Journal of Manufacturing Engineering, December, 2012, Vol. 7, Issue. 4, pp 208-214

A REVIEW ON APPLICATIONS OF EXPERT SYSTEM TO DIE DESIGN

Sachin Kashid[1] and *Kumar S[2]

[1]Research Scholar, Department of Mechanical Engineering, S.V. National Institute of Technology, Surat- 395007, India.
[2]Associate Professor, Department of Mechanical Engineering, S.V. National Institute of Technology, Surat- 395 007, India.

ABSTRACT

Die design is one of the major activities in tool design department of sheet metal industries. The traditional process of die design is complex, time consuming and requires highly experienced die designers. Recently, various artificial intelligence (AI) techniques are being used in this area to minimize the dependency on human expertise and time taken in design process as well as to improve design efficiency. Expert system is one of the most powerful tools for solving engineering design problems which require human expertise. This paper presents a review on applications of expert systems to die design. Published literature in the domain area is summarized in tabular form. Based on the critical review of available literature, scope for further research work is identified.

Keywords: *Sheet Metal Industries, Die Design, Artificial Intelligence and Expert systems.*

1. Introduction

Sheet metal parts are important structural members of car bodies, aircraft, beverage cans, home appliances, telecommunication equipments and medical implants. To manufacture these parts various sheet metal operations are used in stamping industries because of their repeatability and high productivity [1]. Current market demands that sheet metal parts should be produced to accurate shape or near accurate shape with improved mechanical properties, a smooth surface finish, good dimensional accuracy and material savings depending on service conditions. Sheet metal industries require press tools or dies of good quality to carry out sheet metal operations economically without causing any surface or internal defects on parts and with high productivity. Die design is one of the important tasks in the production of these sheet metal parts. A typical compound die is shown in figure 1.Traditional procedure of die design is complex, tedious, time-consuming and highly dependent on human expertise [2]. Also, the quality of design depends on the designer's skill, experience and knowledge [3].

Computer aided design (CAD) systems are being used in sheet metal work since last 30 years. These systems provide assistance in drafting and analysis of sheet metal process, but human expertise is still needed to arrive at the final design [5]. Also, sometimes the high cost associated with setting up such systems is quite often beyond the reach of small and medium sized sheet metal industries, especially in developing countries. Various artificial intelligence (AI) techniques are being used for solving complicated problems efficiently in almost all areas of engineering. Expert system (ES) is one of the most powerful tools of AI for solving engineering problems which are complex, time consuming and highly experience-based. The basic idea behind the development of ES is simply that expertise, which is the vast body of task-specific knowledge, is transferred from human experts to a computer. This knowledge is then stored in form of coding in the computer and users call upon the computer for specific advice as needed. The computer can make inferences and arrive at a specific conclusion.

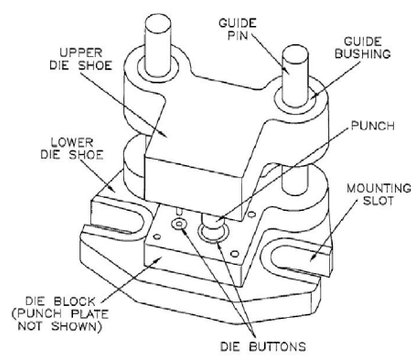

Fig. 1 A Typical Compound Die [4]

Recently, some researchers have developed expert systems for manufacturability analysis of sheet

*Corresponding Author - E- mail: skbudhwar@med.svnit.ac.in

metal parts, process planning and die design. In this paper, major published literature in the area of applications of expert systems to die design is reviewed. Salient features of some important systems developed by worldwide researchers are presented in tabular form and then finally, need of future work is identified.

2. Review of Expert System for Die Design

Traditional methods of die design being used in sheet metal industries involve numerous calculations and decisions which have to be made on the basis of experience, knowledge and practice without the computer aids. With the advances in computer graphics and CAD/CAM systems, some researchers have started to exploit these for the design and manufacture of dies.

Later on, some AI techniques were developed by researchers. But the die designers have realized the applications of AI tools around 1980. Some researchers have worked on development of expert systems for process planning and design of dies to ease the difficulty of die designers and process planners and to reduce manufacturing lead time of sheet metal parts.

Nakahara et al. [6] introduced a progressive die design system that examines the part design data to decide whether it can be stamped by blanking operation or not. However, the system was not capable to check internal and external design features for assessing manufacturability on progressive die. Also there is no report about the tests carried out to prove its capabilities in real life. Xiao et al. [7] developed an expert system using a set of production rules and frames for process planning of axisymmetric deep drawing parts. The system is suited to the process planning of general drawing process and to the strip layout of progressive drawing of axisymmetric parts. Hoffmann et al. [8] developed a bending-sequence generator using expert system approach to computerize the process-planning of sheet-metal parts. But planner's interaction is still required. Fang and Tolouei-Rad [9] developed a rule-based expert system for process planning of complex circular shells produced by deep-drawing process. Rules are framed from plasticity theory and empirical knowledge. System is coded in AutoLISP language. Lin and Peing [10] proposed an expert system on a PC/AT for sheet metal bending design. This expert system utilizes the qualitative data in a knowledge base and the quantitative data in a database, together with empirical design data to aid the user in design of sheet metal bending. Tisza [11] reported to develop a metal forming expert system called METEX using principles of group technology for process planning of multi-stage forming processes. It uses AutoCAD software and AutoLISP language to generate possible forming solutions for deeply formed or drawn shapes. It adopts a hybrid classification utilizing both geometric features and manufacturing characteristics for coding of parts to form part families for automatic process planning. Further, Tisza [12] proposed two main approaches one of them may be regarded as knowledge based (KB) process planning, whilst the other as simulation based process planning for deep drawing processes. He integrates knowledge and simulation based approach by linking commercial CAD and FEM systems. Goel and Chen [13] used an expert system network approach for development of a system of material selection in engineering design. The expert network is comprised of an expert system integrated with neural network. The neural network was developed using C++. The neural network is used in conjunction with an expert system. The PDC prolog is used for developing the expert system. Cheok and Nee [14] proposed KBS approach for planning and design of progressive dies. Sing and Rao [15] proposed a knowledge-based process layout system for axisymmetrical deep drawing using decision tables. The knowledge in system is represented using decision tables. The decision table contains production rules, fuzzy sets, or frames. The system consists of two main modules. One module determines the drawn cup type and other one module determines the generative design process. System is coded using C and AutoLISP language. AutoCAD is used to input the part geometry and output representation. Singh and Shekhon [16] reported to develop an expert system for optimal selection of a press for sheet metal operations. This system comprises of a shop-specific data base on press machines and a knowledge base comprising of a set of production rules of the IF–THEN variety. Production rules are coded in AutoLISP language. The system is capable of computing the minimum force required for carrying out a given sheet metal operation, identifying the suitable presses, computing the unit manufacturing cost corresponding to each candidate machine and selecting the best press machine. But this system can handle only simple shearing operations. Futher, they [17] also developed a low-cost expert system for assisting process planners working in small and medium sheet metal industries. The system helps in the selection of an optimal process plan for sheet metal operations.

Choi et al. [18] developed an automated CAD system for progressive working of irregular shaped metal products and lead frame for semiconductors. This system is developed for piercing operations using knowledge-based rules. It is written in AutoLISP using AutoCAD on a PC and the I-DEAS drafting programming language on the I-DEAS master series drafting with an HP 9000/715(64) workstation.

Transference of data between AutoCAD and I-DEAS master series drafting is accomplished using DXF and IGES methods. This system is structured in form of five modules, which are input and shape treatment, production feasibility check, strip-layout, data conversion, and die-layout modules. Further Choi with other team of researchers [19] developed a modular design support system for axisymmetric deep drawing process. This System used case based reasoning (CBR) approach to suggest various possible process sequences for a product. Reasoning code and FE simulation code constructed by means of C language and GUI system built by means of Visual C++ were integrated into a system. Pilani et al. [2] used a hybrid intelligent systems approach for die design in sheet metal forming. In this approach artificial neural networks (ANNs), knowledge-based systems (KBSs) and finite-element analysis (FEA) for modeling the design process are used. Thereafter, a simulation-based design approach is used for the die design process. ANN module is trained from FEA results for a generic set of component geometries, process conditions, and material properties. The final die design validation is carried out by FEA. Intelligent framework incorporates rules for material selection, process parameter selection and their modification. Kang and Park [20] proposed a computer-aided process planning system for rotationally symmetric deep drawing products. The production rules are generated and upgraded by interviewing field engineers. The system consists of three modules - 3D modeling module, blank design module and process planning module. It is written using AutoLISP language integrated into AutoCAD software. Shi et al. [21] developed a knowledge-based process planning system to support auto panel die development and design automation. Case-based and rule-based reasoning approaches are used and supported with the CAD tool UGII. Knowledge is coded in Intent programming language of UGII. Park and Prasad [22] reported to develop a computer-aided process planning system for non-axisymmetric deep drawing products. A surface area calculation for non-axisymmetric deep drawing products with elliptical shape was constructed for a design of blank shape of deep drawing products by using AutoLISP function of AutoCAD software. The system consists of four modules – recognition of shape module, 3-D modeling module, blank design module and process planning module. The production rules based on the industrial practice were generated for elliptically shaped deep drawing products and the system was constructed for non-axisymmetric deep drawing products. Kumar and Singh [23] proposed production rule based low cost KBS framework for design of progressive die. This framework recommends for developing various KBS modules to tackle major activities for die design. Based on this framework they [24-27] developed modules for selection of die-set, selection of other major components of progressive die; automatic modeling of progressive die and strip-layout design for sheet metal work on progressive die. Production rules incorporated in all modules are coded in AutoLISP language and designed to be loaded in the prompt area of AutoCAD software. All modules of the system are user interactive.Ramana and Rao [28] proposed an automated manufacturability evaluation system for sheet metal components in mass production. The prime objectives of the system are design evaluation, process planning, and data and knowledge modeling. The system unites the features of rule- and plan-based methods of evaluation and all the three manufacturability verification, manufacturability quantification and manufacturability optimization phases of evaluation for shearing and bending processes. Lee et al. [29] developed an expert system for the trim die design in the automotive industry. The system consists of a rule-base, a design process control module and a geometric modeler. The rule-base includes design rules and know-how of design specialists and CATIA is used to provide CAD environment. Lin and Kuo [30] proposed an integrated CAD/CAE/CAM system for stamping die development of trunk lid outer panels using a concurrent engineering approach. The system is based on 3D surface construction CAD software STRIM, CAD/CAE software CATIA, stamping formability analysis software DYNAFORM, CAM software CADCEUS, a stamping design KBS, and a product database. It was claimed that the system can greatly reduce the development time and cost, improve the product quality and reduce the manufacturing lead time. Lin and Hsu [31] proposed an automated design system for drawing dies. It uses pre-built design knowledge base and database to design the main components of a drawing die, such as upper dies, lower dies and blank holders. The user is required to enter inputs of design information of blank lines, die faces, punch open lines, press data, and types of subcomponents such as hooks, guides, and stopper seats. This system is built on top of CATIA V5, and makes use of its built-in modules, including Part Design, Automation and Scripting, and Knowledge Advisor. Hussein [32] developed an expert system for sheet metal dies. Visual Basic is used to implement the main control module, which guides the data transfer between all the system modules. Script files embedded in Visual Basic are used to construct modules for design of 14 different blanking die shapes. The system is claimed to perform some important tasks related

Table 1: Summary of Major Research Work in the Area of Applications of ES to Die Design

Authors	System Details	Remarks / Limitations
Nakhara et al. [1978]	Used the concept of basic pattern as per standard punches interactive strip layout.	Not capable for checking design features of sheet metal parts.
Hoffmann et. al. [1992]	A bending-sequence generator using ES approach to computerize the process-planning of sheet-metal parts.	Deals with only bending parts. Also experienced planner's interaction is required.
Lin and Peing [1994]	ES consisting of knowledge base (KB), data base and design experience KB, possesses flexible developing capabilities concerning sheet-metal bending design.	Deals with only sheet metal bending design.
Tisza [1995]	Rule based ES based on the principles of Group Technology (GT) for process planning of multi-stage forming processes of deep drawing die.	Semi-automatic approach. Need inputs from experienced designer.
Cheok and Nee [1996]	Used KBS approach for planning and design of progressive dies.	Semi-automatic approach. Developed specifically for progressive dies only.
Sing and Rao [1997]	Knowledge in the system is represented using decision tables. The decision table contains production rules, fuzzy sets, or frames for process planning of axisymmetric deep drawing parts.	Developed for the process planning of only deep drawing parts.
Singh and Shekhon [1999, 2005]	Used ES for selection of suitable press machine and for process planning of sheet metal operations.	Developed mainly for shearing operations performed on a blanking die.
Choi et al. [2000]	An automated CAD system for progressive working of irregular shaped metal products and lead frame for semiconductors. This system is developed for piercing operations using knowledge-based rules.	Developed for specific application and for piercing operations only.
Kang and Park [2002]	Production rule based CAPP system written in AutoLISP for rotationally symmetric deep drawing products.	Deals with only rotationally symmetric deep drawing parts having elliptical shapes.
Shi et al. [2002]	Case-based and rule-based reasoning approaches are used and supported with the CAD tool UGII. Knowledge is coded in Intent programming language of UGII. Developed case-based and rule-based system for design of auto panel die	Developed for specific application (auto panel) and expert designer is required to operate the system.
Ramana and Rao [2005]	Used the features of rule- and plan-based methods of evaluation and all the three (manufacturability verification, manufacturability quantification and manufacturability optimization) phases of evaluation for shearing and bending processes.	Developed for design evaluation and process plan generation for typical sheet metal parts to be produced by shearing and bending processes only.

Kumar and Singh [2004, 2005, 2007, 2008]	Production rule based ES for design of progressive dies. Rules are coded in AutoLISP language. System generates intelligent advices for selection of die components and drawing of strip-layout, die components and die assembly of progressive die	Developed specifically for design of progressive dies.
Lin and Hsu [2008]	Used pre-built design knowledge base and database to design the main components of a drawing die. The die design system is built on top of CATIA V5.	Developed specifically for drawing die. Need expert designer to operate the system.
Hussein [2008]	Production rule based ES for design of blanking dies. Visual Basic is used to implement the main control module, which guides the data transfer between all the system modules.	Developed specifically for blanking die.
Hwang et al. [2009]	Used rule based KBS for automated design of progressive die.	Developed specifically for design of progressive die.
Babu et al. [2010]	Used ES approach using ANN model to predict the deep drawing behavior of welded blanks made of steel grade and aluminium alloy base materials.	Developed for specific application.
Naranje and Kumar [2011, 2012]	Used production rule based KBS approach to design deep drawing die. Rules are coded in Auto LISP language and user interface is created using Visual Basic 6 on AutoCAD platform.	Developed specifically for design of deep drawing die.

to blanking die design including shape recognition of sheet metal part data in 2D, data extraction, data analysis, optimum die type selection, checking manufacturability, die block design and automation of design process of blanking dies. The system is based on interactive method for optimizing and automating blanking die design in both 2D and 3D. Further Hussein and Kumar [33] proposed a computerized retrieval system for sheet metal parts. This system assists die designers and process planners in reducing the manufacturing cost of sheet metal parts through retrieval of old designs available in the data base of the tool design department of company. Hwang et al. [34] developed an automated progressive design system with multiple processes such as piercing, bending and deep drawing for manufacturing products. The knowledge required for this system is formulated from plasticity theories, experimental results, and the empirical knowledge of field experts. The system is based on knowledge-based rules and is designed in consideration of several factors, such as the material and thickness of a product, the piercing, bending and deep drawing sequence, and the complexities of blank geometry and punch profiles. The system is claimed to perform the task of strip-layout and die design automatically.

Babu et al. [35] proposed an expert system using artificial neural network (ANN) model to predict the deep drawing behavior of welded blanks made of steel grade and aluminium alloy base materials. PAM STAMP 2G finite element (FE) code is used to simulate the forming behavior and to generate output data needed for training the ANN. Tsai et al. [36] developed a process planning and die design system for automotive panel production using knowledge-based engineering (KBE) methodology. Naranje and Kumar [37] proposed a low cost expert system framework for design of deep drawing die. The task of building the system is structured into various modules for major activities of the design of deep drawing die. A manufacturability assessment module of the proposed framework is also developed to check the design features of deep drawn parts. Further they [38] developed a KBS for selection of components of deep drawing die. The system uses production rule based approach and consists of eight modules. Production rules are coded in AutoLISP language and user interface is created in Visual Basic 6 on AutoCAD platform.

Major research work in the area of applications of expert systems to die design is summarized in Table.1.

3. Comments on Reviewed Literature

From the review of available literature it is found that the applications of expert system are explored mainly in the area of manufactuability assessment of sheet metal parts, process planning and design of single operation dies. Very few systems are reported in the literature for design of multi-operations dies. Even these systems are not capable to fully automate the die design process. In addition these require skilled and experienced die designers to take appropriate decision during various stages of process planning and design of die. Literature is not available in the area of development of expert systems for design of compound dies.

4. Conclusion and Scope of Further Research

Traditional process of die design is manual, complex, time-consuming and costly as it uses design methodologies based on physical prototyping. Commercially available CAD/CAM/CAE systems are also not capable to ease burden of experienced die designers. With the advancement in artificial intelligence (AI) techniques and CAD, various researchers have developed computer aided systems to reduce complexity; minimize human error and time taken in design process as well as to improve die design efficiency. But most of the systems developed using AI techniques are having limitation in extraction and representation of part feature data in more interactive format for displaying output. Also, nobody has tried to develop an expert system for design of compound die. Therefore, there is stern need of development of such system for design and modeling of compound dies. This type of system will provide a great help to the process planners and die designers working in sheet metal industries. The developed expert system must have low cost of implementation so that it can be easily affordable by small and medium scale stamping industries, especially in developing countries.

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