Int J Adv Manuf Technol (2003) 21:807–819
Ownership and Copyright

The International Journal of
Advanced Manufacturing Technology

A Parametric-Controlled Cavity Layout Design System for a Plastic Injection Mould

M. L. H. Low and K. S. Lee
Department of Mechanical Engineering, National University of Singapore, Singapore

Today, the time-to-market for plastic products is becoming shorter, thus the lead time available for making the injection mould is decreasing. There is potential for timesaving in the mould design stage because a design process that is repeatable for every mould design can be standardised. This paper presents a methodology for designing the cavity layout for plastic injection moulds by controlling the geometrical parameters using a standardisation template. The standardisation template for the cavity layout design consists of the configurations for the possible layouts. Each configuration of the layout design has its own layout design table of all the geometrical parameters. This standardisation template is pre-defined at the layout design level of the mould assembly design. This ensures that the required configuration can be loaded into the mould assembly design very quickly, without the need to redesign the layout. This makes it useful in technical discussions between the product designers and mould designers prior to the manufacture of the mould. Changes can be made to the 3D cavity layout design immediately during the discussions, thus saving time and avoiding miscommunication. This standardisation template for the cavity layout design can be customised easily for each mould making company to their own standards.

Keywords: Cavity layout design; Geometrical parameters; Mould assembly; Plastic injection mould design; Standardisation template

1. Introduction

Plastic injection moulding is a common method for the mass production of plastic parts with good tolerances. There are two main items that are required for plastic injection moulding. They are the injection-moulding machine and the injection mould. The injection-moulding machine has the mould mounted on it and provides the mechanism for molten plastic transfer from the machine to the mould, clamping the mould by the application of pressure and the ejection of the formed plastic part. The injection mould is a tool for transforming the molten plastic into the final shape and dimensional details of the plastic part. Today, as the time-to-market for plastic parts is becoming shorter, it is essential to produce the injection mould in a shorter time.

Much work had been done on applying computer technologies to injection mould design and the related field. Knowledge-based systems (KBS) such as IMOLD [1,2], IKMOULD [3], ESMOLD [4], the KBS of the National Cheng Kang University, Taiwan [5], the KBS of Drexel University [6], etc. were developed for injection mould design. Systems such as HyperQ/Plastic [7], CIMP [8], FIT [9], etc. are developed for the selection of plastic materials using a knowledge-based approach. Techniques have also been developed for parting design in injection moulding [10–12].

It has been observed that although mould-making industries are using 3D CAD software for mould design, much time is wasted in going through the same design processes for every project. There is great potential for timesaving at the mould design stage if the repeatable design processes can be standardised to avoid routine tasks. A well-organised hierarchical design tree in the mould assembly is also an important factor [13,14]. However, little work has been done in controlling the parameters in the cavity layout design; thus this area will be our main focus. Although there are many ways of designing the cavity layout [15,16], mould designers tend to use only conventional designs, thus there is a need to apply standardisation at the cavity layout design level.

This paper presents a methodology for designing the cavity layout for plastic injection moulds by controlling the parameters based on a standardisation template. First, a well-organised mould assembly hierarchy design tree had to be established. Then, the classification of the cavity layout configuration had to be made to differentiate between those with standard configurations and those with non-standard configurations. The standard configurations will be listed in a configuration database and each configuration has its own layout design table that controls its own geometrical parameters. This standardisation

Correspondence and offprint requests to: K. S. Lee, Department of Mechanical Engineering, National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260. E-mail address: mpeleeks@nus.edu.sg
Received 8 January 2002
Accepted 16 April 2002

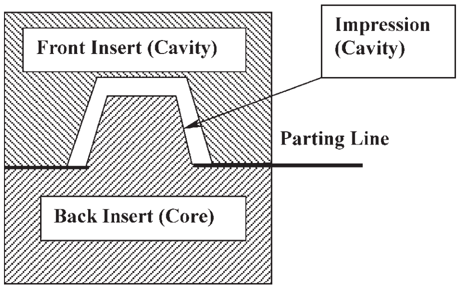


Fig. 1. Front insert (cavity) and back insert (core).

template is pre-defined at the layout design level of the mould assembly design.

2. Cavity Layout Design for a Plastic Injection Mould

An injection mould is a tool for transforming molten plastic into the final shape and dimensional details of a plastic part. Thus, a mould contains an inverse impression of the final part. Most of the moulds are built up of two halves: the front insert and the back insert. In certain mould-making industries, the front insert is also known as the cavity and the back insert is known as the core. Figure 1 shows a front insert (cavity) and a back insert (core). Molten plastic is injected into the impression to fill it. Solidification of the molten plastic then forms the part. Figure 2 shows a simple two-plate mould assembly.

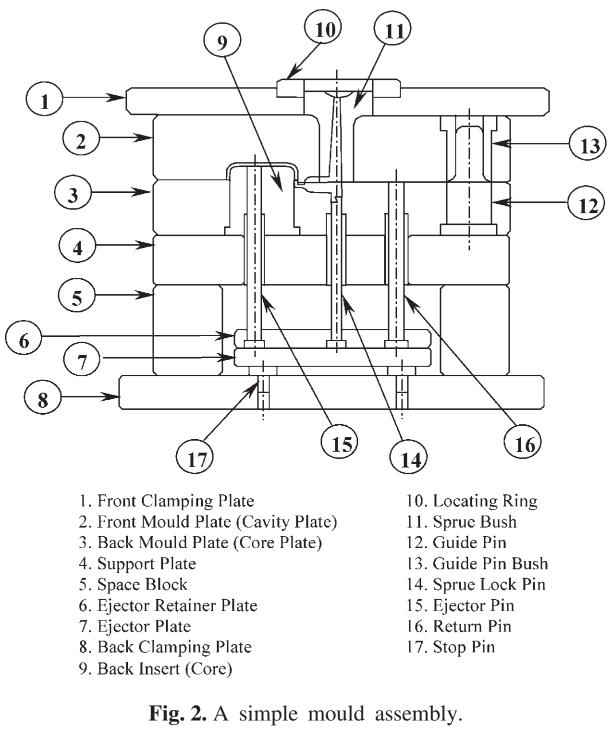


Fig. 2. A simple mould assembly.

2.1 Difference Between a Single-Cavity and a Multi-Cavity Mould

Very often, the impression in which molten plastic is being filled is also called the cavity. The arrangement of the cavities is called the cavity layout. When a mould contains more than one cavity, it is referred to as a multi-cavity mould. Figures 3(*a*) and 3(*b*) shows a single-cavity mould and a multi-cavity mould.

A single-cavity mould is normally designed for fairly large parts such as plotter covers and television housings. For smaller parts such as hand phone covers and gears, it is always more economical to design a multi-cavity mould so that more parts can be produced per moulding cycle. Customers usually determine the number of cavities, as they have to balance the investment in the tooling against the part cost.

2.2 Multi-Cavity Layout

A multi-cavity mould that produces different products at the same time is known as a family mould. However, it is not usual to design a mould with different cavities, as the cavities may not all be filled at the same time with molten plastic of the same temperature.

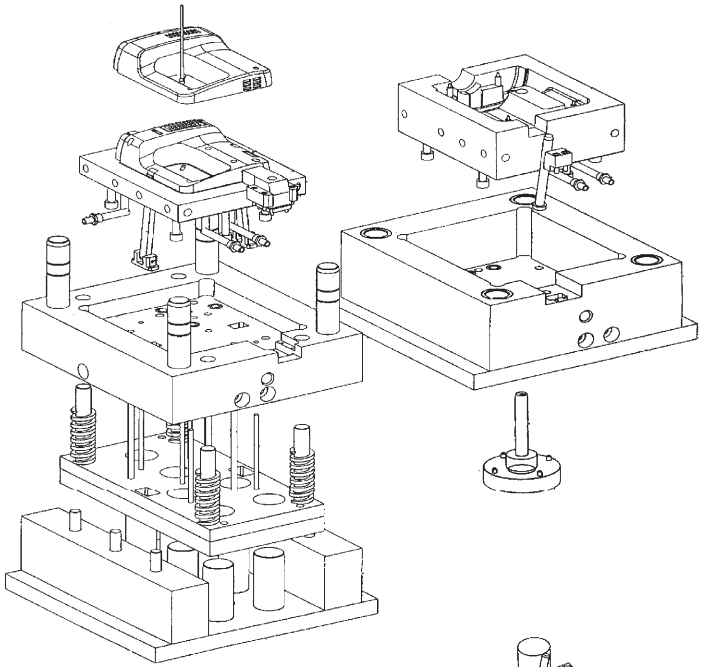
On the other hand, a multi-cavity mould that produces the same product throughout the moulding cycle can have a balanced layout or an unbalanced layout. A balanced layout is one in which the cavities are all uniformly filled at the same time under the same melt conditions [15,16]. Short moulding can occur if an unbalanced layout is being used, but this can be overcome by modifying the length and cross-section of the runners (passageways for the molten plastic flow from the sprue to the cavity). Since this is not an efficient method, it is avoided where possible. Figure 4 shows a short moulding situation due to an unbalanced layout.

A balanced layout can be further classified into two categories: linear and circular. A balanced linear layout can accommodate 2, 4, 8, 16, 32 etc. cavities, i.e. it follows a 2^n series. A balanced circular layout can have 3, 4, 5, 6 or more cavities, but there is a limit to the number of cavities that can be accommodated in a balanced circular layout because of space constraints. Figure 5 shows the multi-cavity layouts that have been discussed.

3. The Design Approach

This section presents an overview of the design approach for the development of a parametric-controlled cavity layout design system for plastic injection moulds. An effective working method of mould design involves organising the various subassemblies and components into the most appropriate hierarchy design tree. Figure 6 shows the mould assembly hierarchy design tree for the first level subassembly and components. Other subassemblies and components are assembled from the second level onwards to the *n*th level of the mould assembly hierarchy design tree. For this system, the focus will be made only on the “cavity layout design”.

(*a*)



(*b*)

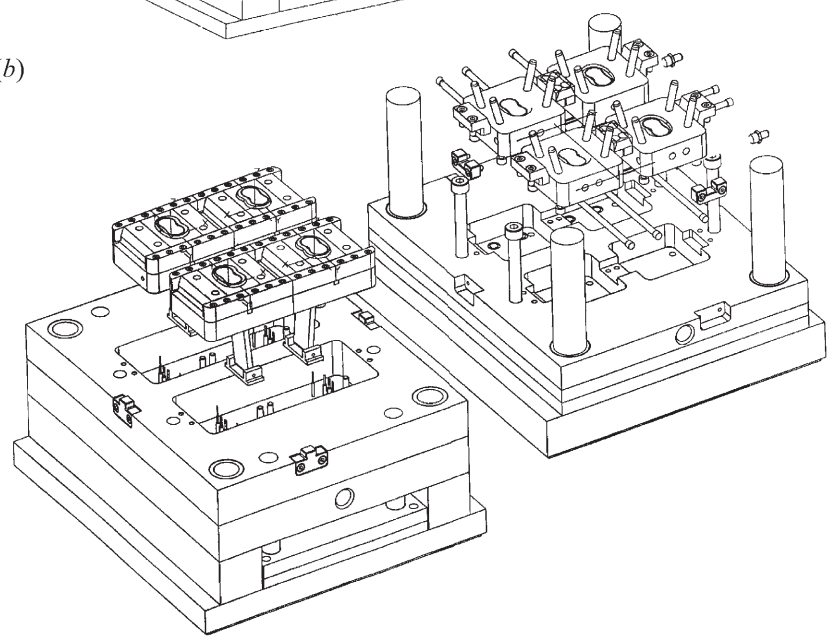


Fig. 3. (*a*) A single cavity mould. (*b*) A multi-cavity mould.

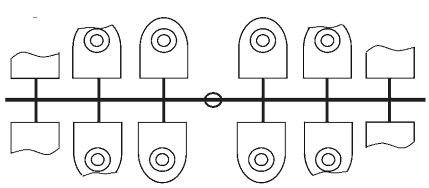


Fig. 4. Short moulding in an unbalanced layout.

3.1 Standardisation Procedure

In order to save time in the mould design process, it is necessary to identify the features of the design that are commonly used. The design processes that are repeatable for every mould design can then be standardised. It can be seen from Fig. 7 that there are two sections that interplay in the standardisation procedure for the "cavity layout design": component assembly standardisation and cavity layout configuration standardisation.

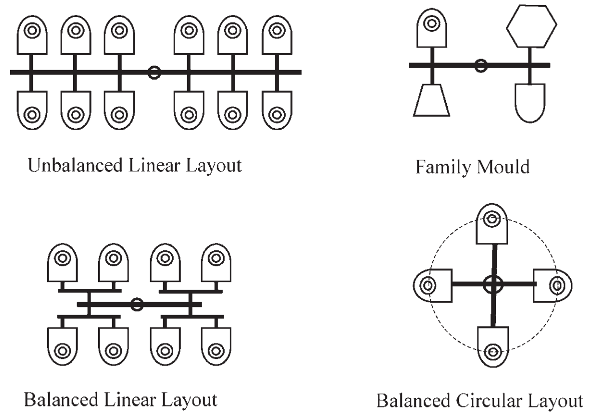


Fig. 5. Multi-cavity layouts.

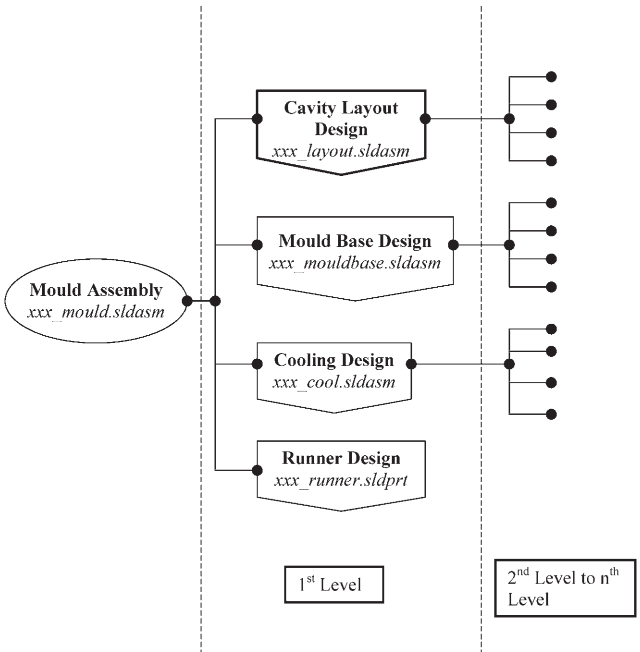


Fig. 6. Mould assembly hierarchical design tree.

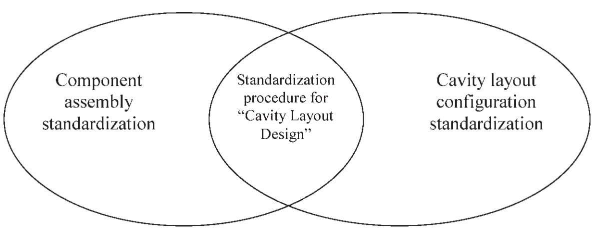


Fig. 7. Interplay in the standardization procedure.

3.1.1 Component Assembly Standardisation

Before the cavity layout configuration can be standardised, there is a need to recognise the components and subassemblies that are repeated throughout the various cavities in the cavity layout. Figure 8 shows a detailed "cavity layout design" hierarchy design tree. The main insert subassembly (cavity) in the second level of the hierarchy design tree has a number of subassemblies and components that are assembled directly to it from the third level onwards of the hierarchy design tree. They can be viewed as primary components and secondary components. Primary components are present in every mould design. The secondary components are dependent on the plastic part that is to be produced, so they may or may not be present in the mould designs.

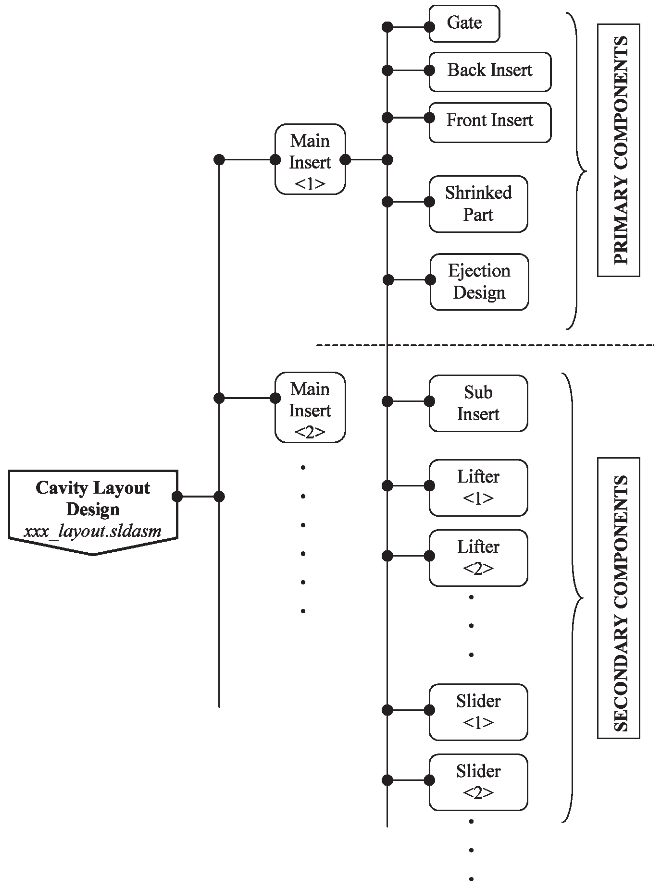


Fig. 8. Detailed "cavity layout design" hierarchical design tree.

As a result, putting these components and subassemblies directly under the main insert subassembly, ensures that every repeatable main insert (cavity) will inherit the same subassemblies and components from the third level onwards of the hierarchy design tree. Thus, there is no need to redesign similar subassemblies and components for every cavity in the cavity layout.

3.1.2 Cavity Layout Configuration Standardisation

It is necessary to study and classify the cavity layout configurations into those that are standard and those that are non-standard. Figure 9 shows the standardisation procedure of the cavity layout configuration.

A cavity layout design, can be undertaken either as a multi-cavity layout or a single-cavity layout, but the customers always determine this decision. A single-cavity layout is always considered as having a standard configuration. A multi-cavity mould can produce different products at the same time or the

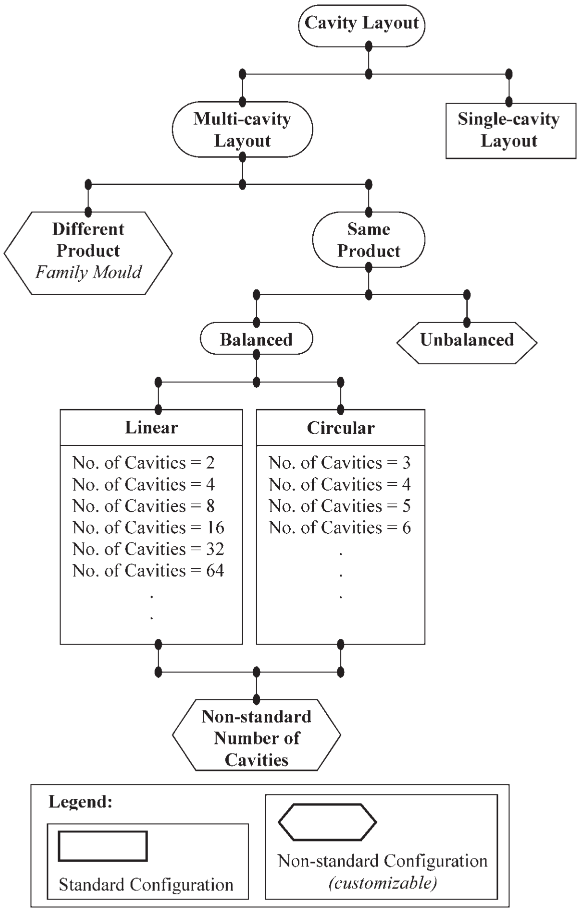


Fig. 9. Standardisation procedure of the cavity layout configuration.

same products at the same time. A mould that produces different products at the same time is known as a family mould, which is a non-conventional design. Thus, a multi-cavity family mould has a non-standard configuration.

A multi-cavity mould that produces the same product can contain either a balanced layout design or an unbalanced layout design. An unbalanced layout design is seldom used and, as a result, it is considered to possess a non-standard configuration. However, a balanced layout design can also encompass either a linear layout design or a circular layout design. This depends on the number of cavities that are required by the customers. It must be noted, however, that a layout design that has any other non-standard number of cavities is also classified as having a non-standard configuration.

After classifying those layout designs that are standard, their detailed information can then be listed into a standardisation template. This standardisation template is pre-defined in the cavity layout design level of the mould assembly design and supports all the standard configurations. This ensures that the required configuration can be loaded very quickly into the mould assembly design without the need to redesign the layout.

3.2 Standardisation Template

It can be seen from Fig. 10 that there are two parts in the standardisation template: a configuration database and a layout design table. The configuration database consists of all the standard layout configurations, and each layout configuration has its own layout design table that carries the geometrical parameters. As mould-making industries have their own standards, the configuration database can be customised to take into account those designs that are previously considered as non-standard.

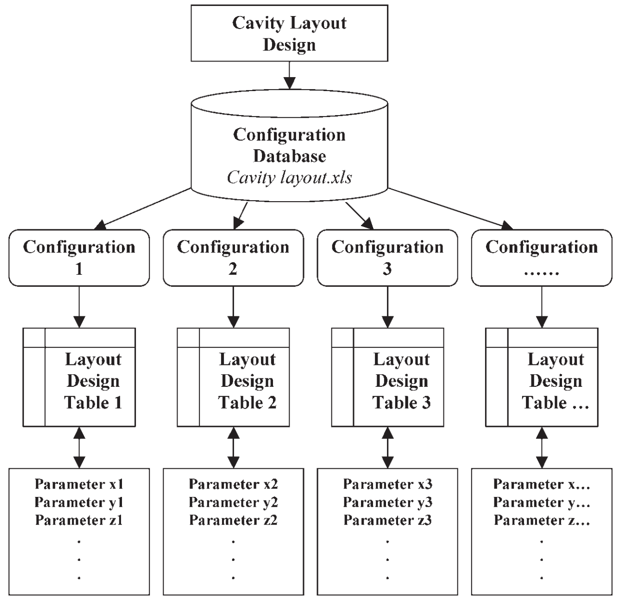


Fig. 10. The standardization template.

3.2.1 Configuration Database

A database can be used to contain the list of all the different standard configurations. The total number of configurations in this database corresponds to the number of layout configurations available in the cavity layout design level of the mould design assembly. The information listed in the database is the configuration number, type, and the number of cavities. Table 1 shows an example of a configuration database. The configuration number is the name of each of the available layout configurations with the corresponding type and number of cavities. When a particular type of layout and number of cavities is called for, the appropriate layout configuration will be loaded into the cavity layout design.

3.2.2 Layout Design Table

Each standard configuration listed in the configuration database has its own layout design table. The layout design table contains the geometrical parameters of the layout configuration and is independent for every configuration. A more complex layout configuration will have more geometrical parameters to control the cavity layout.

Figures 11(*a*) and 11(*b*) show the back mould plate (core plate) with a big pocket and four small pockets for assembling the same four-cavity layout. It is always more economical and easier to machine a large pocket than to machine individual smaller pockets in a block of steel. The advantages of machining a large pocket are:

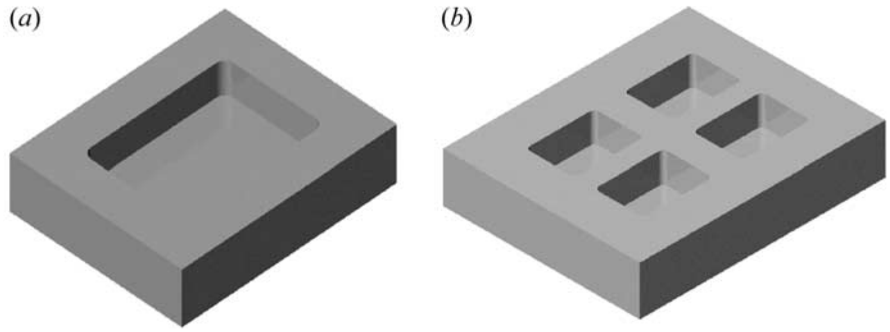


Fig. 11. The back mould plate with pocketing.

Table 1. Sample of the configuration database.

Configuration number	Type	Number of cavities
S01	Single	1
L02	Linear	2
L04	Linear	4
L08	Linear	8
L16	Linear	16
L32	Linear	32
L64	Linear	64
C03	Circular	3
C04	Circular	4
C05	Circular	5
C06	Circular	6

1. More space between the cavities can be saved, thus a smaller block of steel can be used.
2. Machining time is faster for creating one large pocket compared to machining multiple small pockets.
3. Higher accuracy can be achieved for a large pocket than for multiple smaller pockets.

As a result, the default values of the geometrical parameters in the layout design table results in there being no gap between the cavities. However, to make the system more flexible, the default values of the geometrical parameters can be modified to suit each mould design where necessary.

3.3 Geometrical Parameters

There are three variables that establish the geometrical parameters:

1. Distances between the cavities (flexible). The distances between the cavities are listed in the layout design table and they can be controlled or modified by the user. The default values of the distances are such that there are no gaps between the cavities.
2. Angle of orientation of the individual cavity (flexible). The angle of orientation of the individual cavity is also listed in the layout design table which the user can change. For a multi-cavity layout, all the cavities have to be at the same angle of orientation as indicated in the layout design table. If the angle of orientation is modified, all the cavities will be rotated by the same angle of orientation without affecting the layout configuration.
3. Assembly mating relationship between each cavities (fixed). The orientation of the cavities with respect to each other is pre-defined for each individual layout configuration and is controlled by the assembly mating relationship between cavities. This is fixed for every layout configuration unless it is customised.

Figure 12 shows an example of a single-cavity layout configuration and its geometrical parameters. The origin of the main insert/cavity is at the centre. The default values of X1 and Y1 are zero so that the cavity is at the centre of the layout (both origins overlap each other). The user can change the values of X1 and Y1, so that the cavity can be offset appropriately.

Figure 13 shows an example of an eight-cavity layout configuration and its geometrical parameters. The values of X and Y are the dimensions of the main insert/cavity. By default, the values of X1 and X2 are equal to X, the value of Y1 is equal to Y, and thus there is no gap between the cavities. The values of X1, X2, and Y1 can be increased to take into account the gaps between the cavities in the design. These values are listed in the layout design table.

If one of the cavities has to be oriented by 90°, the rest of the cavities will be rotated by the same angle, but the layout design remains the same. The user is able to rotate the cavities by changing the parameter in the layout design table. The resultant layout is shown in Fig. 14.

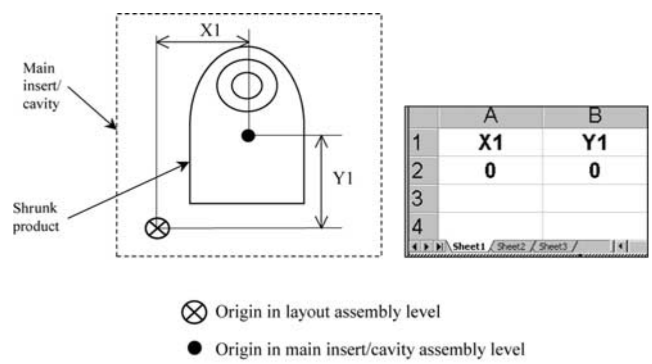
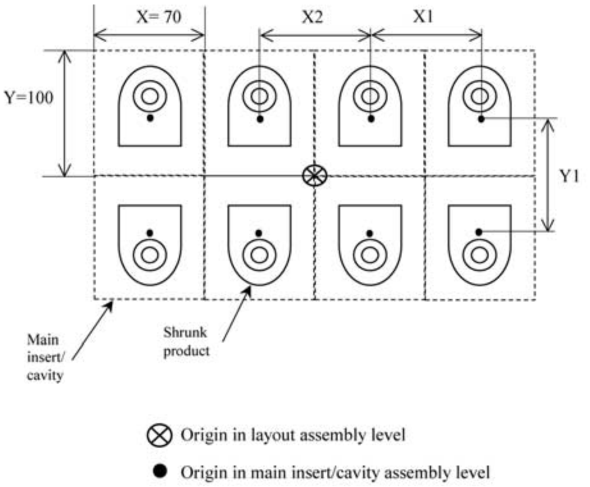
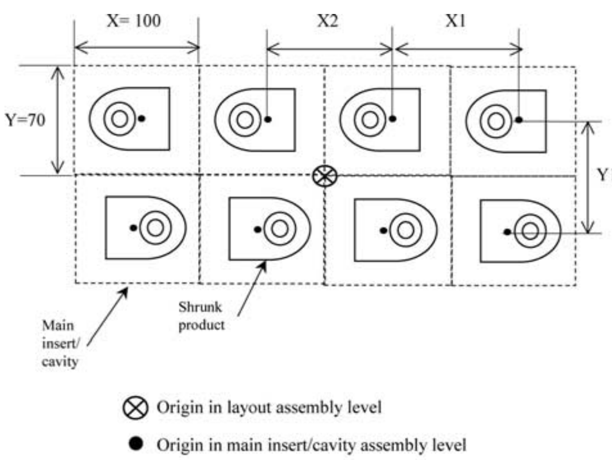


Fig. 12. Single-cavity layout configuration and geometrical parameters.



	A	B	C	D
1	**X1**	**X2**	**Y1**	**ANGLE**
2	**70**	**70**	**100**	**0**
3				

Fig. 13. Eight-cavity layout configuration and geometrical parameters without cavity rotation.



	A	B	C	D
1	**X1**	**X2**	**Y1**	**ANGLE**
2	**100**	**100**	**70**	**90**
3				

Fig. 14. Eight-cavity layout configuration and geometrical parameters with cavity rotation.

A complex cavity layout configuration, which has more geometrical parameters, must make use of equation to relate the parameters.

4. System Implementation

A prototype of the parametric-controlled cavity layout design system for a plastic injection mould has been implemented using a Pentium™ III PC-compatible as the hardware. This prototype system uses a commercial CAD system (SolidWorks 2001) and a commercial database system (Microsoft Excel™) as the software. The prototype system is developed using the Microsoft Visual C++ V6.0 programming language and the SolidWorks API (Application Programming Interface) in a Windows NT™ environment.

SolidWorks is chosen primarily for two reasons:

1. The increasing trend in the CAD/CAM industry is to move towards the use of Windows-based PCs instead of UNIX workstations mainly because of the cost involved in purchasing the hardware.
2. The 3D CAD software is fully Windows-compatible, thus it is capable of integrating information from Microsoft Excel files into the CAD files (part, assembly, and drawing) smoothly [17].

This prototype system has a configuration database of eight standard layout configurations that are listed in an Excel file. This is shown in Fig. 15(*a*). Corresponding to this configuration database, the layout design level, which is an assembly file in SolidWorks (layout.sldasm), has the same set of layout configurations. The configuration name in the Excel file corresponds to the name of the configurations in the layout assembly file, which is shown in Fig. 15(*b*).

Every cavity layout assembly file (layout.sldasm) for each project will be pre-loaded with these layout configurations. When a required layout configuration is requested via the user interface, the layout configuration will be loaded. The user interface shown in Fig. 16 is prior to the loading of the requested layout configuration. Upon loading the requested layout configuration, the current layout configuration information will be listed in the list box.

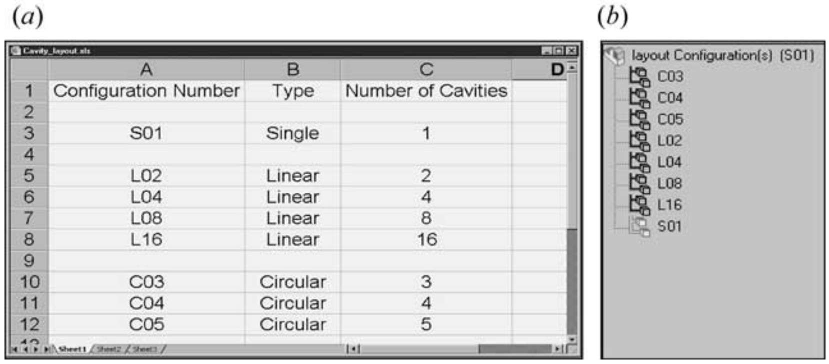
The user is then able to change the current layout configuration to any other available layout configurations that are found in the configuration database. This is illustrated in Fig. 17.

The layout design table for the current layout configuration that contains the geometrical parameters can be activated when the user triggers the push button at the bottom of the user interface. When the values of the geometrical parameters are changed, the cavity layout design will be updated accordingly. Figure 18 shows the activation of the layout design table of the current layout configuration.

5. A Case Study

A CAD model of a hand phone cover, shown in Fig. 19, is used in the following case study.

Prior to the cavity layout design stage, the original CAD model has to be scaled according to the shrinkage value of the moulding resin to be used. The main insert is then created to encapsulate the shrunk part. This entire subassembly is known as the main insert subassembly (xxx_cavity.sldasm),



	A	B	C	D
1	Configuration Number	Type	Number of Cavities	
2				
3	S01	Single	1	
4				
5	L02	Linear	2	
6	L04	Linear	4	
7	L08	Linear	8	
8	L16	Linear	16	
9				
10	C03	Circular	3	
11	C04	Circular	4	
12	C05	Circular	5	

Fig. 15. The configuration database and layout template for prototype system.

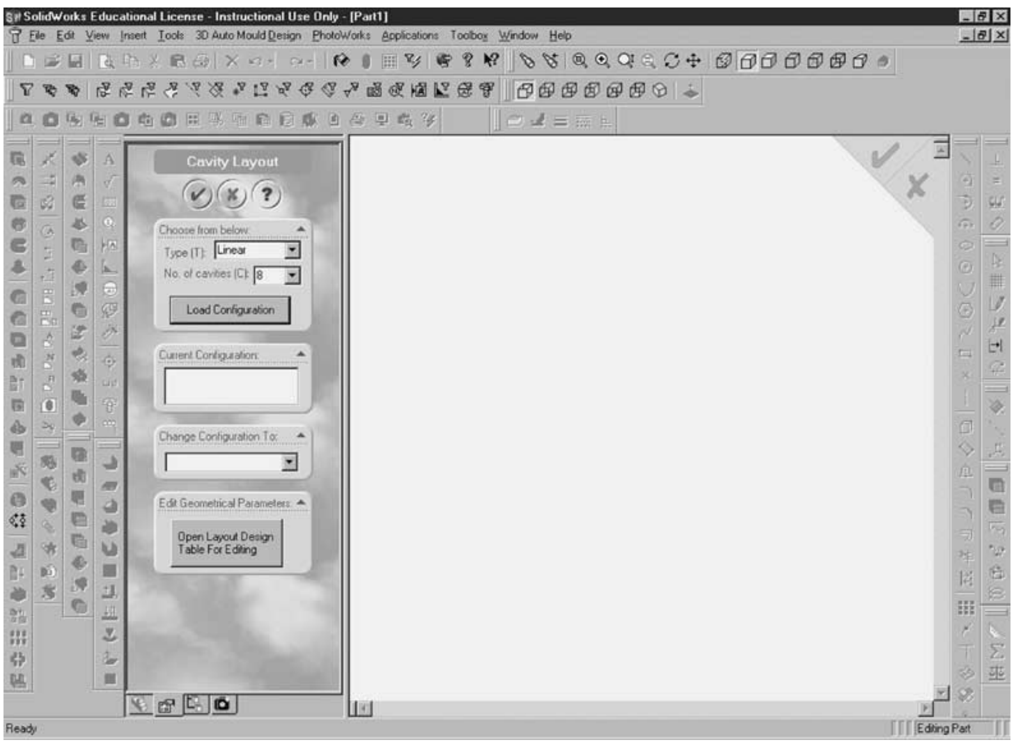


Fig. 16. The user interface prior to loading of the requested configuration.

where "xxx" is the project name. Figure 20 shows the main insert subassembly. After the main insert subassembly is created, the cavity layout design system can be used to prepare the cavity layout of the mould assembly.

5.1 Scenario 1: Initial Cavity Layout Design

In a mould design, the number of cavities to be built in a mould is always suggested by the customers, as they have to balance the investment in the tooling against the part cost. Initially, the customers had requested a two-cavity mould to be designed for this hand phone cover. After the creation of the main insert subassembly, the mould designer loads a layout configuration that is of a linear type which has two cavities using this cavity layout design system. The corresponding configuration name is L02 and is listed in the user interface as shown in Fig. 21.

5.2 Scenario 2: Modification in the Cavity Layout Design

Technical discussion sessions between the customers and mould designers are common. This enables changes to be made to the 3D CAD files of both the product and mould as soon as possible, prior to mould manufacture. Changes are almost always inevitable and mould designers are never given any extension in the lead time.

In this case, during a technical discussion session, the customers changed their minds and needed a linear four-cavity mould instead of a two-cavity mould so that the production

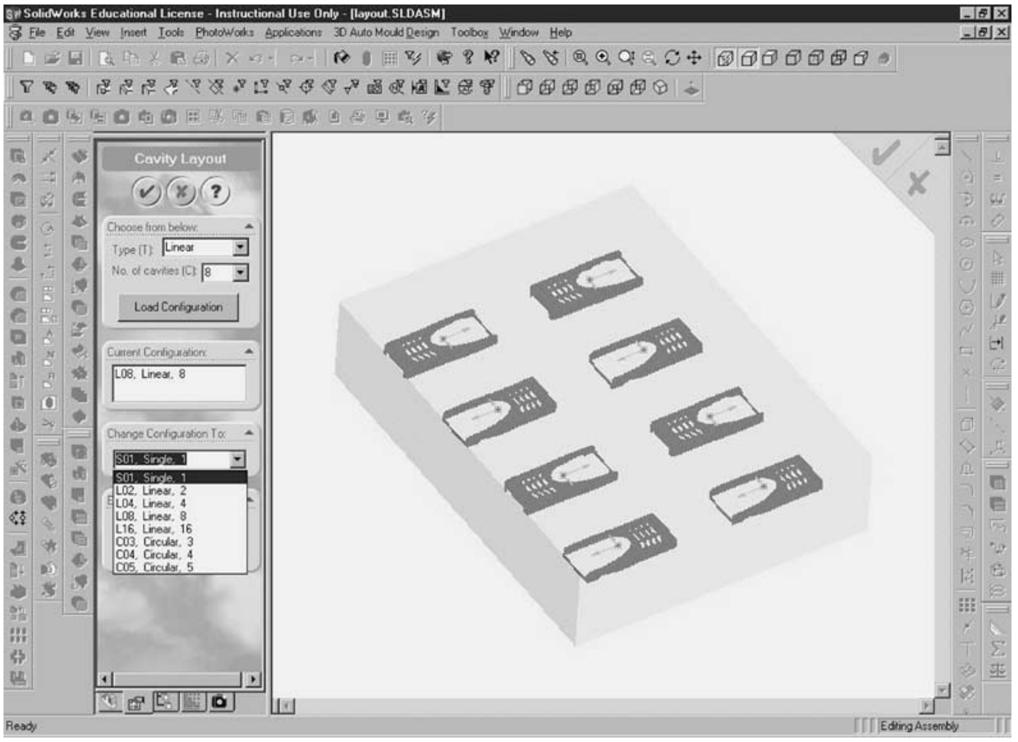


Fig. 17. The user interface after loading of the requested configuration.

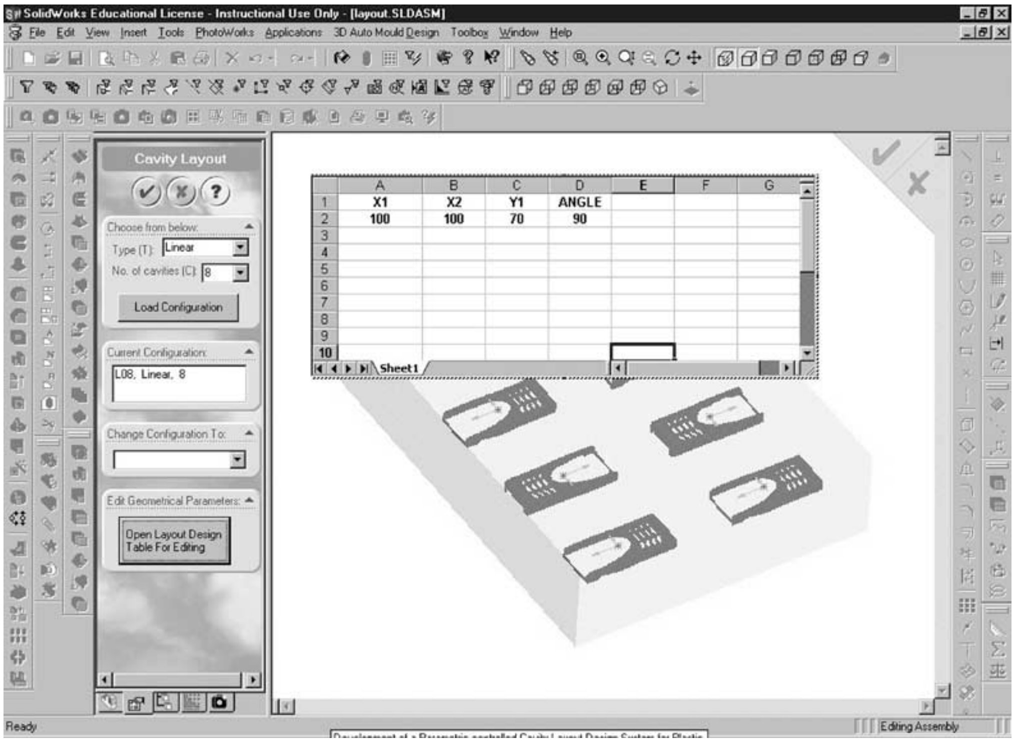


Fig. 18. The user interface with the layout design table.

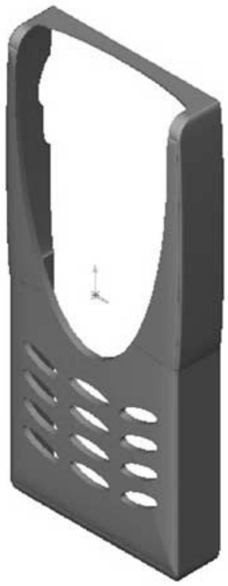


Fig. 19. The CAD model of a hand phone.

Fig. 20. The main insert encapsulating the shrunk part.

rate of the hand phone covers can be increased. The mould designer can use the cavity layout design system to modify the existing cavity layout design to a linear four-cavity mould. The required new layout configuration can be selected from the available layout configurations that are listed in the configuration database. This is shown in Fig. 22.

5.3 Scenario 3: Gap is Required Between Cavities

Finally, in another technical discussion session, the mould designer is required to introduce a gap of 20 mm between the cavities in the longitudinal direction, as shown in Fig. 23.

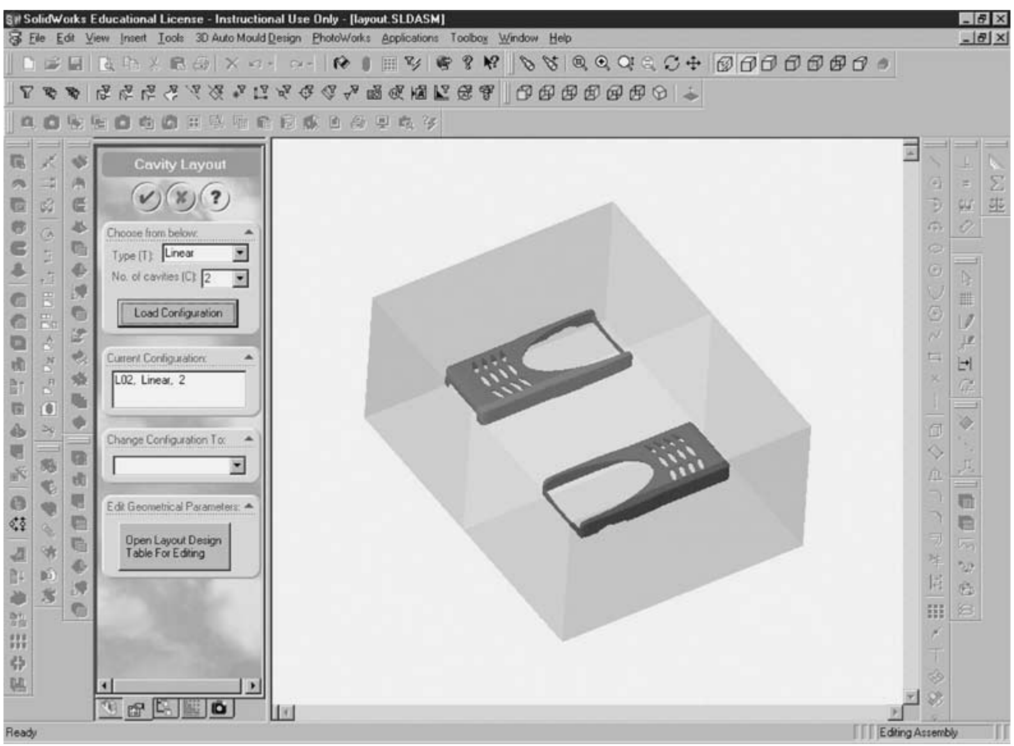


Fig. 21. A linear two-cavity configuration.

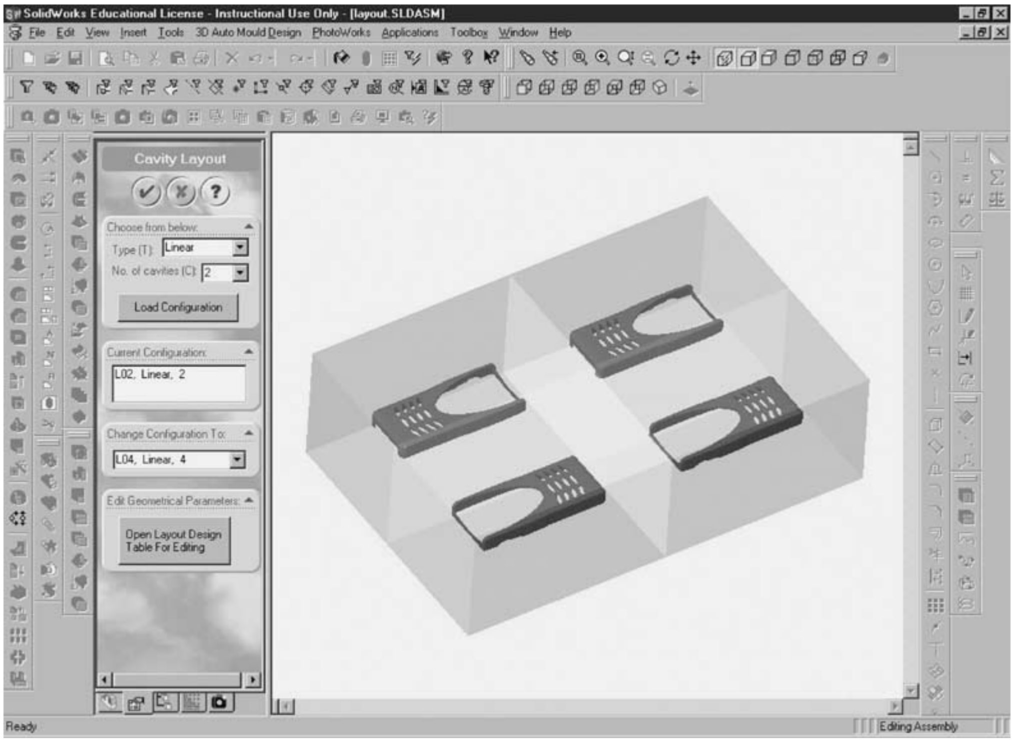


Fig. 22. A linear, four-cavity layout configuration (after a change in the layout configuration).

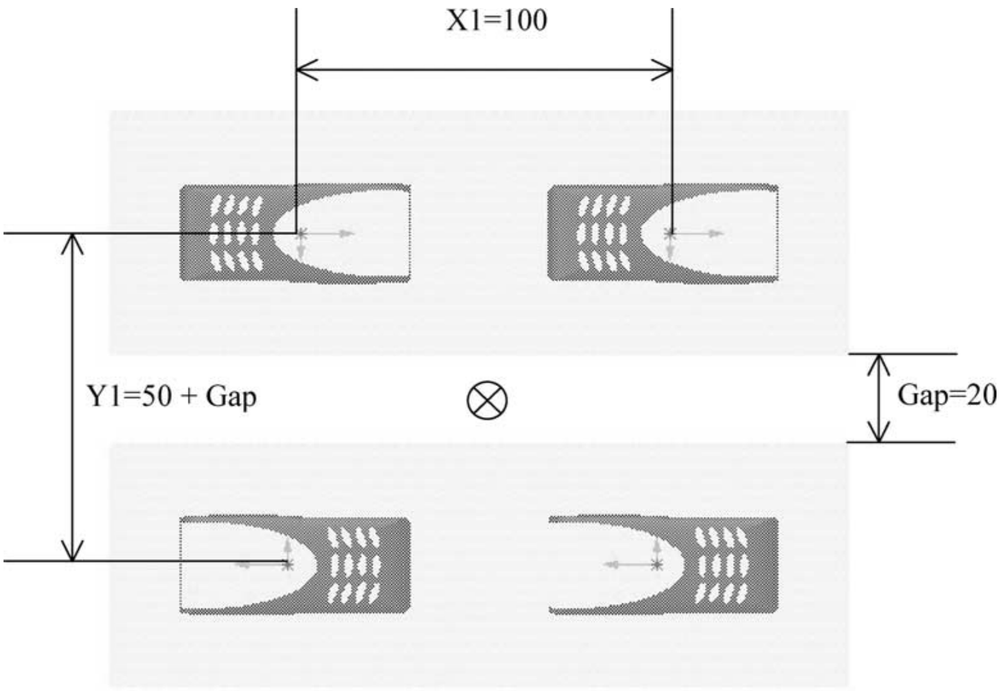


Fig. 23. The introduction of a gap between the cavities.

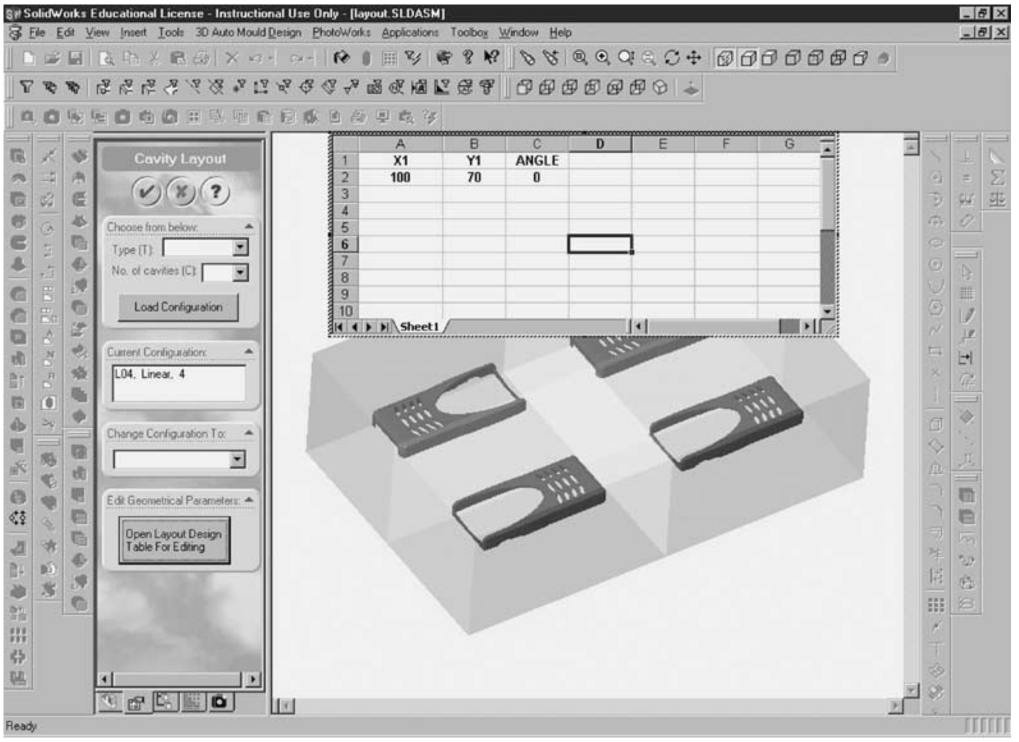


Fig. 24. Modifying the value of Y1 in the layout design table.

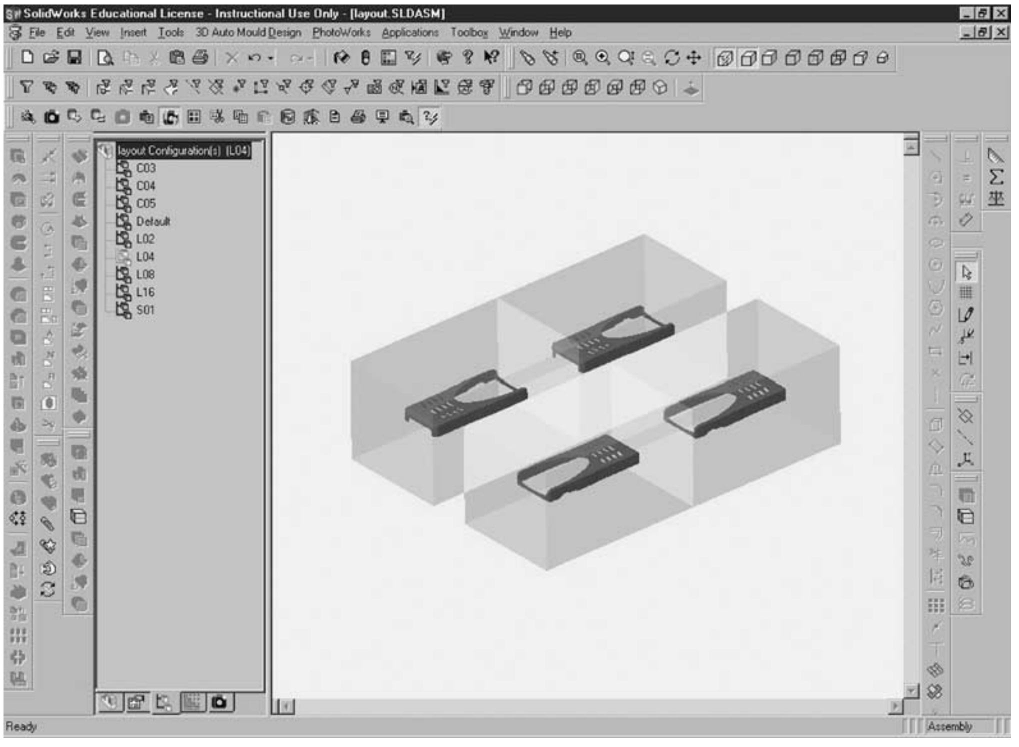


Fig. 25. The final design after the addition of the gap.

In the cavity layout subassembly level, the mould designer uses the cavity layout system to activate the layout design table of the current layout configuration. The value of Y1 is changed from 50 mm to 70 mm to introduce a gap of 20 mm between the cavities in the longitudinal direction. Figure 24 shows the change of the value of Y1 in the layout design table. The result of the final design, after addition of the gap, is shown in Fig. 25.

6. Conclusions

In this paper, an approach using a standardisation template is proposed for the development of a parametric-controlled cavity layout design system. Since this approach makes use of standardisation, it can be further applied to other components for mould assembly design if their design processes are repeatable or they have features that are commonly used for every mould design. The advantages of the developed cavity layout system are as follows:

1. The developed system has user-friendly interfaces.
2. Since it makes use of databases, it is highly flexible, and mould-making industries that have their own standards can customise the databases to suit their needs.
3. Because a pre-defined standardisation template is available in the layout design level of the mould assembly design, the required layout configuration can be loaded very quickly into the mould assembly design without the need to redesign the layout.
4. This system enables product designers and mould designers to have more useful technical discussions prior to mould manufacture as changes to the layout can be made immediately during the discussions.
5. This system saves time in the mould design process because it removes redundant work. This is very important for the mould-making industries since the lead time for mould making is decreasing.

The developed system has some limitations. Although the databases and layout design tables can be customised, customisation will be more difficult for more complex non-standard configurations because the correct geometrical parameters have to be determined. We are currently working on applying a standardisation template for other components in mould design.

References

1. K. S. Lee, J. Y. H, Fuh, Y. F. Zhang, A. Y. C. Nee and Z. Li, "IMOLD: an intelligent plastic injection mold design and assembly system", Proceedings of the 4th International Conference On Die and Mould Technology, pp. 30–37, Malaysia, 4–6 June 1997.
2. K. S. Lee, Z. Li, J. Y. H, Fuh, Y. F. Zhang and A. Y. C. Nee, "Knowledge-based injection mold design system", CIRP International Conference and Exhibition on Design and Production of Dies and Moulds, pp. 45–50, Turkey, 19–21 June 1997.
3. C. K. Mok, K. S. Chin and John K. L. Ho, "An interactive knowledge-based CAD system for mould design in injection moulding processes", International Journal of Advanced Manufacturing Technology, 17, pp. 27–38, 2001.
4. Kwai-Sang Chin and T. N. Wong, "Knowledge-based evaluation for the conceptual design development of injection molding parts", Engineering Application of Artificial Intelligence, 9(4), pp. 359–376, 1996.
5. Rong-Shean Lee, Yuh-Min Chen and Chang-Zou Lee, "Development of a concurrent mold design system: a knowledge-based approach", Computer Integrated Manufacturing Systems, 10(4), pp. 287–307, 1997.
6. A. A. Tseng, J. D. Kaplan, O. B. Arinze and T. J. Zhao, " Knowledge-based mold design for injection molding processing", Proceedings of the 5th International Symposium on Intelligent Control, pp. 1199–1204, 1990.
7. K. Beiter, S. Krizan and K. Ishii, "HyperQ/Plastics: an expert system for plastic material and process selection", Proceedings Computers in Engineering, ASME, 1, pp. 71–76, 1991.
8. W. R. Jong and K. K. Wang, "An intelligent system for resin selection", Proceedings ANTEC'89, SPE, pp. 367–370, 1989.
9. M. Wiggins, "Expert systems in polymer selection", Proceedings ANTEC'86, SPE, pp. 1393–1395, 1986.
10. L. L. Chen, S. Y. Chou and T. C. Woo, "Parting directions for mould and die design", Computer-Aided Design, 25(12), pp. 762–768, 1993.
11. A. Y. C. Nee and M. W. Fu, "Determination of optimal parting directions in plastic injection mold design", Annals CIRP, 46(1), pp. 429–432, 1997.
12. B. Ravi and M. N. Srinivasan, "Decision criteria for computer-aided parting surface design", Computer-Aided Design, 22(1), pp. 11–18, 1990.
13. X. G. Ye, "Feature and associativity-based computer-aided design for plastic injection moulds", PhD thesis, National University of Singapore, 2000.
14. X. G. Ye, J. Y. H. Fuh and K. S. Lee, "Automated assembly modeling for plastic injection moulds", International Journal of Advanced Manufacturing Technology, 16, pp. 739–747, 2000.
15. G. Menges, How to Make Injection Molds, Chapter 4, Hanser, Munich, 1986.
16. Joseph B. Dym, Injection Molds and Molding: A Practical Manual, Chapter 7, Van Nostrand Reinhold, New York, 1989.
17. SolidWorks 2001 Training Manual, "SolidWorks Essentials parts assemblies and drawings", SolidWorks Corporation, Concord, Massachusetts 01742, 2001.