STUDY OF THE EFFECT OF DIE CASTING MACHINE UPON DIE DEFLECTIONS

A Thesis
Presented in Partial Fulfillment of the Requirements for
the Degree Master of Science in the
Graduate School of The Ohio State University

By

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* * * * *

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ABSTRACT

Die casting die deflection depends to some degree on the die casting machine. Models of structural members of the die casting machine, i.e., platens, tie bars and C-frame that account explicitly for the deflection of the die were developed. Once the behavior of these machine elements is known, the machine can be accounted for by an equivalent model when predicting die deflections, thus avoiding the need to include the geometry of the machine explicitly in the deflection models. In this research computer models were developed to study die casting machine deflections and the simulation results were validated with field data. A spring / platen model was developed to account for the machine while simulating die casting die deflections. This model is a approximate model of an machine and is more accurate than the previous models. A design of experiment study was conducted to establish the behavior of the effect of different machine variables on platen deflections and also on the maximum separation at the parting plane. The parameters that were varied are tie bar diameter, platen thickness and die position. An experimental array was designed for studying
the effect of the above variables and also the interaction between these variables upon platen deflection.
DEDICATION

Dedicated to my mother, father and chanda kaka
ACKNOWLEDGMENTS

I wish to thank my advisor, Dr. R. A. Miller, for intellectual support, encouragement, and enthusiasm which made this thesis possible.

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I also wish to thank Dr. Horacio Ahuet-Carza, for offering me helpful comments and suggestions during the course of this work.

I also thank my friends Sanjay Dedhia and Abhijeet Chayapat for proof reading my thesis.
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CHAPTER 1

INTRODUCTION

1.1 Introduction

Manufacturing is a human activity that pervades all phases of our life. The history of manufacturing is marked by gradual developments. One of the notable developments in modern manufacturing practice is the production of complex parts by injecting molten metal into steel dies or mold cavities at high pressure. During the past few years, this industry has witnessed significant improvements in the design, development and production of castings. The advent of fast and powerful computers has allowed to develop different numerical techniques such as the Finite Element Method (FEM) and Finite Difference Method (FDM) which helps in reducing the time spent in design and analysis stage.

The current research focuses on the use of FE simulations to predict the deflections in die casting dies. Once the deflection is obtained, corrective measures can be taken to prevent die deflections by proper design of dies before they are actually manufactured. This will result in better quality castings.
1.2 The Die Casting Process

The die casting process is a permanent-mold casting process in which molten metal is forced into the die cavity at pressures ranging from 0.7-700 MPa (0.1-100 ksi). A simple die casting die (as shown in Figure 1.1) consists of two halves made of steel called the cover die and ejector die. The cover die is fastened to the stationary platen of the die casting machine and does not move during the casting cycle. The ejector die is mounted in the movable platen of the machine. A cavity to form the part that is to be cast is machined in each of these dies. Molten metal is injected through the shot sleeve (Cold chamber machine) or forced through the gooseneck (Hot chamber machine) and is held under pressure until it solidifies in the die. Then ejector pins are used to eject the part from the ejector cavity after the die casting machine opens.

1.3 The Die Casting Machine

The typical die casting machine consists of a fixed front plate called the cover platen, a moving platen called the ejector platen, a crosshead, and a rear platen, all connected together by tie bars. The moving platen and the rear platen are connected together through the toggle linkage and provide the motion for opening and closing the die. The toggle linkage also produces the required clamping force by stretching the tie bars. The clamping force should be sufficient to keep the die closed while the metal is being injected.
Figure 1.1: Schematic of a simple die casting die.
into the cavity. If clamping force is not sufficient to hold the dies together, the die will open while the cavity is being filled.

There are two basic types of die-casting machines hot-chamber and cold-chamber which differ only in the method by which molten metal is injected into the die.

In the hot chamber machine (Figure 1.2, SME Metals Handbook, Vol. 15 [1]), the plunger and the cylinder are submerged in the molten metal in the holding furnace. When a shot is made, the control valve opens causing the shot cylinder to force the plunger down, which forces the molten metal into the cavity through the gooseneck and nozzle. Since the gooseneck and nozzle are submerged in the molten metal, the system refills automatically when the plunger is withdrawn. Low melting point alloys such as zinc, tin, and lead are commonly cast by this process.

The cold chamber machine shown in Figure 1.3 (Doehler, 1951 [2]) uses a hydraulically operated plunger to force molten metal into the die. The metal is first poured into the shot sleeve by a ladle. Immediately after the pouring, the plunger is advanced, which forces the metal charge into the locked die under high pressure. These machines are used to cast parts made of magnesium, aluminum and copper which have higher melting point.

The die closing sequence of a cold chamber die casting machine is shown in Figure 1.4 (Herman, 1988 [3]). Initially the dies are open and the toggles are loose (Figure 1.4 (a)). As the toggles straighten (Figure 1.4 (b)), they
Figure 1.3: Basic components of a typical cold-chamber machine [Doehler, 1951].
Figure 1.4: Schematic showing die closing sequence of a cold chamber die casting machine.
close the die by displacing the moving platen, and then, as they reach the position of the highest mechanical advantage, they stretch the tie bars to develop the holding force on the die (Figure 1.4 (c)). During die closing the four tie bars become stressed. Stress will increase when the two die halves are in contact until the toggles are extended. The forces raised in the tie bars will be transferred to the platens, which causes bending of the platens and give rise to bending moments in the tie bars. The toggle linkage as shown in Figure 1.5 (Takah, 1995 [4]) will oppose bending of the platen in X and Y axis, but it will not oppose in the Z axis. The function of the closing unit should be monitored to ensure proper distribution of tie bar load and relatively high useful locking force in relation to the closing force.

1.4 Problem Statement

The dies in a die casting process are the costliest parts. A typical die for a transmission casing costs at least $0.5 million. Thus, if the cost of the castings are to be economical with respect to the dies, the dies must last for a long time. Earlier work has shown that die casting dies deflect during a casting cycle. This may result in molten metal escaping into the parting plane. The result may be a casting that is over-size and with excess flash. Metal may be forced into the gaps of the core slides which will hinder the slide movement. More force will be required to close the die and eliminate the separation at the parting plane. This may also lead to catastrophic failure of the die. Effort has
Figure 1.5: Moving platen bending with toggle system [Takach, 1995].
been made to predict elastic die deflections through FE analysis using commercially available software. By predicting the magnitude of the deflection of the die, design modifications may be made to a die before parts are produced. This will improve the dimensional quality of the part, which is our ultimate goal. The quality of the casting process may also be improved by reducing flashing, avoiding metal flow into gaps etc.

To this date, no work has ever been attempted to account for the support that the die casting machine provides to the dies during the die casting operation. The results of the original work can be improved by including the effect of the die casting machine upon the deflections of the die.

1.5 Thesis Outline

A literature survey and an overview of the research objective are presented in Chapter 2. Chapter 3 presents a general outlook of the development of the FEM model of a die casting machine and discusses the different modeling aspects. The results of the case study and experimental verification are presented in Chapter 4. Chapter 5 describes the development of a spring/platen model to include the effect of die casting machine in die deflection simulations and also the effect of different parameters on the performance of the machine. Chapter 6 concludes the thesis and recommends future work in this field.
CHAPTER 2

LITERATURE REVIEW AND RESEARCH APPROACH

2.1 Literature Review

With the object of gaining an understanding about the support provided by the die casting machine during a die casting operation, a review of some of the literature relevant to the analysis and modeling of the die casting process is presented in this chapter. Both the theoretical and experimental work are included.

2.2 Die casting deflection studies at the Ohio State University

There has been much research interest in predicting die casting die deflections using finite element simulations following the work done by Padiyar and Miller [5], Hegde et al [6] and, Ahuett-Garza et al [7]. In June 1995 a preliminary study of die casting die deflections was completed at the Ohio State University Ahuett-Garza et al [13]. Their work represented both thermal and mechanical loads of a casting operation, addressed some of the issues in the simulation of die casting die deflections, and produced data regarding the
parting plane separation of a flat plate die. In their work the machine was not modeled explicitly. Instead the cover die was assumed to be mounted on a rigid support. All the nodes on the back surface of the cover die half were constrained in all six degrees of freedom. The total clamping tonnage was applied as an equivalent pressure on the back of the ejector support. It is also stated by them that by assuming the cover die to be rigid, the elasticity of the support the machine provides is neglected.

Ahuett-Garza et al [8] provided a picture of the characteristics of the loads and die behavior in a die casting operation:

- The effect of momentum and hydrodynamic loads upon the magnitude of die deflection are negligible under typical casting conditions.

- Injection pressure may induce a dynamic response in the die structure only under specific circumstances.

- In majority of cases, maximum deflections are reached at the point of intensification.

This work suggested that the intensification pressure and heat released from solidification have to be accounted for in deflection simulations but, the effect of heat released during fill can be neglected.
2.3 Experimental studies related to die deflections

Prince et al [9] reported the measurement of platen deflections, slide movement and parting plane separation during the die casting operation. He also observed distortion of four-slide case die during lock up and shot on 2000 ton die casting machine by varying the clamping load of the machine. Their results indicate that in all instances where an existing die was operated at a lower clamping loads, no degradation in produced parts was found.

Garber et al [10] studied the effect of process variables such as intensification pressure, fast shot-plunger velocity, die temperatures, metal temperatures and cycle time on the internal quality of the casting. They reported that high levels of intensification pressure do not necessarily assure high levels of internal quality. When the fast shot-plunger velocity was decreased, the average defects were decreased in the casting. When the metal temperature was decreased there was an increase in the number of defects on the casting. Increase in die temperature and decrease in cycle time had only small effects on the internal quality of the casting. However, there is no indication of how these results are in comparison to the real world die casting.

During closing of a die, some factors will cause a reduction of the effective locking force. Takach [4] presents an overview of the factors influencing this force.

These are:
• Proportion of die surface area to the platen size
• Die construction
• Flash build up in the parting plane
• Uneven preload in tie bars
• Die temperature

2.4 Deflection studies in other metal forming processes

Although little work has been done on the prediction of die deflection for die casting dies, literature does exist in areas of forging, extrusion and injection molding. One can argue that the die deflection modeling in injection molding would be similar to the die casting conditions, but there is a significant difference in the metal solidification as opposed to plastic solidification. The biggest difference is the thermal conductivity of the metal and plastic during solidification. There is also a huge pressure difference between die casting and injection molding process.

The essential difference in the nature of the die deflections in die casting dies and other forming operations is the source of deflection. Mechanical contact pressure in other forming process is large compared to die casting, where intensification pressure may be significant compared to deflections of the die due to clamping pressure.

Menges and Mohren [11] describe a procedure for computing cavity deformation as a superposition of the deformation of the mold, molding
machine, slides, cams, etc. The difference in various deformations were distinguished as follows:

- deformation in the direction of clamping or ejection
- deformation transverse to the direction of ejection
- deformation of machine platen
  - relative deformation of platen
  - lowering of platen
- deformation of ejector pins

Menges developed graphs for estimating deflections of cores subject to shown pressure profiles and values. Unfortunately the assumption of the pressure profiles over slides and cores in die casting is very difficult to obtain. There are a large number of other unknown factors such as the stage of solidification, pressure transmission of molten metal, effect from molten machine operation which are different in die casting and which are very important in determining deformation have been left ignored.

Menges [11] also suggested an analytical procedure for calculating the deformations of the whole system by dividing it into separate elements. Each individual element can be considered as a spring and the whole system can be computed as a set of springs. Figure 2.1 shows an equivalent diagram of the machine and the mold when the deformations and forces are considered in the direction of the clamping force. The machine components, cover platen,
Figure 2.1: Schematic of the clamping unit and mold [Menges & Mohren, 1986].
ejector platen and the tie bars are first stressed by the clamping force. In addition to this force, they are also stressed by the cavity pressure during the injection of the molten metal. The part of the mold at the cavity area is first stressed by the clamping force but then more or less relieved by the relative forces from cavity pressure. Thus cavity deformation does not only depends on the rigidity of the mold but also on that of the clamping unit.

2.5 Objective of Current Research

The die casting machine influences the magnitude of the deflections of the die. In fact, there are many anecdotal reports of dies that perform well in a given machine, but will fail to function in a different machine of the same capacity. To predict die casting die deflections by FE simulations, the behavior of different machine components need to be studied. An accurate die deflection modeling scheme should be developed to account for the stiffness of the machine.

The objectives of this research are:

- Identify the factors that can be used to characterize the machine as an entity that supports a die.
- Develop a FEM model of a die casting machine to simulate the platen deflections.
- Validate simulation results with experimental data.
- Determine the effects of various size cut-outs for the shot sleeve in the platen.

- Study the support provided by the die casting machine to the dies and thereby, come up with a new model to include the effect of machine in die deflection simulations.

- Evaluate the performance of a die casting machine by variation of platen thickness, tie bar diameter and location of die with respect to platen.
CHAPTER 3

FEM MODELING OF DIE CASTING MACHINE

3.1 Introduction

Die casting die deflection depends to some degree on the die casting machine. Models of structural members of the die casting machine, i.e., platens, tie bars and C-frame account explicitly for the deflection of the die. The goal of this research is to study the effect of the die casting machine upon die deflections. Ultimately, we would like to account for the machine through the use of either spring elements or an alternate model, thus avoiding the need to include the geometry of the whole machine explicitly in our models of die deflections. This requires a thorough understanding of the support that the machine provides for the die. To accomplish this, FE models that simulate the clamping action of the die casting machine were developed. A case study and experimental verification of the results are presented in the next chapter.
3.2 The finite element modeling scheme adopted in current research

A good modeling user must have a thorough understanding of the theory behind the modeling technique in order to take full advantage of its power and understanding its limitations and assumptions in modeling a given phenomenon. This is especially true in the current research, where a general purpose FE tool is utilized with simplifying assumptions about heat transfer and stress analysis at the interfaces of the die surfaces for the solution of the thermo-elastic problem. The finite element method is a popular modeling technique which is based on the theory of variational calculus. Many of these codes are displacement based i.e., the solution is basically the dependent variable of the governing differential equation and the other quantities such as heat flux, strains or stresses are later derived from the displacement variables.

The FE method is characterized by the following features. The domain of the problem is represented by a collection of simple sub-domains called finite elements [12]. The collection of elements is called finite element mesh. Over each finite element, the physical process is approximated by functions of desired type and algebraic equations relating physical quantities at selected points on the boundary and / or interior of the element, called nodes are developed. The approximation functions are derived using concepts from interpolation theory. The degree of the interpolation functions depends on the number of nodes in the element and the order of differential being
solved. The element equations are then assembled using continuity and / or balance of physical quantities and the equations are solved.

The die casting process is a very complex phenomenon. A fully coupled simulation which includes cavity filling, solidification, heat transfer and stress / deformation analysis may be required for an accurate FE model representation of the various phenomena in die casting. Modeling deflection of die casting dies using available FE codes by representing all the above interactions explicitly will be extremely complicated. In order that the simulation be completed in a reasonable time using available computing equipment and software, some simplifying assumptions are necessary. In the model used in the current research, heat analysis is done first to get the temperature fields inside the die. The nodal temperature and values obtained from the above simulation are stored in a file, and this data is used later in the stress analysis. The procedure followed for calculating the heat transfer coefficients were defined in the NADCA’s ANNUAL Report, 1995 [13].

3.3 Model preparation in IDEAS

A 3-D model of the die casting machine and die are built in the I-DEAS Master Modeler [14]. Figures 3.1 and 3.2 presents the dimensional characteristics and machine specifications used in the FE model for the current study. The die is a Chrysler transmission casing die whose design was
Figure 3.1: Overall dimensions of Delaware's Die.
Table 1

Machine Specifications

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<td>11&quot;</td>
</tr>
<tr>
<td>Space between tie bars (As)</td>
<td>65&quot; x 65&quot;</td>
</tr>
<tr>
<td>Movable Platen</td>
<td></td>
</tr>
<tr>
<td>T x W x H</td>
<td>19&quot; x 87&quot; x 87&quot;</td>
</tr>
<tr>
<td>Stationary Platen</td>
<td></td>
</tr>
<tr>
<td>T x W x H</td>
<td>20&quot; x 87&quot; x 97&quot;</td>
</tr>
<tr>
<td>Rear Platen</td>
<td></td>
</tr>
<tr>
<td>T x W x H</td>
<td>18&quot; x 87&quot; x 97&quot;</td>
</tr>
</tbody>
</table>

Figure 3.2: Schematic of the components of the die casting machine that are accounted in the model and the specifications (from HPM catalog).
provided by Delaware Machinery [15]. This die has three slides that are supported by two horn pins placed at the back of each slide. Because we were interested in predicting the deflection of the platens, the slides are not modeled explicitly instead it is modeled as an open / close die. Other geometric details of the die are also ignored to avoid meshing problems.

The components of the machine that are being accounted for in this model are highlighted in Figure 3.2 (HPM Catalog, 1996 [16]). All the three platens were modeled. The toggle linkage mechanism was not modeled. Instead the toggle support blocks through which the clamping force is exerted on the platens were modeled. The support blocks are used with displacement boundary condition which will be explained in detail later in this chapter. The model also includes the C-frame which supports the injection systems during the injection of molten metal.

The model constructed was partitioned into several volumes for creating different FE models for the different structural members of the die casting machine. This helps in defining the contact surfaces at all the interfaces.

Because we were concerned with obtaining macroscopic deflection results, the actual geometry was modified by modeling the rounded edges as straight edges to avoid meshing problems. These modifications do not affect the deflection results significantly, although the stress pattern might be different in regions where rounded edges were replaced by straight edges. But
since the research concentrated on obtaining only the deflection results, these modifications were considered acceptable.

After the geometry is built, a finite element mesh is created by using I-DEAS FE module. Figure 3.3 shows the finite element mesh of the machine components and the die generated by this module. In the current research, a free mesh with 4-noded linear tetrahedron element was used to create the FE models. The physical properties of the elements (i.e., the die casting machine and die) are defined during the meshing process. After the meshing is completed, various elements and nodes are grouped together. This is required to define the special boundary conditions.

3.4 Boundary conditions

The boundary conditions for the die and the machine are shown in Figure 3.4. A roller support was applied at the bottom of the cover platen at the locations where it is bolted to the foundation. This allows the platen to move in the die opening direction and rotate in X-direction only, while constraining it in the other degrees of freedom. The ejector platen on the other hand has no restraint and is squeezed between the die and the toggle linkages. A roller support was also applied at the bottom of the ejector platen as it is free to move.

The rear platen is held by the four tie bars and it can move in any direction except in the direction of gravity. To prevent the platen from
Figure 3.3: Finite element mesh of the die and the machine.
Figure 3.4: Diagram showing the boundary conditions used in the simulation when the die modelled with the machine.
moving in the negative Y-direction an extra support block was created at the bottom of the rear platen and a contact surface was applied between them.

Tie bar nodes at either end of the tie bars were fixed to their corresponding platen nodes. The assumption is that the tie bar and the platens (cover and rear) are attached to each other at this junction. Nodes at the bottom of the C-frame were tied to the nodes at the C-frame support and a contact surface was applied. Coulomb friction was assumed at all steel - steel interfaces.

3.4.1 Displacement boundary condition

Die casting machine is a statically indeterminate system which makes it difficult to calculate all the force components in the machine. In order to avoid the above problem a displacement boundary condition was used instead of the force. Also in an actual machine, the total clamping force required to hold the dies together is generated by stretching of the tie bars. To model the same in our models, a displacement boundary condition was applied at the back of the toggle support blocks on both ejector platen and rear platen. The loads on the tie bars caused by this displacement were calculated. The displacement was adjusted until the total load on the tie bars equaled a specified clamping force.
3.4.2 Modeling of bolted joints using ABAQUS

To apply a bolted joint at any surface, the nodes that lie at the junction of the two surfaces have to be grouped together. Then the corresponding nodes (i.e., the node with same nodal locations) should be “tied” together so as to allow them to have same degrees of freedom. This causes these pairs of nodes to move together. The other nodes on the surface were free to move independently. This was considered to approximately model the bolt, because a similar condition exists in a region around the bolt. Figure 3.5 shows the way this was modeled. Appendix B describes the ABAQUS [17, 18] commands that can be used to model the tieing of the nodes.

If there are large temperature changes, then large distortions can occur at an interface during simulations. This may cause extreme stresses to be developed at the regions where the nodes are “tied”, which may not happen in an actual bolt. In the present simulation, such large temperature changes did not occur near the bolted joint because the bolted joint was far away from the cavity. Also the current simulations assumed the machine was at room temperature.

3.4.3 Modeling of contact surface in ABAQUS

Interfaces can be created by introducing gap elements (stress analysis) and interface elements (heat analysis) or by use of contact surfaces at any
Figure 3.5: Modeling bolted joint.
Figure 3.6: Models for defining contact surface behavior in ABAQUS.
specified plane. In the current research contact surfaces were used to define the various interfaces in the FE model.

The concept of contact surface is illustrated in Figure 3.6. To define contact surfaces, ABAQUS uses a "master-slave" concept to enforce the contact constraint. Each potential contact condition is defined in terms of "master" surfaces and "slave" surfaces. The contact direction is always normal to the master surface. The nodes of the master surface can penetrate into the slave surface, but not the other way around. Generally the master surface should be chosen as the surface of the stiffer body if the materials are different, or as the surface with the coarser mesh. When defining a contact surface between two surfaces of which one is rigid, then the rigid surface must be the master surface. If the material and the mesh density is same for both the surfaces, then either of them can be a master surface.

Appendix B describes the ABAQUS commands that can be used to model the contact surface.

3.4.4 Modeling of spring elements in ABAQUS

ABAQUS has the capability of modeling spring elements in different ways. The spring behavior may be linear or non-linear. If it's a linear spring, a constant stiffness is provided. In case of a non-linear spring, the force is applied as a function of relative displacement in the spring and is defined by
giving force and relative displacement values in ascending order of relative displacement.

In our case we are dealing with only linear springs. Two kinds of spring elements were used in this simulation. They are node-to-ground (SPRING 1) and node to node (SPRING 2) as shown in Figure 3.7.

3.5 Preparing model file for ABAQUS input file

The model constructed was partitioned into several volumes for creating nine finite element meshes for the different structural members of the machine and the die. This helps in defining the contact surface at all the interfaces. After the FE models were prepared, the model files were exported to ABAQUS for solution. The files were combined together and modified to include the boundary conditions and the contact surfaces.

The I-DEAS Data Translator is used for converting an I-DEAS model to/from ABAQUS. Appendix A shows a typical file exported from I-DEAS. Many of these cards or commands assigned by I-DEAS to the boundary conditions have to be modified to define the different steps in the die casting operation. A typical input file for ABAQUS input is shown in Appendix B.

The following are the limitations of the current model:

- Large model files
- 35 thousand elements
Figure 3.7: Model for defining spring elements by using ABAQUS.
• input file size is about 4 MB
• limits the elements size

3.6 Solving and post processing

After the input file was ready ABAQUS was used to solve the problem. Since the input file was big, special care had to be taken to avoid memory problems. The pre_memory and post_memory in the ABAQUS environment file was set to the required values.

Post processing can be done either by using I-DEAS or ABAQUS. I-DEAS provides different tools for displaying results and is very user-friendly. Though different kinds of results could be displayed, the current research focused on displaying displacement and stress results only. In I-DEAS, results at a particular cross-section, selected as a calculation domain can be displayed. This capability was used to display the stress in the tie bar at any cross-section (as shown in Figure 3.8). These stress values can be used to calculate the load on each tie bar. Displacement time history of a particular nodes can also be plotted so as to check valuable information about the effects of pressure on die deflection.

One of the draw backs of ABAQUS post is that it is not an user-friendly software. Particularly, one has to remember all the commands to execute it. The only advantage of using this post processing is the displaying of contact surface information which is not possible while using I-DEAS post
Figure 3.8: Locations for measurement of tie bar stress.
processing. Different commands can also be used in the input file to record maximum separation and contact surface information on the data file.

The methodology developed in this chapter will be applied to different models and the results will be experimentally verified in the next chapter.
CHAPTER 4

CASE STUDY AND EXPERIMENTAL VERIFICATION

4.1 Introduction

In Chapter 3 an effort was made to develop an FE model of a die casting machine. A description of the process that resulted in the definition of an FE model of a die casting machine that can be used for the study of the support provided by the machine to the dies during metal injection is now presented. Experimental data received from industry collaboration will be used for validation of simulation results.

4.2 Experimental data

Platen deflection data was obtained for a 700 ton cold chamber die casting machine. A trip was made to a die casting machine manufacturing company in February 1997 to conduct an experiment for collecting platen deflection data for a similar 700 ton die casting machine. This trip also helped to clarify some of the issues regarding the boundary conditions at the bottom of the platens.
Figure 4.1: Schematic of the experimental setup and location of the dial indicator.
The experimental setup as shown in Figure 4.1 consisted of a beam attached to a structure which was not a dedicated mounting fixture. The machine was not anchored to the floor. The structure was placed near the cover platen. A dial indicator was mounted on the beam to record the platen deflections and the indicator was set to zero. Another dial indicator was mounted on the foundation near the base of the cover platen to verify its displacement. Clamping was done very slowly. The dial indicator mounted on the beam was used for recording platen deflection at eight different locations on one half of the platen (see Figure 4.2). Four readings were taken for each location. The dial indicator reading went back to zero after the machine was unlocked.

Two points on the other half of the platen were included in the measurements to verify if symmetry of the deflection pattern of the platen (Figure 4.2). Deflection at those locations suggested that platen deflection was fairly symmetric.

Details of the machine construction that were relevant for our modeling which were confirmed during this trip were:

- The base frame on which the machine is placed is not bolted to ground
- Cover platen is bolted at the bottom to the base. It moves by .0005" to .001" towards the shot sleeve
Figure 4.2: Diagram showing the locations on front of cover platen where data was collected.
- Ejector platen is squeezed between the die and the toggle linkages
- The C-frame is bolted to the base
- Material used for platens is 1018 steel
- Material used for the tie bars is 4340

Another set of platen deflection data was received for a similar 700 ton machine in June 1997. In this case a Lieca Laser Tracking System was used to measure the platen deflections.

The three sets of data obtained are shown in Table 4.1 (first set - Machine 1), Table 4.2 (second set - Machine 2) and Table 4.3 (third set - Machine 3) respectively. The locations where data were collected is shown in Figure 4.2. Deflection patterns for the three cases i.e., machine 1 (data received on 1/7/97), machine 2 (data collected during our visit to Prince) and machine 3 (data measured by using Lieca Laser Tracking System) are shown in Figure 4.3.

It can be seen that there is a significant variability in the deflection patterns and values for the three machines, especially when machine 1 is compared with the two other machines. At section A, deflection values for machine 1 are lower than those of the other two machines. However at section B deflections values for machine 1 are higher than those of the others. Furthermore, the difference in deflection values at location 5 is around 0.004”. This difference may be due to gaps in the assembly structure of
<table>
<thead>
<tr>
<th>Locations</th>
<th>Measured Deflection (inches)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Machine1</td>
</tr>
<tr>
<td>1</td>
<td>0.0090</td>
</tr>
<tr>
<td>2</td>
<td>0.0090</td>
</tr>
<tr>
<td>3</td>
<td>0.0075</td>
</tr>
<tr>
<td>4</td>
<td>0.0065</td>
</tr>
<tr>
<td>5</td>
<td>0.0030</td>
</tr>
<tr>
<td>6</td>
<td>0.0170</td>
</tr>
<tr>
<td>7</td>
<td>0.0150</td>
</tr>
<tr>
<td>8</td>
<td>0.0125</td>
</tr>
</tbody>
</table>

Table 4.1: Measured deflections for first set of data (Machine 1)

<table>
<thead>
<tr>
<th>Locations</th>
<th>Measured Deflection (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Machine1</td>
</tr>
<tr>
<td>1</td>
<td>0.0100</td>
</tr>
<tr>
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<td>0.0105</td>
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<tr>
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Table 4.2: Measured deflections for second set of data (Machine 2)
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<td>Machine3 (6/26/97)</td>
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<td>10</td>
<td>0.0186</td>
</tr>
</tbody>
</table>

Table 4.3: Measured deflections for third set of data (Machine 3)
Deflection for two 700 ton machine

Note
Machine 1: Data received on 1/7/97.
Machine 2: Data collected during our visit to Prince.
Machine 3: Data received on 6/26/97.

Figure 4.3: Behavior of deflection pattern shown by three different 700 ton machine.
the machine, difference in stiffness of the components of the machine, inaccuracies in the calibration of the instruments used for the measurement of platen deflection, unbalanced load distribution in the structure or a combination of all these factors.

At this point it seems that it would be reasonable to compare simulation results with the platen deflection data of machine 2 and machine 3. More field data will be required for similar machines to study the pattern followed by this machine series.

4.3. Actual model of die casting machine

Figures 4.4 and 4.5 show the components of the machine and the dimensional characteristics of the dummy die (load cell) that were simulated. The dummy die is a structure that consists of two plates welded with four pillars between them. The die casting machine modeled is a 700 ton machine for which design and platen deflection data were available.

Much attention was paid to the modeling of the cover platen to include the details such as the T-slots, shot sleeve and the holes near the C-frame as shown in Figure 4.6. The ejector and rear platen were modeled as a simple plates with holes that guide the tie bars. A group of I-beams was used to represent the model of the C-frame. Due to the symmetry of the problem, only one-half of the geometry was used for simulation (Figure 4.7).
Table 1

<table>
<thead>
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<th>Machine Specifications</th>
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<tbody>
<tr>
<td>Rated tonnage</td>
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</tr>
<tr>
<td>Tie bar diameter</td>
<td>6.75&quot;</td>
</tr>
<tr>
<td>Space between tie bars</td>
<td>32.75&quot;</td>
</tr>
<tr>
<td>Movable platen</td>
<td>11.75&quot;x54.5&quot;x61.5&quot;</td>
</tr>
<tr>
<td>Stationary platen</td>
<td>10.75&quot;x54.5&quot;x54.5&quot;</td>
</tr>
<tr>
<td>Rear platen</td>
<td>10.75&quot;x54.5&quot;x54.5&quot;</td>
</tr>
</tbody>
</table>

Figure 4.4: Schematic of the components of the die casting machine that are accounted for in the model.
Figure 4.5: Schematic and dimensions of the load cell (dummy die).
Figure 4.6: a) Front of the cover platen showing the details of the model.  
b) Detail of C-frame modeled as a group of I-beams.
Figure 4.7: Schematic of the die casting machine used in simulation. Only half model simulated due to symmetry.
4.4 Simulation conditions

The boundary conditions for the dummy die and the machine are shown in Figure 4.8. The basic boundary conditions used were same as defined in Chapter 3 except as noted below.

In the experimental setup, grease was applied to the front of the cover platen to avoid damage to the platen and the dummy die was not clamped to this platen. To model this, a contact surface with a zero friction coefficient was applied at this interface. The dummy was bolted at four different locations to the ejector platen in the experimental setup (see Figure 4.9). The nodes at corresponding locations (in the ejector platen and dummy) were tied together to represent the bolts.

In the experimental setup, the load on each tie bar was equal to 175 tons. Different displacements were applied at the rear and ejector toggle support blocks to match the load in all the tie bars as well as the platen deflections. Our results indicate that when a total displacement of .054 in. and .052 in. are applied at the top and bottom toggle support block respectively, the total tie bar force is 700 ton (as shown in Figure 4.10) just before the application of cavity pressure.

The heat load was not included in the current FE model because the experimental study was performed under the clamping conditions only. No metal was injected during the measurement of platen deflections.
Figure 4.8: Diagram showing the boundary conditions used in the simulation.
Figure 4.9: Location of clamps on the ejector side.
Figure 4.10: Simulations results showing tie bar load before application of cavity pressure.
4.5. Issues of modeling and boundary conditions

The maximum deflection of a structure depends upon its stiffness. The T-slots and the shot holes in the cover platen must be explicitly modeled. Otherwise the platen model is significantly different from the actual model which makes the platen stiffer. Similarly, the C-frame must be modeled as I-beams. To check the effect of these variables a simulation was run in which in one case the cover platen was modeled with no t-slots and the C-frame was modeled as a solid. In another case the cover platen was modeled with t-slots and the C-frame was modeled as a group of I-beams. The platen deflections obtained for both the cases (as shown in Figure 4.11) shows that the deflections for the case when the machine modeled with cover platen with t-slots is about 4% more than the case when the machine modeled with cover platen with no t-slots.

The platens of the die casting machine deflect under the clamping loads. The cover platen deflects more with respect to the ejector platen because the later is free to move and the former is bolted at the bottom to the frame. Also the reaction forces at the corners of the cover platen due to tie bars results in bowing of the platen. To obtain the same deflection pattern, different clamping conditions were tested at the bottom of the cover platen. The deflection patterns and values were very sensitive to the boundary conditions applied at the bottom of the cover platen and C-frame. The optimum results in terms of the deflection pattern and values was obtained
Figure 4.11: Graph showing comparison of results for the cases when machine modelled with cover platen with and without t-slots.
by application of roller support as a boundary condition at the bottom of cover platen.

For the application of displacement boundary conditions, the theoretical elongation on each of the tie bars was calculated using the procedure described by Herman [Herman, 1988]. The theoretical displacement obtained was divided into two halves and applied on the back of the support blocks. Then the displacements were changed to achieve the required tonnage. In an actual machine, the locking force required to keep the dies closed during injection of molten metal is produced by stretching of the tie bars. To model this in our FE model is not feasible. The same elongation in the tie bars is achieved in our model by applying the displacement at the back of the toggle support blocks.

The total displacement applied on the back of the ejector and the rear support block was divided in the ratio of 40 : 60 respectively to match the simulation results with field data. The explanation for applying the displacement in this ratio needs further investigation.

4.6. Results

Figure 4.12 (b) summarizes the deflection pattern obtained from our simulation results and the field data for the two sets of data. The location of data points and the two cross sections where data were collected are shown in the Figure 4.12 (a).
Figure 4.12: a) Platen deflection locations. b) Comparison of field data with simulation results at cross section A and B.
Simulation results for locations 1, 2, 3, 4, 6, 7 and 8 were within 10% and location 5 was within 15% of experimental data for machine 2 and 3 (field data). Results at locations 1, 2, 3, and 8 were close to experimental data for machine 1 (field data). However results differ considerably from field data at locations 4, 5, 6 and 7 for machine 1.

4.7. Conclusion

Deflection patterns match well with field data. The deflection values were within 10% - 15% with respect to field data. This discrepancy is small considering the large number of variable factors that needed to be included in building the model. Also this model can be used for the purpose of the development of an alternate model to account for the die casting machine in die deflection simulations. However it is important to note that further validation is required before any recommendations are made.
CHAPTER 5

DEVELOPMENT OF SPRING / PLATEN MODEL AND STUDY OF THE PERFORMANCE OF THE DIE CASTING MACHINE

5.1 Introduction

Predictions of die casting die deflections can be improved by accounting for the effects of the die casting machine. The simulation procedure and issues regarding the geometry modeling, loads, boundary conditions and certain simulation parameters in an FE simulation of a die casting machine were discussed in previous chapter. In the current exercise an effort was made to study the support provided by the die casting machine to the dies and to come up with a new model to include the effect of machine in die deflection simulations. A parametric study was also conducted to study the effect of different machine parameters on platen deflections.

5.2 Comparison of old model to new model

5.2.1 Procedure

The aim of this phase of work was to compare the behavior of our previous models i.e., when the die is modeled explicitly and die modeled with spring elements to account for the machine with the case when the die
Table 1
Machine Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
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<td>Rated tonnage</td>
<td>800</td>
</tr>
<tr>
<td>Tie bar diameter</td>
<td>7.5&quot;</td>
</tr>
<tr>
<td>Space between tie bars</td>
<td>36.5&quot;</td>
</tr>
<tr>
<td>Movable platen</td>
<td>12.75&quot;x60&quot;x70&quot;</td>
</tr>
<tr>
<td>Stationary platen</td>
<td>11.75&quot;x60&quot;x60&quot;</td>
</tr>
<tr>
<td>Rear platen</td>
<td>11.75&quot;x60&quot;x60&quot;</td>
</tr>
</tbody>
</table>

Figure 5.1: Schematic of the components of the die casting machine and machine specifications for a 800 ton machine.
Figure 5.2: a) Schematic showing the geometry of the die used in the simulation. b) Dimensions of the part selected for an 800 ton machine.

Note: All dimensions are in inches.
modeled with the die casting machine. The main difference between these models is the way they account for the die casting machine. Figure 5.1 shows the schematic of the die and the machine used for simulations. The machine considered was an 800 ton die casting machine. The die modeled was an open close die whose dimensions are shown in Figure 5.2 (a). This die covers 65% of platen area within the center of the tie bars. The casting used for this set of simulations was a box type, the dimensions of which are shown in Figure 5.2 (b). The casting was selected on a basis to fit in an 800 ton machine. The symmetric nature of the model facilitated modeling of only one half of the geometry. Following were the cases modeled for running single cycle simulations:

1) Case 1 In Case 1 the die was modeled with the whole die casting machine. The boundary conditions used for this case were same as defined in Chapter IV except that the cover die was clamped at four different locations to the cover platen (Figure 5.3).

2) Case 2 This was the original case used by Ahuett-Garza et al [Ahuett-Garza, 1995] in earlier simulations. Figure 5.4 (a) shows the boundary conditions used for this case. The cover platen was assumed to be mounted on a rigid support. All the nodes on this surface were clamped. The total clamping tonnage on the ejector support was applied as an equivalent pressure.

3) Case 3 In this case spring elements were placed behind the cover and ejector dies (as shown in Figure 5.4 (b)) to represent the machine (DOE
Figure 5.3: Diagram showing the boundary conditions used in the simulation when the die modelled the whole machine.
Case 2: Rigid Machine

Cover platen assumed to be rigid support

P = clamping pressure
   = \frac{F}{\text{area of die}}

(a)

Case 3: Die with spring elements

Cover platen flexible support

K_1 = \text{Cover platen stiffness}
K_2 = \text{Ejector platen stiffness}
K_3 = \text{Toggle / Tie Bar stiffness}

(b)

Figure 5.4: a) Boundary condition for Case 2 rigid machine model.
b) Boundary condition for Case 3 (model that accounts for elasticity of support by spring elements).
Annual Report dated 09/26/96 [19]). On the cover side, spring elements were used to account for the flexibility of the platen. In the ejector side, two different sets of spring elements were used. One represents the ejector platen and the other one represents the toggle / tie bar arrangement. In addition, a clamping force was applied at the toggle / platen junction. The important issue in this case is to determine the stiffness of each spring. The procedure followed was to estimate equivalent stiffness of the springs by calculating the stiffness of the different components and then calculating an overall stiffness for the series / parallel arrangement.

5.2.2 Test of resolution of the FEM model

A study was performed to test the resolution and CPU time taken for simulation of the current FE models. The procedure followed for this simulation was:-

- Run single cycle simulations for the same FE model with different number of elements (500, 1500, 4500, 10500, 15000, 20000) for the die. Obtain the separation at the parting plane and record the CPU time taken for each simulation.

A graph was plotted for the % increase in number of element along the X-axis and % increase in predicted average separation along Y-axis as shown in Figure 5.5 (a). A similar graph was plotted by plotting % increase in CPU time along the Y-axis (see Figure 5.5 (b)). It can be seen that a minimum of 10000
Figure 5.5: Effect of number of elements on simulation results and CPU time.
elements should be used to get consistent results. Although the % increase in CPU time in parabolic, it is of a good practice to use more elements to get better results.

5.2.3 Comments on results

Maximum separation at the parting plane at different nodal locations along the cavity for all the cases are shown in Figure 5.6. Although the pattern of the parting plane separation for all the cases is similar, the magnitudes are quite different at most of the locations. The parting plane separation for Case 1 i.e., the case when the die was modeled with the whole machine is 150% and 100% higher than Case 2 and Case 3 respectively. This indicates that the stiffness assumed in Case 2 and Case 3 are higher than the actual case. In fact, when the stiffness of the springs in Case 3 was reduced to 10% of its original value, the separation obtained was almost equal to that of Case 1 (see Figure 5.7).

5.3 Development of the spring / platen model

As defined by Ahuett-Garza et al [Ahuett-Garza, 1996] the main source of inaccuracy in the model of the flat plate die is the manner in which the support for die casting machine is modeled. By fully constraining cover side of the die and applying a uniform pressure on the ejector support block, the
Figure 5.6: Comparison of simulation results for three different cases.
Figure 5.7: Comparison of results for Case 3 when different stiffness were used.
elasticity of the support the machine provides is totally ignored. A different model that accounts for this factor may be built either by

- modeling the whole die casting machine (Case 1)
- use spring elements to model the platen support behind the die (Case 3)
- a different model in which only the cover and ejector platen are explicitly modeled (spring / platen model)

Modeling the whole die casting machine is usually a very time consuming process. The total modeling time would be approximately 2 days and the time required to run the simulation with proper resolution and multiple cycles would be around 18 hr. of CPU time. The difficulty with modeling the die with spring elements is determining the exact stiffness of the springs. Also as shown in Case 3, the calculated stiffness of the machine components was higher than in actual case.

In order to avoid the above problems, a spring / platen model was developed to account for the machine (as shown in Figure 5.8). Instead of modeling the whole machine, only the cover and ejector platen was modeled. Figure 5.8 (b) shows the boundary conditions used for this case. A constant pressure was applied at the back of the toggle support block on the ejector side to represent an equivalent clamping force. Spring elements were used at the back of the cover platen at the locations where the tie bars are bolted to the platen to represent the tie bar stiffness. Contact surfaces were used at all the interfaces.
Figure 5.8: a) Schematic of the components of the spring/platen model accounted for die casting machine in the simulation. b) Boundary conditions used for this model.
Because the effect of heat is not included in this model, the die growth due to thermal loads is neglected in these models.

Figure 5.9 shows the comparison of maximum separation obtained for the above case and when the die was modeled with machine. A graph was plotted by plotting the maximum separation along the primary X-axis and the different locations along the Y-axis. The % difference in parting plane separation between the two cases for all the locations was plotted along the secondary Y-axis. Deflection results for a model that was built using this approach show that in general, the pattern remain the same. Also the deflection values differ by only 6% to 7% at all the locations.

5.4 Effect of C-frame force

A separate model was designed to find the force generated by the C-frame during the injection of molten metal upon the cover platen which indirectly effects the parting plane separation. Figure 5.10(a) shows the FE model of the C-frame and the cover platen. A roller support was applied at the bottom of the cover platen and an equivalent cylindrical force was applied at the location shown in the figure. As shown in Figure 5.11, simulation results indicate that the resultant force due to C-frame on the cover platen is around $3.7 \times 10^4$ N (top) and $6.5 \times 10^4$ N (bottom) at the instant of intensification.

In order to check whether this force has any effect on the parting plane separation, a simulation was run by applying this force in the actual model at
Figure 5.9: Comparison of simulation results for the case when the die is modeled with the machine and the spring/platen model.
Figure 5.10: a) Diagram showing the geometry and boundary conditions for C-frame and cover platen. b) Locations where force due to C-frame will be applied.
Figure 5.11: Simulations results showing stress in the C-frame.
the locations shown in Figure 5.10 (b). Results show that the force generated by the C-frame during the intensification has least effect on the cover platen deflection (Figure 5.12). For the purpose of modeling the support provided by the machine to the dies, the effect of C-frame was neglected. If one wants to include this effect in the model the above procedure can be followed.

5.5 Verification with different part geometry

To verify the authenticity of the spring / platen model two additional parts were modeled. The two cases were:

1. Part 1 A flat plate die was modeled with an 800 ton Prince die casting machine. The basic die geometry and the nodal locations where data was collected are shown in Figure 5.13 (a) and Figure 5.13 (b) respectively.

2. Part 2 A two cavity box type part was modeled. The machine modeled was a 1000 ton Prince machine. The basic die geometry and the nodal locations where data was collected are shown in Figure 5.14 (a) and Figure 5.14 (b) respectively.

Figures 5.15 and 5.16 show the locations of nodes where data was recorded and comparison of results obtained for the above two cases. Results show that the difference in maximum separation at the parting plane when the die is modeled with the whole machine and with the spring / platen model is around 6% to 8%.
Figure 5.12: Comparison of results with and without C-frame force.
Figure 5.13: a) Wireframe geometry of flat plate die. b) Schematic of the casting used in the simulation.
Figure 5.14: a) Basic schematic of the two cavity die used in simulation.
b) Geometry of the casting.
Figure 5.15: (a) Nodal locations where maximum separation was recorded (Part 1). (b) Comparison of simulation results for flat plate die.
Figure 5.16: a) Nodal locations where maximum separation was recorded (Part 2).
b) Comparison of simulation results for two cavity die.
5.6 Effect of machine dimensions on platen deflections (Machine modeled with dummy die)

A parametric study was conducted to establish the behavior of the effect of different machine variables on platen deflections. A series of simulations were carried out to determine the range of deflections of the platen as a function of these parameters. The parameters that were varied are (as shown in Figure 5.17):

- Tie bar diameter (DTB)
- Platen thickness (PT)
- Die position (DP)

An experimental array was designed for studying the effect of the above variables and also the interaction between all the variables upon platen deflection. The tie bar diameter (A) was varied from 5.5 to 8.0 in. with 6.75 in. as the nominal value. The platen thickness (B) was varied from 9.00 to 14.5 in. with 11.75 in. as the nominal value. The die position was varied from 0 to 12.5 in. with 6.25 as the nominal value. When the die position is at 6.25 in., the die is centered with respect to the platen. When the die position is at zero, the die is aligned to the top tie bar center. When the die position is at 12.5 in., the die is aligned to the bottom tie bar center. Each variable had 5 levels. An experimental design approach was used rather than a simple pairwise comparison approach as described by Ozdemirel et al [20] for three
<table>
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<tr>
<td>B. platen thickness (PT)</td>
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<tr>
<td>C. die position (DP)</td>
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<td>12.50</td>
</tr>
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</table>

**COVER DIE/PLATEN**

Figure 5.17: Schematic showing the variables of the machine that are varied.
### $\Pi_{11.3}(5)$ array

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### inches

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<td>9.38</td>
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</table>

Table 5.1: Cases for parametric study
main reasons:

- Experimental design provides a way of deciding which particular configurations to simulate before any runs are made, so that the desired information can be obtained with minimum number of simulation runs

- Experimental design provides the analyst with a tool for determining which factors have the greatest effect on output performance measures or which combination of factor levels leads to the optimal performance

- Full or fractional factorial experiments are the only means of studying the interaction effects between two or more factors

The fractional factorial design cases and the values for different variables are shown in Table 5.1. An FE model was built for each case described in Table 5.1. The model and boundary conditions used for this set of simulations is the same as shown in Figure 4.4 and 4.8 (Chapter IV) except that the sizes vary based on different cases.

For each case, the magnitude of the platen deflection at the back of the cover platen at eight (see Figure 4.12) locations were recorded at the instant of clamping of the machine. These deflections were used to create the response surface of the interactions between tie bar diameter and die position. The response surface created is shown in Figure 5.18. Clearly, it can be seen from this figure that as the diameter of the machine increases means an increase in
Figure 5.18: Response surface for the interaction between the tie bar diameter and die position.
Maximum Deflection (without static deflection)
Tie Bar Diameter = 6.75 in.

Figure 5.19: Response surface for the interaction between the platen thickness and die position.
Maximum Deflection
(without static deflection)
Platen Thickness = 11.75 in.

Figure 5.20: Response surface for the interaction between the tie bar diameter and die position (Platen thickness = 11.75 in.).
Figure 5.21: Response surface for the interaction between the tie bar diameter and die position (Platen thickness = 14.5 in.).
Figure 5.22: Response surface for the interaction between the tie bar diameter and die position (Platen thickness = 9.00 in.).
stiffness of the machine results in smaller platen deflection. In order to study the support provided by the machine platen to the dies when the above variables are varied, two procedure was used. In one approach the deflection for all the nodes at the back of cover platen were recorded. Then the average of these deflections was subtracted from the deflection of the above eight locations to create a response surface without the static deflection. Figures 5.19 shows the response surface created for the interaction between the platen thickness and die position. Figures 5.20, 5.21 and 5.22 shows the response surface created for the interaction between the tie bar diameter and die position for three different platen thickness. As the charts shows, when the die is positioned at the center of the platen, the deflection is minimum. The deflection increases when the position of the die is shifted up or below the center of the platen.

The deflection decreases with increase in platen thickness and tie bar diameter. This means an increase in stiffness will result in a reduction of platen deflection. Therefore, an increase in stiffness of the machine by increasing the platen thickness and tie bar diameter is an outcome sought. In another approach the contact pressure between the platen and the dies were recorded. The contact pressure indicates the percentage area of the die that is in contact with the platen. The areas with zero contact pressure means the load cell and the platen are not in contact. Figure 5.23, 5.24, and 5.25 shows the contact pressure between the load cell and the platen on the ejector
Figure 5.23: a) Contact stress between the cover die and the cover platen. 
   b) Contact stress between the ejector die and the ejector platen.
Figure 5.24: a) Contact stress between the cover die and the cover platen.
b) Contact stress between the ejector die and the ejector platen.
Figure 5.25: a) Contact stress between the cover die and the cover platen. 
b) Contact stress between the ejector die and the ejector platen.
and cover side for nominal, best and worst case respectively. It can be seen from that for the best case (Figure 5.24) the contact area is maximum and the contact stress are also evenly distributed. For the worst case (Figure 5.25), the contact area is minimum and the stress are very poorly distributed.

From the point of view of the platen deflection, investigating the role of the platen thickness, tie bar diameter was very useful. For example, from the above graphs in can be concluded that the maximum deflection in a platen can be reduced by around 18.5 % if the tie bar diameter is increased by 35%. Also with 20% increase in platen thickness, the net deflection can be reduced by 20%.

Die position is the most important effect with respect to the support provided by the machine to the dies and platen bowing. From these graphs it can be concluded that the die has to be positioned at the center with respect to the platen to minimize the deflection and bowing of the platen.

5.7 Effect of machine dimensions on maximum separation at parting plane (Machine modeled with die)

A similar set of simulations were carried out to study the effect of different machine variables on maximum separation at the parting plane of the dies. The machine variables that were varied and the experimental array used for this case is the same as shown in Table 5.1.
Figure 5.26: Response surface for the interaction between the tie bar diameter and die position.
Parting Plane Separation
Tie Bar Diameter = 6.75 in.

Figure 5.27: Response surface for the interaction between the platen thickness and die position.
For each case the magnitude of the maximum separation at the parting plane was recorded at the instant of application of intensification pressure. These values were used to create the response surface of the interactions between tie bar diameter and die position and also between platen thickness and die position. Figure 5.26 and 5.27 show the response surface for the above interactions. It can be seen from these figures that when the die is shifted up from the center the maximum separation increases, but when the die is shifted below the center there is not much variation in maximum separation. This is due to the fact that, although the die is placed at the center of the platen, the center of gravity of the casting is about 1.5 inch above the center of the platen. As a result when the die is shifted up from the center, more pressure is exerted on the top half than the bottom half. But when the die is shifted to the bottom half, the pressure distribution becomes more uniform and the maximum separation is less.

When the die is aligned to the top tie bar center, the maximum separation decreases with increase in tie bar diameter, but it seems to be insensitive when the die is aligned to the bottom tie bar center.

The maximum separation decreases with increase in platen thickness when the die is shifted from the center of the platen, but the percentage decrease in maximum separation is higher when the die is shifted up from the center of the platen.
Figure 5.28: a) Contact pressure between cover die and platen at the instant of clamping. b) Contact pressure between cover die and platen at the instant of intensification (Case 5 - center).
Figure 2.29: a) Contact pressure between cover die and platen at the instant of clamping. b) Contact pressure between cover die and platen at the instant of intensification (Case 3 - up).
Figure 5.30: a) Contact pressure between cover die and platen at the instant of clamping. b) Contact pressure between cover die and platen at the instant of intensification (Case 4 - down).
Figures 5.28, 5.29 and 5.30 show the contact pressure between the die and the platen on the cover side for the cases when the die is positioned at the center, above the center and below the center respectively. The areas with zero contact pressure indicates that the surfaces are not in contact. It can be seen from these figures that the contact pressure distribution is fairly symmetric when the die placed at the center at the instant of clamping. The contact pressure is higher at the bottom when the die is shifted up and the contact pressure is higher at the top when the die is shifted below the center of the platen. At the point of intensification, the top portion of the die opens up when the die is aligned to the top tie bar center. The bottom portion of the die opens up when the die is aligned to the bottom tie bar center. In all the cases there is a patch of stress concentration near the box cavity.
CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Research Contributions

In this research a finite element model of a die casting machine to predict platen deflection was developed. The model was tested against field data. Also a methodology for the simulation of die casting die deflection including the effect of die casting machine was introduced. Given the fact that machine platen deflection data was available, a certain degree of confidence was obtained about the capacity of this model to reproduce maximum separation at the parting plane in a die casting die. In fact the model was also verified by applying it to dies with different cavity dimensions and shape. It is however important to note that further validation is required before any recommendations are made.

The results of the parametric study presented in Chapter 5 (response surfaces) can be used by design engineers to calculate the maximum deflection as a function of the cover platen thickness and die position with respect to the platen.
6.2 Recommendations for modeling

It was shown in this research that the stiffness of the machine components and dies ultimately determines the magnitude of the maximum deflections. This stiffness is a function of the design of the above components. Proper care should be taken while modeling the different components of the machine and die.

6.3 Basic requirements for creating the spring / platen model

To create the spring / platen model one should have the geometry dimensions and process conditions of the following machine and die components:

- Cover platen including the t-slots, shot hole dimensions and locations
- Ejector platen
- Ejector toggle support locations and dimensions
- Tie bar (to calculate the stiffness of the spring used on the back of cover platen)
- Die geometry and cavity dimensions
- Clamping tonnage and cavity pressure
6.4 Future work

Future work should be directed towards the following:

- Determine the effect that the joint design at the toggle/platen interface has upon the behavior of the platen and the die. Study the effect of support provided when a machine has a two way toggle closing system and a four way toggle closing system.

- Determine how the cover platen responds as the size (area) of the die is varied.

- Use sensitivity analyses to determine effects of out-of-square machines, poorly adjusted tie bars, worn linkage components, etc. on deflection. Also study the effect of dents, corrosion between the dies and platens on machine deflections.

- Determine how does the length of the die (i.e. along the tie bar axial direction) affects the locking action of the machine? Tie bar bend is clearly affected by where the movable platen is when dies are clamped.

- Evaluate the performance of a die casting machine by modeling different die sizes on the same machine. This will help in selecting the optimum die size suitable for a particular machine.

- Run multiple cycle simulations including the effect of heat due to solidification.
• Models do not include the effect of dents, corrosion between dies and platens
APPENDIX A

INPUT FILE GENERATED BY I-DEAS
A.1 The input file for stress analysis generated in I-DEAS

The file shown below gives the general format of the ABAQUS input file generated in I-DEAS. The file has to be modified to define all the loads and combine the different model files. Many elements and nodes from the file are deleted, because of space considerations.

*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR 21-Jun-97 15:02:38
*NODE, SYSTEM=R

     1500,-1.6509999E-01,-3.3655000E-01, 3.2480249E+00
     1501,-1.6509999E-01,-3.3655000E-01, 2.7146249E+00
     1502,-1.6509999E-01,-7.1754998E-01, 2.7146249E+00
     1503,-1.6509999E-01,-7.1754998E-01, 3.2480249E+00
     1504,-2.4765000E-01,-7.9374999E-01, 3.3369250E+00
     --
     1699,-1.2382500E-01, 6.6675001E-01, 3.5727820E+00
     1700,-1.2382500E-01, 5.1435000E-01, 2.9813249E+00
     1701,-1.2382500E-01, 5.1435000E-01, 2.8272316E+00
     1702,-1.2382500E-01, 5.1435000E-01, 3.1354184E+00

*ELEMENT, TYPE=C3D4 , ELSET=E0000001        --> Element definition
     5000,  162,  1663,  1659,  1660
     5001,  1666,  1662,  1663,  1659
     5002,  1666,  1663,  1662,  1664
     5003,  1663,  1662,  1668,  1660
     5461,  1537,  1540,  1643,  1536
     5462,  1539,  1540,  1643,  1537
     5463,  1539,  1643,  1540,  1646

*SOLID_SECTION, ELSET=E0000001, MATERIAL=M0000001       --> Material property Definition
*MATERIAL, NAME=M0000001
*ELASTIC, TYPE=ISOTROPIC
*DENSITY
7.820E+03
*EXPANSION,TYPE=ISO,ZERO=21.85
1.170E-05
*CONDUCTIVITY,TYPE=ISO
4.500E+01

*STEP,AMPLITUDE=STEP,INC=10
*STATIC
** BOUNDARY CONDITION SET 1
** RESTRAINT SET 1
*BOUNDARY,OP=NEW
BS000001, 1,, .00000E+00
BS000001, 5,6, .00000E+00
** BOT
modified for application of contact surfaces
*DLOAD,OP=NEW
  5088, P1, 1.00000E+00
  5098, P1, 1.00000E+00
  5099, P1, 1.00000E+00
BS000002, P2, 1.00000E+00
BS000003, P4, 1.00000E+00
** TOP
*DLOAD,OP=NEW
  5460, P2, 1.00000E+00
  5454, P3, 1.00000E+00
  5457, P4, 1.00000E+00
  5459, P4, 1.00000E+00
** CFRAME
*DLOAD,OP=NEW
  5274, P2, 1.00000E+00
  5267, P3, 1.00000E+00
  5269, P3, 1.00000E+00
  5271, P3, 1.00000E+00
BS000004, P4, 1.00000E+00
*NODE FILE,FREQUENCY= 1,GLOBAL=YES
** END STEP
*NSET,NSET=BS000001
1508,1509,1510,1511,1512,1513,1515,1517,1518,1519,1528,1529,1530,1531,1532
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1627,1629,1630,1631,1632,1633,1635,1652,1653,1654,1655,1656,1657,1658
*ELSET,ELSET=BS000002
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*ELSET,ELSET=BS000003
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APPENDIX B

MODIFIED INPUT FILE
B.1 Bolts

The command used for defining bolts in ABAQUS are the following:

*MPC
TIE,79,6594

The first column of the second line indicates the command ‘tie’ for tying the nodes while the second and third column indicates the corresponding nodes at the interface.

B.2 Contact Surfaces

The contact surfaces are defined in the following way:

*SURFACE DEFINITION, NAME=EJTOG2
TG000011, S2
...............  
*SURFACE DEFINITION, NAME=EJPTO2
PL000044, S4
...............  
*CONTACT PAIR,INTERACTION=CONT ,SMALL SLIDING
EJTOG2,EJPTO2
*SURFACE INTERACTION,NAMe=CONT

The first and the fourth line defines the definition of the element sets for both master and slave surfaces. The option in the seventh line ‘CONTACT PAIR’, defines potential contact between objects. The contact pair option used helps in defining different mesh sizes between the master and slave surfaces. The first column of the eighth line indicates the slave surface
name, while the second column indicates the master surface name. The
nineth line provides the definition of the surface interaction properties for
surfaces involved in contact pairs.

B.3 Spring Elements

The spring elements are defined in the following way:

*SPRING, ELES=SP2
3,3
1.7237E+10

The first column of the second line indicates the direction in which the
first node can move, while the second column indicates the direction in
which the second node can move (ignore the second column of second line
for node-to-ground spring elements). The value of the third line is the
stiffness value for the spring element.

B.4 The input file for stress analysis after modification

The file obtained after making all the necessary modifications for the
stress analysis is shown below. A few loads and boundary conditions are
explained.

*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR 11-MAY 1997 10:23:13
*RESTART,WRITE,FREQUENCY=100 ------------------------> Used to write a restart file for
using ABAQUS post-processing
*PREPRINT, ECHO=NO, HISTORY=NO, MODEL=NO -------> This command helps in
reducing the size of the data file
**CHRYSLER DIE AND HPM MACHINE
**with location of channels, with c frame
**with displacement boundary condition on ejector and rear toggle support
**with horn pin force
**with hole in cover platen

The following are the nodal locations and elements created using I-DEAS and translated using ABAQUS file translator:

*NODE, SYSTEM=R,NSET=NPLA (Platen nodal locations) -------> Node definition
  1,-8.9534998E-01, 4.4450000E-01, 4.9262285E+00
  ****
  4063, 5.7150000E-01,-3.3019999E-01, 4.7568951E+00
*NODE, SYSTEM=R,NSET=NCOV (Cover die nodal locations)
  4500,-6.7309999E-01, 5.9689999E-01, 4.4182286E+00
  ****
  5024, 3.9179611E-01, 8.7880033E-01, 4.0380788E+00
*NODE, SYSTEM=R,NSET=NEJE (Ejector die nodal locations)
  5200,-4.7624999E-01, 9.5249999E-01, 3.2814260E+00
  ****
  5959,-1.0810875E+00,-4.0640000E-01, 3.8593426E+00
*NODE, SYSTEM=R,NSET=NTOG (Toggle support nodal locations)
  6200, 6.2230003E-01, 8.0010003E-01, 3.8100001E-01
  ****
  6385,-3.6068001E-01, 8.4666669E-01, 2.7353261E+00
*NODE, SYSTEM=R,NSET=NTIE (Tie bars nodal locations)
  6500, 6.8590337E-01, 9.5787311E-01, 4.4182286E+00
  ****
  8286,-8.2550001E-01, 9.5243651E-01, 4.4182286E+00
*ELEMENT,TYPE=C3D4,ELSET=E0000001, PLATEN -------> Element Definition
  1, 2472, 2518, 2469, 2471
  2, 2518, 2469, 2515, 2472
  ****
  16299, 11, 921, 4063, 924
**COVER:
  17000, 4654, 4755, 4659, 4517
  ****
  18893, 4840, 4879, 4843, 4605
**EJECTOR
  19000, 5730, 5729, 5736, 5733
  ****
  21998, 5381, 5384, 5382, 5371
**TOGGLE
  22500, 6239, 6246, 6203, 6245
  ****
  22821, 6327, 6376, 6334, 6333
**TIE BARS
  23000, 7002, 8006, 7005, 6906
  ****
  28069, 7728, 8213, 7726, 6671

115
*SOLID SECTION,ELSET=E0000001,MATERIAL=M0000001

Material property
Definition
*MATERIAL,NAME=M0000001
*ELASTIC,TYPE=ISOTROPIC
2.068E+11 2.900E-01
*DENSITY
7.725E+03
*EXPANSION,TYPE=ISO,ZERO=21.85
1.170E-05
*CONDUCTIVITY,TYPE=ISO
3.000E+01

**CONTACT SURFACES ::::SURFACE DEFINITIONS
----------- Contact surface definitions
**
*SURFACE DEFINITION, NAME=COVER
CO000005, S1
****
*SURFACE DEFINITION, NAME=EJECT
EJ000005, S1
******
******
*SURFACE DEFINITION, NAME=EJTOG2
22626, S1
TG000011, S2
*SURFACE DEFINITION, NAME=EJPTO2, TRIM=YES
14465, S1
PL000044, S4
*CONTACT PAIR,INTERACTION=CONT,SML SLIDING
EJTOG2,EJPTO2
*SURFACE INTERACTION,NAME=CONT
*FRICITION
----------- Friction coefficient
0.5

** MPC CONSTRAINTS
----------- BC for tieing nodes
*MPC
TIE,79,6594
TIE,412,6689
****
*****
*****
TIE,82,6571
TIE,415,6666
**

********CYCLE 1 ********
**
**
*INITIAL CONDITIONS,TYPE=TEMPERATURE
----------- Initial conditions
NTIE,50.0
****
*STEP,AMPLITUDE=STEP,INC=100
----------- Load step definition
*STATIC
----------- Analysis type
.25,1,.,
----------- Time step
** BOUNDARY CONDITION SET
** CLAMPING

*BOUNDARY, OP=NEW

PL000001, 1, 2, .00000E+00
TG000001, 3, -.11000E-02
TG000002, 1, 2, 0.00000E+00
TG000002, 4, 6, 0.00000E+00
TG000003, 3, .11000E-02

*TEMPERATURE, FILE=w-new-test2-h, BSTEP=1

*NODE FILE, FREQUENCY=2, GLOBAL=YES

U

*EL FILE, FREQUENCY=2, POSITION=NODES

S

*NODE PRINT, FREQUENCY=0

*EL PRINT, FREQUENCY=0

**CONTACT PRINT, SLAVE=COVER, MASTER=EJECT, FREQUENCY=100

**CSTRESS, CDISP

*END STEP

*****

**STEP

*STEP, AMPLITUDE=STEP, INC=100

*STATIC

0.025, 0.1,

**DIE CLOSED-ALUMINIUMS INJECTED

** CAVITY PRESSURE

*DLOAD, OP=NEW

CO000009, P1, 7.2400E+07
CO000010, P2, 7.2400E+07

*****

** CLAMPING

*BOUNDARY, OP=NEW

PL000001, 1, 2, .00000E+00

*****

*TEMPERATURE, FILE=w-new-test2-h, BSTEP=2

*NODE FILE, FREQUENCY=3, GLOBAL=YES

U

*EL FILE, FREQUENCY=3, POSITION=NODES

S

*NODE PRINT, FREQUENCY=0

*EL PRINT, FREQUENCY=0

*END STEP

*****

*****

**STEP1

*STEP, AMPLITUDE=STEP, INC=100

*STATIC

0.25, 15.9,

**STEP 3

**DIE CLOSED-ALUMINIUMS INJECTED

** CAVITY PRESSURE

*DLOAD, OP=NEW
** CLAMPING
*BINARY, OP=NEW
PL000001, 1, 2, .00000E+00
****
*TEMPERATURE, FILE=w-new-test2-h, BSTEP=3
*NODE FILE, FREQUENCY=10, GLOBAL=YES
U
*EL FILE, FREQUENCY=10, POSITION=NODES
S
*NODE PRINT, FREQUENCY=0
*EL PRINT, FREQUENCY=0
*END STEP
*****

*****
**STEP 4
*STEP, AMPLITUDE=STEP, INC=50
*STATIC
.2, 1., 0.001, 5
** STEP 8 DIES ARE CLOSED AGAIN(AFTER THE
** HEAT REMOVAL OPERATION
** CLAMPING
*BINARY, OP=NEW
PL000001, 1, 2, .00000E+00
****
** CAVITY PRESSURE
*DLOAD, OP=NEW
CO000009, P1, 0.0000E+00
CO000010, P2, 0.0000E+00
*****
*TEMPERATURE, FILE=w-new-test2-h, BSTEP=8
*NODE FILE, FREQUENCY=2, GLOBAL=YES
U
*EL FILE, FREQUENCY=2, POSITION=NODES
S
*NODE PRINT, FREQUENCY=0
*EL PRINT, FREQUENCY=0
*END STEP
***
**
**
******CYCLE 2 *******    ----------> Beginning of cycle 2
**
**
*NSET, NSET=PL000001
137, 138, 161, 162, 197, 198, 199, 200, 491, 492, 493, 494, 495, 496, 497, 498
****
****
*ELSET, ELSET=EJ000011
19188, 19191, 19260, 19261, 19263, 19284, 19286, 19288, 19496, 19498, 19522, 19756
BIBLIOGRAPHY


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