

# **EXPERT SYSTEM FOR DFM OF DIE CAST COMPONENTS**

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## **ABSTRACT**

Design and manufacturing are two very fundamental engineering processes in mechanical related fields. Traditionally design has been a manual process separated from manufacturing but concept of Concurrent Engineering with Design For Manufacture (DFM) and Design For Assembly (DFA) not only coupled both these but also increased complexity of design and thus brought about the application of computers. Expert systems have enabled designers to incorporate huge knowledge bases in a rule base system for domain specific problems thereby helping to automate the process of design.

Keeping this in view it was decided to develop a software which can automate the design process along with manufacturing consideration. The work aims for development of such software as an expert system for DFM with specific application to die cast components. The software is developed in two modules namely feature based modelling and expert system. The features identified are section/wall thickness, ribs, bosses, cores, fillets/radii, drafts etc.

## 1. INTRODUCTION

Design process is very complex and iterative. It requires not only a detailed knowledge of the specific field but also principles of CAD, CAM, CIM, concurrent engineering, DFM, DFA, Group Technology, Value Engineering etc. The overall design should not only be functionally sound but also cost effective and economically feasible.

The design of die casted components involve careful consideration of guidelines or rules like "section thickness should not vary much", "sharp corners should be avoided", "proper draft should be given", "fillet radii should be as large as possible", "material concentration should be avoided" and many more. These guidelines are very extensive and sometimes even conflicting which makes it difficult for a designer, who may not be a die casting expert, to take care of all these along with functional, feasibility, aesthetic requirements. Also a human is prone to make errors and the danger increases if number of requirements and guidelines is high. These errors if discovered at the manufacturing stage add cost and increase cycle time.

This work seeks to develop software as a tool for designer for avoiding errors by automating the application of DFM guidelines. The software which tackles these kinds of problems which are traditionally solved by human experts is called expert system and such design is called intelligent design.

The technology of Artificial intelligence and expert systems enabled computers to be applied to less deterministic design tasks which require symbolic manipulations and reasoning, instead of only routine number processing [7]. Expert systems are very powerful tools for solving problems like design which are application of knowledge base of designer to that specific situation for taking decisions. Design is a typical decision making process so application of knowledge engineering and expert system is suitable for it. Expert systems are very well suited for database manipulations and decisions making. Greatest advantage of expert system is that, it is modular and so changes or expansion can easily be done by merely changing or adding facts and rules.

Design guidelines are applicable to manufacturing features whereas solid modeller store information in terms of geometric entities like lines, arcs, curves, faces etc which do not give any idea of manufacturing operations and technological parameters. That is why solid model in terms of features like plates cylinders, ribs, bosses is desirable. A feature represents a shape and technological parameters associated with manufacturing operations and thus it represents the engineering meaning of the geometry of the model. For identifying features three alternatives are available - Automatic Feature Recognition, Design by Features and Feature Based Modelling. Research in automatic feature recognition is yet to come to a functional stage and thus was out of the scope of present work. Design by feature requires a very big library of features to assist the designer and it is very difficult to include all possible features in the library. Moreover this method restricts the designer to select the features amongst available thus inhibiting him to experiment with shapes. Feature based modelling requires designer to model only those features which are needed for design guidelines application, with help of library of existing features and rest of the modelling can be done freely with all kind of shapes and surfaces. Thus this method provides the designer full flexibility with very few restrictions and serves the purpose of feature extraction also. For these reasons present work uses feature based modelling for feature recognition.

The choice of proper platform for the solid modeller and expert system was influenced by functionality, ease of programming and availability of hardware and software. The solid modeller chosen was UNIGRAPHICS. User Functions of UNIGRAPHICS were used for developing a shell for feature based modelling. User functions are library routines which can be called by a C programme and give access to the

model for extracting geometric information, provide basic input output routines in UNIGRAPHICS and provide modelling features. Since the major portion of the software was expert system, the choice of proper shell was very crucial. Various alternatives were Prolog, Level V Object and CLIPS[4]. CLIPS was chosen among these. The choice of CLIPS was mainly influenced by the modular design, object oriented approach and availability of the source code.

## **2. DESIGN GUIDELINES FOR DESIGN OF DIE CAST COMPONENTS**

General design guidelines applicable to any design process and any casting process are applicable to the die casting also but as a different process it has some specific design considerations applicable only to it. The design guidelines both general and specific can be grouped based on the feature on which these are applicable. These groups are wall thickness based guidelines, ribs and bosses based guidelines, cored hole based guidelines, draft based guidelines and fillet radii based guidelines etc. Sources of these guidelines are [3] and [9].

### **2.1 Section/Wall Thickness Based Guidelines**

Since the cost of casting increases with increase in weight, designer should try to use thinnest section that can meet strength, stiffness and other design requirements. Thin section cool quickly in the die. Hence it can be opened sooner than for thicker sections and the casting cycle time is reduced. The thin sections are likely to be smoother and have minimum surface porosity. But extremely thin sections do not allow the molten metal to fill the cavity and thus there is a limit to minimum allowable section thickness which should be taken. The thickness depends on surface area of the wall and must conform to the values shown in Table 1. It is also highly desirable to have sections of reasonably uniform thickness and if changes in section thickness is unavoidable then to have changes smooth and gradual.

### **2.2 Ribs Based Guidelines**

Ribs are mainly incorporated into a die casting to reinforce it structurally replacing heavy sections that would be otherwise necessary. To avoid sinks, ribs should not be much wider than the thickness of the casting wall and no higher than 4 times their width for complete filling. Ample draft (at least  $2^\circ$  per side) must be given for easy ejection. If ribs are designed to cross, they should do at right angles as far as possible.

### **2.3 Boss Based Guidelines**

Boss are projections, often quite shallow, though frequently quite deep and are usually provided where an attachment or fastening comes or where a part such as a bearing on some mating part is to be applied or supported. It is always desirable to avoid undue metal concentration at bosses, as then boss may be porous. Whenever possible bosses should be cored and ribs may be applied to stiffen the boss and the walls around it. Heavy bosses behind the surface cause visible sink on other side of the wall thus the boss should be moved away from the wall and connected to the wall with a short rib of the same thickness, as shown in fig 1.

### **2.4 Core Based Guidelines**

The die casting process can accommodate the coming in holes into the body of the casting at right angles to the parting line. As a thumb rule it is often cheaper to drill or pierce than to core small holes, especially where depth does not exceed 3.0 mm. Optimum greatest depth of cored holes as related to diameter are shown in Table 2. Cores

must also be drafted adequately to assure their longevity. Minimum draft requirements must conform to the values shown in Table 3. Lower limit on core diameter of 3.0 mm for aluminium and magnesium alloys and 1.5 mm for zinc alloys should be observed.

### 2.5 Fillet Radii Based Guidelines

Sharp internal corners in a die casting are to be avoided as when the casting shrinks, induced stresses are concentrated at sharp corners instead of being distributed through the surrounding mass thus making the parts weaker at such corners. The abrupt change in metal flow direction during injection can cause subsurface porosity at corner to weaken this area further. Sharp edges on dies are also prone to premature erosion due to hot spot at corners. Therefore radii and fillets should be as generous as possible and should be around 1.5 times wall thickness for both internal and external radii fig 2.

### 2.6 Draft Based Guidelines

The sidewalls of die casting and other features perpendicular to the parting line must be tapered/drafted as much as possible to facilitate removal from the die. Draft angle should be large as without it even the slightest depression in the drafted surface of the die will prevent ejection without causing drag marks in the surface of the casting. Draft angle also depends on the alloys and varies inversely with wall depth as shown in Table 4.

## 3. DESCRIPTION OF EXPERT SYSTEM

The expert system is written in Expert system shell CLIPS which is called from main programme menu displayed in UNIGRAPHICS. The communication between UNIGRAPHICS generated feature based model and expert system is done with help of ASCII files. There is a separate ASCII file for each of the six section thickness, ribs, bosses, cores, radii and drafts. The ASCII file is written in form of facts which can be read directly by CLIPS. All these files are prepared when user generates feature based model of die casting. The expert system runs and checks rule violation for all facts contained in a particular file and writes back the information and suggestions, if any. When programme control returns back to UNIGRAPHICS the output files are interpreted by it to display warnings and make suggestions.

The typical format of a fact file for section thickness module is

```
(alloy Zinc)
(section_thickness (surface_area 25.0) (thickness 3.5) (nth 1))
:
```

The first fact tells that the alloy used for die casting is zinc.

Subsequent facts are values of thickness and surface area of that wall at which section is taken.

Knowledge base i.e. tables, minimum or maximum values are also written, in form of facts which can be directly loaded into CLIPS for modification and editing thus knowledge base can be acquired and maintained interactively by the user. The knowledge base can also be edited by using any editor like vi.

The typical format of table 1 is

```
(table 1 (alloy zinc) (area_low 0.0) (area_up 25.0) (thickness_low 0.38)
(thickness_up 0.75))
:
```

The knowledge acquisition module takes help of user for knowledge base modification. The user can interactively select the database to be modified and data to be changed. This module is organised around a set of menus/sub-menus which permit the

user to conveniently modify the knowledge base. The modified knowledge base is finally saved after verification.

as only table 4 is part of the knowledge base which can be modified.

#### **4. DESCRIPTION OF FEATURE BASED MODELLER**

The feature based modeller is developed in C language with help of user functions of UNIGRAPHICS. Apart from being merely a feature based modeller this also serves as shell on top of the UNIGRAPHICS and acts as main programme displaying main menu asking to select one of the options of "Modelling by Features", "Run Expert system", "View Expert System's Results" and "Quit". Depending upon user's response the action is taken. If user selects 'Run Expert System', the CLIPS is invoked and expert system module is run. But before that modelling is required to be done. Selection of the 'Modelling by Feature' option, displays a new menu asking to select one of the options of Add Feature, Modify Feature and Delete Feature. Each of these sub menu item have six feature which can be added, modified or deleted. Selecting the 'View Expert System's Result' option, displays sub menu asking to select all or any particular feature results. The last option 'Quit' causes to quit the main programme and ends the session.

The algorithm and strategy adopted for each feature is different as each has different parameters and attributes, not all available in user functions. For example facts for ribs, bosses, radii and core are automatically generated as soon as these are modelled. However facts for section thickness and draft are generated with help of user which is required to furnish further information about these.

The task of automating the identification of section thickness at various points of die casting could not be achieved because there is a large number of possibilities of selection of planes where section could be taken. Further without help of user, improper sections probably parallel to the wall can be taken causing false alarms. This is because excessively thick sections will then be identified. For these reasons the user interaction is required. The user is asked to select a plane where section should be taken and the section is displayed. Further user is asked to select points where section thickness should be measured. The user is also required to select a face where he/she has taken points for thickness measurement.

In rib modelling, the dimensions shown in fig 3 are required to be supplied by the user. A single rib is made by extrusion of rib section. The multiple ribs are made by transforming this with translation and rotation.

The boss modelling is done by creating cylinder and joining it to the wall of the part. The user is asked to furnish dimensional details and cylinder is created.

The core modelling is done by creating a cone with chopped vertex as core have a draft so it can not be modelled as cylinder. This core is subtracted from the part previously created.

To start with a model is created with modelling features provided by software and UNIGRAPHICS. The part thus created may have sharp corners. Fillets are then added at these sharp corners once the user selects the edge where fillet is required.

The walls of model is created by creating blocks, cylinders etc without any draft. The drafts are added later by creating planes and cutting walls.

#### **5. CASE STUDIES**

The model for this case study is shown in figure 4. The features present in this model are boss, core, section thickness and fillet radii. The facts generated for boss are

(boss (dia 4.0) (distance 0.0) (thickness 2.0) (nth 1)) ; 1 1  
(boss (dia 4.0) (distance 0.0) (thickness 2.0) (nth 2)) ; 1 1  
(boss (dia 4.0) (distance 0.0) (thickness 2.0) (nth 3)) ; 1 1

(boss (dia 4.0) (distance 0.0) (thickness 2.0) (nth 4)) ; 1 1  
 (boss (dia 4.0) (distance 0.0) (thickness 2.0) (nth 5)) ; 1 1  
 (boss (dia 4.0) (distance 0.0) (thickness 2.0) (nth 6)) ; 1 1  
 (boss (dia 5.0) (distance 0.0) (thickness 2.0) (nth 7)) ; 0 0  
 (boss (dia 4.0) (distance 0.0) (thickness 2.0) (nth 8)) ; 1 1  
 (boss (dia 4.0) (distance 0.0) (thickness 2.0) (nth 9)) ; 1 1

Each fact has the information of the dia of the boss, its distance from the side wall and thickness of the side wall. The suggestion generated by the software are

Found rule violation for boss number 7.

Diameter of the boss = 5.0 mm.

Distance of the boss from wall = 0.0 mm.

Thickness of the wall = 2.0 mm.

Suggestions :-

Decrease the diameter of the boss to 4.0 mm.

Increase the distance of the boss from wall to 5.0 mm.

Boss number 7 is found to be thick and so the suggestion for reduction in thickness is generated. Also the thick boss is near a thin wall so it is advised to increase the distance from the wall.

The facts generated for core are

(core (dia 8.0) (depth 10.0) (draft 2.0) (through\_blind blind) (nth 1)) ; 1 1 1 0  
 (core (dia 10.0) (depth 10.0) (draft 3.0) (through\_blind blind) (nth 2)) ; 1 1 1 1  
 (alloy zinc)

Each fact has the information of dia, depth and draft of the core and whether the core is blind or through. The suggestion generated by the software is

Found rule violation for core number 1.

Core dia = 8.0 mm.

Core depth = 10.0 mm.

Core draft = 2.0 mm.

Suggestions :-

Increase draft of the core to 2.5 Deg.

The draft on core number 2 is found to be less than recommended in table 3 so it is advised to increase it to minimum of 2.5°.

The facts generated for section thickness are

(section\_thickness (area 18.0) (thickness 4.0) (nth 1)) ; 1 1 1  
 (section\_thickness (area 2.0) (thickness 2.0) (nth 2)) ; 1 1 0  
 (section\_thickness (area 45.8) (thickness 2.0) (nth 3)) ; 1 1 1  
 (section\_thickness (area 45.8) (thickness 2.0) (nth 4)) ; 1 1 1  
 (section\_thickness (area 28.3) (thickness 2.0) (nth 5)) ; 1 1 1  
 (alloy zinc)

Each fact has the information of the side wall thickness and its area. The suggestion generated by the software is

Found rule violation for section number 2.

Thickness at this section = 2.0 mm.

Thickness of previous section = 4.0 mm.

% change in section thickness = 100.0 %.

Suggestions :-

Decrease the % change in section thickness to 50.0 %.

The section thickness from section 2 to section 1 increase by 100% i.e. doubles which is not desirable

The facts generated for radii are

(radii\_thickness (radii 2.0) (thickness 2.0) (nth 1)) ; 1

```
(radii_thickness (radii 2.0) (thickness 2.0) (nth 2)) ; 1
(radii_thickness (radii 2.0) (thickness 2.0) (nth 3)) ; 1
(radii_thickness (radii 2.0) (thickness 2.0) (nth 4)) ; 1
(radii_thickness (radii 2.0) (thickness 2.0) (nth 5)) ; 1
(radii_thickness (radii 1.0) (thickness 2.0) (nth 6)) ; 0
```

Each fact has the information of the value of the fillet radii and the thickness of the wall at that point. The suggestions generated by the software are

Found rule violation for radii number 6.

Given fillet radii = 1.0 mm.

Thickness of the wall = 2.0 mm.

Suggestions :-

    Increase the radii to 2.0 mm.

Sixth radii is found to be less than recommended value of thickness at that section and so the suggestion to increase the fillet radii is generated.

## 6. CONCLUSIONS

The aim of the present work was achieved with successful run of software for various kind of input out of which one case study discussed above. Main feature of software are:

1. Feature based modelling : The modelling of components is done with help of six categories of features provided by the software.
2. Designer not constrained : The feature based modelling is incorporated in the software and except six features the designer is free to do modelling without any constraint.
3. Incorporation of expert knowledge : The expert system module contain knowledge base which has been developed by many experts over years.
4. Knowledge base updation easy : The learning module provides easy and interactive way of modifying knowledge base which changes with time. The storage strategy of knowledge in form of facts also facilitate easy expansion on knowledge base as new facts can be added very easily without much change in the programme.
5. Separation of expert system module from modelling module : Both the modules are totally separated with data exchange in between two module with help of ascii files. The separation facilitates easy expansion and maintenance of the software.
6. User friendly interface : The complete software runs in a very user friendly way by displaying various menus and navigation between menus and submenus at different levels is very easy.
7. Straight Forward Suggestions: Suggestions generated by the expert system are very straight forward and easy to incorporate. Moreover all suggestions can be overruled by the designer in case he wants to do so.

## 7. SCOPE FOR FUTURE WORK

The present software includes six categories of features and six categories of rules which can be extended to more categories. In each category more rules can also be added with more specialised knowledge of die casting. The software deals with design of components only. Inclusion of design of gating system and design of die can result in a very useful software tool for design and manufacturing companies.

## 8. REFERENCES

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Figure 1 Boss near thin wall should be relocated  
by using a short rib to avoid surface  
shrinks

Figure 2 Dimensional constraints on fillet radii

Figure 3 Dimensional constraints on rib

Figure 4 Case study model

Figure 4 Case study model (Isometric View)

Figure 5 Case study model (Orthographic View)

Table 1 Die Casting Wall Thickness

Table 2 Optimum Greatest Depth of Cored Holes as Related to Diameter

Table 3 Draft Requirements for Cored Holes in Die Castings

Table 4 Draft Requirements for Die Castings

The Director (Technical)  
The Institution of Engineers (India)  
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Dt: 1st Nov, 1996

**Sub:** Paper submission for the Journal of Mechanical Engineering.

Dear Sir,

Enclosed please find the text for a paper titled "*Expert System for DFM of Die Cast Components*" authored by myself, Dr K RaviRaju and Amit Gupta. Kindly consider it for publication in the Journal of Mechanical Engineering of the Institution of Engineers.

Thanking You,

(Dr A Chawla)