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CADDS: an automated die design system for sheet-metal blanking

This article reports on the design and implementation of a Computer-Aided Die Design System (CADDS) for sheet-metal blanks. The system is designed by considering several factors, such as the complexity of blank geometry, reduction in scrap material, production requirements, availability of press equipment and standard parts, punch profile complexity, and tool elements manufacturing method. The interaction among these parameters and how they affect designers' decision patterns is described. The system is implemented by interfacing AutoCAD with the higher level languages FORTRAN 77 and AutoLISP. A database of standard die elements is created by parametric programming, which is an enhanced feature of AutoCAD. The greatest advantage achieved by the system is the rapid generation of the most efficient strip and die layouts, including information about the tool configuration.

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Introduction

Tool design is one of the most important tasks to be performed in the manufacture of sheet-metal components. Tool design in sheet-metal, after many years of experience, today still remains more an art than a science. This is due to the complexities involved in the tool design procedure, where several mutually interacting factors must be considered.

It is commonly believed by most of the industry that tool design is essentially a trial-and-error process, and that only with experience and observation can you become a tool design expert. So far, such a belief has prompted companies to invest substantial amounts of time and money in training beginners, but not much is done in developing a scientific approach to die design. Therefore, the state-of-the-art is such that much of die design is done empirically by human experts with little or no computer aids, which is more time-consuming and involves higher costs.

An integrated CAD/CAM system for die design would result in quantifiable cost and time savings by improved standardisation, and could provide a permanent and confidential source of expertise. Furthermore, such a system could serve as a valuable consultant for experts and as a dependable training aid for beginners.

Literature review

An ideal press tool design should yield minimum wastage, minimum cycle time, optimum tonnage and optimum load centre etc. Since there are too many parameters to be considered for press tool design, it may not be possible to study different alternatives manually. To reduce such problems, several CAD systems for die design have been developed.[1-11]

The foundation for CAD in sheet-metal manufacture appears to have been laid when Schaffer[1] developed the Progressive Die Design by Computer (PDDC) system in 1971. Later Fogg and Jaimeson[3] improved the PDDC system by considering various factors which influence the die design, and they also explained how the factors were interrelated. They split their system into ten different modules; each would perform a specific task for the designer. A novel feature of this system is that the user is given full control; this retains a proportion of individuality for the designer. The limitations of the PDDC system are that the system is semi-automatic and it takes a very long processing time.

Shibata and Kunitomo[5] developed an experimental sheet-metal CAD/CAM system, whose main purpose is the design of blank and die layouts with the aid of a graphics display. However, the system cannot generate full-dimensioned mechanical drawings ready for use. Nakahara *et al.*[6] introduced a die design system for progressive dies, in which the procedure is divided into ten steps, each independent of the other. As a result, the procedure for the design of new dies and modifications for old dies is greatly simplified. In this system, they also introduced the concept of basic patterns corresponding to the standard punches; by using this concept, the most effective blank and strip layouts and tool configuration can be created. However, this system has not been implemented, and its capabilities in real life have not been tested.

Shirai and Murkami[7] developed a CAD/CAM system for progressive dies. The system is capable of generating assembly drawings and dimensioned part drawings as the final outputs. However, the limitation of the system is that the strip layout and die layout have to be done manually by the designer. The Cold Press Die Design and Manufacturing System (CPDDMS) developed by Ying[10] has overcome some of the above-mentioned limitations. However, this system is supported only on a mainframe computer, with advanced database support (Unify), which is beyond the means of the

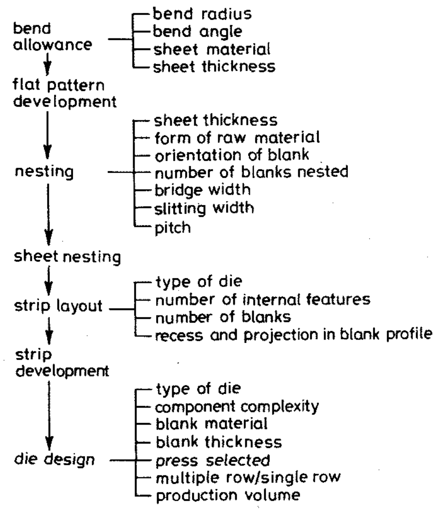

Fig. 1 Factors affecting die design

average tool and die company.

The system developed by Nee[11] consists of three modules. A blank layout module is developed first, followed by flat pattern development and design considerations of progressive dies. The limitations of Nee's system are the approximation of blank profiles by means of straight lines and the inaccuracy in calculating the bend allowance. The bend allowance parameter calculated in the flat pattern development module may not be accurate enough, because it is calculated by considering only the geometry of the bend without reference to the material properties.

With the advent of CAD/CAM technology, several software packages for die layout and progressive die design systems have become commercially available. Auto-Trol, Intergraph, Radan Computational and Computervision are some of the organisations involved in promoting the commercial systems. However, these packages are often supported on expensive systems that are beyond the reach of a small tool and die manufacturer. In addition, these commercially available systems could not be customised easily to suit the various in-house practices and rules of individual companies.

This article deals with the design and implementation of a Computer-Aided Die Design System (CADDS) for sheet-metal blanks. Although the present system[12,13] is not comparable with many of the existing systems in terms of facilities, it is within the reach of small manufacturers, since it is implemented on a mini-computer and it works without any additional software support. Another additional advantage of this system is that it can be used by a novice who may not have any knowledge of tool design.

Factors influencing system design

Many of the metal stampings that form part of a product element are two-dimensional; some may have been formed into intricate and complicated profiles by bending and drawing operations. In order to design press tools for producing these types of metal stampings, a tool designer has to know their developed shapes to calculate the correct size of the blank to be cut. Accurate dimensions on the developed blank can be assigned only when all the bending allowances and the position of the related features, such as holes and slots from the bend lines, have been carefully considered. To design a stamping die, it is also necessary that the blanks are accurately laid in the strip/sheet in order to optimise the material utilisation, after considering constraints such as grain orientation and bridge width.

After evaluation and completion of the nesting stage, the actual tool design commences with an initial strip layout stage. The information calculated in the previous stages, such as pitch, slitting width, blank orientation etc., is used as a basis for the strip and die layouts. Fig. 1 shows the various stages involved and the factors affecting die design for sheet-metal blanks.

Modular structure of the system

The modular structure of the Computer-Aided Die Design System (CADDS) is shown in Fig. 2. The functional description of various modules of the system is presented below.

Input module: this module gathers the geometric and technical data about the blanks. It receives geometric information about the blanks, the angle of orientation, the number of blanks, slitting width, pitch, and production requirements from the nesting stage. This module accepts the geometric data about the blank or cluster of blanks in any standard data exchange format, such as DXF.

Graphic interface module: this module converts the geometric information about the blank into numeric form and stores it in the CADDS database. The stored geometric information is then transferred to the technology check module for testing the feasibility of manufacturing the blank. The same graphic interface module is used to convert the numeric information generated by the die design module into the final assembly drawings.

Technology check module: the purpose of this technology check module is to assess the feasibility of the given sheet-metal blank for the blanking process. It checks whether the given blank profile can be easily produced by sheet-metal stamping. This includes identification of those geometric regions that make the blank profile more complex, and that make it either difficult or impossible to produce it by sheet-metal blanking. A checking algorithm has been implemented to prove the acceptability of the blank profile.

The input required for the technology check module is the sheet thickness, sheet material properties and geometrical information about the blank. Once this information is available, the technology check module examines the acceptability of

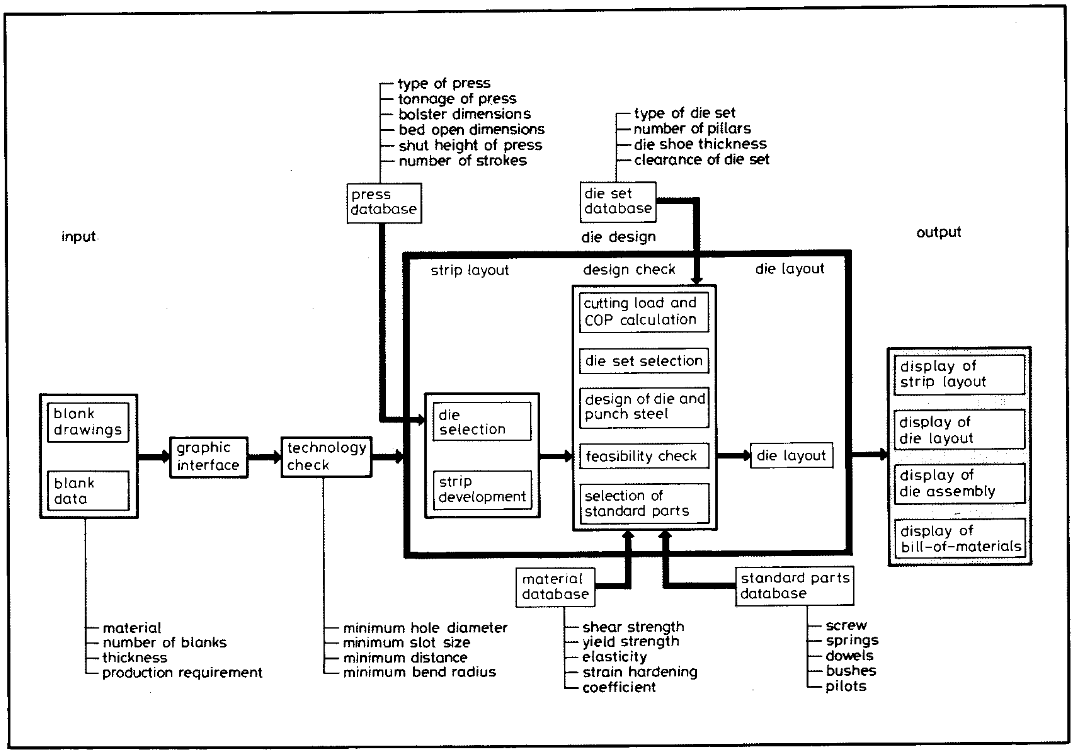

Fig. 2 Modular structure of CADDS

the blank profile according to the incorporated rules.[9] In the case of an unacceptable blank profile, the algorithm identifies the unacceptable areas with necessary recommended values to match the requirements of the sheet-metal blanking. It suggests to the designer the possible changes in the blank profile for easier manufacturing. Fig. 3*a* shows a blank profile that is difficult to produce by stamping, and Fig. 3*b* shows the blank profile that is the result of the technology checking module.

Die design module: this module has three further sub-modules, namely, the strip layout module, design check module and die layout module. The overall structure of the die design module is shown in Fig. 4.

In the strip layout module, the die type is selected, depending on the input parameters such as sheet thickness, accuracy of the blank to be produced, production requirements and the complexity of the blank geometry. The factors influencing the selection of the type of die are shown in Fig. 5. If the selected die is progressive, strip development is subsequently carried out. The details of the strip layout, such as the number of stages, pitch, slitting width and punch profile details in each stage, are transferred to the design check module. If the selected die is a compound or simple die, the geometric information from the nesting stage is directly transferred to the design check module.

The design check module reports some of the design procedures incorporated in the development of CADDS. This module is mainly responsible for the calculation of the centre of pressure (COP) and cutting force,[16] the design of various elements of the die such as die and punch steel, stripper, punch holder, back-up plates, and so on. This module also checks the feasibility of the designed elements against safety and manufacturing constraints. In addition, the design check module interacts with standard parts libraries and extracts standard parts, such as fasteners, springs, dowels and bushes,

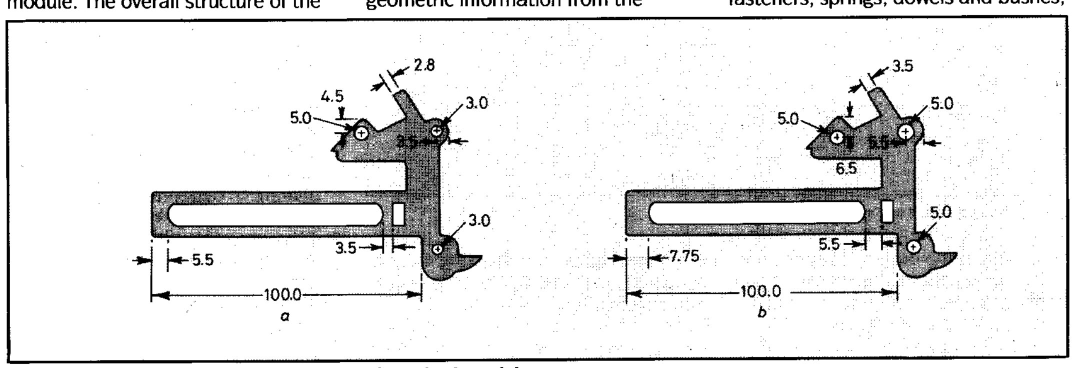

Fig. 3 Blank profile resulting from the technology check module

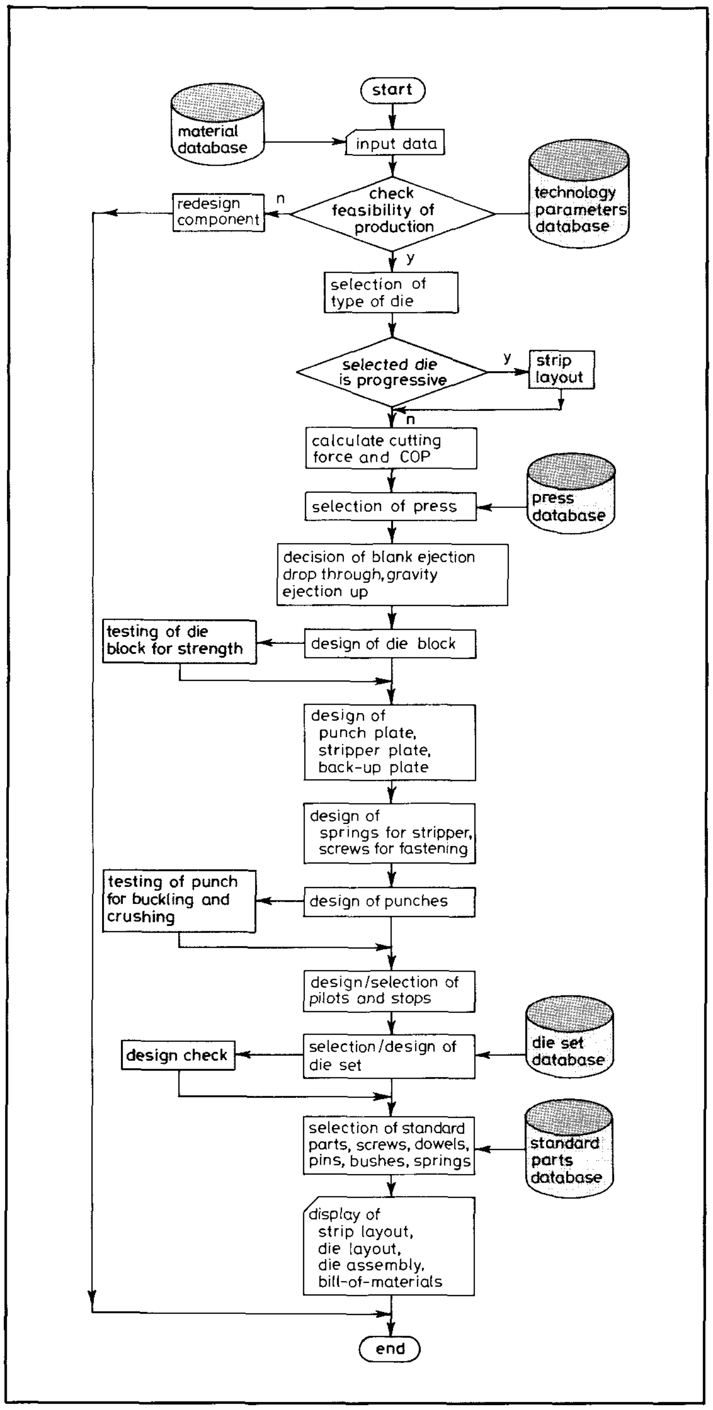

Fig. 4 Overall structure of the die design module

according to the design requirements.

The die layout module obtains information from the design check module. For the developed strip layout, and subsequent die design, this module generates the assembly of the die layout by extracting various standard parts and by designing other non-standard elements, along with a detailed bill-of-materials. This module transfers the complete geometric data about the die assembly and all other relevant details to the output module for display purposes.

Output module: this module receives data from the die design module. It displays the two views of the complete die assembly by making use of the graphic interface module. It also displays the strip layout, die layout and detailed bill-of-materials of the designed die assembly. In addition, the system is also capable of displaying detailed part drawings of the assembly on different layers, details of the selected press, die set type and standard parts.

Design considerations for strip layout

Individual operations performed in a progressive die are often simple, but when combined with several stations, the most practical design for the optimum die becomes difficult to devise.[2,8] The sequence of operations in a strip and the details of each operation must be precisely developed in order to produce a blank economically. Certain basic rules incorporated in the system[4,14] for the strip layout are summarised as follows:

- The system analyses the blank profile, for division into small shapes suited to the machining technique to be employed, by considering tooling strength calculations whenever complex or weak sections are present. If the overall cutting dimensions of the blank are less than 300 mm, the complete blank profile is produced in one stage; otherwise, the system performs strip development by dividing the blank profile into simple shapes in order to avoid using complicated punches. This constraint is imposed by considering the limitations of the wire-cut EDM machine on which the die block and punches are machined.
- The system analyses the internal features of the blank in order to identify pilot holes. Piercing these pilot holes is done in the first stage. If any interrelated features exist within these holes, they are also processed in the first stage, provided that their punch mounting permits them to do so.
- The system distributes the pierced holes over several stages, if they are close together and functionally not related. In case pitch notches exist, they are pierced in the first stage.
- If the minimum distance between the edge of the internal features and the edge of the die block is less than twice the die block thickness,[15,16] the system recommends an idle station to strengthen the die block, stripper

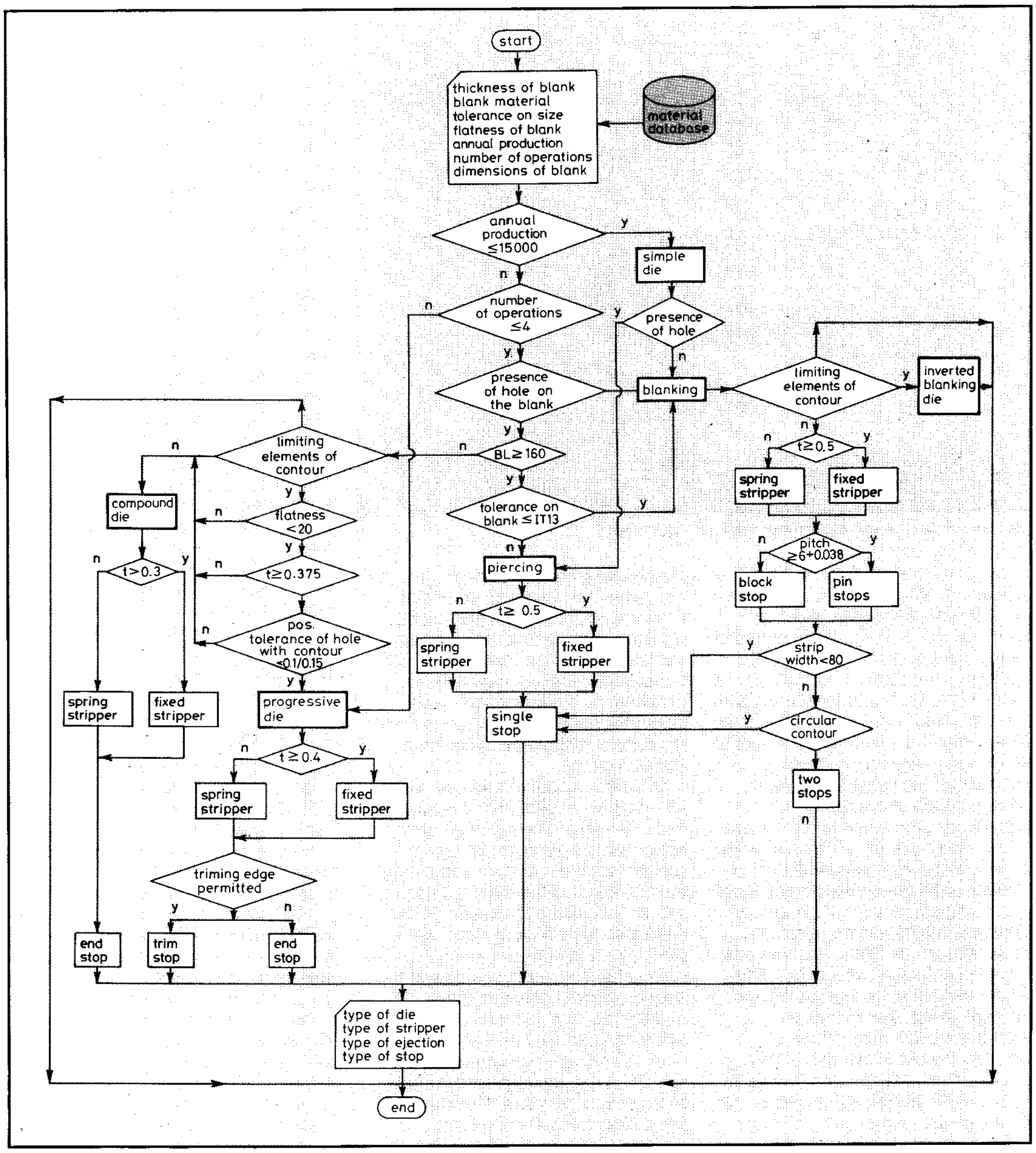

Fig. 5 Flowchart for the selection of die

plate and punch retainers.

- While developing the strip layout, the system has sufficient bridge width to provide maximum strength for the bridges and carriers.
- The system locates cutting and forming areas to provide uniform loading of the press. The system also determines where a 'cutting' operation must be used in order to avoid developing excessive cutting forces in die projections.
- The system also designs the strip in such a way that it enables the component and its scrap to be ejected without interference.

Database for standard die elements

The database is developed by creating part libraries for various standard die elements. The part libraries are created according to IS standards, company standards and manufacturers' standards. In the IS standards, the data files are created according to Indian standards, whereas in the manufacturers' standards, the data files are created for different standard manufacturers for different products, such as UNBRAKO for fastening elements, DANLY EUROP for die springs and other components of die sets, and VICTOR DIE SETS for die sets, pillars and bushes, and so on. Depending on the user's requirement, the particular standards are called by the system.

Overall functioning of the system

The input of the component geometry can be given through any standard graphic package that supports a data exchange format (DXF) facility. The system explodes

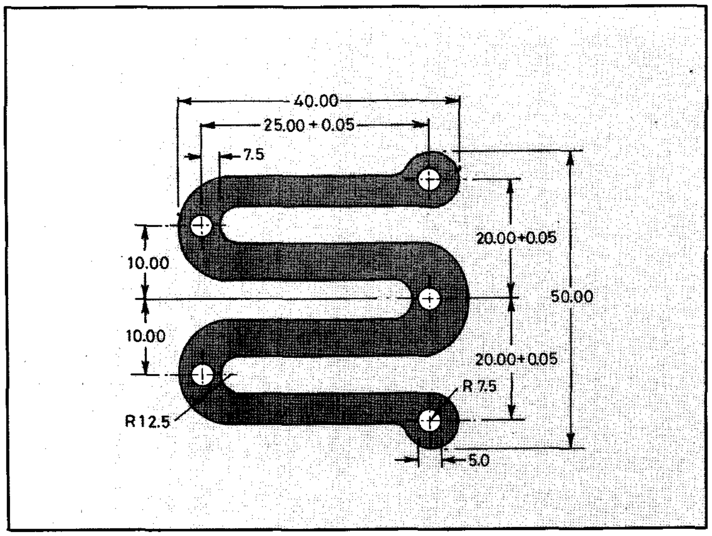

Fig. 6 Detailed drawing of a component for die design

blank geometry into basic entities such as arc, line and circle. It stores co-ordinates of the start and end points for line entities, co-ordinates of centre, start and end points for the arc entity, and centre and radii for the circle entity. The input for the CADDS is extracted from the output file of the CASNS module[13] and stored in a data file with the angle of orientation, thickness of the sheet and other features, which are used for subsequent processing in the system.

Once the input file is created by the system, it checks the feasibility of producing the given sheet-metal blank by a stamping process. It checks the relationship between two geometric elements such as fillets, recesses and projections. It also checks the bridge width between the blank profile and the edge of the sheet, between internal features of the blank, between the blank external profile and the internal features of the given blank profile, and finally it checks the minimum size of the hole/slot that exists in the blank profile. If they are too small, smaller than the usual recommendations, the material tends to slip at the cutting edges and also the layers of work-hardened material between the two sheared sections may interfere. The interference of work-hardened layers leads to the complete hardening of the material between the layers, which further leads to cracking. In the case of unacceptability in the blank profile or in the relationship between the different features, the system identifies unacceptable areas and suggests the recommended values to match the requirements of the sheet-metal stamping.

Initially, the system decides the type of die to be designed to produce the given component by considering the complexity of the blank profile, production requirements, accuracy of the blank and other related parameters. If the selected die is progressive, it develops the strip layout for the given blank according to the rules incorporated in the strip layout module.

Once the system completes the strip layout, it calculates the cutting force, centre of pressure and other related parameters necessary to complete the die design, and checks the feasibility of the design. First, the system calculates the length of the cutting contour from the developed strip layout, and then it calculates the cutting force in order to determine a setting position between the press and the die, and to calculate the stripping force. Depending on the number of stages and punch profiles in each stage, the system calculates the centre of pressure. Depending on the cutting force and overall dimensions of the blank, the system calculates the dimensions of the sub-guide posts, the number of springs, the number of screws for holding the die block, the stripper plate and the punch retainer. The positioning of the knock pins and springs are arranged around the punch contour at equal pitch. The screws and dowels are located around the perimeter of the die block in a straight line at equal pitch. If any error at equal pitch occurs, it is adjusted at the central position.

The system calculates the geometrical shapes of the die bushes and punches based on the shape of the blank profile in each stage of the strip layout, so that the shape may be automatically compensated for. The system then calculates the dimensions of the 'die layout area'. Based on the value of the die layout area, the system selects the suitable die set from the database, which includes thicknesses of lower and upper shoes, daylight of the die set, the diameter of the guide post, working length and width of the die set. Finally, the system selects other standard parts from the part libraries in accordance with the dimensions of the parts calculated in earlier stages, and then generates the detailed bill-of-materials.

Case study

The Computer-Aided Die Design System is implemented on an Apollo (Nexus-3000) workstation. This is a 32-bit mini-computer with a Motorola 68020 series CPU with 4 MB of main memory. The system is implemented in FORTRAN 77 under the AEGIS environment in a highly automated manner. The database for various standard die elements has been created in AutoLISP with the Parametric Programming Technique. The system extracts input information from the nesting module and stores this for subsequent processing. A sample blank tested on the CADDS system is shown in Fig. 6. The strip layout generated by the strip layout module for the given blank profile is

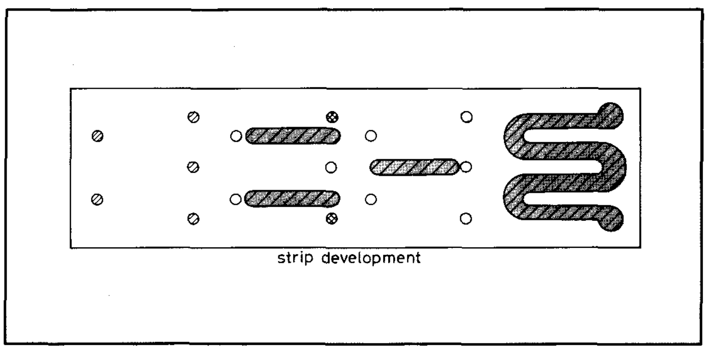

Fig. 7 Output of the strip layout module

21	flat spring	9-1204-11	sp. steel	3
20	intermediate stop	standard	standard	2
19	stripper bolt	M16 x 100	10·8 steel	6
18	guide bush	DR 19	standard	2
17	pilot	D5·6 x 11	tool steel	2
16	dowels	PR 65	standard	2
15	spring for stop	9-0606-11	sp. steel	3
14	CS screw	M5 x 30	12·9 steel	8
13	HSHC screw	M8 x 40	12·9 steel	6
12	dowel pin	PR 65	standard	2
11	pin stop	standard	standard	3
10	lower die shoe	DR 19	cast iron	1
9	die block	standard	tool steel	1
8	piercing punch	standard	col. steel	5
7	stripper	standard	CR steel	1
6	blanking punch	standard	col. steel	3
5	punch plate	standard	1040 SAE steel	1
4	back-up plate	standard	hrd steel	1
3	guide pillar	DR 19	standard	2
2	upper die shoe	DR 19	cast iron	1
1	shank	standard	semi steel	1
S.number	description	catalogue number	material	quantity

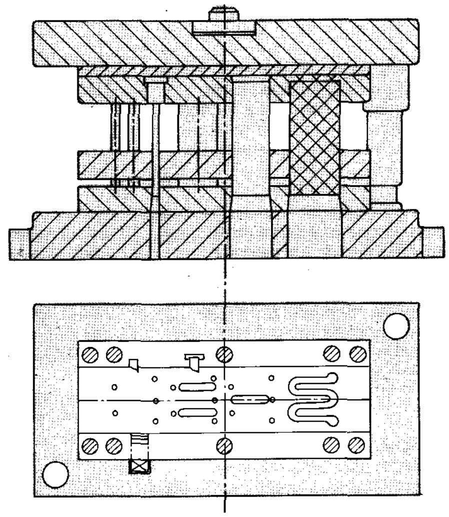

Fig. 8 Output of the die design module

shown in Fig. 7. Fig. 8 shows the die layout, die assembly and the detailed bill-of-materials, which is generated by the die design module for the given blank.

Conclusion

CADDS has been implemented on Apollo (Nexus-3000) workstation. The input for this system can be provided through any standard graphic package that supports the data exchange format (DXF). The system implementation is achieved by interfacing AutoCAD to run an external program coded in AutoLISP and FORTRAN. AutoLISP is used for parametric programming in order to create the libraries for standard parts. The system has been tested for a wide variety of sheet-metal components, and proved to be powerful and easy to handle because of its highly interactive nature. Current research effort is underway to improve CADDS by adding facilities such as an automatic dimensioning module and an extension for the design of the compound dies, and to integrate the Computer-Aided Sheet Nesting System with the present system through bend allowance and flat pattern development modules.

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