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An Internet-based intelligent design system for injection moulds

C.K. Mok[a,*], K.S. Chin[a], Hongbo Lan[a,b]

[a]Department of Manufacturing Engineering and Engineering Management, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong
[b]School of Mechanical Engineering, Shandong University, Jinan 250061, China

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Abstract

The rapid growth of Internet and information technologies in recent years provides a solution to support and facilitate collaborative product developments among different geographically distributed enterprises. An effective and feasible tool to aid the collaborative development of injection moulds can be realized by developing an Internet-based mould design system as one of the modules of a collaborative product development system. This paper presents a prototype Internet-based intelligent design system for injection moulds. The architecture of the system consists of an interactive KB mould design system embedded in an Internet environment. A Java-enabled solution together with artificial intelligence techniques is employed to develop such a networked interactive CAD system. In this system, the computational module, the knowledge base module and the graphic module for generating mould features are integrated within an interactive CAD-based framework. The knowledge base of the system would be accessed by mould designers through interactive programs so that their own intelligence and experience could also be incorporated with the total mould design. The approach adopted both speeds up the design process and facilitates design standardization which in turn increases the speed of mould manufacture. A practical case study is presented to illustrate the operations of the Internet-based mould design system.

Keywords: Internet; Knowledge-based expert systems; Injection mould design; Collaboration

1. Introduction

Plastic, which is one of the most versatile in the modern age, is widely used in many products throughout the world. Due to its ability to produce complex-shape plastic parts with good dimensional accuracy and very short cycle times, injection moulding has become the most important process for manufacturing plastic parts in the plastic industry today. However, the current plastics industry is under great pressure, due to the globalization of the market, the short life cycle of product development, increasing product diversity, high demand of product quality. To meet such requirements, it is very important for this trade to adopt various advanced technologies which include information and Internet technology, CAD/CAE/CAM integration technology, concurrent engineering, artificial intelligence, and so on, to effectively aid the development of injection-moulded product.

In injection moulding, the design of a mould is of critical importance for product quality and efficient processing. In most cases, quality of mould is responsible for the economics of the entire process. Injection mould design involves extensive empirical knowledge (heuristic knowledge) about the structure and functions of the components of the mould. Nowadays, mould design faces with increasing deadline pressures and the design itself is predominantly based upon experience of the mould designer. Mould designers are required to possess thorough and broad experience, because detailed decisions require the knowledge of the interaction among various parameters. Unfortunately, it is presently impossible to cover the growing demand for such experienced designers. Therefore, intelligent CAD tools that can assist in the various tasks of the mould design process are very important to the productivity of the mould-making industry.

*Corresponding author. Fax: +852 27888423.
E-mail address: meckmok@cityu.edu.hk (C.K. Mok).

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The growing trend in global manufacturing is to a large extent supported by Internet, information technologies and global marketing. Nowadays, it is common to see that design, manufacturing and final assembly of a product are made in companies located in different parts of the world. The various parties concerned would need to share their expertise and experiences during the product development process. The current progress of Internet and information technologies can provide a solution to support and facilitate collaborative product developments among different geographically distributed enterprises. Developing an Internet-based intelligent mould design system as one of the module of a collaborative product development system can provide an effective and feasible tool to aid the collaborative development of injection moulds in the small- and medium-sized enterprises to satisfy the stringent requirements of nowadays competitive global market.

This paper presents an Internet-based intelligent mould design system using Internet technology and knowledge-based approach. The system can shorten the design cycle of injection mould and can effectively aid the design and development works of injection moulds in the small- and medium-sized enterprises to meet the increasing pressure of the current competitive world market. The rest of the paper is organized as follows. Section 2 gives a brief introduction of injection mould design. Section 3 introduces earlier research works on mould design and related fields. The architecture of the Internet-based mould design system is presented in section 4. The knowledge-based part of the mould design system is described in section 5. Section 6 discusses the development of the system. A practical design case is demonstrated in section 7. Conclusion is made in section 8.

2. Injection mould design

The basic features of an injection mould consist of cavity number and layout, feed system, cooling system, ejection system and mould construction. Fig. 1 shows the general procedure of mould design [1]. It can be seen that how interrelated the conditions are and which boundary and secondary conditions have to be met by the main functions.

A mould design project normally starts with economic considerations, namely the question of how many parts can and should be produced in one mould in one shot in order to meet the delivery date and other requirements. This is followed by consideration of the arrangements of the cavities in the mould frame, which might directly include thoughts on the ease of ejection and subsequently, the connection between mouldings and runners and part quality (number, position and shape of gates). The feed system accommodates the molten plastic material coming from the injection nozzle of the moulding machine and distributes it into each cavity. To remove the heat from the moulding, it is necessary to provide the mould with a cooling system. After the moulding has solidified and cooled down, it has to be removed from the mould by the ejection system. Mould is normally constructed by stacking several metal plates to form a rigid body. It has to house various mould components in correct positions for the proper functioning of the mould. Mould construction normally involves the selection of mould bases and standard mould parts. For complicated plastic parts, some other mechanisms such as slides, unscrewing device, etc., might also be involved in the whole mould structure.

3. Related research

A number of research activities have been carried out on mould design and its related field over the years using computer-aided techniques. These research activities range from studying specific areas of mould design to investigating mould design as a whole integrated system. They can broadly be classified into three areas: the functional and initial mould designs; the algorithms to automate mould generation; and system development of mould design.

Hui and Tan [2] presented a heuristic search approach based on sweep operations to develop automated mould design systems for determining parting direction, parting line, side core, etc. Huang et al. [3] used solid modelling techniques to build mould plates and library of standard mould components. Chen and Liu [4] have developed a cost model, which depicts the relationships between cost factors and product development activities as well as their relationships with product geometry, for cost-effectiveness design for injection moulding. Fu et al. [5] proposed an efficient methodology which systematically presents the undercut feature definition, classification, undercut feature parameters, and the recognition criteria of all types of undercut features for undercut feature recognition in an injection mould design system. Chen et al. [6] presented a method for determination of parting direction based on dexel model and fuzzy decision-making. Li JC [7] presented a neural network approach for modelling and optimization of injection mould gate parameters. Li CL [8] used a feature-based approach to design the cooling system of injection moulds. Chung and Lee [9] proposed a framework of collaborative design environment for injection moulding in which geographically distributed, multi-disciplinary designers can collaborate with one another. Ma et al. [10] described the development of a standard component library for plastic injection mould design using an object-oriented approach. Low and Lee [11] introduced a methodology of providing the initial design in 3D solid model instead of 2D drawings using the standardization method. Ashaab et al. [12] described a supporting plastic engineering development system to facilitate the sharing of injection moulding information and knowledge between interested parties via the Internet for the collaborative design of injection mould. Li et al. [13] used graph-based technique and developed a heuristic search algorithm to automate the layout design of plastic injection mould cooling system.

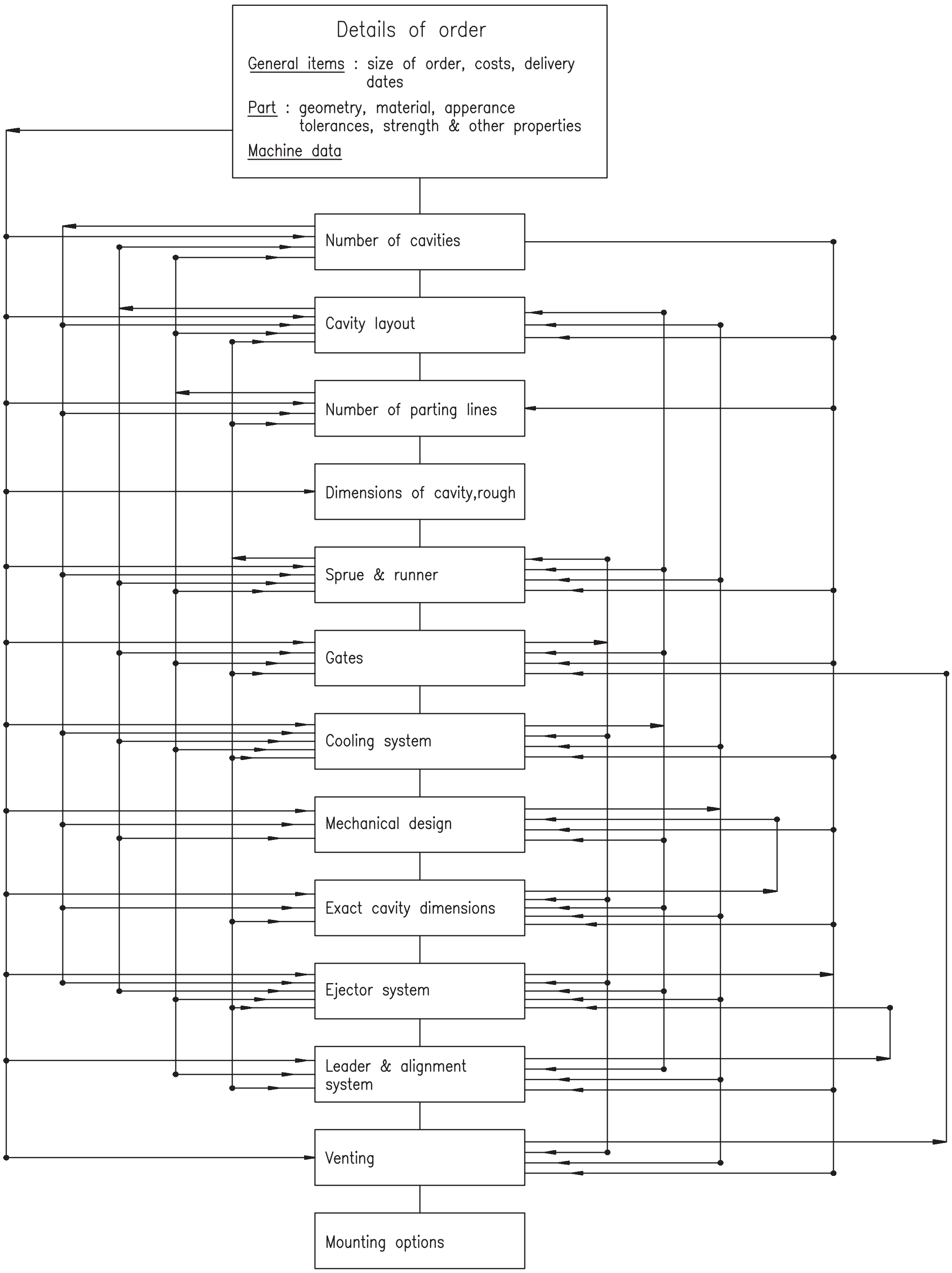


Fig. 1. The general procedure of mould design [1].

Researchers have started to adopt a knowledge-based approach to solve the injection moulding and mould design problems in recent years. DTMOULD-1 [14] is a KBS for of injection moulds cost estimation. EIMPPLAN-1 [15] incorporated mouldability considerations into part designs and addressed the conceptual design development of injection-moulded parts. CADFEED [16] was 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. Bozdana and Eyercioglu [17] developed an expert system for the determination of injection moulding parameters of thermoplastic materials. Chan et al. [18] presented the basic structure of a CAD knowledge-based assisted injection mould design system which covers both the mould design process and mould knowledge management.

From the above review it can be seen that most of the previous work consider only certain aspects of the total design and some of them are too theoretical to be applied for practical mould design which involves a substantial practical knowledge component about functions and structure of a mould, human heuristic knowledge and empirical type of knowledge. The KB system has demonstrated great potential to assist the designer to interact with a CAD system for conceptualized design as well as the final engineering design of a mould by using engineering rules of thumb with extensive analytical means. In addition, there is still relatively few research works on Internet-based intelligent system for injection mould design.

4. Architecture of the Internet-based mould design system

4.1. Overview

At the present time, most CAD systems provide only the geometric modelling functions which facilitate the drafting operations of mould design, and do not provide mould designers with necessary knowledge to develop good mould designs. Conventional computer-aided engineering packages are usually good at data processing for information-intensive problems or at number manipulation for formulation-intensive problems. The former comprehends the computer-aided drafting and graphics, and data reduction and transformation; while the latter involves numerical (or mathematical) modelling and analysis. However, in design problem, especially in mould design which involves a substantial practical knowledge component about functions and structure of a mould, human heuristic knowledge and empirical type of knowledge are needed in addition to the information-intensive and formulation-intensive knowledge. Therefore, conventional computer-aided design technology is unsuitable for processing heuristic and empirical type of knowledge which is critical in the mould design problems. In general, the major advantage of the KB system for mould design over conventional computer-aided design systems is the explicit representation and manipulation of a body of knowledge, representing the human expertise.

An Internet-based mould design system using Internet technology and knowledge-based approach can provide an effective and feasible tool to aid the collaborative development of injection moulds in the small- and medium-sized enterprises to satisfy the stringent requirements of nowadays competitive global market. Moreover, there is a consistent need to check and update the information to ensure that the data is accurate and updated as mould manufacturers and standard components suppliers continually improve and upgrade their equipments and processes. By taking full advantage of the fast evolving computer network and information technologies, an Internet-based mould design system could have the ability to continually update and upgrade the large amount of information related to injection mould design in a prompt and convenient manner.

4.2. System architecture

Based on the practical mould design procedures and the issues to be considered in this stage, the architecture of an Internet-based intelligent injection mould design system is proposed as shown in Fig. 2. It consists of a

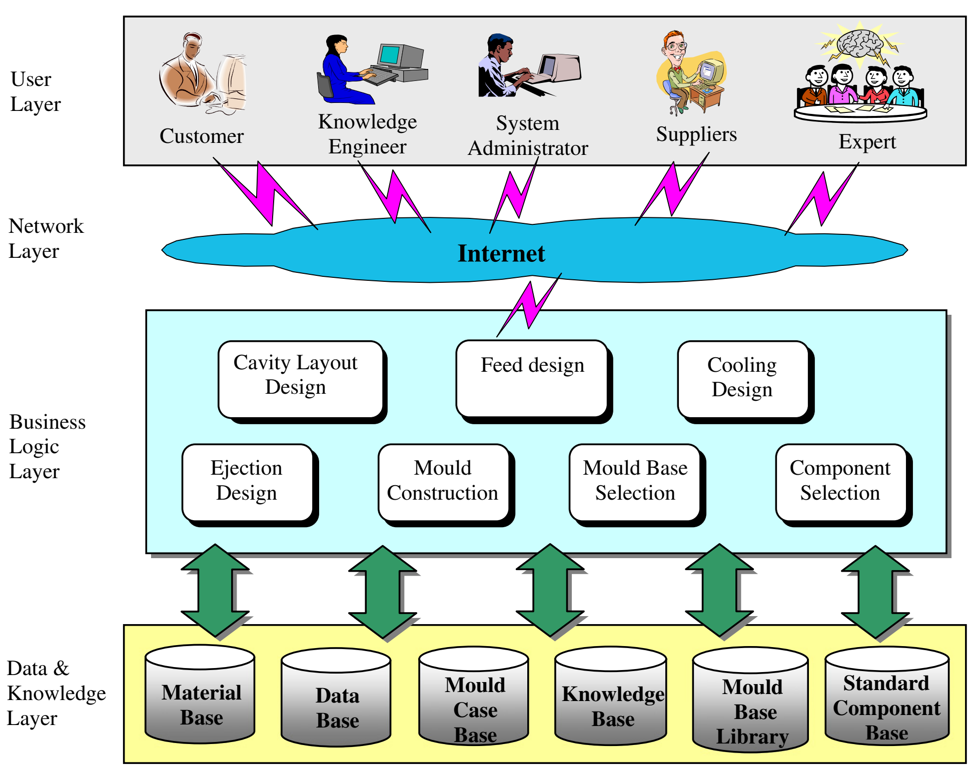


Fig. 2. Architecture of the Internet-based mould design system.

knowledge-based mould design system embedded in an Internet-based environment. Mould design generally involves complex and multi-related 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 sub-problems (functional designs, e.g. feed system, cooling system, etc.) and developing a knowledge base of solutions for the various sub-problems. All design activities are organized in seven functional modules, namely, cavity layout design, feed design, cooling design, ejection design, mould construction, mould base selection and standard components selection. These modules are used to generate the functional designs including cavity layout, feed design, cooling circuit, ejection devices, mould construction and to select the standard mould base and ancillary components including register rings, guide bushes, guide pillars, fasteners, etc.

5. The knowledge-based mould design system

The knowledge-based part of the Internet-based mould design system is shown in Fig. 3. By using a coding system as the mechanism of inference engine, the knowledge base

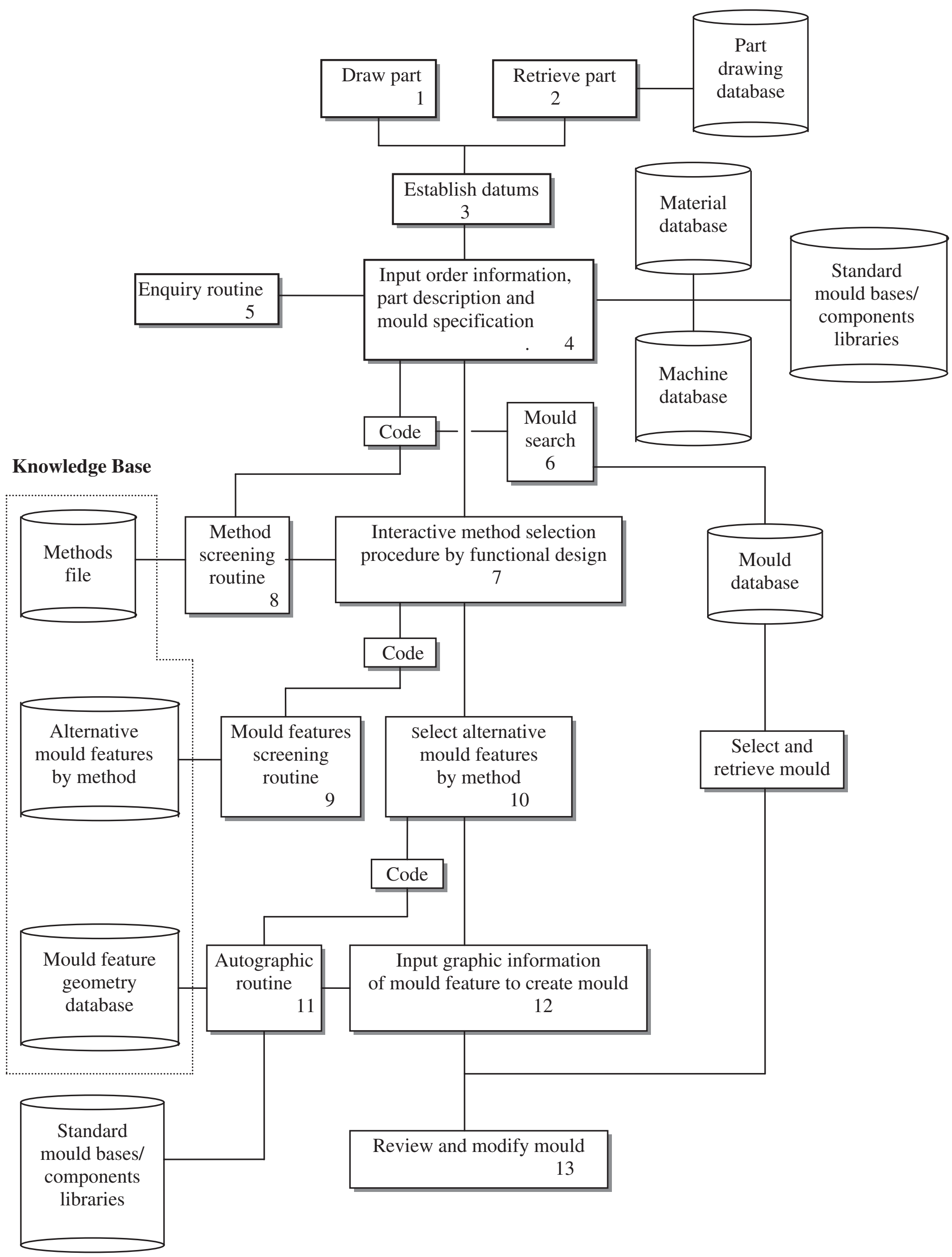


Fig. 3. The interactive design procedure of the KB system.

is accessed from independent interactive programme, 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 detailed operations of the system are described as follows.

Firstly, a remote user in the client side submits the plastic part which may be drawn or retrieved from the part drawing database and its requirements to the server side. Then an enquiry routine (block 5) selects which questions to put forward 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 answering all the questions, the system would create a coded description of the part and the mould. The use of the code is two-fold. Firstly 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 whether they are suitable for use. It is normally required to modify existing moulds to tune them up to a different part but this can usually be done fairly quickly using the system's 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 of achieving the various functional designs of an injection mould. Since only some of these methods are applicable to the particular part under consideration, thus it is necessary to filter out the possible list of methods to be posed to the designer for his selection. This task is now done by the method screening routine (block 8) which uses the part code to select the recommended list of methods. Once method has been selected a code associated with each chosen method would be generated. It is quite often that one method has alternative mould features (hardware arrangements). The code associated with the chosen method is then used to access and pose 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). By separating the fundamental methods from their technical details in the present procedure would guide the designer to focus on basic methods before dealing with their implementation. This logical approach would also speed up the design process by reducing the variety of choices. When particular mould feature of chosen method has been selected, a code associated with each mould feature would be produced and is then used to access and prompt the designer to input information concerning individual dimensions, position and orientation from the knowledge base of mould feature geometry through the autographic routine. In the knowledge base of mould feature geometry, the detailed dimensions of the geometry of all the mould features are stored in terms of parameters. Once the graphic information has been inputted, the geometry of the chosen mould feature would be drawn. Afterwards the designer then proceeds to the design of another functional design through similar procedure as mentioned above. When all the functional designs have been completed, a complete drawing would be generated. Finally all the designer has to do is to review and modify the mould drawing if necessary.

5.1. The coding system

The code is a coded representation of all necessary information about the plastic part such as shape, undercut features, material and other specifications. In designing the coding system considerations have been made 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 indefinitely. 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 [19] 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 12 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.

5.1.1. 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.

5.1.1.1. 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 $H/D \leqslant 0.5$.
(2) Circular part with $0.5 < H/D < 3$.
(3) Circular part with $H/D \geqslant 3$.
(4) Variational circular part.
(5) Non-circular part with $H/\mathrm{De} \leqslant 0.5$.
(6) Non-circular part with $0.5 < H/\mathrm{De} < 3$.
(7) Non-circular part with $H/\mathrm{De} \geqslant 3$.

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 ($\text{De} = \sqrt{(4LW/\pi)}$). Parts belong to Class 1 and Class 3 are like flat discs and long cylinders respectively. Parts belonging to Class 5 and Class 7 are like flats and long prisms, respectively.

5.1.1.2. Part external shape. The second digit depends on which class the part belongs 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.

5.1.1.3. Undercut feature. Mould designers are frequently encountered 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 products 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.

5.1.1.4. Material class. Plastic material used for moulding the part is classified according to its material constant n [20]. There are four positions for the fourth digit.

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

5.1.2. The second section: the relationship between the part and the mould

This section consists of only one digit—the fifth digit. It describes the relation between the directions of the part axis and the mould parting line and is classified as below.

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

5.1.3. The third section: mould description

This section contains the last seven digits, i.e. the sixth to the 12th digits. It represents the mould specifications in terms of number of cavities, mould design features, etc.

5.1.3.1. Number of cavities. There are nine positions for the sixth digit.

Position	1	2	3	4	5	6	7	8	9
No. of cavities	1	2	3–5	6	8	10	12	14	16

5.1.3.2. External undercut release mechanism. There are three positions for the seventh digit.

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

5.1.3.3. Internal undercut release mechanism. There are three positions for the eighth digit.

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

5.1.3.4. Runner system. There are four positions for the ninth digit.

(1) Cold runner.
(2) Insulated runner.

(3) Insulated hot runner.
(4) Hot manifold.

5.1.3.5. Gating system. There are eight positions for the 10th digit.

(1) Sprue gate.
(2) Edge gate.
(3) Submarine gate.
(4) Pinpoint gate.
(5) Tab gate.
(6) Fan gate.
(7) Film gate.
(8) Diaphragm gate.

5.1.3.6. Cooling system. There are five positions for the 11th digit.

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

5.1.3.7. Ejection system. There are four positions for the 12th digit.

(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. The coded representation of all necessary information about a plastic part together with its respective plastic mould is illustrated in Fig. 4.

5.2. The knowledge base

The knowledge base in this system was acquired from a literature search and from a number of mould making companies. There are a number of useful injection mould design and mould-making rules as well as technical data in the technical papers, handbooks and trade standards. The expert knowledge and empirical rules were also collected through interviews and case discussions with the experts of some local companies. The scope of knowledge covers the most widely used methods and elements of mould features for the main functional design modules for standard two-plate moulds, stripper moulds, split moulds and three-plate moulds.

The internal structure of the knowledge base consists of three parts namely the methods file, the alternative mould features by method database and mould feature geometry database. The methods file contains a long list of methods of achieving the various functional designs of an injection mould. The method screening routine (block 8 in Fig. 3) uses the part code to select the recommended list of methods. Once method has been selected a code associated with each chosen method would be generated and is then used to access the alternative mould features of the chosen method through the mould feature screening routine (block 9 in Fig. 3). When particular mould feature of chosen method has been selected, a code associated with each mould feature would be produced and is then used to access and prompt the designer to input information concerning individual dimensions, position and orientation from the mould feature geometry database through the autographic routine (Fig. 3). In the mould feature geometry database, the detailed dimensions of the geometry of all the mould features are stored in terms of parameters. Once the graphic information has been inputted, the geometry of the chosen mould feature would be drawn. The schematic representation of the internal structure of the KB is illustrated in Fig. 5.

A rule-based knowledge-representation method was used to develop the knowledge base. This method is the most popular and versatile of all the representation schemes. Knowledge is represented in the form of production rules. Rules are written as IF-THEN statements to provide a formal way of representing strategies, directives and recommendations. This scheme is appropriate for a variety of KB systems problem domains. More than 500 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, the rules for the cavity layout and part of the rules for the cooling system are shown in Tables 1 and 2, respectively.

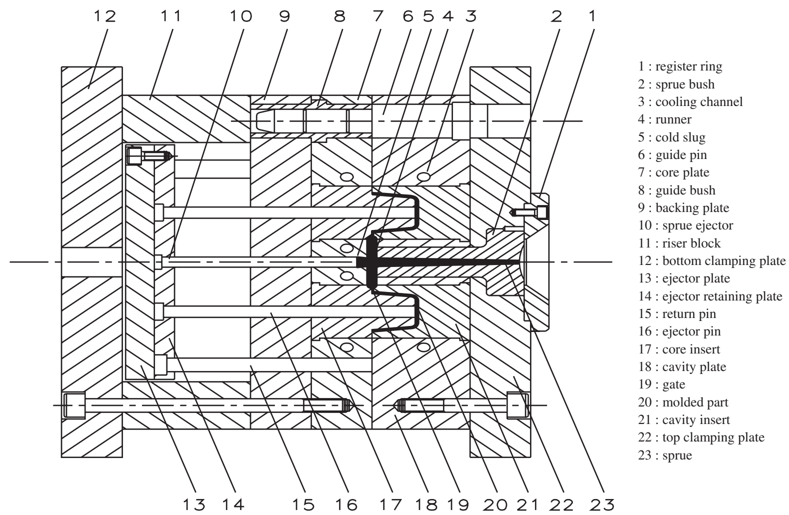
The JESS 4.4 expert system shell [22–24] was selected to develop the knowledge base of the Internet-based mould design system. JESS is a forward chaining production system implemented in the Java programming language. Rules are written in CLIPS/JESS language, which can easily call and be called by Java programs. The programme for the knowledge base was written in modular structure consisting of the five basic functional systems of injection mould design, namely cavity layout, feed system, mould construction, cooling system, and ejection system. The capability of the knowledge base can be further expanded through continual refinements in the rules and databases of the system. Using the system's editing facilities, it is fairly easy to add and delete rules in the knowledge base. In addition, the assignments and combinations of certainty factors can be added, and user queries can also be added or deleted where it seems appropriate.

6. System implementation

A prototype system has been implemented based on J2EE. This system is combined with a commercial 3D

Part Name: Circular cover

Mould



	Description	**Code**
Part class	Circular part with 0.5 < H/D < 3	2
Part external shape	Smooth, having a uniform diameter along the entire height	1
Undercut feature	No undercut	1
Material class	Material constant = 0.8	3
Relationship: part and mould	Part axis is perpendicular to the mould parting line	1
No. of cavity	4	3
External undercut release mechanism	0	0
Internal undercut release mechanism	0	0
Runner system	Cold runner	1
Gating system	Edge gate	2
Cooling system	1	1
Ejection system	Ejector pins	1

Code = 211313001211

Fig. 4. The coded representation of a circular cover and its mould.

CAD system (SolidWorks 2003) and a commercial database (Microsoft Access 2000). As mentioned in Section 5.2, the JESS 4.4 expert system shell was used to develop the knowledge base of the system. The programme was written in JSP/Servlets and the SolidWorks API (Application Programming Interface). The SolidWorks application programming interface (API) is an OLE programming interface to SolidWorks. The API contains hundreds of functions that can be called from Visual Basic, VBA, C, C++, or SolidWorks macro files. These functions provide the programmer with direct access to SolidWorks functionality such as creating a line, extruding a boss, or verifying the parameters of a surface [25,26]. Java Server Pages (JSP) is a better solution in generating dynamic web pages in contrast to Active Server Pages (ASP), Person Home Pages (PHP), and Common Gateway Interface (CGI). JSP together with Servlets provide an attractive alternative to other types of dynamic web scripting/programming that offers platform independence, enhanced performance, separation of logic from display, ease of administration, and ease of use. Nowadays, there are a lot of database management systems available in the commercial market such as Oracle, Sybase, MySQL, and Informix. Microsoft Access 2000 was adopted for reasons of ease of use and better-cost performance.

7. Design case study

In order to have a more detailed understanding of the operations of the Internet-based intelligent mould design

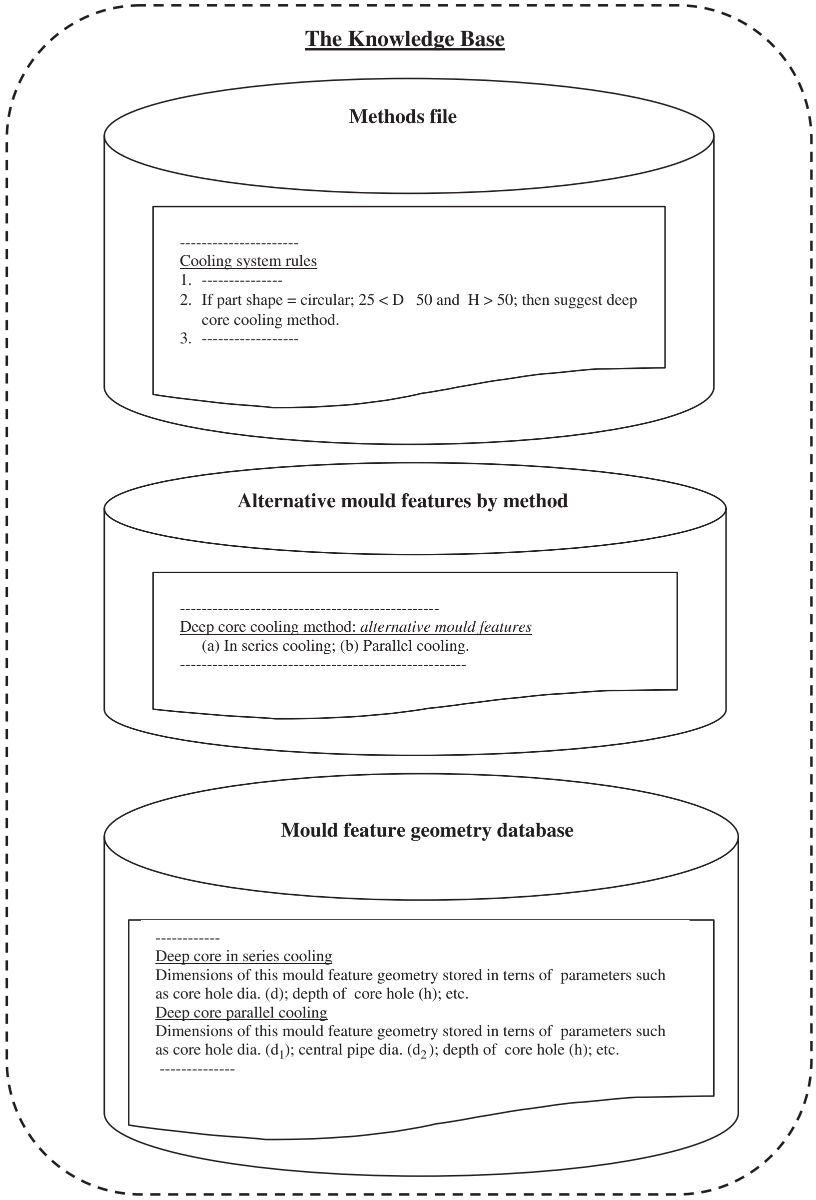


Fig. 5. The schematic representation of the internal structure of the KB.

Table 1
Rules for cavity layout [20,21]

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

Table 2
Part of cooling system rules for core insert cooling [20,21]

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

system, it is better to go through a real design study with this prototype package. From experience in using this programme 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. The design example is a mouse whose 3D CAD model is shown in Fig. 6. It is made of acrylonitrile butadiene styrene (ABS). The size of the part is 96 mm (length) × 68 mm (width) × 27 mm (height), and the wall thickness is 2 mm. According to the customer requirements, a mould with four cavities is required and is to be operated in a Kawaguchi K180-I injection machine. As it would be too lengthy to list out all the steps involved in carrying out such design exercise here, a summary of the major actions of this design example is presented in the following paragraphs.

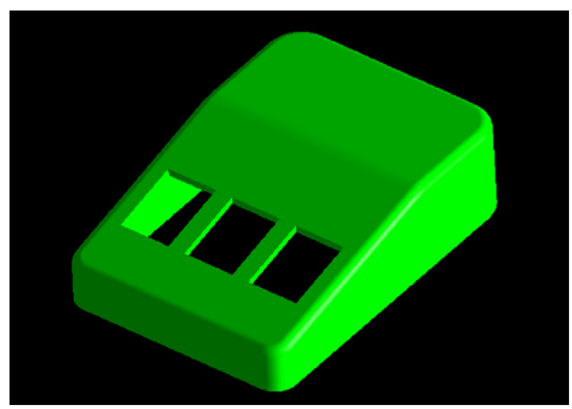


Fig. 6. The test part.

1 Firstly, a remote user in the client side submits the CAD file of the mouse part which may be drawn or retrieved from the part drawing database and its requirements to the server side.
2 After answering all the questions concerning the part and customer mould specifications, a standard mould base is now 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 eight basic functions, i.e. File, Edit, View, Modeling, Pre-design, Application (cavity layout design, feed design, cooling design, ejection design and mould construction, etc), Collaboration, and Help. At this stage, the designer has to select the cavity layout design function according to the general mould design procedure. The knowledge base of the programme suggests a symmetry cavity layout. The designer then designs the cavity and core inserts around the cavity layout using the system's CAD facilities. Next the designer selects feed system function. At this moment, the knowledge base would sort 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 programme would then automatically size the runner and gate. The cavity layout, the core inserts and the feed system are displayed as shown in Fig. 7.
4 Next, the designer selects mould construction from the design menu. The knowledge base already identified the type of mould needed from the part code, i.e. a

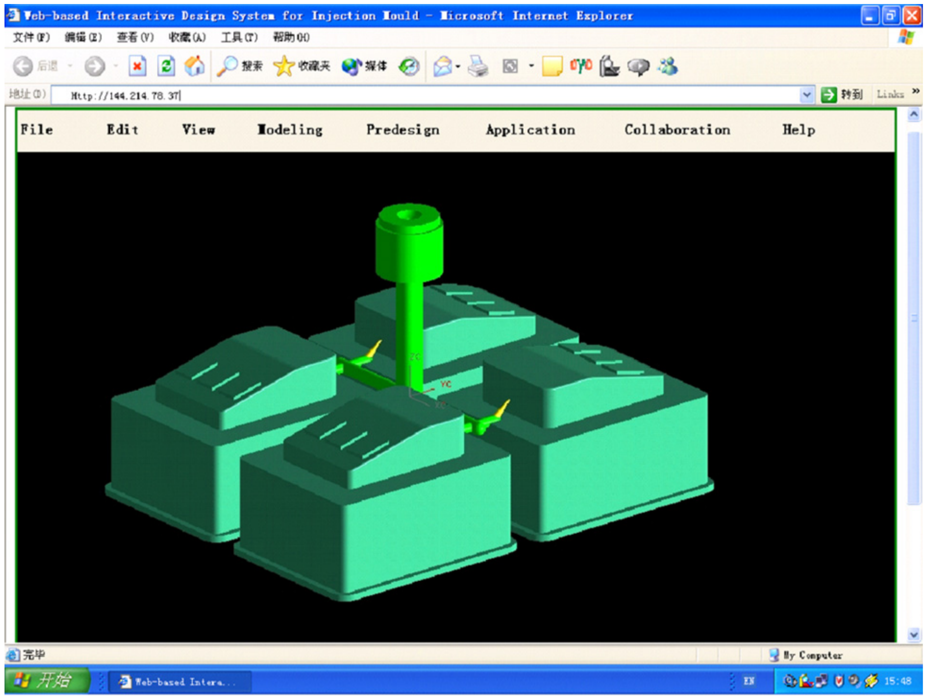


Fig. 7. The cavity layout, the core inserts and the feed system.

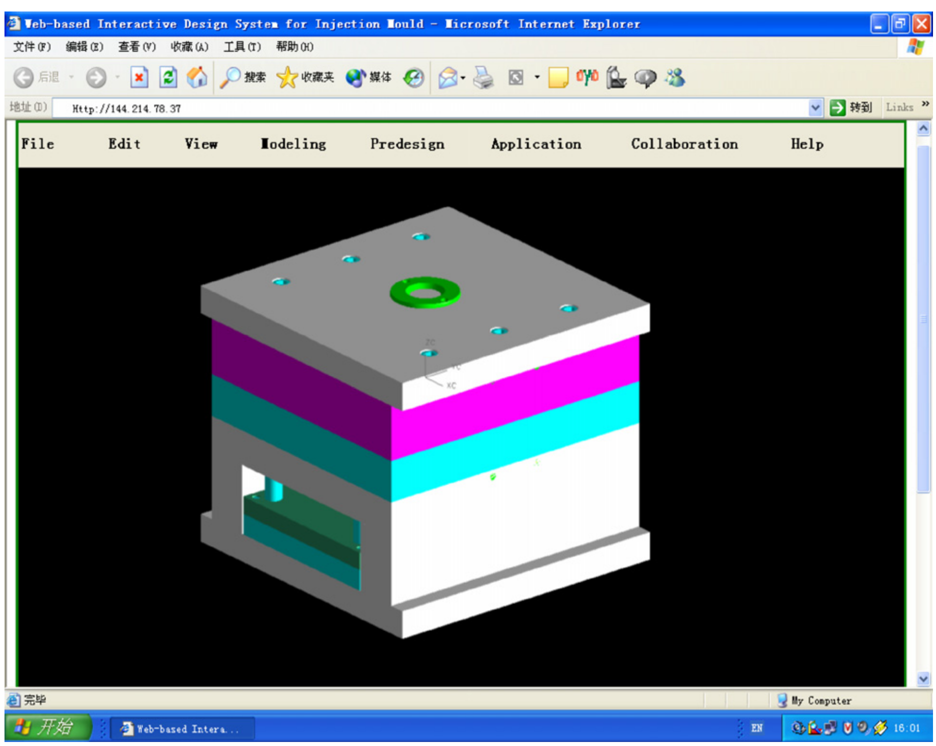


Fig. 8. The detailed design of the mould base.

two-plate mould. The screen would then display the whole mould base as shown in Fig. 8.

5 Next the designer chooses cooling system. The knowledge base recommends the core and cavity cooling design with U-circuit. The screen then displays the cooling system in the drawing as shown in Fig. 9.

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. 10. The remaining job will be to review and modify the mould drawing if found necessary.

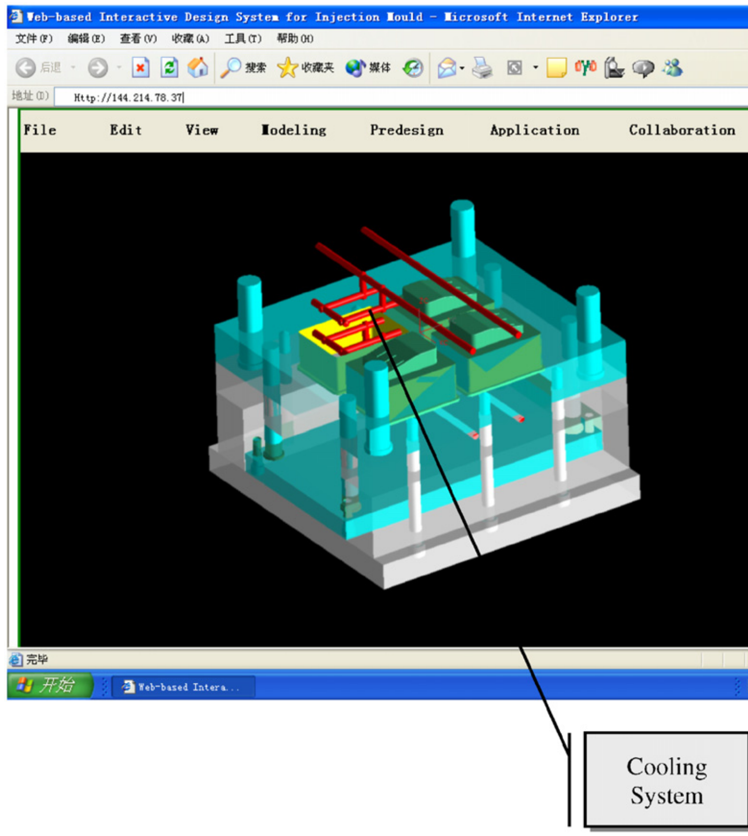


Fig. 9. The detailed design of the cooling system.

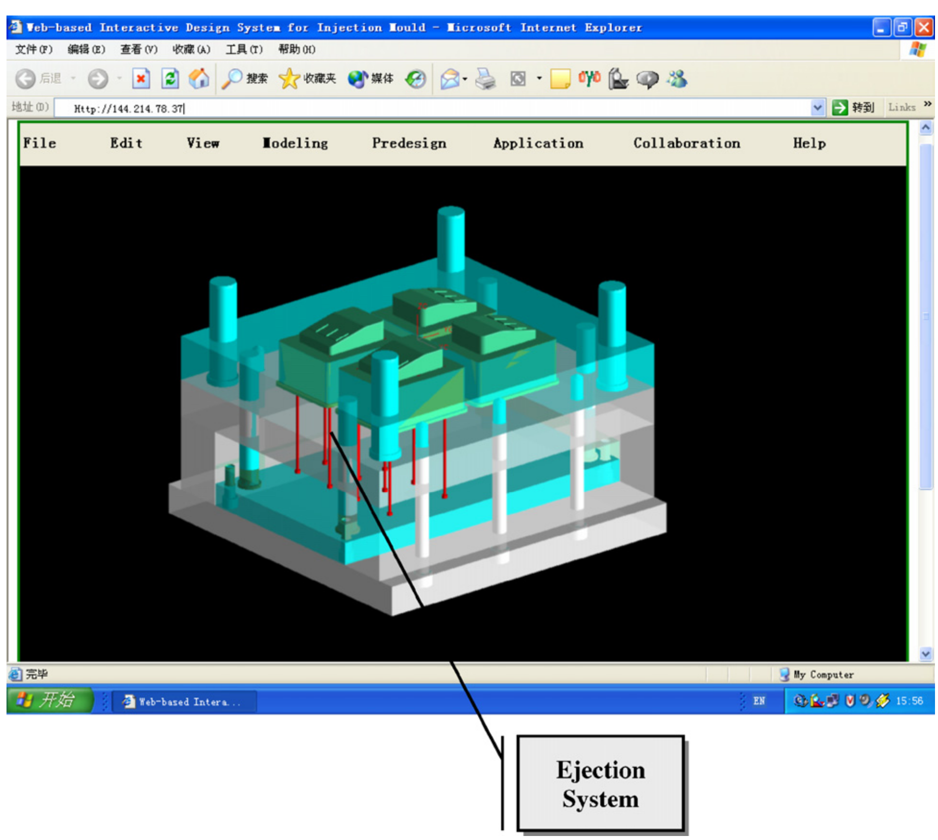


Fig. 10. The detailed design of the ejection system.

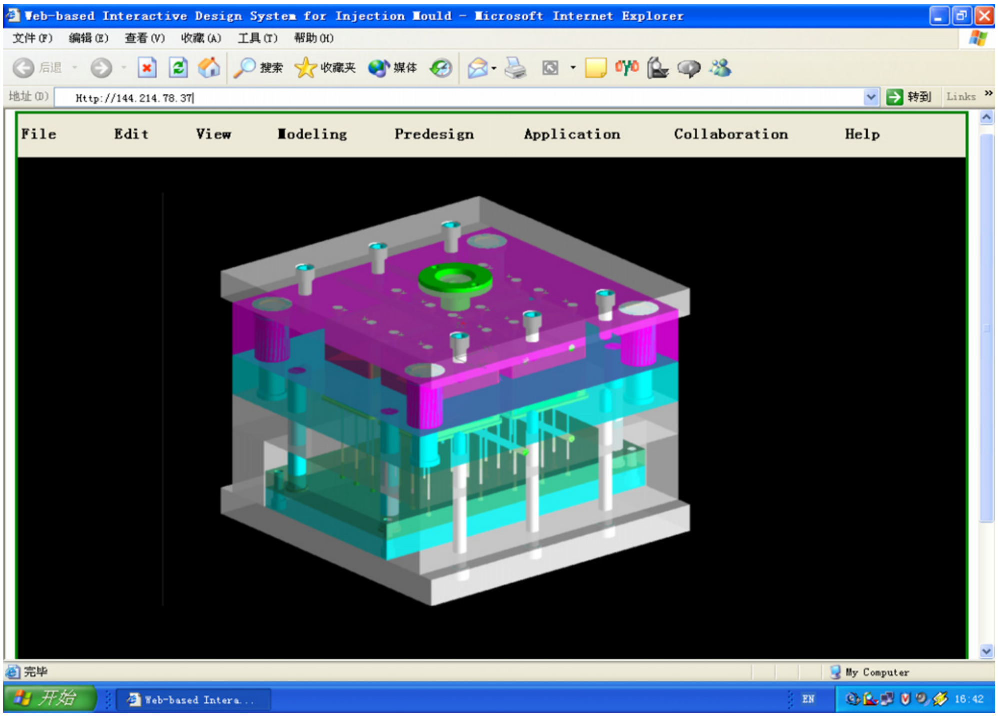


Fig. 11. The finished injection mould for the mouse part.

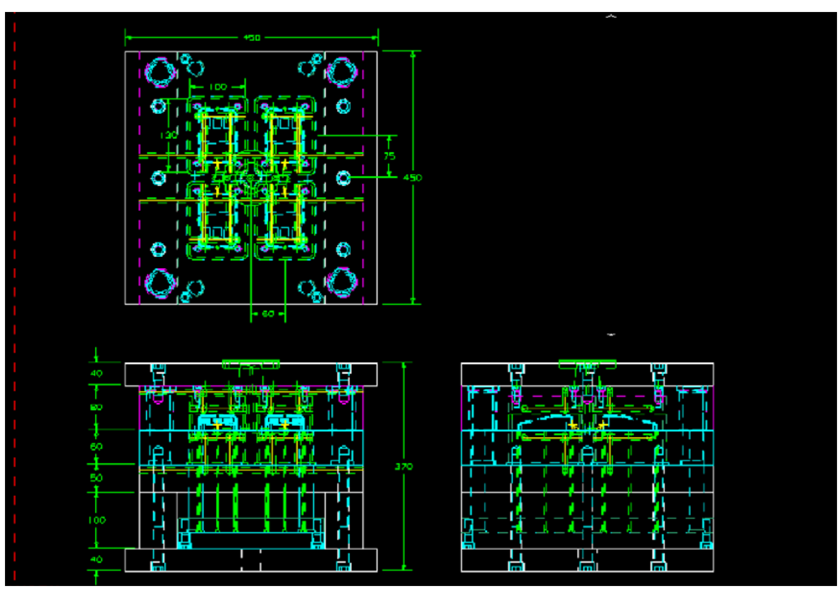


Fig. 12. The 2D engineering drawings of the mould.

Modifications such as hatching, addition of dimensions, etc. can then be done at this stage, but these can usually be done fairly quickly using the system's CAD facilities.

The 3D CAD model of the complete injection mould is illustrated in Fig. 11. Finally, its 2D CAD engineering drawings can also be generated as shown in Fig. 12.

8. Conclusion

The development of a prototype Internet-based intelligent system for injection mould design has been described in this paper. The architecture of the system consists of an interactive KB mould design system embedded in an Internet environment. A Java-enabled solution together with artificial intelligence techniques is employed to develop such a networked interactive CAD system. Mould design generally involves complex and multi-related 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 sub-problems (functional designs, e.g. feed system, cooling system, etc.) and developing a knowledge base of solutions for the various sub-problems. By using a coding system as the mechanism of inference engine, the knowledge base is accessed from 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. In the implementation of the methodology, the program was written in modular structure to facilitate access to the knowledge base and to ensure its further development and extension. The approach adopted both speeds up the design process and facilitates design standardization which in turn increases the speed of mould manufacture. The system can be incorporated as one of the modules of a collaborative product development system to provide an effective and feasible tool to aid the collaborative design and development works of injection moulds in the small- and medium-sized industries to satisfy the stringent requirements of nowadays competitive global market.

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