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An Interactive Knowledge-Based CAD System For Mould Design in Injection Moulding Processes

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This paper presents a practical prototype knowledge-based system, called IKMOULD, for mould design in the injection moulding process. It attempts to tackle the problem in a practical and integrative way, unlike the stand-alone and mathematical programs which have been developed in the past to solve only a part of the problem. A total quantitative and structured approach is not feasible in dealing with the complex and multirelated design problems generally involved in mould design. In this system, the computational module, the knowledge-based module and the graphic module for generating mould features are integrated within an interactive CAD-based framework. The knowledge base of the system can be accessed by mould designers through interactive programs so that their own intelligence and experience can also be incorporated with the total mould design. The approach adopted both speeds up the design process and facilitates design standardisation which in turn increases the speed of mould manufacture.

Keywords: CAD/CAM; Injection mould design; Interactive design procedure; Knowledge-based expert systems

1. Introduction

Plastic, which is one of the most versatile materials in the modern age, is widely used in many products throughout the world. The injection moulding process is the most common moulding process for making plastic parts. It is a process by which plastic pellets or powders are melted and pressurised into a cavity to form a complex 3D part in a single cyclic operation. The engineering tasks involved in injection moulding are the design of the geometry of parts and moulds, machining and polishing of cavity/core surfaces and cooling lines, assembly of plates, pins and mould bases, and prototype tests with a proper choice of material and processing parameters.

In injection moulding, the design of the moulds is of critical importance for product quality and efficient processing. In most cases, the quality of the mould is responsible for the economics of the entire process. For example, cycle times are determined primarily by mould temperature control (cooling time). The quality of the moulded parts is determined primarily by the mould, even though constant machine conditions, achievable through improved machine fabrication technology and the use of process control systems combined with uniform material properties, are also an essential prerequisite. Frequently, moulding problems are traceable to moulds which either show signs of premature wear or cause processing difficulties because of poor thermal and rheological design, or else they are characterised by operating tolerances which are too close for the machine to guarantee its constant machine parameters.

Production start-up is usually delayed owing to the long time required for mould design and manufacture and, especially, to the very frequently required mould corrections which, in the final analysis, are attributable to poor mould design. Moreover, the requirements increase as high-quality industrial parts are increasingly demanded. These facts clearly show that currently, the moulds could become the weakest link in the product development cycle. Hence, in any improvement programs, moulds must receive the major attention, which should be concentrated mainly in the area of mould design. Such efforts should be directed primarily to improving the entire design process in terms of the results achieved, to accelerate production start-up, and to enable all designers to make use of currently available mould design knowledge in a practicable manner.

Nowadays, mould design faces increasing deadline pressure and the design itself is predominantly based upon the experience of the mould designer. Mould designers are required to possess thorough and broad experience, because detailed decisions require a knowledge of the interaction between different parameters. A change of an individual factor in a more favourable direction could have a negative effect on other critical factors. Unfortunately, at present, it is impossible to cover the growing demand for experienced designers.

At present, most CAD systems provide only the geometric modelling functions which facilitate the drafting operations of mould design, but do not provide mould designers with

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the necessary knowledge to develop good mould designs. Conventional computer-aided engineering packages are usually good at data processing for information-intensive problems or good at number manipulation for formulation-intensive problems. The former involves the computer-aided drafting and graphics, and data reduction and transformation [1], whereas the latter involves numerical (or mathematical) modelling and analysis [2]. However, in design problems, especially in mould design which involves a substantial practical knowledge component about the functions and structure of a mould, human heuristic knowledge and empirical knowledge are needed in addition to information-intensive and formulation-intensive knowledge. Therefore, conventional computer-aided design technology is unsuitable for processing the heuristic and empirical type of knowledge which is critical in the mould design problems.

Injection mould design involves extensive empirical knowledge (heuristic knowledge) about the structure and functions of the components of the mould. It thus has very good potential for success as a knowledge-based system application. This paper describes a prototype CAD-based mould design procedure developed by using a knowledge-based approach. The procedure provides a mould designer with an interactive computer-aided design system for a knowledge base, incorporating methods, and elements of mould features; and graphic modules for constructing mould assemblies and parts. The procedure begins with the plastic part which is to be moulded and finishes by generating a general configuration and detailed drawings of a completed mould.

The system can now handle the design of small-sized injection moulds of four common types, namely standard two-plate moulds, stripper moulds, standard sliding-splits moulds and three-plate moulds.

2. A Summary of Injection Mould Design

This summary of injection mould design establishes the terminology and introduces aspects of the design procedure involved. Figure 1 illustrates the basic components of a typical injection mould.

(a) *Feed system*. The feed system accommodates the molten plastic material coming from the injection nozzle of the moulding machine and distributes it into each cavity. Normally, the feed system consists of a sprue (23), runner (4) and gate (19).

(b) *Cooling system*. To remove the heat from the moulding, it is necessary to supply the mould with a system of cooling channels (3) through which a coolant is pumped.

(c) *Ejection system*. After the moulding has solidified and cooled down, it has to be removed from the mould. After the mould is opened, the ejector of the machine will actuate the ejection system to move forward to knock out the mouldings. In Fig. 1, ejector pins (16) and sprue ejector (10) are used to eject the parts and runner, respectively. The return pins (15) are used to push the ejector plate assembly (13, 14) back when the mould is closed.

(d) *Mould construction*. A mould is normally constructed by stacking several metal plates to form a rigid body. It has to house various mould components in the correct positions for the proper functioning of the mould. Major components include: register ring (1) for location of mould with machine; core/cavity inserts (17, 21) for shaping of the material; guide pins (6) and guide bushes (8) for mould alignment; and clamping plates (12, 22) for mould mounting. For complicated plastic parts, some other mechanisms such as slides, unscrewing devices, etc., might also be involved in the whole mould structure.

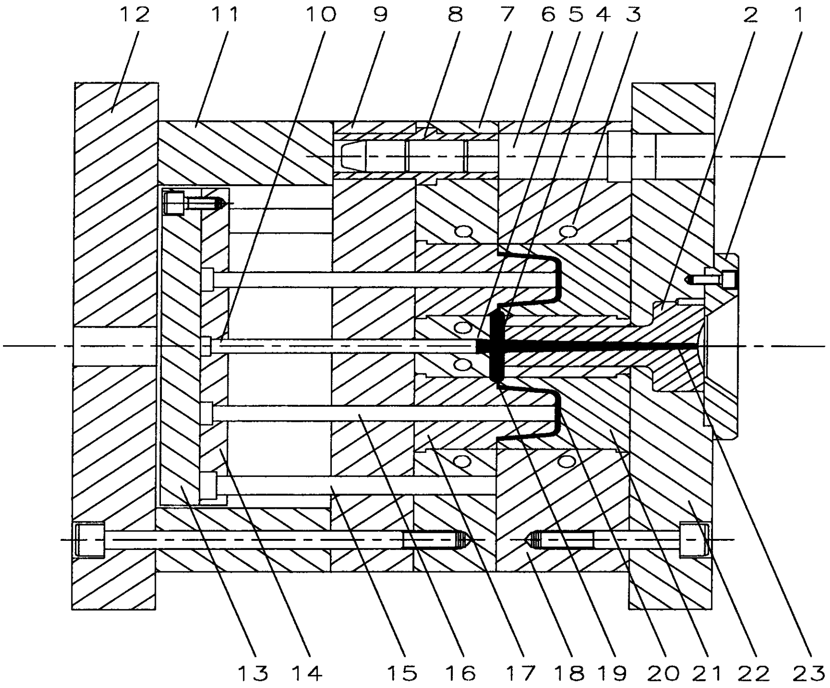
3. Knowledge-Based Approach

A knowledge-based approach broadly means to build up a system, usually called a knowledge-based system (KBS), for solving complex decision problems in a specific domain. A KBS, normally in the form of an intelligent computer program, uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. The knowledge of a knowledge-based system consists of facts and heuristics. The “facts” constitute a body of information that is widely shared, publicly available, and generally agreed upon by experts in a field. The “heuristics” are mostly private, little-discussed rules of good judgement (rules of plausible reasoning, rules of good guessing) that characterise expert-level decision-making in the field.

The typical structure of a knowledge-based system is shown in Fig. 2. It comprises the knowledge base, containing encoded expertise from the domain expert. The inference engine on the other hand provides strategies for processing the encoded knowledge in order to reach KB solutions. The KB system also provides a user interface for KB system/user interaction, and, possibly, sensors for the collection of data from monitoring devices. Finally, links to a traditional database provide the KB system with the opportunity to import and use data in the inferencing or reasoning process.

4. Development of Computer/KBS Techniques in Mould Design

Previous work in applying computer technologies in the field of injection moulding covered many aspects of injection moulding and mould design activities. Bezier [3], Goult [4], and Kishinami et al. [5] defined sculptured surfaces and mould cavities with complex shapes; and generated offset surfaces, i.e. generating the inner wall of a mould cavity at a constant thickness. Zwigel [6] and Abrahams [7] calculated the surface area and volume of the mould and strength and deformation of the mould by means of finite-element analysis programs. Schumacher [8] and Wubken and Bangert [9] simulated the cavity filling and cooling of the mould. Hui and Tan [10] presented a heuristic search approach based on sweep operations to develop automated mould design systems for



1 : register ring
2 : sprue bush
3 : cooling channel
4 : runner
5 : cold slug
6 : guide pin
7 : core plate
8 : guide bush
9 : backing plate
10 : sprue ejector
11 : riser block
12 : bottom clamping plate
13 : ejector plate
14 : ejector retaining plate
15 : return pin
16 : ejector pin
17 : core insert
18 : cavity plate
19 : gate
20 : molded part
21 : cavity insert
22 : top clamping plate
23 : sprue

Fig. 1. Basic components of a typical injection mould.

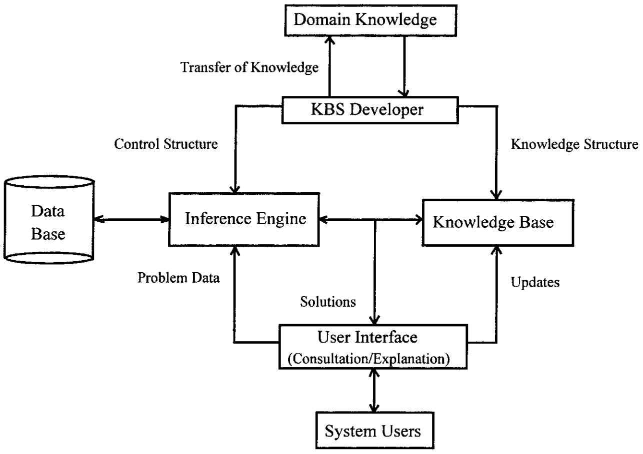


Fig. 2. The typical structure of a knowledge-based system.

determining parting direction, parting line, side core, etc. Lye and Yeong [11] established a computer-aided tool for the selection of injection machines, the size and position of injection guns, the ejectors, and the steam vents. Huang et al. [12] used solid-modelling techniques to build mould plates and a library of standard mould components. Computer-aided engineering techniques have been used to represent the injection moulding process mathematically and to assist the mould design by simulation analysis. MOULDFLOW from Mouldflow Australia, FLOW ANALYSIS from Plastics & Computer Inc., C-FLOW from Advanced CAE Technology Inc., POLYCOOL from Structural Dynamics Research Corporation, and MOULD-COOL from Application Engineering Corp., are typical commercially available packages for modelling the mould filling process and/or cooling analysis.

Researchers have started to adopt a knowledge-based approach to solving the injection moulding and mould design problems in recent years. IMPARD [13] is an expert system developed for injection moulded part design. IMES [14,15] solved injection moulding part-quality problems. GERES [16], FIT [17], CIMP [18], HyperQ/Plastic [19], PLAssex [20], etc., were developed for the selection of plastic materials. DTMOULD-1 [21] is a KBS for injection mould cost estimation. MOULDX [22] and EIMPPLAN-1 [23] incorporated mouldability considerations into part designs and addressed the conceptual design development of injection moulded parts. ICAD [24], the KBS of Drexel University [25], the KBS of the University of Massachusetts at Lowell [26], CADFEED [27], etc., were developed for injection mould design. They are, however, limited to specific design areas or simple parts, and are not mature and practical enough to cover general mould design.

From the above review, it can be seen that most of the previous work considers only certain aspects of the total design and some is too theoretical to be applied to practical mould design which involves a substantial practical knowledge component about functions and structure of a mould, human heuristic knowledge and empirical knowledge. The KB system has demonstrated great potential to assist designers in interacting with a CAD system for conceptualised design as well as for the final engineering design of a mould by using engineering rules of thumb with extensive analytical procedures. In general, the major advantage of a KB system for mould design over conventional computer-aided design systems is the explicit representation and manipulation of a body of knowledge, representing human expertise.

5. System Structure and Development

5.1 System Requirements

Mould design does not result from a quantitative analysis but comes within a range of design procedures which are partly creative and partly require existing items to be brought together as assemblies. Individual elements of the design may be subjected to quantitative analysis but these do not help the designer to establish the overall form of the assembly. Thus, it would not be practical to automate the design procedure completely as mould design lacks a quantitative and structured approach. An alternative approach was decided upon to structure as much of the procedure and methodology of mould design as could be structured; and to establish and appropriately configure a knowledge base which would incorporate the methods and elements of the mould features. This knowledge base will be accessed by designers through interactive programs so that their intelligence and experience can also be incorporated within this total CAD integrated design procedure.

The further requirement is to computerise as much of the procedure as possible in a way which will ensure that cost-effective and functional mould designs are produced. This means that a minimum number of simple parts should be used in the design of a mould and that standard parts should be used as far as possible. The system also has to be “user friendly” and has to be practically applicable in the local plastic industry. If it can make use of the mould designers’ skill and experience and provide some challenge to them then this is likely to enhance its acceptability. As it is impossible for any design procedure developed to consider beforehand every requirement of mould design, the procedure, its software and the knowledge base have to be designed so that it can be easily developed and extended as experience is gained in using it.

5.2 System Structure and the Interactive Design Procedure

Figure 3 shows a block diagram of the whole structure of the system. The modular system structure facilitates further development and extension and it also makes the switching of the program from one CAD platform to another relatively simple. The operation of the system is described in the following paragraphs.

First, the plastic part has to be drawn or retrieved from the part drawing database. Then an enquiry routine (block 5) selects the questions to put by reviewing answers given about the part in terms of its geometry, dimensions, material, etc., and also about the mould specifications in terms of number of cavities, mould design features, etc. After the designer answers all the questions, the software creates a coded description of the part and the mould. The purpose of the code is two-fold. First, it is used to make reference to the existing mould database and look for part codes identical to or close to the existing part (block 6). If the search finds appropriate part(s) and their respective mould(s), then they can be retrieved and reviewed to see whether they are suitable for use. It is normally required to modify existing moulds to make them suitable for a different part, but this can usually be done fairly quickly using the system CAD facilities. The second and main use of the code is to access the knowledge base of the system.

Within the next stage of the design procedure, a functional design analysis is performed so that the methods related to the various functional designs can be chosen (block 7). The methods file forms part of the knowledge base and it contains a long list of methods for achieving the various functional designs of an injection mould. Since only some of these methods are applicable to the particular part under consideration, it is necessary to extract the list of possible methods to be posed to the designer for his selection. This task is now carried out by the method screening routine (block 8) which uses the part code to select the recommended list of methods. Once a method has been selected, a code associated with each chosen method is generated.

Often, a method has alternative mould features (hardware arrangements). The code associated with the chosen method is then used to access and show to the designer the alternative mould features of the chosen method from the knowledge base of the alternative mould features through the mould feature screening routine (block 9). Separating the fundamental methods from their technical details in the present procedure guides the designer to focus on basic methods before dealing with their implementation. This logical approach speeds up the design process by reducing the variety of choices.

When a particular mould feature of a chosen method has been selected, a code associated with each mould feature is produced and used to access and prompt the designer to input information concerning individual dimensions, and position and orientation from the knowledge base of mould feature geometry through the autographic routine. In the knowledge base of mould features geometry, the detailed dimensions of the geometry of all the mould features are stored in terms of parameters. Once the graphic information has been input, the geometry of the chosen mould feature is drawn.

The designer then proceeds to another functional design through a similar procedure. When all the functional designs have been completed, a complete drawing is generated. Finally, all the designer has to do is to review and modify the mould drawing if necessary.

5.3 System Development

The program was written in UNIX C and implemented on the McDonnell Douglas Unigraphics II CAD System. This program was written in the “C” programming language primarily for two reasons. First, it is efficient, both in memory and speed which enables the inference program to run on small computers, such as IBM PC compatibles. Secondly, it is portable across a variety of computers. Thus, switching of the program to another CAD package can be sorted out without much difficulty.

The Unigraphics system is a very powerful CAD software. It possesses many internal user functions to facilitate programming and enhance program capability in graphic displays. It is also fully compatible with the most widely used flow

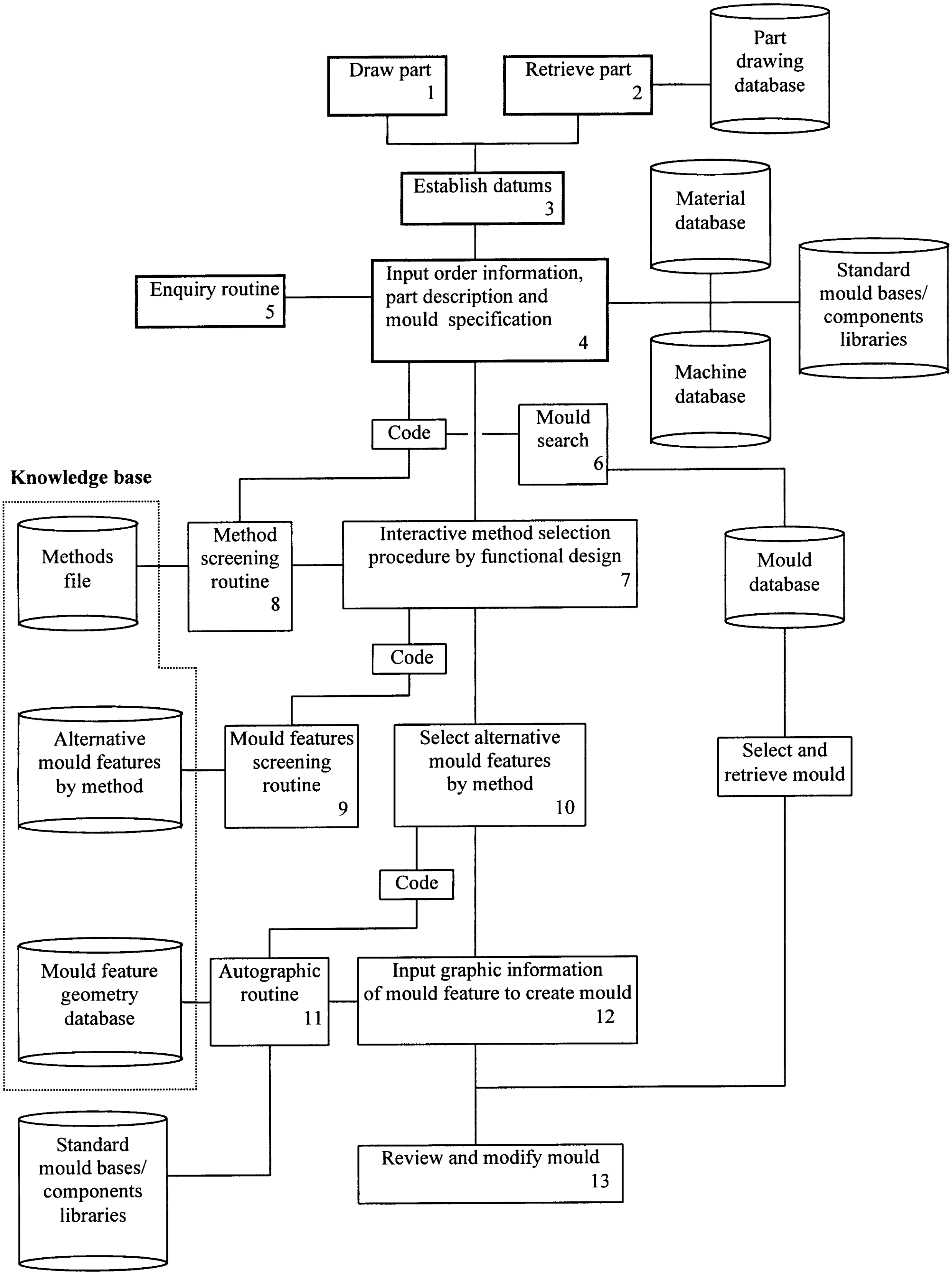


Fig. 3. Block diagram of IKMOULD.

simulation software "MOULDFLOW". This feature allows for the future expansion of the program to link up with MOULDFLOW to provide a more comprehensive mould design knowledge-based system.

5.4 The Coding System

The code is a representation of all the necessary information about the plastic part such as shape, undercut features, material, and other specifications. In designing the coding system, consideration has been given to the characteristics of most injection moulded parts and moulds. The design of injection moulds depends critically on the shape and features of the product. It is almost impossible to develop a unique definition for all the shapes of plastic parts as their shapes can vary infinitely. Nevertheless, in real-life the shapes of a large percentage of commonly encountered plastic parts can be approximated as either rectangular or circular. For example, most of the plastic housings and casings are basically rectangular in shape; and most of the knobs, buckets, and cups are basically circular in shape. The Opitz system [28], which is the popular classification system for mechanical parts, has also been referred to in developing part of the coding system.

The code is divided into three sections and has a total of twelve digits. The first section which describes the plastic part contains the first four digits. The second section which describes the relation between the part and the mould includes the fifth digit. The third section which describes the mould contains the last seven digits.

5.4.1 The First Section: Part Description

This section includes the first four digits. They represent the part class, part external shape, undercut features and material class, respectively.

5.4.1.1 Part Class. The first digit distinguishes the part as a circular part or a non-circular part. There are seven numeric positions for this digit as shown below.

1. Circular part with $H/D \leq 0.5$
2. Circular part with $0.5 < H/D < 3$
3. Circular part with $H/D \geq 3$
4. Variational circular part
5. Non-circular part with $H/De \leq 0.5$
6. Non-circular part with $0.5 < H/De < 3$
7. Non-circular part with $H/De \geq 3$

Here, H is the height of the part measured from the parting line, D is the diameter of a circular part, De is the equivalent diameter of a non-circular part with length L and width W ($De = \sqrt{(4LW/\pi)}$). Parts belonging to class 1 and class 3 are like flat disks and long cylinders, respectively. Parts belonging to class 5 and class 7 are like flats and long prisms, respectively.

5.4.1.2 Part External Shape. The second digit depends on which class the part belongs to and the classification rules are as follows:

Class 1–3

1. Smooth, having a uniform diameter along the entire height.
2. Cone, diameter stepped to one end.
3. Having various diameters along the entire height.

Class 4

1. Curved rotating axis.
2. More than one parallel rotating axes.
3. More than one non-parallel rotating axes.

Class 5

1. Rectangular with no deviation in corner.
2. Rectangular with one deviation right-angle or triangular.
3. Rectangular with circular deviation.
4. Flat part, regularly arched or dished.
5. Irregular contoured flat part.

Class 6, 7

1. Straight axis, uniform cross-section, no deviation in corner.
2. Straight axis, uniform cross-section, with one deviation.
3. Straight axis, uniform, other than rectangular cross-section.
4. Straight axis, varying cross-section stepped to one end.
5. Straight axis, varying cross-section along the entire height.
6. Curved axis.

5.4.1.3 Undercut Feature. Mould designers are frequently faced with demoulding problems resulting from undercuts existing on the plastic parts. An undercut can be defined as any interference occurring between the mould and the moulded part when the part is knocked out from the mould in the withdrawal direction. The design of an appropriate mould for this type of product is inevitably more complicated than for those without any undercuts. In general, undercuts can be classified into three types, external undercut, internal undercut, and internal thread. The undercut feature is represented by the third digit which has the following positions.

1. External undercut only.
2. Internal undercut only.
3. Internal thread only.
4. External undercut and internal undercut.
5. External undercut and internal thread.

5.4.1.4 Material Class. Plastic material used for moulding the part is classified according to its material constant *n*. There are four positions for this digit.

Position	1	2	3	4
Material constant *n*	0.6	0.7	0.8	0.9

5.4.2 The Second Section: The Relationship Between the Part and the Mould

The fifth digit describes the relation between the directions of the part axis and the mould parting line and is classified as:

1. Part axis is perpendicular to the mould parting line.
2. Part axis is parallel to the mould parting line.

5.4.3 The Third Section: Mould Description

The sixth to the twelfth digits represent the mould specifications in terms of number of cavities, mould design features, etc.

5.4.3.1 Number of Cavities. There are nine positions for digit 6.

Position	1	2	3	4	5	6	7	8	9
Number of cavities	1	2	3–5	6	8	10	12	14	16

5.4.3.2 External Undercut Release Mechanism. There are three positions for digit 7.

1. Side core.
2. Sliding splits.
3. Angled-lift splits.

5.4.3.3 Internal Undercut Release Mechanism. There are three positions for digit 8.

1. Angled form pin.
2. Collapsible core.
3. Unscrewing.

5.4.3.4 Runner System. There are four positions for digit 9.

1. Cold runner.
2. Insulated runner.
3. Insulated hot runner.
4. Hot manifold.

5.4.3.5 Gating System. There are eight positions for digit 10.

1. Sprue gate.
2. Edge gate.
3. Submarine gate.
4. Pin point gate.
5. Tab gate.
6. Fan gate.
7. Film gate.
8. Diaphragm gate.

5.4.3.6 Cooling System. There are five positions for digit 11.

1. With cooled cavity plates.
2. With cooled cores.
3. With cooled cavities.
4. With cooled cores and cavities.
5. Optimum cooling.

5.4.3.7 Ejection System. There are four positions for digit 12.

1. Ejector pins.
2. Stripper plate.
3. Ejector sleeves.
4. Air ejection.

It can be seen that this coding system has catered for very complicated parts. For example, a non-circular part which has varying cross-section along its entire height and both external undercuts and internal undercuts/thread can be coded by this system.

5.5 The Knowledge Base

The knowledge base developed in this work is based on the following sources:

1. Handbooks and technical papers.
2. The authors' expertise, accumulated over ten years in the plastic manufacturing industry.
3. Knowledge acquired through interviews and case discussions with the experts of some local companies.
4. Consultations with the plastic technology experts at the City University of Hong Kong.

At present, the scope of knowledge covers the most widely used methods and elements of mould features for the four main functional systems designs for standard two-plate moulds, stripper moulds, split moulds, and three-plate moulds. A rule-based knowledge-representation method was used to develop the knowledge base of IKMOULD. More than five hundred rules have been established in this work.

The various functional designs of injection moulds are related to part information and mould specifications by rules developed in the knowledge base. For example, parts of the rules for the feed system and cooling system are shown in Tables 1 and 2, respectively.

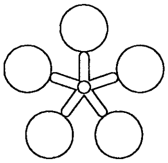
The program for the knowledge base was written in a modular structure consisting of the four basic functional systems of injection mould design, namely feed system, mould construction, cooling system, and ejection system. Using the editing facilities provided by the UNIX system, it is fairly easy to add and delete rules in the knowledge base.

6. Design Case Study

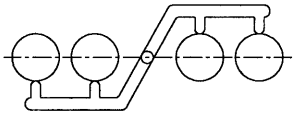
In order to have a more detailed understanding of the operations of IKMOULD, it is desirable to carry out a real design study with this prototype package. From experience in using this program for a number of actual designs, it normally takes about 100–200 steps of mouse clicks and/or keyboard inputs to complete the whole design of a certain plastic part, depending on the complexity of the part. As it would be too lengthy to list all the steps involved in carrying out such a design exercise here, a summary of the major actions of the following design example is presented in the following paragraphs.

Table 1. Feed system rules for runner layout.

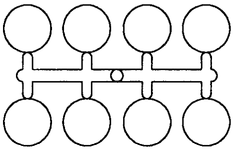
Runner layout type	Conditions
Single cavity layout	Cavity number = 1
In-line layout	Cavity number = 2, 4, 6 or 8; sliding-splits mould for external undercut Cavity number = 2 or 4; unscrewing mould for internal thread
Circular layout	$3 \le$ cavity number ≤ 6; no external undercut cavity number = 2 or 3; side core mould
Series layout	$2 \le$ cavity number ≤ 16; cavity number = even number; no external undercut $2 \le$ cavity number ≤ 6; cavity number = even number; side core mould
Symmetry layout	cavity number = power of 2; cavity number ≤ 16; no external undercut cavity number = 2 or 4; side core mould



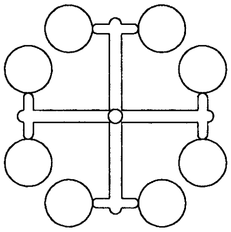
Circular layout



In-line layout



Series layout



Symmetry layout

Table 2. Part of cooling system rules for core insert cooling.

Cooling design [29, 30, 31]	Conditions
Archimedean spiral	Part shape = circular; $D > 150$; $H \le 100$
Circular milled	Part shape = circular; $50 < D \le 150$; $H \le 50$ Part shape = non-circular; $L \le 3\ W$; $50 < W \le 150$; $H \le 50$
Helical channel	Part shape = circular; $D > 150$; $H > 100$ Part shape = non-circular; $L \le 3\ W$; $W > 150$; $H > 100$
Deep chamber	Part shape = circular; $50 < D \le 150$; $H > 50$ Part shape = non-circular; $L \le 3\ W$; $50 < W \le 150$; $H > 50$
Deep core	Part shape = circular; $25 < D \le 50$; $H > 50$ Part shape = non-circular; $L \le 3\ W$; $25 < W \le 50$; $H > 50$
Baffled deep core	Part shape = circular; $10 < D \le 25$; $H > 30$ Part shape = non-circular; $L \le 3\ W$; $10 < W \le 25$; $H > 30$
Baffled hole	Part shape = non-circular; $L > 3\ W$; $W > 50$; $H > 50$
Angle hole	Part shape = non-circular; $L > 3\ W$; $25 < W \le 50$; $H > 50$
Stepped hole	Part shape = non-circular; $L > 3\ W$; $25 < W \le 50$; $H > 50$
U-circuit	Part shape = non-circular; $L > 3\ W$; $W > 50$; $H \le 50$

Here H is the height of the part measured from the parting line. D is the diameter of a circular part. L and W are the length and width of a non-circular part, respectively.

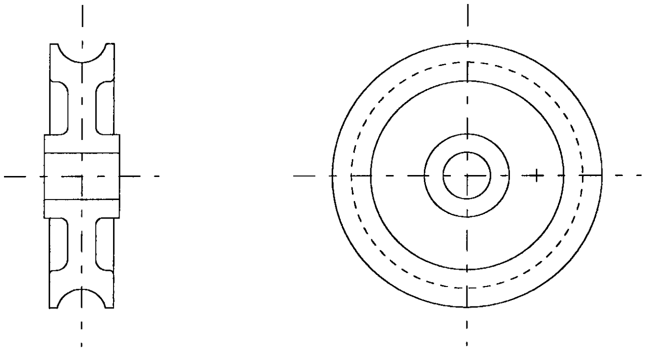


Fig. 4. Part drawing retrieved.

Design Example

Part name	wheel
Dimensions	Ø38 mm × 12 mm(height) × 3 mm(thickness)
Material	nylon
Number of cavity	2
Customer requirement	Kawaguchi K80-I Injection Machine

Major Design Stages

1. The part drawing is drawn or retrieved from the part database as shown in Fig. 4.

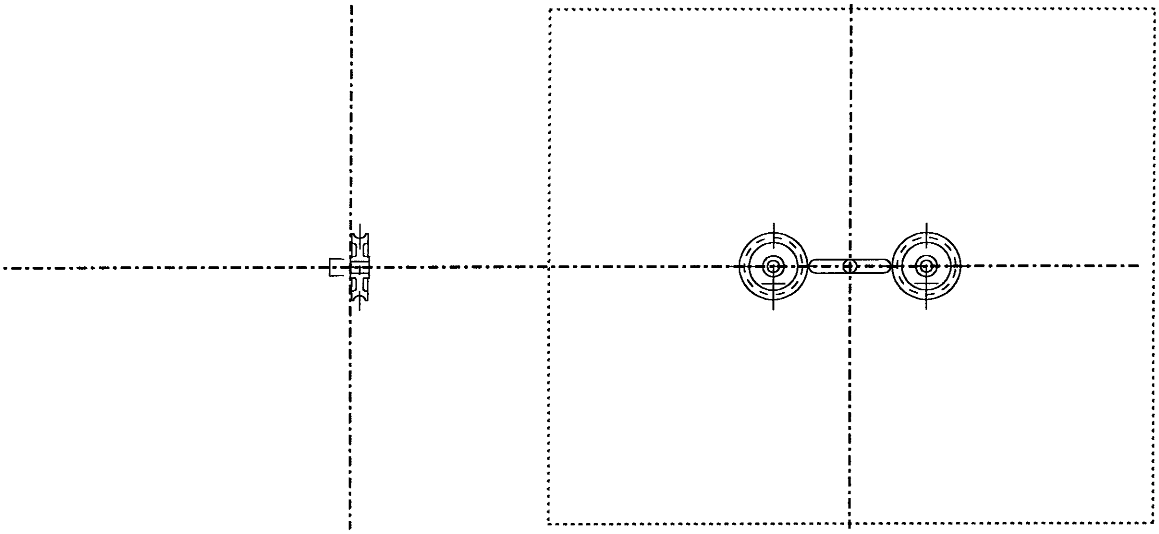


Fig. 5. Feed system completed.

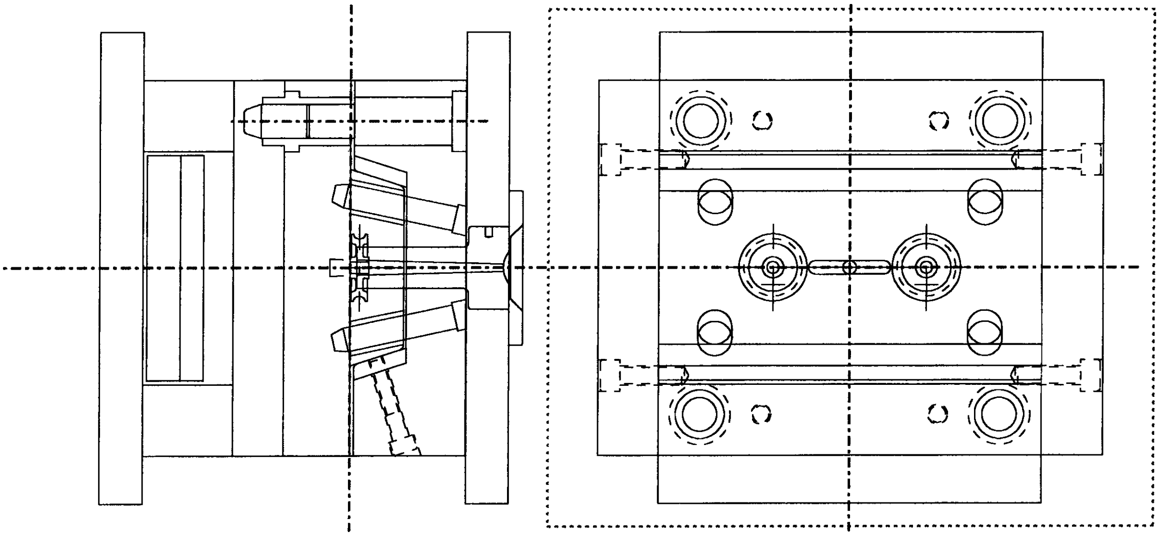


Fig. 6. Mould base construction completed.

2. After answering all the questions concerning the part and customer mould specification, a standard mould base is automatically selected from the mould base database (at present only HASCO mould bases are included in this database) and its dimensions would be displayed for confirmation.
3. The design menu consists of the four basic functional systems designs, i.e. feed system, cooling system, ejection system, and mould construction. First, the designer selects *feed system*. At this moment, the knowledge base of the program sorts out the recommended methods for the design of feed system for this part. Then, the designer has to select one from this sorted list (*edge gate*, *tab gate*, and *fan gate*), in this case he selects *edge gate*. The computational routine of the program would then automatically size the runner and gate. The feed system together with the part are displayed as shown in Fig. 5.
4. Next, the designer selects *mould construction* from the design menu. The knowledge base identified the type of mould needed from the part code, i.e. *sliding-splits* mould design and it also recommends the methods for actuating the sliding splits, i.e. *finger cam*, *dog-leg cam*, and *cam track*. Then, the designer has to select one, in this case he selects *finger cam*. The screen then displays the mould construction for finger cam design, including the whole mould base as shown in Fig. 6.
5. Next the designer chooses *cooling system*. The knowledge base recommends the core/cavity plate cooling design with alternative hardware configurations, i.e. *straight circuit* or *U-circuit*. In this case, the designer selects the former design, and the screen then displays the cooling system in the drawing as shown in Fig. 7.
6. Next, the designer selects *ejection system*. The knowledge base recommends the use of *ejector pins*. After entering the information concerning individual sizes, locations, and orientations, the ejection system is then displayed as shown in Fig. 8. The mould drawing will be reviewed, and modified if necessary. Modifications such as addition of mould inserts, hatching, or dimensionings can then be carried out at this stage, but these can usually be done fairly quickly using the system's CAD facilities.

7. System Testing and Evaluation

A local-based medium-sized mould making factory, Evergreen Mould Factory, was invited to test and evaluate IKMOULD. Evergreen has a plant in Hong Kong and a plant in China. It has a total workforce of about 200. Their main business is to produce plastic injection moulds for the local toy industry. Major customers are local or foreign toy manufacturers and traders in Hong Kong. A limited trial with the new software showed an average saving in design time of 70% compared with drawing board based design. Their mould designers had little trouble understanding the menus, prompts, and answers that are displayed on the computer screen during consultations because of their familiarity with the terms used. They were interested that the knowledge base of the system was accessed by mould designers through interactive programs so that their own intelligence and experience could be incorporated with the total mould design. They also formed the opinion that IKMOULD could be used as a training tool for inexperienced mould designers if used in conjunction with a trained instructor.

Some improvements to the software were found to be necessary. One of these was in accommodating incorrect responses or responses which the designer may subsequently wish to alter. Modifications have been incorporated to detect incorrect responses. Some of the prompts were found to be misleading and these have been amended. Means of exiting from the program and re-entering it are also being improved. Other changes are being made as experience in using the software is gained.

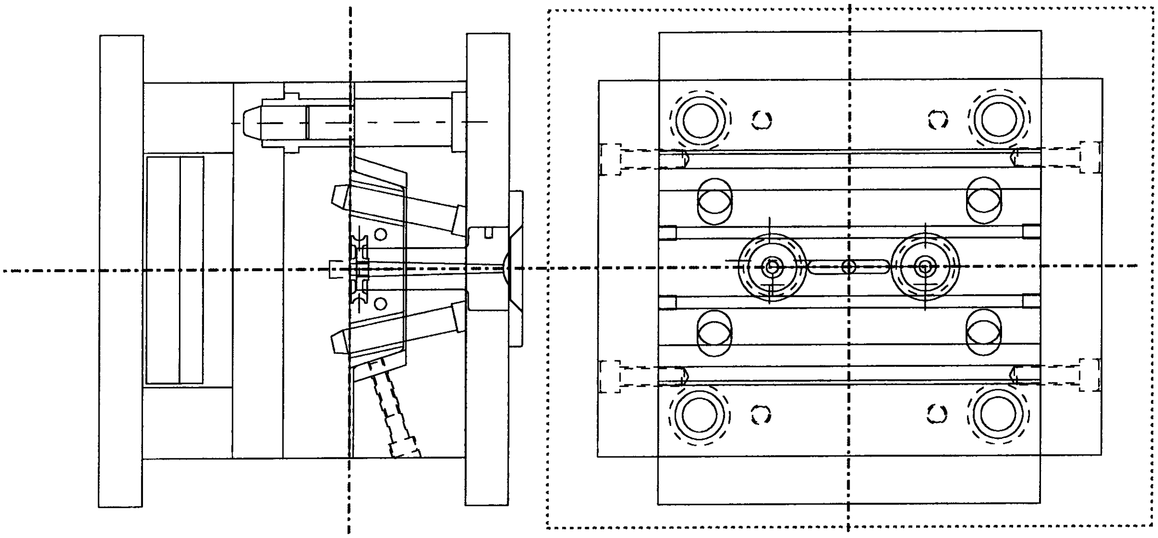


Fig. 7. Cooling system completed.

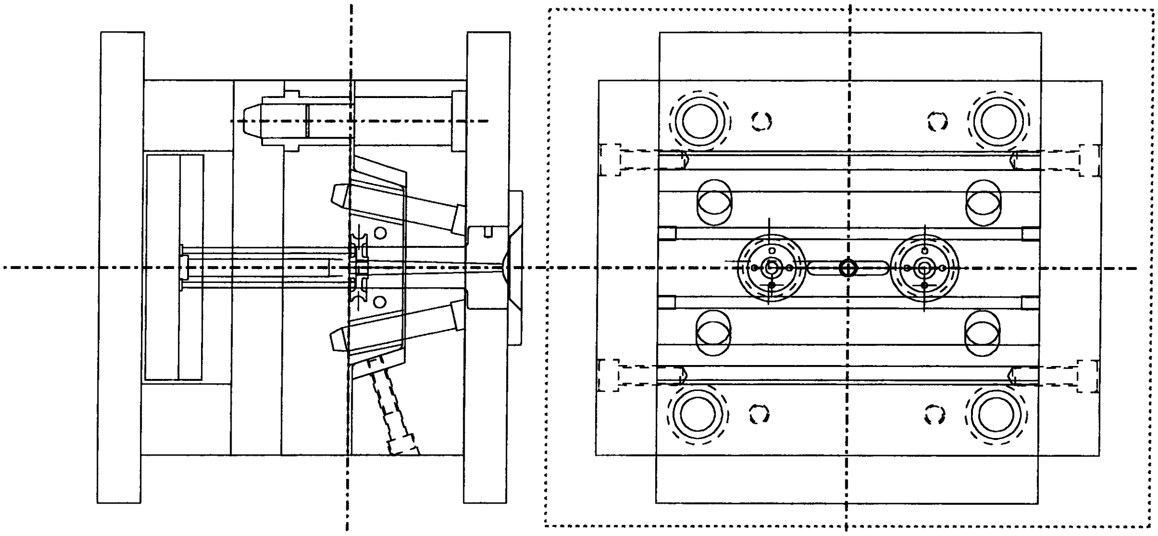


Fig. 8. Whole design completed after ejection system designed.

8. Conclusion

The development of a prototype knowledge-based CAD system for injection mould design has been described in this paper. Mould design generally involves complex and multirelated design problems and thus lacks a complete quantitative and structured approach. The present methodology has involved breaking down the complete design problem into a number of subproblems (functional designs, e.g. feed system, cooling system, etc.) and developing a knowledge base of solutions for the various subproblems. By using a coding system as the mechanism of inference engine, the knowledge base is accessed from an independent interactive program, which aids the designer to select a number of recommended solutions to the particular functional design under consideration. The selection of the actual solutions and their final development into a finished design is left to the mould designer so that their own intelligence and experience could also be incorporated with the total mould design. The content of the knowledge base could also be tailor-made to suit a particular organisation and this would facilitate standardisation which in turn would increase the speed of mould design and manufacture. In the implementation of the methodology, the program was written in a modular structure to facilitate access to the knowledge base and to ensure its further development and extension. The future direction of this research is along two lines, namely: enhancing the "intelligence" of IKMOULD; and extending the system to the mould-making process planning.

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