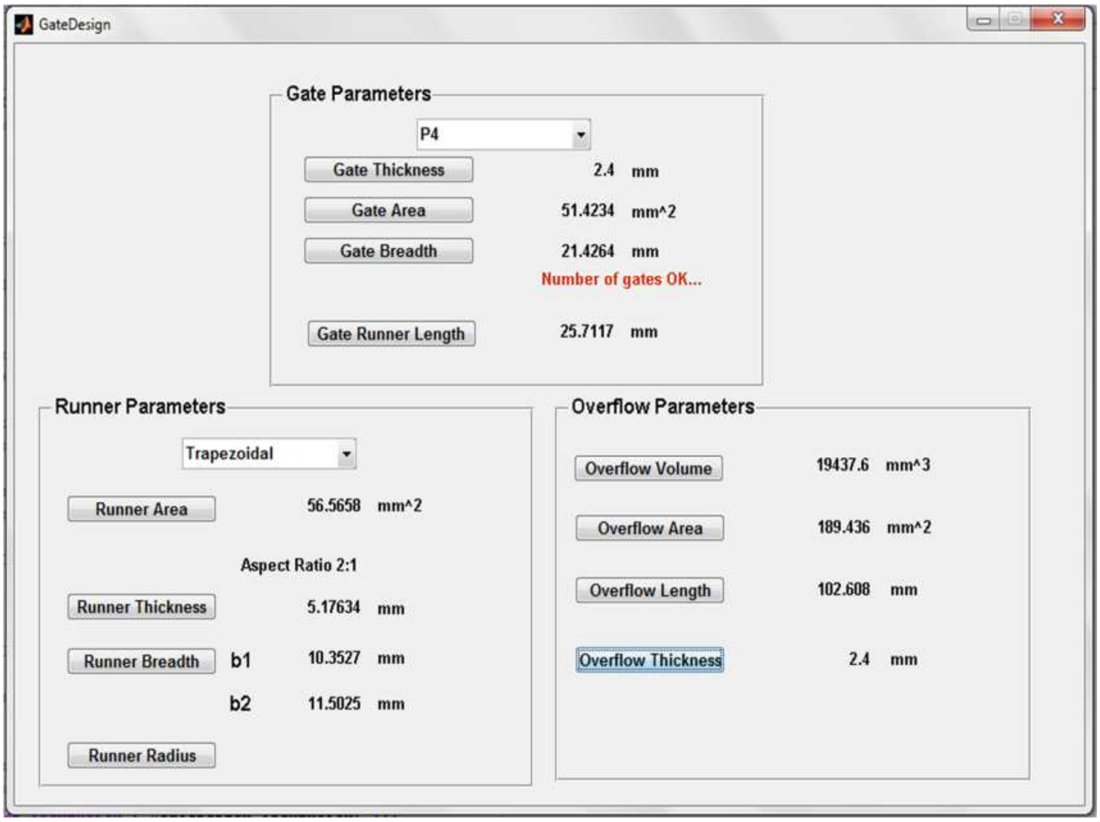

Fig.5.4: Output of the GUI interface for gating system

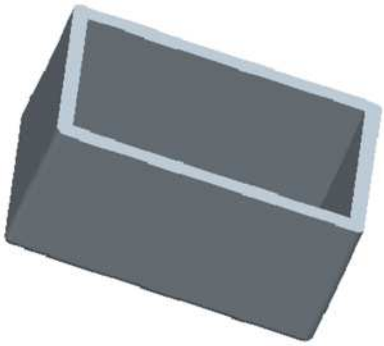

Fig.5.5: Die–casting part 1

A simple die-casting part shown in Figure 5.9.The part data like dimensions, volume, projected area has been given in table no. Part data along with process and machine data has been used to generate gating system parameters. The results of the system are depicted in table no.5.1

Table.5.2: Gating system parameters for part 1

GATE PARAMETERS		**RUNNER PARAMETERS**		**OVERFLOW PARAMETERS**	
Area (mm^2)	12.2372	Area (mm^2)	13.4609	Area (mm^2)	189.436
Thickness(mm)	1.2	Thickness (mm)	2.52315	Volume (mm^3)	2312.78
Breadth (mm)	10.1977	Breadth (b1)(mm)	5.0525	Length (mm)	12.2088
Gate Runner Length (mm)	12.2372	(b2)(mm)	5.6115	Thickness(mm)	1.2

Fig.5.6: Die–casting part 2 (Casing-Hero Honda)

A die casting part name casing of carburettor have been shown in Figure 5.10.The part data like dimensions, volume, projected area has been given in table no. Part data along with process and machine data has been used to generate gating system parameters. The results of the system are depicted in table no.5.2

Table.5.3: Gating system parameters for part 2

GATE PARAMETERS		RUNNER PARAMETERS		OVERFLOW PARAMETERS	
Area (mm^2)	8.51085	Area (mm^2)	9.36193	Area (mm^2)	189.436
Thickness(mm)	2.4	Thickness (mm)	2.10585	Volume (mm^3)	3217.03
Breadth (mm)	3.54619	Breadth (b1)(mm)	4.21171	Length (mm)	16.9821
Gate Runner Length (mm)	4.25542	(b2)(mm)	4.67949	Thickness(mm)	2.4

Fig.5.7: Die–casting part 3 (Mortgage lock)

An another die-casting part name mortgage lock have been shown in Figure 5.11.The part related data like dimensions, volume, projected area has been given in table no. Part data along with process and machine data has been used to generate gating system parameters. The results of the system are depicted in table no.5.3

Table.5.4: Gating system parameters for part 3

GATE PARAMETERS		RUNNER PARAMETERS		OVERFLOW PARAMETERS	
Area (mm^2)	30.848	Area (mm^2)	33.9223	Area (mm^2)	189.436
Thickness(mm)	1.6	Thickness (mm)	4.00897	Volume (mm^3)	2312.78
Breadth (mm)	19.278	Breadth (b1)(mm)	8.01795	Length (mm)	41.0309
Gate Runner Length (mm)	23.1336	(b2)(mm)	8.90847	Thickness(mm)	1.6

Fig.5.8: Die–casting part 4 (Side Cover-Hero Honda)

A die-casting part name casing of carburettor have been shown in Figure 5.12.The part data like dimensions, volume, projected area has been provided in table no. Gating system parameters has been generated using process, machine and part data. The results of the system are depicted in table no.5.4

Table.5.5: Gating system parameters for part 4

GATE PARAMETERS		RUNNER PARAMETERS		OVERFLOW PARAMETERS	
Area (mm^2)	51.4234	Area (mm^2)	56.5658	Area (mm^2)	189.436
Thickness(mm)	2.4	Thickness (mm)	5.17634	Volume (mm^3)	19437.6
Breadth (mm)	21.4264	Breadth (b1)(mm)	10.3527	Length (mm)	102.638
Gate Runner Length (mm)	25.7117	(b2)(mm)	11.5025	Thickness(mm)	2.4

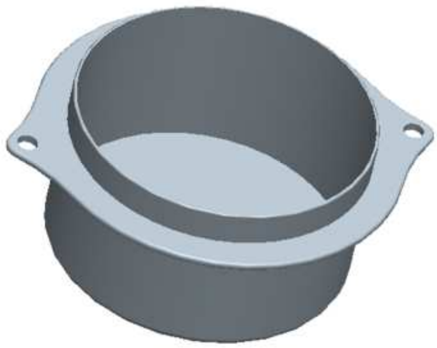

Fig.5.9: Die–casting part 5

A die casting part have been shown in Figure 5.13.The part data like geometrical dimensions, volume, projected area has been given in table no. Part data along with process and machine data has been used to generate gating system parameters. The results of the system are depicted in table no.5.5

Table.5.6: Gating system parameters for part 5

GATE PARAMETERS		RUNNER PARAMETERS		OVERFLOW PARAMETERS	
Area (mm^2)	177.536	Area (mm^2)	195.289	Area (mm^2)	189.436
Thickness(mm)	1.6	Thickness (mm)	9.61801	Volume (mm^3)	44738.1
Breadth (mm)	110.96	Breadth (b1)(mm)	19.236	Length (mm)	236.164
Gate Runner Length (mm)	133.152	(b2)(mm)	21.3725	Thickness(mm)	1.6

5.3 IMPLEMENTATION OF COMPLETE SYSTEM

Figure 5.10 shows the implementation of complete system on die-casting part 4 shown in figure 5.8. The regarding number of cavities and gating system parameters are shown in table 5.7

Table.no: 5.7 Cavity number and gating system parameters for die-casting part 4

NUMBER OF CAVITIES	GATE PARAMETERS		RUNNER PARAMETERS		OVERFLOW PARAMETERS	
4	Area (mm^2)	51.4234	Area (mm^2)	56.5658	Area (mm^2)	189.436
	Thickness (mm)	2.4	Thickness (mm)	5.17634	Volume (mm^3)	19437.6
	Breadth (mm)	21.4264	Breadth (b1)(mm)	10.3527	Length (mm)	102.638
	Gate Runner Length (mm)	25.7117	(b2)(mm)	11.5025	Thickness (mm)	2.4

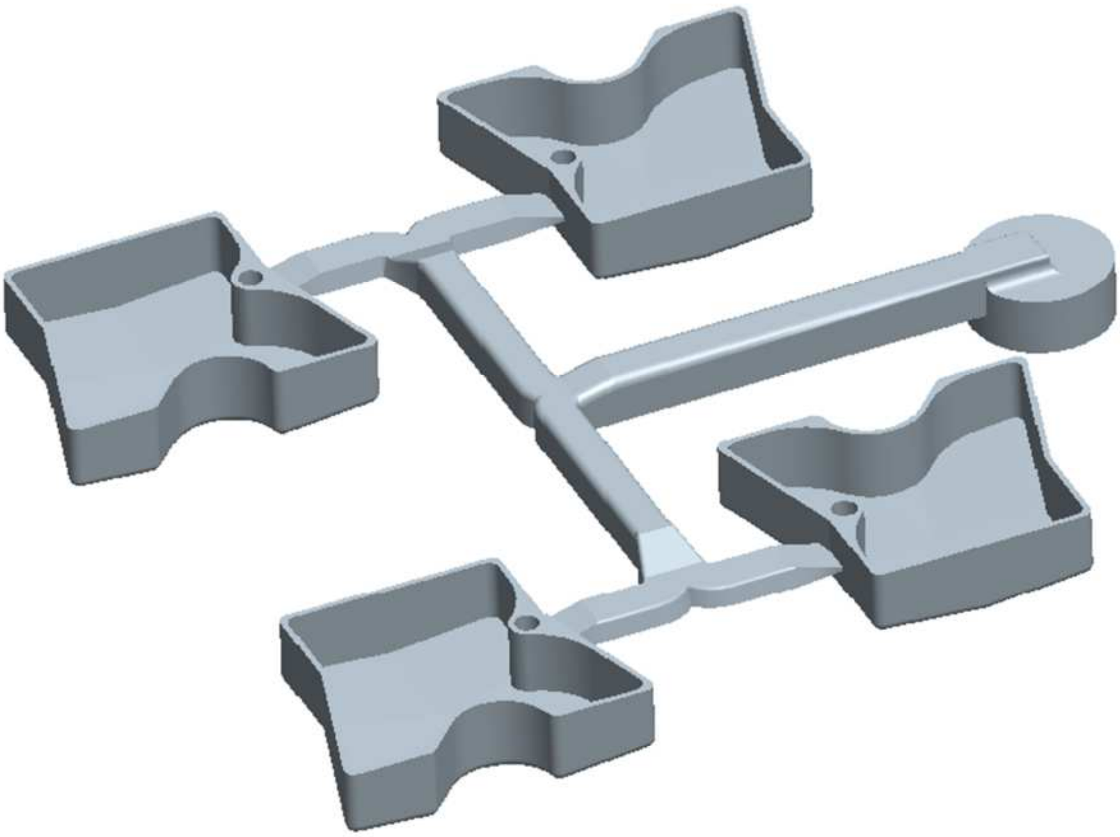

Fig.5.10: Complete system implementation on die-casting part 4 (Side Cover Honda)

CHAPTER 6

CONCLUSION AND SCOPE FOR FUTURE WORK

6.1 CONCLUSION

An parametric approach towards automated determination of gating system along with determination of number of cavities has been developed. The system is constructed with die design algorithm and MATLAB. Traditionally, gating parameters are generated by trial and error methods which are solely on die design engineer. The proposed system is established to bridge the gap between design and manufacturing activities of die casting parts. A novice who may not have any experience can perform die design with only little knowledge of die-casting. The salient features of the present system are listed below:

- Able to capture the knowledge of die-design expert.
- Determines the number of cavities in an automated fashion.
- Proposes the cavity layout for multiple cavities.
- Determines the gating system parameters using various databases like production, machine and part database.
- Has a feature library in Pro-E for simplifying the gating design.
- Reduces the effort and time of die-design expert.
- The results from the system could be applied to the part in modeling softwares like Pro-E, solid works etc.

6.2 SCOPE FOR FUTURE WORK

The current work is an initiative to integrate the design-manufacturing of the die-casting process. There are certain assumptions made to make the problem a bit manageable in the light of the constraints of time and effort required for this research work. Some of the assumptions are as follows:

- The die-casting part is simple i.e. without any undercut feature.
- Part material is aluminum alloy.
- The layout of the cavities is balanced/symmetric only.
- Gate location.

- The gating system consider only single type of gate i.e. Fan Gate.

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ANNEXURE - A

NOMENCLATURE

K_r = Rejection factor (1.05)

t_c = Cycle time of every product (sec)

L = Lot size of the product

t_m = Time available for production (sec)

b_d = Minimum casting machine rate ($/hr)

t_m = Die casting machine cycle time (hr)

C_{rt} = Trim press and operator rate ($/hr)

t_{po} = trimming cycle time (hr)

C_d = Cost of single-cavity die casting die ($)

C_t = Cost of single aperture trim die ($)

m = Multi-cavity die cost exponent (0.7)

F_c = Maximum clamping force (N)

A_p = Projected area of each cavity, its overflow and runner (mm^2)

P_M = Maximum metal pressure (M Pa)

K = Factor of safety against flashing (1.75)

M_{ss} = Shot size of system (mm^3)

V = Volume of each cavity, its overflow and runner (mm^3)

L_{die} = The allowable maximum length of the die used (mm)

W_{die} = The allowable maximum width of the die used (mm)

L_{ins} = The length of the cavity inserts (mm)

W_{ins} = The width of the cavity inserts (mm)

L_{mar} =Minimum margin between the edges of the die and inserts (mm)

L_{dis} = Minimum distance between the cavity inserts (mm)

int is Mathematic function to round off the given numeral to an integer

Q_a = The volume of cavity (mm^3)

V_g = Filling speed of molten metal (m/sec)

L_G = Gate-runner length (mm)

T_G = Gate thickness (mm)

B_G = Gate breadth (mm)

A_g = Gate area (mm^2)

t_g = Filling time of molten metal in cavity (sec)

k = Emprically derived constant for die steel

T_i = Metal temperature at the in-gate (^oc)

T_f = Minimum flow temperature of metal alloy (^oc)

T_d = Die temperature (^oc)

S = Percent solids at the end of fill,

Z = Solids units' conversion factor, degree to %,

h = Wall thickness (mm)

B1 = Runner breadth (mm)

B2 =Large Runner Breadth in trapezoidal runner (mm)

T_R = Runner thickness (mm)

X = Base dimension (mm)

A_R = Runner area (mm)

D = Runner diameter (mm)

O_B = Overflow breadth (mm)

O_V = Overflow volume (mm^3)

O_A = Overflow area (mm)

Annexure – B

Table.1: Production data

Cycle Time of Every Product (Sec)	Lot Size	Time Available for Production (Hours)
30	10000	32
35	20000	40
20	100000	280
20	100000	440
45	75000	360

Table.2: Aspect Ratio of different runner cross-sections

Type of Runner	Aspect Ratio (breadth : thickness)
Trapezoidal	2:1
Rectangular	2:1
Square	1:1

Table.3: Properties of alloys

Alloy	Density	Cost $/kg	Injection temp ^0C	Liquidus temp ^0C	Die Temperature	Ejection Temperature	Cavity Pressure (MN/m^2)	Thermal Conductivity(cal /mm/sec/°C)	Specific heat cal/g °C	Latent Heat	Solidus Temp
Zinc	6.6	1.78	440	387	175	300	21	132	234	2324	323
Alminium	2.7	1.65	635	585	220	385	48	121	963	3232	323
Magnesium	1.8	2.93	655	610	275	430	48	156	456	1313	332

Table.4: Part data

Part No.	Length	Width	Height	Projected Volume	Longest Hollow Part	Projected Area	Average Wall Thickness	Number of Undercuts	Half Thickness of Cast
1	60	30	38	13604.6	35	2243.4	1.5	0	19
2	58	55	30	18923.7	27	3258.94	3	0	15
3	242.32	76	13	45721.9	11	23390.68	2	0	6.5
4	160	130	40	114339	37	15996.66	3	0	20
5	279.3	46	40	263165	38	38142.14	2	0	20

Table.5: Machine data

Machine No.	Clamping Force (kN)	Shot Size(Mss) (cm^3)	Dry Cycle Time (sec)	Clamp Stroke (cm)	Platen Size length (cm)	Platen Size Width (cm)	DieCasting Process Operating Rate ($/h)	Trimming Process Operating Rate ($/h)	Minimum Margin Between die edges and inserts (mm)	Minimum Distance Between Cavity Inserts (mm)(l_{ins})	Die Cost($)(Cd)	Trimming Die Cost($)(Ct)
M1	900	305	2.2	24.4	35	35	66	26	60	60	10000	5000
M2	1800	672	2.8	36	55	55	73	29	60	60	12000	6000
M3	3500	1176	3.9	38	60	60	81	32	60	60	12500	6250
M4	6000	1932	5.8	46	70	70	94	38	60	60	14000	7000
M5	10000	5397	8.6	76	107	107	116	46	60	60	15500	7750
M6	15000	11256	10.2	81	140	140	132	53	60	60	17000	8500
M7	25000	11634	19.9	109	160	160	196	78	60	60	18000	9000
M8	30000	13110	23.3	119	160	160	218	87	60	60	21000	10500