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DESIGN OF DEEP DRAWING DIE: AN EXPERT SYSTEM APPROACH

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ABSTRACT

This paper describes a low cost Expert System (ES) framework for design of deep drawing die and procedure for developing system modules. The task of building the system is structured into different modules for major activities of the design of deep drawing die. A manufacturability assessment module of the proposed framework is developed to check the manufacturability of deep drawn parts. Effectiveness of the proposed manufacturability module is demonstrated by taking industrial part as an example. The technological knowledge is represented by using IF- THEN rules and it is coded in AutoLISP language. The module is designed to be loaded into the prompt area of AutoCAD. The cost of implementation of the proposed system makes it affordable for small and medium scale sheet metal industries.

Keywords: *Expert System, Deep Drawing Die and Manufacturability*.

1. Introduction

Traditionally the task of design of deep drawing die is performed by highly experienced die designers. Several factors are to be considered during design of deep drawing die, such as material properties, lubrication between die and work material, press rigidity, punch and die geometry, die materials and processing methods [1], and it involves numerous activities such as determining number of draws required, calculations for blank holding force and drawing speed, design/selection of various die components etc. [2]. The traditional methods for carrying out these tasks require expertise and are largely manual and therefore tedious, time consuming and error-prone [3]. Also the knowledge gained by die design experts after long years of experience is often not available to others even within the same company. It creates a vacuum whenever expert retires or leaves the company [4]. Commercially available CAD/CAM packages provide some aid to die designers and process planners to perform simple calculation, storage and retrieval of data, and visualization of part geometry. But these software packages are failed to integrate various die design activities and unable to combine logically various functions of die design. Recently, many researchers have worked on the development of expert system (ES) for process planning and design of metal stamping die to ease the difficulty of die designers and process planners and to reduce manufacturing lead time of sheet metal part. As a results, few expert systems in process planning and design of deep drawing die have been evolved in order to improve the decision making process in design of deep drawing die. The expert systems evolved include manufacturability check, selection of type of die, selection of various process planning parameters and die material. Eschel et al. [5] developed a rule based expert system for generation of forming process outlines system for cylindrical deep drawn parts. Xiao et al. [6] proposed a rule based expert system for process planning of axisymmetric deep drawn. Sitaraman et al. [7] developed a hybrid computer-aided engineering (CAE) system for automatic process sequence design for the manufacture of axisymmetric deep drawn parts. System integrates expert system and a process modeling analysis module. Fang et al. [8] developed a rule-based system expert system for process planning of complex circular shells produced by deep-drawing process. Rules are formed from plasticity theory and from empirical knowledge to calculate the initial blank diameter, diameter and other dimensions of the shell, determine annealing necessity, selection of appropriate lubricant and drawing speed. Tisza [9] developed a modular system called Metal Forming Expert System (METEX) for process planning of multi-stage deep drawing. System is coded using AutoLISP and provide an interface of AutoCAD. Sing and Rao [1] proposed a decision table method for development of an expert system for process planning system of axisymmetric deep drawing process. The knowledge of the system is represented using decision tables system and decision table contains production

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rules, fuzzy sets, or frames. The system consists of two main modules. One module determines the drawn cup type and the other module determines the generative design process. The system is coded in AutoLISP. Park et al. [10] developed a computer-aided process planning system for rotationally symmetric deep drawing products parts. Pilani et al. [11] has been reported to have developed a hybrid system using ANN and ES approach to optimal design the die faces of forming die. Zhang et al. [12] developed a computer-aided process planning for multi-stage, non-axisymmetric sheet metal deep drawing using a case-based reasoning (CBR) approach. Lin et al. [13] proposed an integrated CAD/CAE/CAM system for designing stamping dies for trunk lid outer panels of automobile.

Literature review reveals that most of systems developed for design automation of deep drawing die are prototypes in nature and restricted to specific application. Also these prototypes are unable to handle information from various sources effectively. Therefore, an expert system (ES) is required for the design of deep drawing die, which must have rich knowledge of experienced die designers, can logically integrate all design task of deep drawing die and have low cost of implementation. The present work describes ES framework for design of deep drawing die and a procedure for developing system modules. The proposed system will have low cost of implementation.

2. Proposed Expert System Framework

The proposed ES framework for design of deep drawing die is presented in Fig. 1. This proposed framework comprises of ES modules for different activities of design of deep drawing die. The user can interact with these modules through a user interface. Through user interface, the user inputs essential the part related data to the system and it displays the intelligent advice for the user's benefit. First of all, a module for checking the manufacturability of deep drawn parts is required to be developed. ES module for checking part design, checks the design features of the sheet metal component from manufacturability point of view. Such checks are useful to identify and resolve potential problems on the part such as splitting and excessive thinning or wrinkling. It helps to achieve desired quality and minimum cost for the deep drawn part. The knowledge base of this module must be capable of checking and giving advice for modification, if the design features are not in accordance with the rules of good practices.

The next ES module of proposed framework is for the selection of the type of die. It identifies the type of die for manufacturing the undertaken product in the optimal manner. There are several standard die structures and determinant factors for selection of proper die structure capable of producing a part economically and reliably. For process planning, various modules are required to be developed such as blank size calculation, determining of number of draws, calculation of limiting draw ratio, punch and die radius, drawing and blankholder force, optimum drawing speed, selection of lubricant and determination of other important drawing process parameters. These modules must be capable of handling simple as well as complex part geometry. Next, ES modules for design / selection of die components are required to be developed. The major die components are punch, die, plate elements, die-set, stoppers, fastening and locating elements.

The output of each module must be stored in different data files, which can be further used for modeling of die components, die accessories and die assembly using CAD facilities and suitable AI language. The knowledge base of the proposed system can be written using suitable AI language such as KEE, OOPS, PROLOG and LISP. The procedure being utilized for the development of each module of the proposed framework is described as under.

3. Procedure for Development of Expert System Modules

The procedure of the development of the proposed ES modules for design of deep drawing die is identified and schematically shown in Fig. 2. A brief description of each step is given in the following paragraphs.

3.1 Knowledge acquisition

Knowledge acquisition is the first step in the development of expert system. The domain knowledge of the design of deep drawing die is required to be collected from various sources of knowledge acquisition such as published literature, die design experts, catalogues and manuals of industries etc. The information obtained from the literature is not always the same as what is currently being practiced. The process of knowledge acquisition from die design experts involves presenting a few typical problems to the expert(s) and letting the expert(s) talk about the solution. During the verbal analysis, the expert(s) would be questioned to explain why a particular decision was reached.

3.2 Framing of production rules

The collected knowledge is represented using production rule-based systems. The syntax of a production rule is: IF <condition>, Then <action>. The

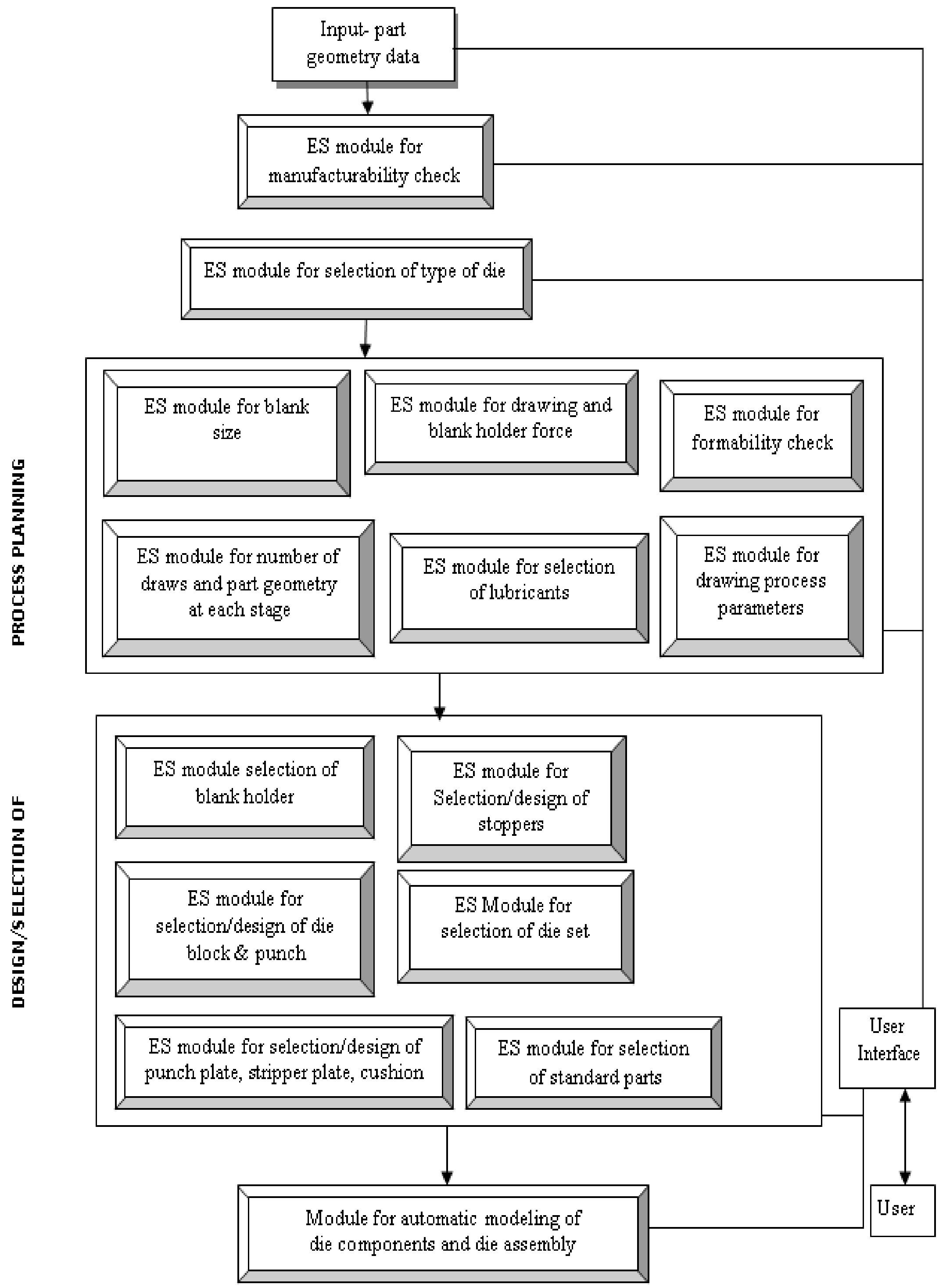

Fig. 1 Proposed ES Framework for Design of Deep Drawing Dies

condition of a production rule, sometimes-called LHS (left-hand side) contains one or more conditions, while the action portion, sometimes called RHS (right-hand side) contains one or more actions.

3.3 Verifications and sequencing of production rules

The knowledge of the design of deep drawing die is generally collected from discussion with die design experts. These rules may differ from industry to industry. Therefore, production rules framed for each module must be crosschecked from die design experts by presenting them IF-condition of the production rule of IF-THEN variety.

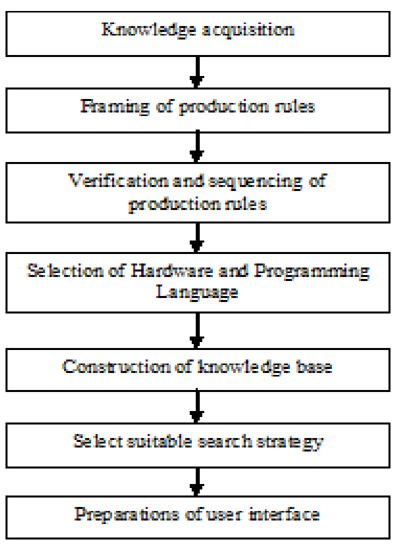

Fig. 2 Procedure for Development of ES Modules for Design of Deep Drawing Dies

The production rules can be presented in either in unstructured (arbitrary) or structured manner. But structured presentation of production rules is simple to refer and consume less time and if query is fired it take less time to get the result. Also ambiguity in understanding the knowledge will be less.

3.4 Selection of suitable hardware and programming language

Suitable hardware elements depending on memory requirement, processing speed and needed configuration should be selected. Today, most of the ES modules are being developed on a PC/AT because it involves low cost. The efficiency, flexibility, development cost and maintenance of ES largely depend on the programming language used. LISP and PROLOG have been won wide acceptance for building ES. But the user of LISP and PROLOG languages encounters difficulties when handling design problems involving graphical information. For this reason, AutoCAD and AutoLISP have found greater acceptance for the development of ES for die design.

3.5 Construction of knowledge base

Knowledge base is a part of the ES that contains domain knowledge, which may be expressed in the form of production rules of IF-THEN variety. The inference mechanism allows manipulating the stored knowledge for solving problems. The rules and the knowledge base must be linked together by an inference mechanism. The user input information provides guidance to the inference engine as to what 'IF-THEN rules to fire and what process of information is needed from the knowledge base.

3.6 Choice of search strategy

Inference mechanisms search through the knowledge base to arrive at decisions. Two popular methods of searching are backward chaining and forward chaining. Forward chaining is a good technique when all on most paths from any one of much initial or intermediate state converges at once or a few goal states. Backward chaining is an efficient technique to use when any of many goal states converge on one or a few initial states

3.7 Preparation of User Interface

ES modules should be interactive in nature. The purpose of user interface in the development of each module is twofold: (1) to enable the user to input the essential sheet metal component data; (2) to display the optimal decision choices for the user's benefit. The former is accomplished by flashing AutoCAD prompts to the user at appropriate stages during a consultation to feed data items. Messages or items of advice are likewise flashed onto the computer screen whenever relevant production rules are fired.

The above procedure has been utilized for the development of one ES module namely MCES (Manufacturability Check Expert System) of the proposed framework. The description of the same is given as under.

4. Expert System Module 'MCES'

Manufacturability assessment plays an important role in concurrent product and process development. It is generally estimated that decisions made at the stage of product design determine 70 to 80 percent of the manufacturing productivity [14]. A manufacturability check module labeled as MCES of the proposed ES framework is developed to check the manufacturability of deep drawn parts at early design stage of part. Heuristic knowledge for the construction of proposed module is obtained from various sources as discussed earlier. A sample of production rules incorporated in present module is given in Table 1.

These rules are coded in AutoLISP. The system incorporates an interface through which it asks the user to input the needed data. The user initially loads the program by using the command (LOAD "A: MCES.LSP") in to the prompt area of AutoCAD. After entering the required input data, the program scans through the production rules one after another. Whenever IF condition in a production rule gets satisfied, the module displays the THEN advice to the user.

5. Results: Sample Run of Module 'MCES'

The proposed module has been tested for manufacturability check of different types of sheet metal parts. Execution of module for one real industrial component (Fig. 3) is given through Table 2. The recommendations obtained are found to be reasonable and very similar to those actually used in industry (M/s Bhagyashree Accessories Pvt. Ltd., Pune Maharashtra, India) for the example component.

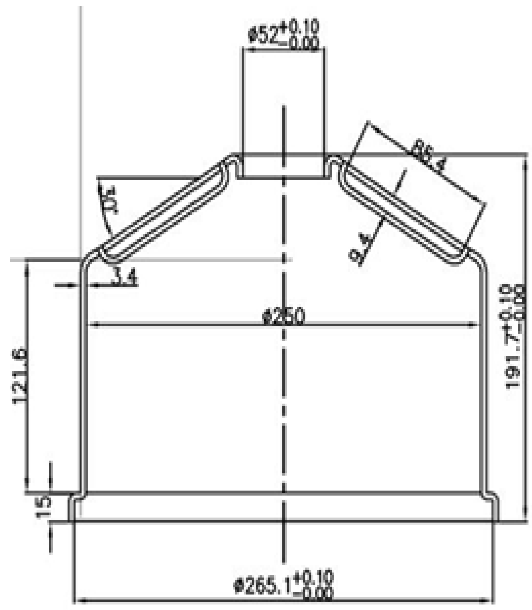

Fig. 3 Example Component (All dimensions in mm)

Table 1: A sample of Production Rules Included in the Proposed Expert System Module

S. No.	IF	Then
1	0.25 ≤ Sheet thickness(t) > 6.25 mm	Accept the sheet thickness
2	Diameter of raw material = Calculate blank diameter(D)	Accept the sheet material
3	Diameter of raw material < Calculate blank diameter > Diameter of raw material	Set diameter of raw material equal to calculated blank diameter
4	Material = EDD and Ratio of aluminum to Nitrogen = 10 %	Accept the sheet material
5	Material = EDD and 0.08 < Carbon contain percentage	Select another suitable material
6	Material = EDD and 0.17 < Anisotropy (n) > 0.25	Accept the sheet material
7	Actual drawing ratio ≤ limiting draw ratio	Accept the drawing ratio
8	Ratio of flange diameter (d_f) to shell diameter (d) < 1.1 and Sheet thickness ratio > 0.5% and shell height ratio ≤ 0.68	Accept shell height ratio
9	Sheet thickness ratio ≤ 0.25 %	Set Sheet thickness ratio > 0.25%
10	4t ≤ Punch radius > 8t, (t – Sheet thickness)	Accept punch radius
11	4t ≤ Die radius > 10t	Accept die radius
12	Ratio of flange diameter (d_f) to shell diameter (d) > 2.8 and Sheet thickness ratio > 0.06~0.2 and shell height to diameter ratio (h/d) ≤ 0.11	Accept shell height ratio

Table 2: Typical Prompts, User Responses and Expert Advice Generated during Execution of the Module

S. No.	Prompt	Example Data entry	Advice to User
1	LOAD "A: MCES.LSP"		Please enter command MCES
2	Please enter sheet material	M.S.EDD	
3	Please enter sheet thickness	3.4 mm	Accept the Sheet thickness
4	Please enter blank diameter	459 mm	Accept the blank Diameter
5	Please enter shell diameter	250 mm	Accept diameter of shell
6	Please enter flange diameter	265.1mm	Accept flange diameter
7	Please enter height of shell	191.7 mm	Accept height of shell
8	Please enter punch radius	5.4 mm	Set punch radius on part in mm = 13.4
9	Please enter die radius	15 mm	Set die radius on part in mm = 12
10	Please enter height of taper	70.1 mm	Accept taper height
11	Please enter taper angle	30 degree	Accept taper angle
12	Enter height to diameter ratio	0.37	Accept height to diameter ratio
13	Enter flange width to blank diameter ratio	1.02	Accept the flange width to blank diameter ratio
14	Enter sheet thickness ratio	0.0065	Accept the sheet thickness ratio

6. Conclusion

In this paper an expert system framework is proposed for design of deep drawing die. The procedure of the development of system modules is explained at some length. This methodology is being pursued for the development of different modules of the proposed framework of design of deep drawing die. The development procedure and execution of one module constructed for manufacturability check of deep drawn parts are also presented.

The rules are coded in the AutoLISP language and loaded into the prompt area of AutoCAD. The system supports the modification in knowledge base of each module depending on the newly acquired knowledge and addition of new modules for updating the system capabilities. The expert system developed using proposed framework can be implemented on a PC and hence has low cost of implementation and user-friendly

References

1. *Singh W and Rao K (1997), "Knowledge-Based Process Layout System for Axisymmentric Deep Drawing using Decision Tables", Computers and Industrial Engineering, Vol. 32, 299-319.*

2. *Lange K (1985), "Handbook of Metal Forming", Third edition, McGraw-Hill, New York.*

3. *Soman A and Campbell M (2002), "A Grammar-Based Approach to Sheet Metal Design", Proceedings of DETC02 ASME Design Engineering Tech Conf, Montreal, Canada, 485-493.*

4. *Kumar S (2006), "A Contribution to the Development of Knowledge Based System for Intelligent Design of Progressive Dies", PhD thesis, Maharshi Dayanand University, Rohtak, Haryana, India.*

5. *Eshel G, Barash M and Chang T (1985), "Rule-Based System for Automatic Generation of Deep Drawing Process Outlines", Intl. Jnl. of Computer Aided Intelligent Process Plan, Vol. 19, 1- 115.*

6. *Xiao X, Chen S, Wang G and Xiao J (1990), "An Expert System for Process Planning for Drawing", Adv. Tech. Plast, Vol. 1, 545 - 549.*

7. *Sitaraman S, Kinze G and Altan T (1991), "A Knowledge-Based System for Process Sequence Design in Axisymmetric Sheet-Metal Forming", Journal of Materials Processing Technology, Vol. 25, 247–271.*

8. *Fang X and Tolouei-Rad M (1994), "Rule-Based Deep-Drawing Process Planning for Complex Circular Shells", Int. Journal of Engineering Applications of Artificial intelligence, Vol. 7, 395 - 405.*

9. *Tisza M (1995), "Expert System for Metal Forming", Journal of Materials Processing Technology, Vol. 53, 423- 432.*

10. *Park S, Choi Y, Kim B and Choi R (1999), "A CAD/CAM System for Deep Drawing Dies in a Simple-Action Press", Journal of Materials Processing Technology, Vol. 8, 258–265.*

11. *Pilani R, Narasimhan K, Narayanasamy R, Maiti S and Singh U (2000), "A Hybrid Intelligent Systems Approach for Die Design in Sheet Metal Forming", Int. Journal of Material Science and Technology, Vol. 16, 370-375.*

12. *Zhang W, Tor S and Britton G (2006), "Indexing and Retrieval in Case-Based Process Planning for Multi-Stage Non-Axisymmetric Deep Drawing", Int. Journal of Advanced Manufacturing Technology, Vol. 28, 12 - 22.*

13. *Lin B and Kuo C (2008), "Application of an Integrated CAD/CAE/CAM System for Stamping Dies for Automobiles", Intl. Jnl. of Advanced Manufacturing Technology, Vol. 35, 1000 - 1013.*

14. *Suh N, Cochran D and Lima P (1998), "Manufacturing System Design", CIRP Annals – Manufacturing Technology, Vol. 47, 627-639.*

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