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Configuration of progressive dies

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Abstract

The computer-assisted configuration of progressive die is a computationally mixed problem. This paper describes the progressive die design problem and reviews some existing research related to the configuration of progressive dies. It explains the model-based reasoning approach used to configure the intermediate and final solutions to the design problem. In particular, the various shape representation and spatial reasoning techniques are presented. Finally, a computer software architecture for the die design system is presented.

Keywords: Progressive Die Design; Knowledge-based System; Model-based Reasoning; Shape Representation; Spatial Reasoning

1. INTRODUCTION

Progressive dies are tools used to mass-produce metal stampings, which are common structural components found in household appliances, office equipment, and other modern utensils. Progressive dies are widely used because they offer a cheap and effective means to produce large quantities of high-quality parts.

The design of progressive die is probably one of the most challenging configuration problems. One of the main reasons is because the engineering models describing the metal stamping part (the input), the flat pattern and strip layout (the intermediate solutions) and the progressive die (the output) are dissimilar to one another. This can be illustrated in Figure 1. In Figure 1, the input model is a 3D representation of the metal stamping part. Because the part is stamped from a coil of sheet metal, it must first be flattened. Next, the stamping operations required to form the part must be selected. As it is impossible to perform all these operations in one go, the stamping operations are staged into several stations so that the part can be progressively formed as the strip of sheet metal is fed progressively from one station to another (hence, the term progressive die). The intermediate planning stage is called the strip layout design. Finally, the 3D representation of the die is configured from the strip layout.

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The steps involved in the design of a progress die are shown in Figure 2. The generation of the flat pattern and selecting the optimum nested arrangement is basically a geometrical problem. The strip layout design process is a typical iterative feedback procedural design process (Boyle, 1989) requiring human intervention to find a combination of the suboptimal solution at the various steps to arrive at the most efficient strip layout. The die configuration assembles the punches, the ancillary components (screws, dowels, springs, pins, guides, bushings, etc.), and the structural plates into a working die from the information provided by the strip layout.

This paper describes a knowledge-based (KB) approach to configure a progressive die.

2. A BRIEF REVIEW OF R & D EFFORTS IN CONFIGURATION OF PROGRESSIVE DIES

The Japanese industries are probably among the first to develop in-house turnkey CAD/CAM systems for progressive dies for industrial use. From the mid 1970s, researchers from Hitachi Ltd. (Murakami et al., 1980; Murakami & Shirai, 1984; Shirai & Murakami, 1985, 1989), Nippon Electric Co. Ltd. (Okada, 1980), Mechanical Engineering Laboratory (Nakahara et al., 1978), Fujitsu Ltd. and Matsushita Electric Works Ltd. (Fukuoka & Horiuchi, 1986), and others (Adachi et al., 1983) have reported extensively their custom-made integrated computer-aided design and manufacturing systems for press tools. These early die design systems attempted to use

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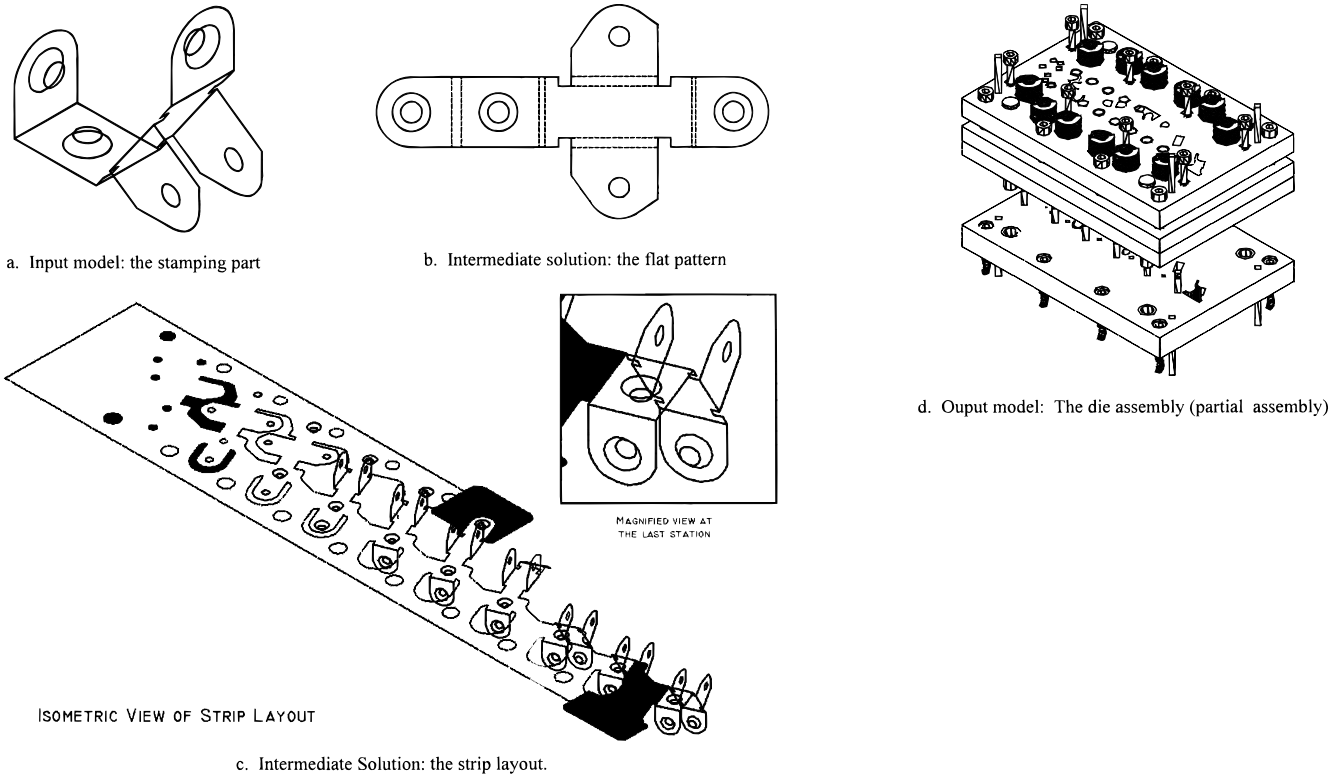


Fig. 1. Engineering models for progressive die design.

basic computer graphics facilities and programs written in FORTRAN to improve the productivity of the die designer. Geometrical information has to be entered laboriously via the keyboard using APT-like command language. The designer makes most design decisions. The computer is used to improve productivity in drawing, perform certain design calculations and NC programming. Yet, they claim to have achieved productivity gains of between 30 and 400% over the manual approach. The attempt to improve their die design productivity in the late 1970s and early 1980s indicates the importance of the metal stamping industry to the electrical and electronic components and equipment manufacturers. At that time, Japan was among the world's largest exporter of electrical and electronic home appliances and office equipment.

The early CAD/CAM systems for progressive die design and manufacturing may appear to be rather primitive by today's standard. However, these efforts have laid solid foundation for future developments. Concepts such as using standard punch shapes as primitive shapes for punch selection and de-composition, standardization of die components, computer modelling of die components, die layout area, and standardization of design procedures are favorably followed by later researchers.

The wide acceptance of CAD/CAM equipment in the mid 1980s provided the second thrust in the design automation of progressive dies. Most CAD/CAM equipment provide programming languages for customization or/and are able to interface directly with a high level programming language such as FORTRAN. Researchers began to exploit these features to develop dedicated CAD/CAM systems for progressive die design (Fukuoka & Horiuchi, 1986; Bergstrom et al., 1988). These second-generation die design systems represent a vast improvement over the first generation in terms of interactive graphics and 3D modelling functionalities. However, as they are still based on procedural programming languages such as FORTRAN, they are only able to automate relatively simple calculations and data extraction (for example, generation of part list and tool dimensions) tasks. The user still interactively decides most of the important decisions such as design of punch shapes, assessment of formability of the part and development of strip layout.

Research and development of progressive die design automation systems was given a new dimension in the late 1980s and early 1990s when the applications of artificial intelligence techniques in engineering design started to take off (e.g., Chryssolouris & Wright, 1986; Boyle, 1989; Pham & Tacgin, 1991; Tong & Siriam, 1992). Now, AI techniques in pattern recognition, production rules and frame-based inferencing and reasoning, fuzzy reasoning, feature-based design, etc. are used increasingly in design systems for the production of metal stampings. However, because of the

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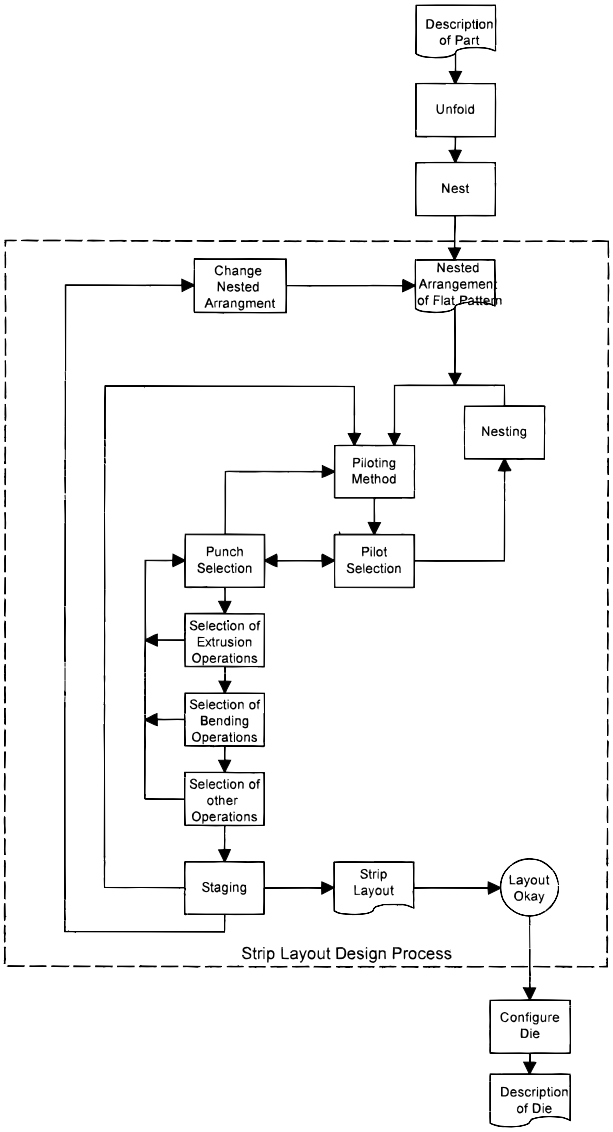


Fig. 2. The progressive die design process.

complexity of the die design process, most of the "intelligent" die design automation prototypes are rather restrictive in their applications.

Several universities and research institutes have adopted a wide variety of AI and traditional computer approaches to develop die design automation systems: Researchers at the National Taiwan Institute of Technology (Lin et al., 1989; Lin & Chang, 1994; Lin & Hsu, 1996) have developed PC-based expert prototypes for the design of shearing cut (blanking and piercing) progressive dies. ESSCP (Lin et al., 1989) is a prototype developed using FORTRAN, Micro Expert (the inference engine), and AutoCAD to plan and develop the progressive dies for the blanking and piercing of 2D parts with simple geometrical profiles. In separate developments, the researchers also studied how uncertainties in design parameters can be processed using fuzzy mathematics for the detailed design of certain components in the die structure (Lin & Chang, 1994), and developed a knowledge-based system that uses a pattern recognition method called the "new combined structural approach" to develop the blank so as to optimize material cost, and a matching combination learning method for press procedures to optimize the number of stations in the die (Lin & Hsu, 1996). It is unclear whether they have integrated these AI techniques into an integrated system for the design of blanking and piercing progressive dies.

Researchers at the Huazhong University of Science and Technology, China also developed knowledge-based CAD/CAM packages for progressive dies of small-sized metal stampings (Li et al., 1990, 1992; Li, 1993; Xiao et al., 1993). Using features, a user can design a product in 3D wireframe; thereafter, the system will unfold it. After manually developing the blank layout, the user can use interactive commands to develop the strip layout. The user can then proceed to design the die structure interactively. Another feature of their research is the use of the directed and weighted graph approach for the automatic splitting of complicated die cavities (Li et al., 1990). Originally the system was developed on a Micro VAX mini-computer. The system is now available on PCs and runs under the AutoCAD environment.

Researchers from the Department of Industrial Studies, University of Liverpool have also worked on expert systems for progressive piercing and blanking die design (Huang et al., 1996; Ismail et al., 1996). Their research concentrated on shape coding and recognition techniques for the decomposing of the bridge scrap into smaller shapes (Ismail et al., 1996). However, their techniques are limited to straightedge workpieces only. They also developed a UNIX-based expert system for the planning and design of progressive piercing and blanking dies (Huang et al., 1996). The system was developed by integrating AutoCAD with Kappa and some C programs.

Researchers at the Department of Mechanical and Production Engineering, National University of Singapore has been developing algorithms for die design automation (Nee, 1989; Nee & Foong, 1992) since the mid 1980s. Initially, the work concentrated on developing heuristics for nesting, automating the staging and punch shape selection, and decomposition process. Later, it was extended to the use of a variety of knowledge-based approaches to extend the capabilities to include bending and forming, automatic punch shape selection, strip layout and 3D die configuration (Cheok et al., 1994, 1996, 1997).

Researchers at the Shanghai Research Institute of Tool and Die Technology (Ruan et al., 1987; Yuan et al., 1990) have also been developing CAD/CAM systems for progressive dies. The systems they developed rely on special relational data structures to describe the workpiece and the die structure. The strip layout is generated interactively.

Researchers at the Department of Industrial and Manufacturing Systems Engineering, University of Hong Kong

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Table 1. *MBR approach for the configuration of a progressive*

Stage	Input Model	Output Model	System Components
Configuring the Flat Pattern	Feature-relationship Tree	Flat Pattern Tree	Metal stamping Features
Configuring the Strip Layout	Flat Pattern Tree	Die Operations Tree	Die Operations
Configuring the Progressive Die	Die Operations Tree	Die Assembly Tree	Die Components

developed BECAM, a CAD/CAM package for sheet metal blanking dies (Choi and Wong, 1992). The program can help develop the blank strip layout, punch and die selection, drafting and generation of NC part programs.

CADDS, an automated die design system for sheet metal blanking, was developed at the Indian Institute of Technology (Prasad & Somasundaram, 1992) using AutoCAD, AutoLISP, and FORTRAN. The software is able to generate strip layout automatically, conduct design checks for various die components, and generate the assembly views and bill of materials for the die.

Finally, there are researchers who seek to reduce the size of the problem by developing systems that concentrate on specific product types or concentrated on specific tasks. For example, a knowledge-based system based on ICAD was developed for the design of progressive dies for door hinges (Duffey & Sun, 1991).

3. MODEL-BASED REPRESENTATION OF THE DESIGN MODELS

A model-based reasoning (MBR) approach has been adopted for the configuration of the die. Dym and Levitt (1991) stated that Knowledge-based Engineering Systems developed in the spirit of MBR "explicitly model the behavior of components—either quantitatively or qualitatively—and propagate effects among topologically linked objects representing system components or subsystems in a manner that model causality in the system as it is understood by the modeller. In the course of their reasoning, therefore such KBESs (Knowledge-based Engineering Systems) will generate descriptions of intermediate and final states of the modeled system (in terms of patterns of system or component attribute values) that can be checked to validate the descriptive power of the model."

The MBR approach for the configuration of a progressive can be divided into three stages as shown in Table 1.

An object-oriented paradigm is used to represent and organize the system components in the input and output models. A rule-based goal-driven forward-chaining approach is used to deduce the description and behavior of the target objects in the output model from the information provided by the source objects in the input model. The goal(s) for the configuration of the target objects in the output model are encapsulated in the respective objects. During the deduction process, the inference engine will step through a selected set of rules until all the goals are achieved.

4. CONFIGURING THE FLAT PATTERN

Features are used to describe the metal stamping part and its topological information is input as a Feature-relationship Tree in the KB system. Figure 3 shows a part and the associated Feature-relationship Tree. The features modelled are walls, bends, holes, and burrings (or extrusion holes). Wall and bends are joint by "connected-to" relationships, while

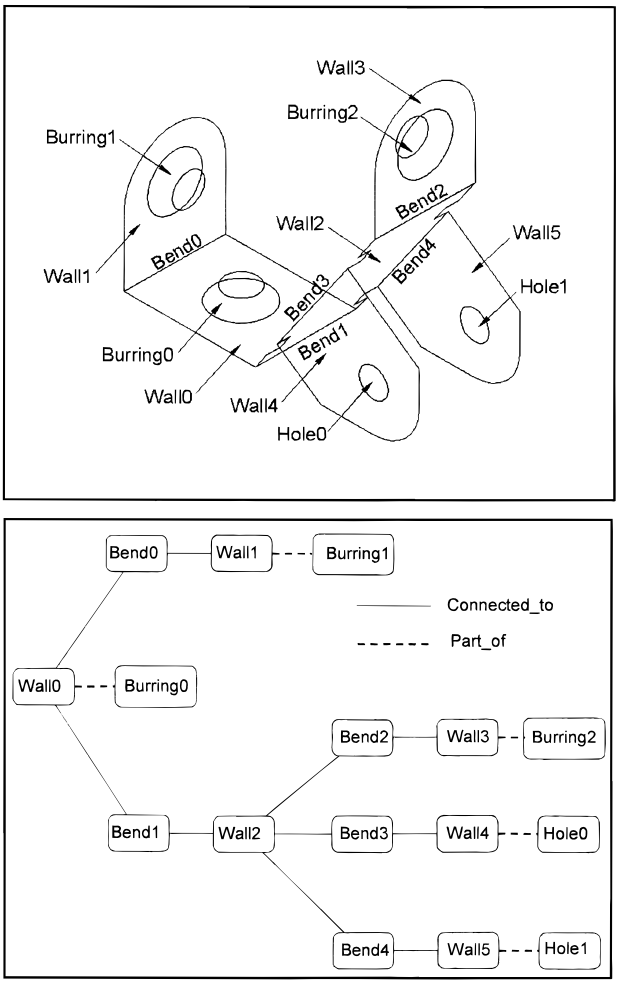


Fig. 3. The Feature-relationship Tree of a part.

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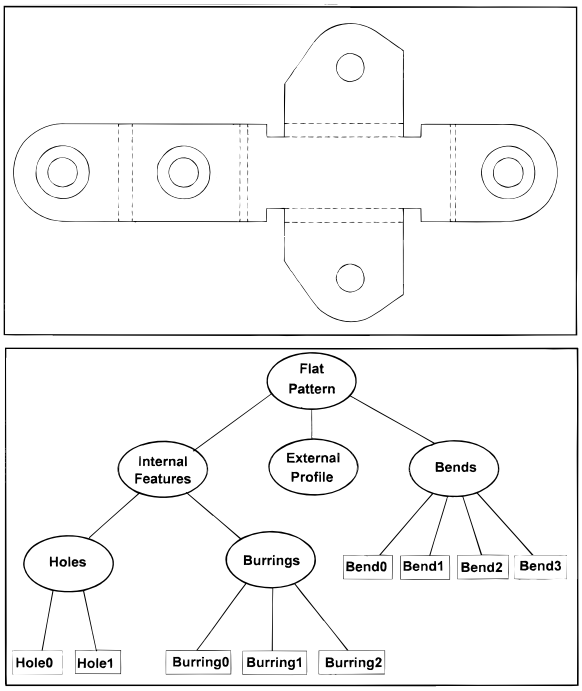


Fig. 4. The flat pattern and the Flat Pattern Tree for part shown in Figure 3.

holes and burrings are "part-of" a wall. The features are described with respect to their respective local coordinate system (LCS). The LCS of the base wall (Wall0) is the world coordinate system (WCS). The base wall is the first wall constructed by Features Modeller. The bend object contains a transformation matrix that describes the geometrical relationship between the LCSs of its two adjacent walls. It also contains methods that are transformation routines to transform the coordinate system of one connecting wall to that of another.

Hence, the 3D description of the stamping part can be deduced from the Feature-relationship Tree by progressively transforming the co-ordinates of the features from their respective LCSs to the co-ordinate system of the base wall (wall0). Similarly, the flat pattern description of the part can be configured from the Feature-relationship Tree by progressively transforming the coordinates of the wall (and its internal features) further away from the base wall to the LCS of the wall closer to the base wall during an unfolding operation. Using Bend2 in Figure 3 as an example, its transformation method will transform the coordinates of Wall3 and Burring2 to the LCS of Wall2, such that Wall3, Wall2, and Burring2 behave as a flat pattern attached to Bend1. Therefore, the progressive "local unfolding" process that begins at the end of the branches and terminates at Wall0 will yield the Flat Pattern Tree shown in Figure 4. The symbolic relationship between the Feature-relationship Tree and the Flat Pattern Tree is illustrated in Figure 5.

This MBR approach has many advantages. First, the geometrical transformation procedure has been made simple and efficient compared to traditional unfolding programs that use cumbersome complex mathematical formulation to unfold the entire model in one go. Second, because the walls joint by a bend can be transformed relative to one another

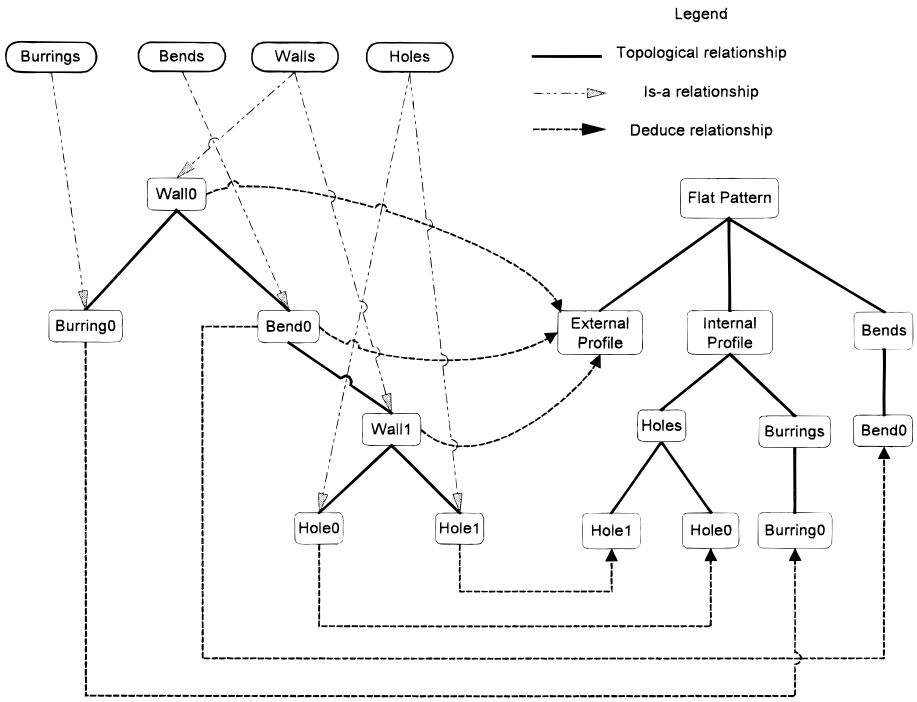


Fig. 5. Symbolic relationship between objects in the Feature-relationship Tree and the Flat Pattern Tree.

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irrespective of the state of the other branches, complex bend simulation studies can be made. Third, the relative position of the bend objects in the Feature-relationship Tree can be used to deduce the sequence of bending operations required to progressively form an intricate part.

5. CONFIGURING THE STRIP LAYOUT

Simple functional reasoning techniques can be used to select the punching operations using information stored in the Flat Pattern Tree. For example, the following configuration rules can be used to guide the selection of a piercing operation:

A hole will be stamped by a piercing operation.

The shape of the piercing punch is derived from the contour of the hole.

The direction of the piercing operation will be same as the burr-side (the burr-side is the additional design specification input by the user during the feature-modelling phase).

If the specified burr height is low, an additional shaving operation is required to shave away the excessive burr height produced by the piercing operation.

Similarly, the following configuration rules can be used to guide the selection of the stamping processes involved in making a burring feature:

A pre-pierce and an extrusion operation are required to produce a burring.

The piercing operation must precede the extrusion operation.

The diameter of the piercing hole can be calculated from a table relating the pre-pierce hole size to the principal dimensions of the burring.

The shape of the extruding punch can be calculated from a table relating the punch dimensions to the principal dimensions of the burring.

As mentioned earlier, the design of the strip layout is a highly iterative process demanding a considerable degree of guidance from the user. Therefore, there is a need for the user to interactively design certain stamping processes and also to guide the overall planning process to develop the strip layout. The design of the notching punches to stamp out the shape of the external profile and the staging of the die operations are two of the activities that require user's attention. These activities require a considerable amount of image processing and cognition skills. Interactive computer aids are provided for the user to input his decisions to the computer. The heuristics involved in these two interactive design activities will not be discussed in this paper, as it has been thoroughly treated in another paper (Cheok et al., 1996).

It is important to highlight some shape representation techniques used to support the spatial reasoning process in developing the strip layout.

First, a 2D boundary description technique is used to characterize objects in terms of the shapes of their boundary. The information can be used for calculation of distances, areas, centroids, and to check whether certain design requirements (such as spatial and strength) are fulfilled. This technique is primarily used to represent the shape information of objects on the strip layout and used to locate the positions of ancillary components (i.e., fasteners, dowels, pins, etc.) of the die on a plate. Boundaries can be described either by the actual profiles of the objects, or by their circumscribing circles/rectangles/polygons. The spatial reasoning of these boundaries are supported by a set of numerical routines performing the following functions:

Location of intersection point(s).

Determination of whether a shape is inside, outside, or overlaps another shape.

Combining two contours into one.

Enlargement of a shape by offsetting its edges.

Calculation of geometrical properties of the boundaries (area, edge length, center of pressure, centroid, etc.)

Transformation of boundary.

Another task in the die design process is to select the standard die components that can be purchased directly from the die component manufacturers. Standard components are preferred to custom-made ones as they are usually cheaper and readily available. A 1D skeletal simplification of 2D shapes approach has been adopted for punch shape recognition. This imaging processing and shape recognition technique has been discussed in greater details in another paper (Cheok et al., 1997).

The deduction of the Die Operations Tree is shown in Figure 6. Here, the Die Operations Tree is constructed from the features stored in the Flat Pattern Tree using the configuration rules described in this article. For example, the object Pierce1 is deduced using information provided in object Hole1, the objects Extrude0 and Pierce1 are deduced from Burring0, etc. The actual strip layout and the Die Operations Tree configured using the techniques described for the part shown in Figure 3 are given in Figure 7. The Die Operations Tree represents all the die operations that are required to fabricate the part while the strip layout is the graphical representation of the spatial arrangement of the corresponding operations on the die.

6. CONFIGURING THE PROGRESSIVE DIE

The main objective for the task of configuring the progressive die is to deduce the 3D geometrical representation of all its components such that when they are assembled together, they form a working die satisfying constraints imposed by operational, strength, and maintenance requirements.

The symbolic description of the synthesis of the 3D description of the die from the 2D strip layout is illustrated in Figure 8. The representation of the Die Assembly Tree in

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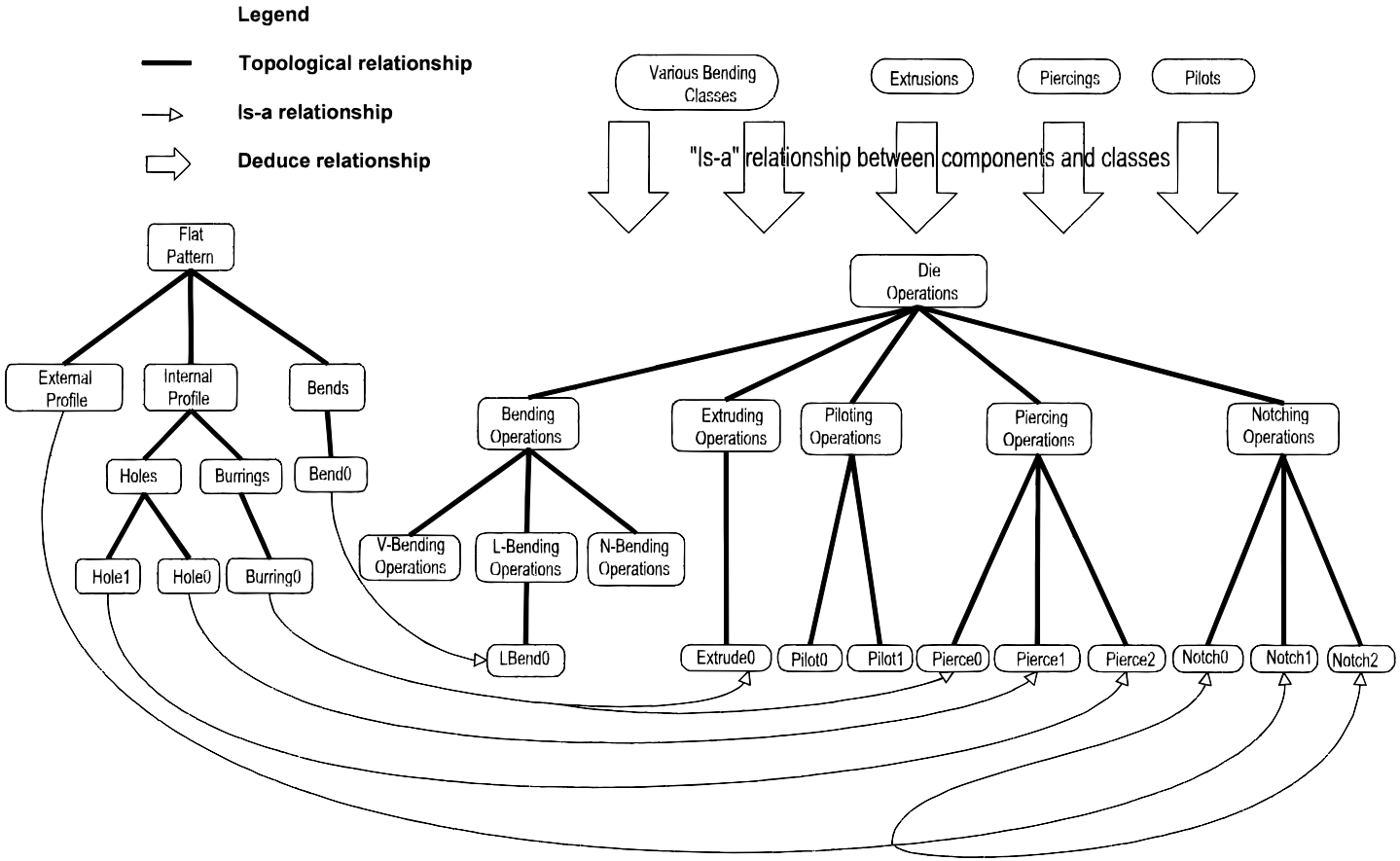
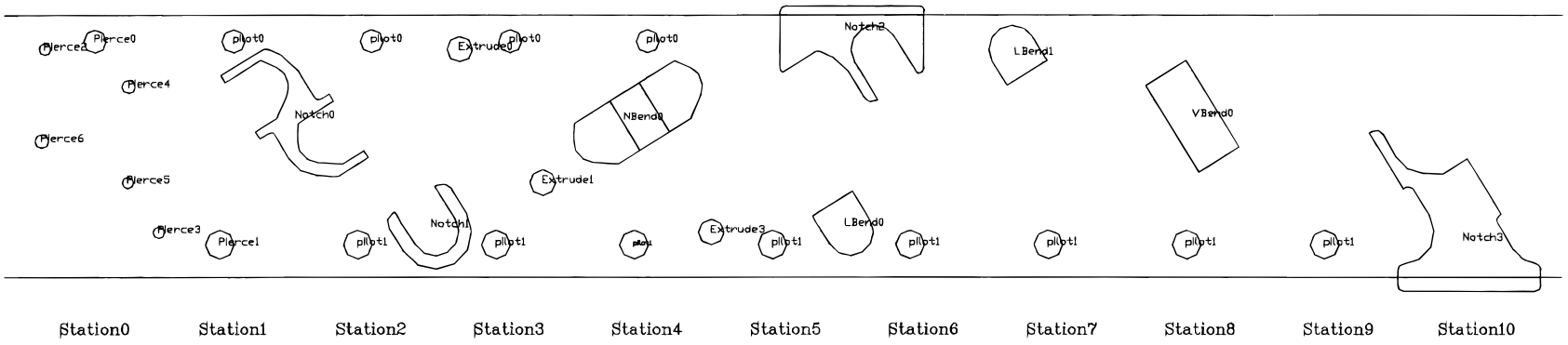


Fig. 6. Symbolic relationship between objects in the Flat Pattern Tree and the Die Operations Tree.

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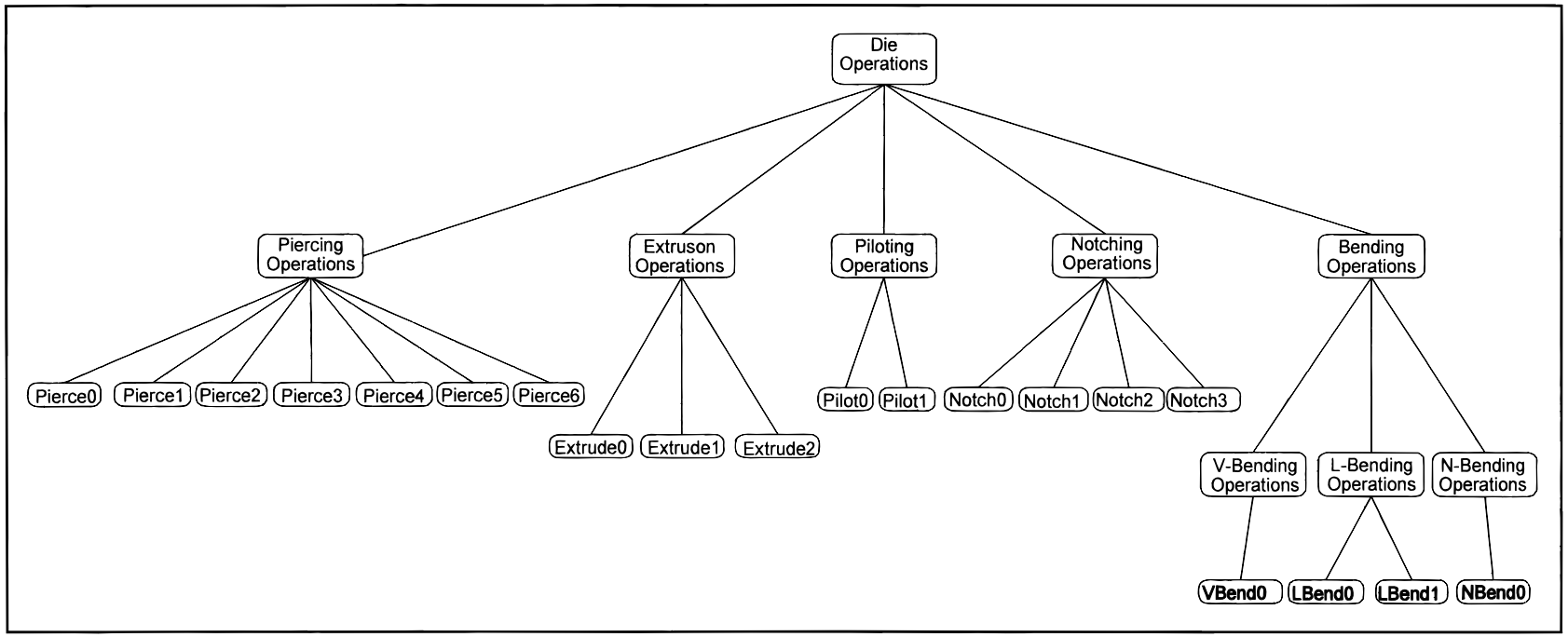


Fig. 7. The strip layout and the Die Operations Tree for the part shown in Figure 3.

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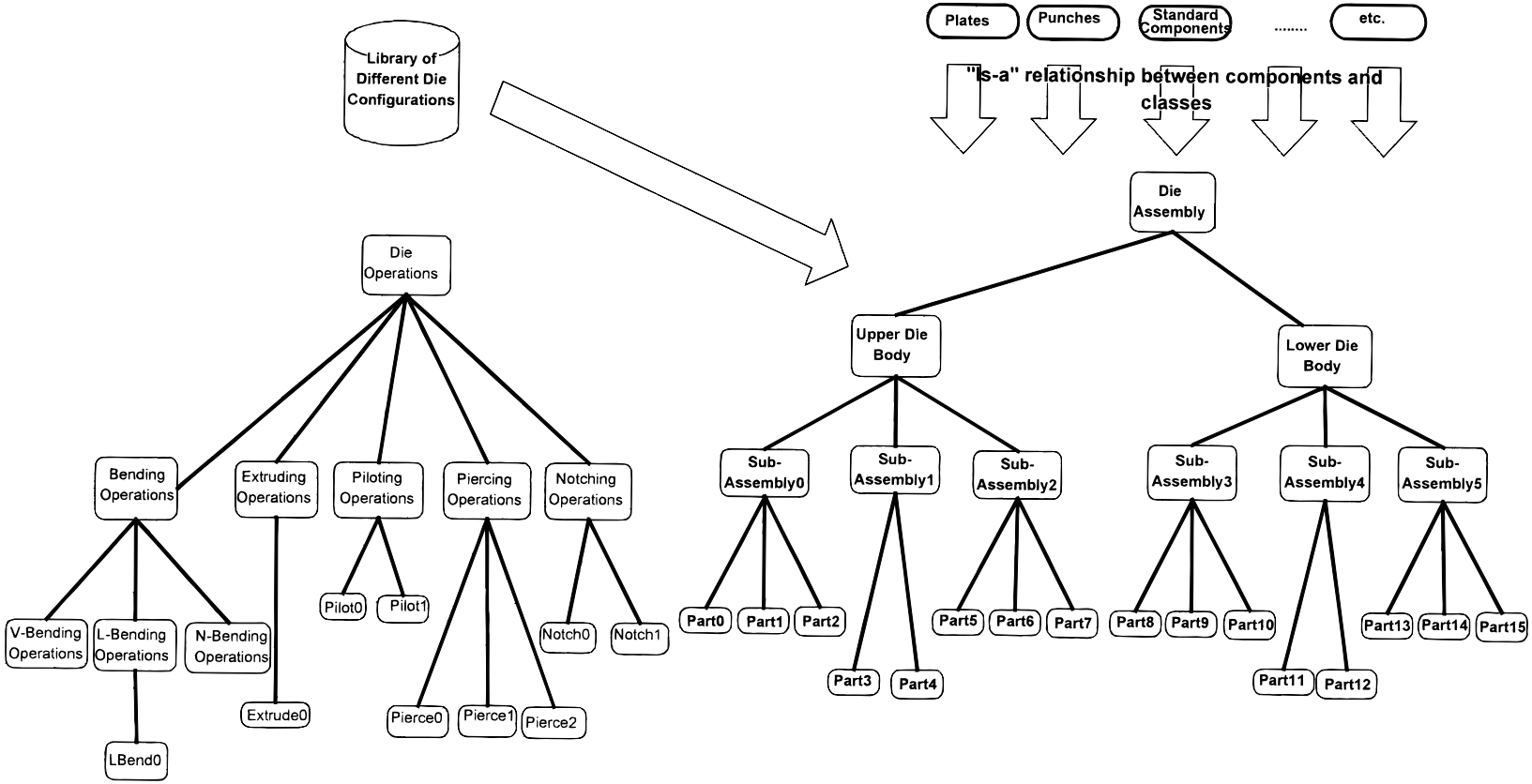


Fig. 8. Symbolic relationship between objects in the Die Operations Tree and the Die Assembly Tree.

Figure 8 is only a simplified symbolic representation. The actual part-of relationships among the tooling components in the Die Assembly Tree are shown in greater details in Figure 9. The configuration of the progressive die is based on the following broad principles.

The overall configuration of the die assembly is not fixed. Instead, it is based on a combination of die plates subassemblies. The combination of die plates to be used for a progressive die varies according to company practice. Hence, a library of template Die Assembly Trees is stored in the computer, and the selection of the actual configuration to be used is made via a dialogue box (Fig. 10).

The dimensional and topological information of the subassemblies are deduced based on either shape-descriptor or type-descriptor of the 2D shape boundary description of the respective die operations.

Some of the 3D descriptions of a punch and its opening at the punch holder plate can be derived from the shape- and type-descriptor based on the following rules.

IF: envelope shape of pierce contour is circular
THEN: use "shoulder" mounting to secure the punch to the punch plate.
IF: envelope shape of pierce contour is rectangular
THEN: use "block" mounting to secure the punch to the punch plate.
IF: envelope shape of pierce contour is irregular
THEN: use "straight" mounting to secure the punch to the punch plate.
IF: mounting type is "straight" Or mounting type is "block"
THEN: there is no need for locating dowel.
IF: mounting type is "shoulder" And punch shape is NOT "circular"
THEN: insert a locating dowel at the punch plate {to prevent the punch from turning about its axis}.

Upper Die Body	
Plating Sub-Assemblies	**Attached Components**
Upper Die Shoe (UDS)	Screw Plugs, Adjust Pins
Upper Backing Plate (UBP)	Nil
Punch Backing Plate (PBP)	Nil
Punch Plate (PHP)	Punches, Pilots, Sub Guide Pins, Stripper Bolt, Dowels, Fasteners, Coil Springs
Bottoming Plate (BTP)	Nil
Stripper Plate (STP)	Burring Die Unit, Fasteners, Sub Guide Bushing, Dowels
Lower Die Body	
Plating Sub-Assemblies	**Attached Components**
Die Plate (DLP)	Screw Plugs, Punch Guide Bushing, Pilots, Screw Plugs, Wire Springs, Fasteners, Guide Lifter
Die Backing Plate (DBP)	Nil
Lower Backing Plate (LBP)	Nil
Lower Die Shoe (LDS)	Adjust Pins, Guide Post.
Parallel Bars (PLB)	Nil

Fig. 9. Part-of relationships in a Die Assembly Tree.

In other situations, standard subconfigurations for other die operations are stored as templates in the die library and the actual subconfiguration selected for use will be based on a "type" descriptor. For example, bending operations are classified as "N" bends, "L" bends, and "V" bends (bend angle not necessarily 90°, direction of bend can be either "Up" or "Down"). For a particular type of bend, a standard subassembly consisting of templates of bending punch, bending block, pressure pad, etc.) are predefined. The actual dimensions of these components are then derived from the dimensions of the features.

A simple Function-Spatial language can be used for the spatial reasoning leading to the location of "orthogonal" parts in the die assembly. The basic syntax of this topological description statement of a part is as follows:

{function} {relative position descriptor} {neighboring part list} {additional description},

where

{function} is a word describing the function of the owner part, for example: Secured, Placed, Inserted, etc.

{relative position descriptor} is a word describing the relative position of the owner part to the {neighboring part list}. For example, AtTop, AtFront, FromTop, Through, etc.

{neighboring part list} is a list identifying the neighboring parts that are used to provide information to calculate the relative location or dimension(s) of the owner part.

{additional description} is a optional word used to provide additional information for the topological description statement. For example, Blind, Through, etc.

The above statement can be used to select the positions and certain dimensions of "boxy" parts that are orthogonal in orientation such as plates, screws, dowels, springs, pins, etc. The arrangement of other components that cannot be handled by this spatial reasoning technique are "hard-coded" into the respective objects. Figure 11 shows two examples of how these topological descriptions are used to assemble die components.

The topological description statements are predefined for each of the relevant class of objects in the die component library and stored as slots in the respective class. Each class of object may have more than one topological description statement. Hence, objects created in the Die Assembly Tree will inherit these statements. All parts in the upper die body take reference from the upper die shoe. In other words, spatial reasoning starts from the plate just below the upper die shoe. Similarly, parts in the lower die body are assembled with respect to the lower die shoe. The spatial reasoning task to assemble the parts is implemented as a goal driven forward-chaining system. For a plate with dimensions that

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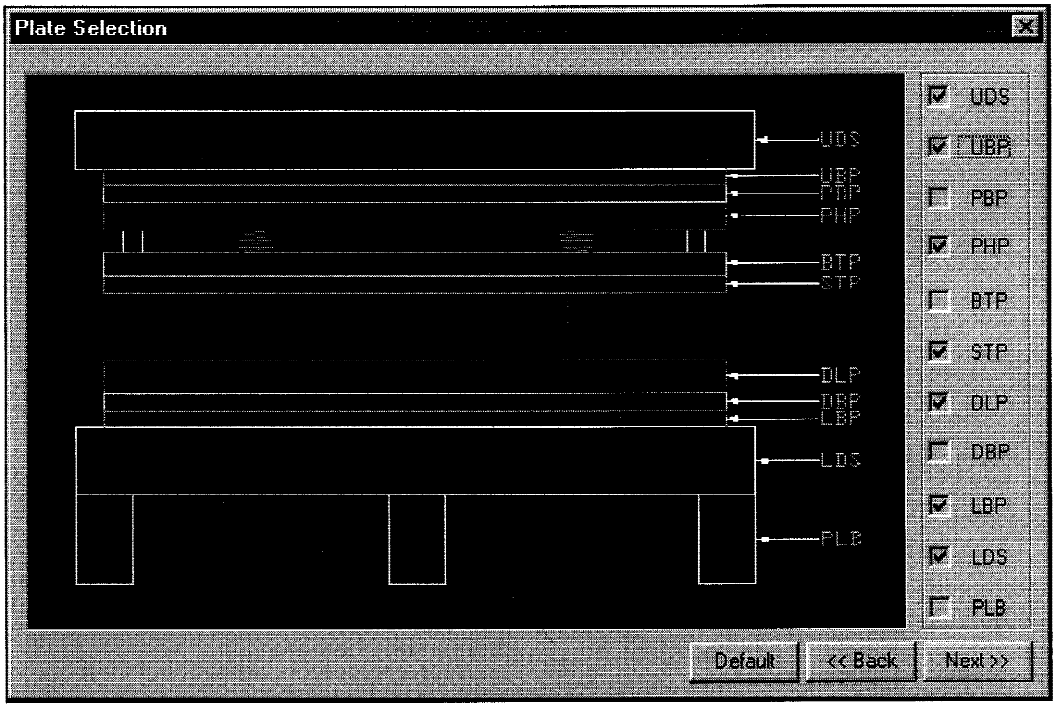


Fig. 10. Dialogue box for the user to select the combination of structural plates as the basic configuration for the progressive die.

are derived from design consideration (and not from topological links), the goal is to find the location of the part. For ancillary components such as screws and dowels, the goals are to find the location and to calculate certain missing dimensions (e.g., the length of a screw).

Using the shape representation and spatial/functional reasoning techniques and model-based reasoning approaches described above, a complete description of the progressive die can be configured and stored in the Die Assembly Tree. Thereafter, a solid model of the die can be generated. Figure 12 shows a partial assembly of the Upper Die Body of a progressive die generated to manufacture the part shown in Figure 3.

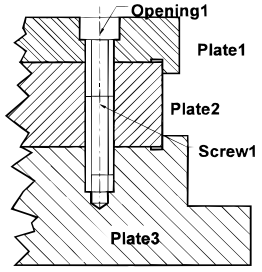
Parts	Statements	Illustrations
Screw1	1. Secured FromTop Plate1,Plate2,Plate 3 Blind 2. Flushed AtTop Plate1	
Plate1	Placed OnTop Plate2	

Fig. 11. Illustrations of some topological description statements.

7. OVERVIEW OF THE COMPUTER SOFTWARE ARCHITECTURE

An overview of the computer software architecture for the configuration of progressive die is shown in Figure 13. It is based on a client–server concept. The overall software architecture can be symbolically represented by two broad layers: an Applications Layer (clients) and a Design Knowledge Layer (server). The Applications Layer provides the front end for the design system. It consists of four main modules for die design, that is, Features Modeller, Unfolder, Strip Layout Planner, and the Die Configurator. These design modules provide the programs to control the man–machine communications during the iterative feedback design cycle and the dynamic data exchange (DDE) conversations and transactions between the clients and the server applications. The Autocad Husk provides the functionalities for the 2D and 3D wire-frame graphical representation of design objects in Autocad. The ACIS provides the functionalities for the construction of 3D solid models to represent die objects for display in Autocad or ACIS viewer. The Design Knowledge Layer is a DDE server application that provides information to the client applications during the design process. It also provides a storage mechanism for the objects and rules required to support die design. The Design Knowledge Layer is supported by a suite of "intelligent" libraries that provides the class and rule-based templates for the construction and manipulation of the various information structures (design trees) representing the product, the flat pattern, the process plan (strip layout) and the progressive die.

This modular software architecture helps to ensure that the design system can be ported from one CAD/CAM sys-

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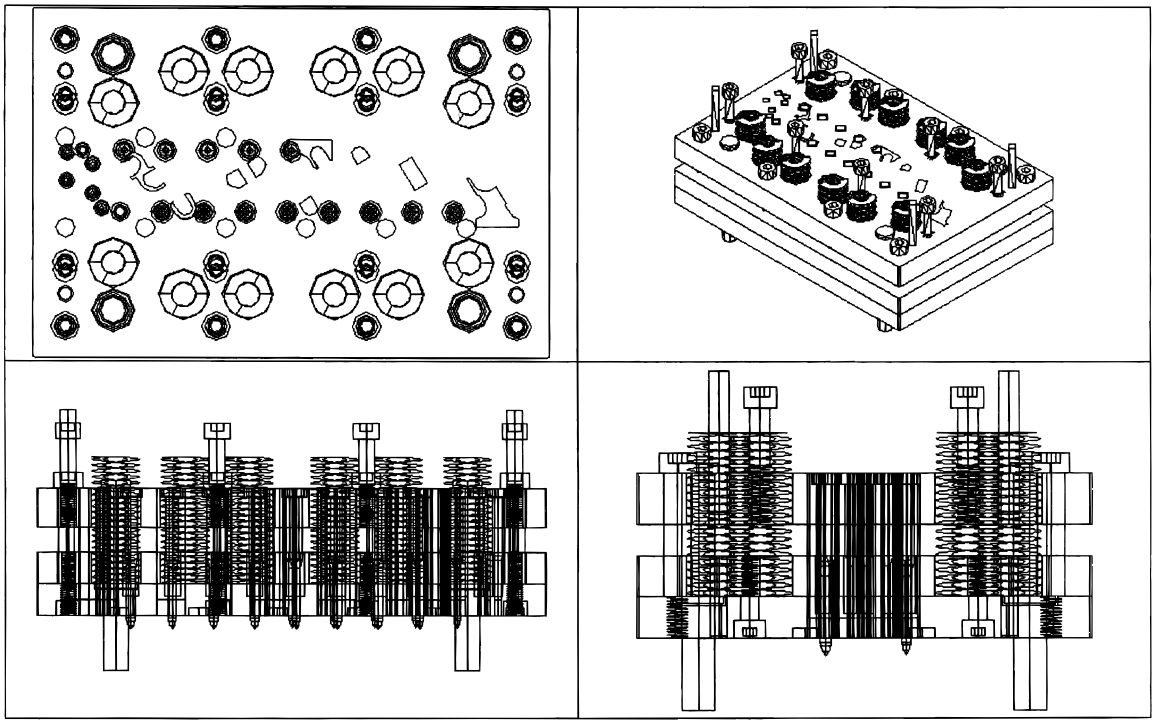


Fig. 12. Wire-frame representation of the upper body of the die that can be used to manufacture the part shown in Figure 3.

tem or solid modelling kernel to another. It is noted that a large portion of the codes for the design system is developed solely using the C^{++} programming language and the Microsoft Foundation Class Library (MFC) provided by Microsoft Visual C^{++}. The only modules that are dependent on the CAD/CAM system and the solid modelling kernel are the husks. This means that the core design modules can be readily integrated with other CAD/CAM systems or solid modelling kernels that run under the Microsoft Windows operating environment. This can be achieved by implementing the appropriate CAD/CAM or solid modelling kernel husks.

8. DISCUSSION AND CONCLUSION

It can be seen that the automation of the die design procedure is a daunting task. Existing commercial die design systems are mostly 2D drafting aids targeted at producing 2D die drawings faster. A review of existing research activities related to automated progressive die design indicates that some researchers tend to concentrate on finding solutions to one specific problem relating to die design without suggesting how the solution can be integrated with the other die design activities. Other researchers concentrated on developing progressive die configuration programs that are limited in capabilities (for example, only piercing and notching or limited to parts will straight orthogonal edges) or for the design of specific products (e.g., door hinges).

A prototype progressive die design system has been developed using the concepts explained in this paper. It has been used successfully to design metal stamping dies of several industrial collaborators. The prototype design system has the following features.

The system allows the die designer to work with 3D models of the metal stamping, the strip layout, and the progressive die. The ability to work with real-life 3D models enhances greatly the productivity of the die designer. Three-dimensional computer models also help to reduce errors as they can be detected quickly by the designer. The automatic generation of 3D die plates also helps to improve the downstream manufacturing productivity as they can be directly input into CAM software for the simulation and generation of tool paths.

The system does not place constraints on the geometry of the metal stamping and is able to design working dies to mass-produce metal stampings of any arbitrary shapes. In other words, it has the potential to be developed into an industrial tool for die design.

The industrial approach in die design is to copy the geometrical information from one 2D drawing to another and continuously synthesize new information. It would take a good die designer several days to develop the production drawings to fabricate components required to make the die to mass-produce the metal stamping described in Figure 3. Using the prototype system, the solid model of the die can be developed in one day.

This paper proposes a unified approach encompassing all the steps involved in progressive die design capable of handling metal stampings found in electronic equipment and appliances. The relative success of the approach described in this paper can be attributed to the following factors.

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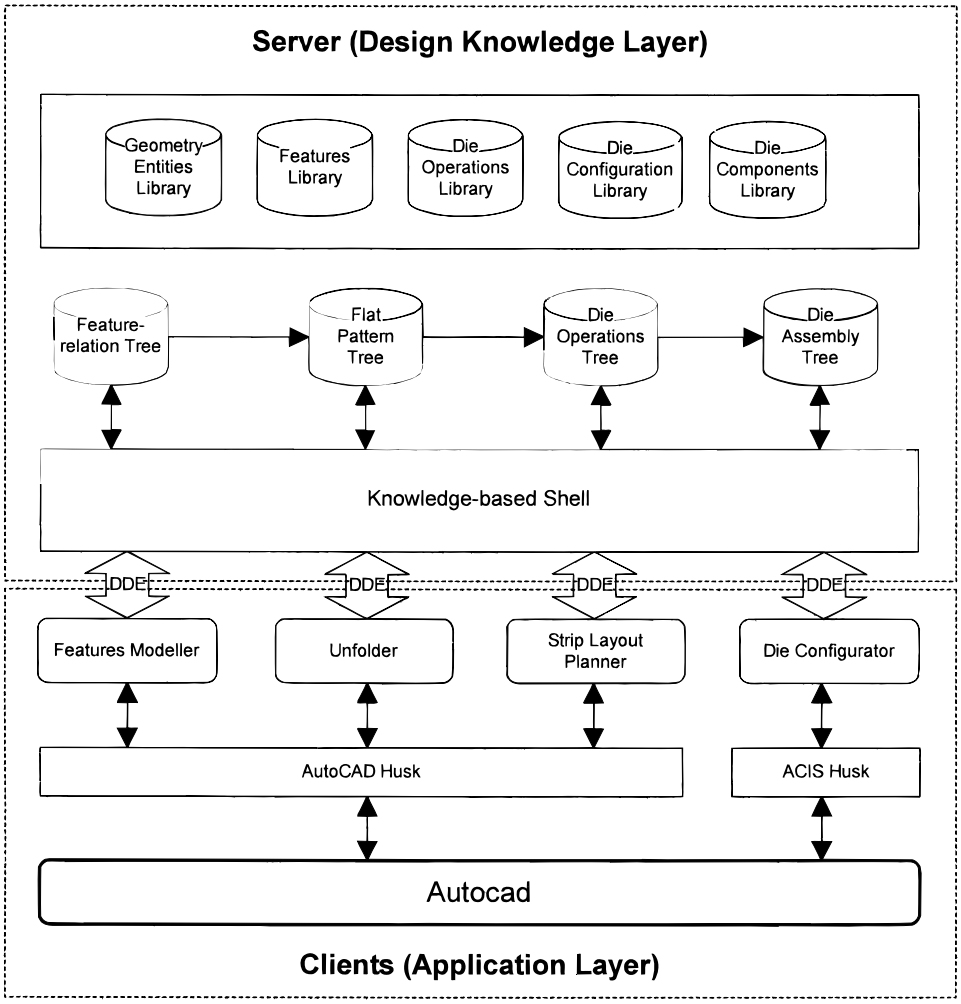


Fig. 13. Computer Software Architecture of the die design system.

Recognition that the die design process is a complex iterative feedback design cycle.

Using the use of superior human skills in pattern recognition, application of cognitive knowledge and decision making to guide the computer-based configuration of progressive die.

De-coupling large complex problems into smaller and more manageable problems.

The use of a consistent and reliable knowledge base to support the configuration process.

It is believed that the prototype system can be further developed into an industrial system that would satisfy the needs and greatly enhance the productivity of the die designer.

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