Journal of Manufacturing Engineering, December, 2011, Vol. 6, Issue. 4, pp 233-239

AN EXPERT SYSTEM FOR SELECTION OF PROCESS PARAMETERS OF DEEP DRAWING PROCESS

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ABSTRACT

The aim of the present work is to propose a low cost expert system (ES) for automatic selection of process parameters of deep drawing process. The production rule based expert system approach is utilized for development of the proposed system. The technological knowledge is represented by using IF- THEN rules and coded in AutoLISP language. The system is designed to be loaded into the prompt area of AutoCAD. The system output includes recommendations on the appropriate values of process parameters suitable for production of deep drawn parts. As the system can be implemented on a PC having AutoCAD software, therefore its low cost of implementation makes it affordable even for small scale sheet metal industries.

Keywords: *Expert System, Deep Drawing, AutoLISP and AutoCAD*

1. Introduction

Deep drawn sheet metal parts are available in variety of shapes, such as circular, box, or more-complex shapes, and their sizes vary from 6 mm in diameter or smaller to aircraft or automotive parts. Several process parameters such as draw ratio, punch load, draw speed, blankholder pressure; clearance etc. play very vital role in economic and defect free production of these parts. Several factors are required to be considered for selection of appropriate values of these process parameters, such as type of sheet material, part geometry, accuracy requirement, press rigidity, die materials, processing methods etc. [1]. Traditional process of selection of process parameters for deep drawing is highly complex, manual, time consuming and error-prone. It requires a high level of theoretical knowledge and practical experience on the part of process planners and die designers. 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 [2]. In some sheet metal industries various general purpose CAD systems are being used to assist process planners and die designers to perform some of the activities (such as drafting, simple calculations etc.) of design of deep drawing parts / die. But these are too narrow in scope, in the sense that they provide only point solutions [3]. The users are forced to use two or more CAD systems that must be compatible with each other, while many of these systems are stand-alone and expensive for small or medium-sized companies. Recently, some researchers have used various artificial intelligence (AI) techniques for solving complex problems in process planning and design of metal stamping dies to ease the difficulty of die designers and process planners and to reduce manufacturing lead time of sheet metal part. For example, Eshel et al. [4], Tisza [5, 6], Sitaraman et al. [7], and Park et al. [8] reported to develop rule based expert systems for generations of process plan for axisymmetric deep drawn parts. Other researchers [9-12] have utilized different techniques and tools of AI, like case based reasoning (CBR), object oriented programming (OOP), fuzzy logic, Artificial Neural Network (ANN) etc. for process planning of deep drawing process. Literature review reveals that very few systems have been developed for deep drawing process. Most of these systems are prototype in nature and restricted to specific application. Therefore, an expert system (ES) is required for the selection of appropriate values of process parameters for deep drawing process. This type of ES must have a knowledge base comprising of rich knowledge acquired from various sources of knowledge acquisition such as experienced die designers, process planners, die design handbooks, industrial brochures etc. It must be capable to logically integrate and consider all the factors which affects selection of appropriate values of these process parameters and have low cost of implementation. The present paper describes an expert system namely 'PPSES' for selection of process parameters for deep

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drawing process using production rule based approach. The system is sufficiently flexible, as its knowledge base can be extended and modified, as old manufacturing facilities are discarded and newer ones are installed.

2. Process Parameters of Deep Drawing Process

The process planner is required to determine/select appropriate drawing parameters such as drawing force, blank holder pressure, draw measure, die profile radius, punch radius, clearance, type of lubricants, draw speed, air-vent size etc. at the planning stage of drawing process. Some major parameters are described briefly as under.

2.1 Drawing force

It is used to estimate the press tonnage and energy required for draw operation. Draw force can be calculated either by theoretical analysis based on the plasticity theory or by the empirical relation based on the practice. One of the common empirical equations for calculation of draw force considers rough estimation of friction, the punch and die corner radius [13].
Draw force at each stage (Fi) = 0.785 × (Diameter of shell at each stage) × (Sheet thickness) × (Ultimate tensile strength) × (Draw ratio - 0.7).

2.2 Blank holder pressure

To avoid defects like tearing, wrinkling, earing, galling, orange peel etc. proper selection /determination of blank holder pressure is utmost important. Considering type of sheet material, thickness ratio, and draw ratio appropriate blank holding force should be determined at various drawing stages.

2.3 Draw measure

Several measures are used to determine the reduction in blank diameter at each stage of drawing operation, such as drawing ratio (β), drawing rate (M) and reduction percentage (R%) [13]. These measures depend on various factors such as part geometry, material properties, press condition, type of lubricants etc.

2.4 Die profile radius

Die profile radius is one of the important parameter in deep drawing process. Large die radius need more punch force and more work required for bending. Too Large radius results wrinkle formation where too small creates cracking at bottom radius of drawn part. Also smaller die radius results local failures in the bending zone by increasing the work hardening tendency, it may cause heat build-up during operation, weakening of die material and faster erosion. In addition to this it makes difficult to lubrication causing more galling. Practically, die radius in the range of four to ten times of sheet thickness is highly desirable. Beyond this range die radius doesn’t have much effect on punch force. Die profile radius are usually determined either by empirical relations or experience.

2.5 Punch radius

Punch nose radius is a major variable in deciding limiting draw ratio. Empirical finding shows that optimum punch radius should be within the range of four to ten times of sheet thickness. If punch radius is taken less than four times of sheet thickness, then failure of part occur due to tearing, while if punch radius is kept more than ten times of sheet thickness, starching may be introduced. In addition to this punch radius should be larger than the die profile radius by factor 3 to 5 times of sheet thickness. Punch radius should never be kept smaller than the die radius otherwise punch might pierce the material.

2.6 Clearance

It plays a very important role in defect free production of deep drawn parts**.** It represents distance between the walls of the drawing punch and drawing die. If clearance is equal to blank thickness or less, ironing or burnishing of metal occurs near the top of the cup [14, 15]. Smaller clearance increases the stresses during the drawing operation which result burnishing of metal and surface finish defects. While larger value may produce square corner instead of a torodial profile around die radius on part results in unsatisfactory part geometry. In general clearance is made larger to allow for metal thickening. Selection of proper clearance depends upon the anticipated thickening and the degree to which burnishing is not wanted. In common industrial practice general rule is that clearance of 7% to 15% of the wall thickness is provided to avoid burnishing.

3. Guidelines for Selection of Process Parameters of Drawing Process

In selection process of process parameters one should consider sheet material, sheet thickness, type of die, accuracy requirement, complexity of part geometry etc. The part quality, set-up accuracy, die life, minimum set-up time and convenience in maintenance and storage should be ensured during the selection of process parameters [4, 13-18]. A sample of these guidelines is given as under.

i. Value of limiting draw ratio (blank diameter to cup diameter) depends on sheet material. It is 1.8

for aluminum; 1.9 for steel; and 2.0 for stainless steel.

ii. Die radius should be four to six times of sheet thickness for low carbon steel and five to ten times for stainless steel and aluminum.
iii. Draw die radius should be absolutely smooth and blend perfectly with the flat surfaces.
iv. The top of the draw post should be left rough to retard the material from stretching around the draw post.
v. Punch radius should be at least four to eight times of sheet thickness for steel, and eight to ten times for aluminum.
vi. Punch-die clearance should be atleast 1.10 times of sheet thickness.
vii. Punch velocity should be 0.3 m/sec for deep drawing steel and 0.15 -0.25 m/sec for stainless steel and strong aluminum alloys.
viii. Lubricants must be checked for compatibility with sheet material.
ix. If depth is more, than number of draw stages will be more and clearance must be set 0.9 times of sheet thickness.
x. In case of small flange cylinder, limiting draw rate should be 0.58 times that of square blanks.

Keeping in view of the basic guidelines and recommendations collected from various sources of knowledge acquisition, an ES labeled as PPSES has been developed for selection of process parameters of axisymmetric deep drawn parts. A brief description of the proposed system is given as under.

4. Proposed System 'PPSES'

Development procedure of the proposed system involves the acquisition of knowledge from various sources of knowledge acquisition, framing of production rules, verification and sequencing of production rules, selection of hardware and programming language, construction of knowledge base, selection of suitable search strategy and preparation of user interface [19]. Knowledge for selection of various process parameters are essentially collected by on-line and off line consultation with experienced die designers, process planners, referring research articles, catalogs and manuals of various stamping industries. The knowledge thus acquired is analyzed and tabulated in form of production rules of 'IF-THEN' variety. Production rules so framed are verified from a team of die design experts and tool manufacturers. Production rules incorporated in the proposed system are arranged in a structured manner. This arrangement allows insertion of new production rules even by relatively less trained knowledge engineer. For searching a solution to a particular problem, forward chaining strategy is used. In forward chaining, the user interactively supplies system data or facts about the problem to be solved. The system searches the IF conditional data to determine which rules are matched by the given facts. Whenever a particular IF condition is found to have been matched the THEN portion of the rule gets activated leading to a conclusion or an advice. The search is continued till the complete solution is found. The proposed system is implemented on PC (Pentium 4 CPU, 3GHz, 2 GB of RAM) with Autodesk AutoCAD 2008. The production rules incorporated in the proposed system have been coded in AutoLISP language. The system comprises of more than 150 production rules of IF–THEN variety. A sample of production rules incorporated in the proposed system is given in Table 1.

Various dependent and independent process parameters such as draw force, blank holding force, draw measures, clearance, die and punch radii, type of lubricant, draw speed, air vent size etc., are selected/determined by the proposed system. Inputs to the proposed system PPSES are blank diameter, part details etc. These inputs are stored in a part data file PART.DAT which may be further utilized during execution of other modules developed for design of deep drawing die [19]. Some inputs are also taken form data files BLANK.DAT and DRAW_NUM.DAT generated during execution of BLANK_DIA and DRAW_NUM modules respectively developed for determination of blank diameter and number of draws require for production of deep drawn parts [19]. The system outputs include recommendations on appropriate values of process parameters at each stage of deep drawing process. These outputs are stored automatically in a data file PROC_PARA.DAT. Execution of PPSES is shown in Fig.1. AutoLISP programming of the proposed system consists of more than 1000 lines. Few lines of AutoLISP coding are depicted in Fig.2.

5. Sample Run of the Proposed System

The proposed system has been tested on various types of deep drawn sheet metal parts for selection of process parameters. Typical prompts, user responses and expert advices obtained during run of the system PPSES for one industrial sheet metal part (Fig. 3) are depicted in Table 2. The recommendations imparted by the system are found to be reasonable and very similar to those actually used in industry M/s General Engineering Corporation, Pune, India for the example component. Notable features of the proposed system are its low cost of implementation because it can be implemented on a PC having AutoCAD software. Further, knowledge base of the system is flexible enough to accommodate new knowledge or editing of existing knowledge easily due to advancement in sheet metal technology in future. The system can also be linked to automatic generation of process sequence of deep drawn parts and die design.

Table 1: A Sample of Production Rules Incorporated in the Proposed Expert System

S. No.	IF	Then
1	Sheet material is mild steel and Draw = first	Set clearance = 1.40 times of sheet thickness
2	Sheet material is mild steel and draw = intermediate draw	Set clearance = 1.25times of sheet thickness
3	Sheet material is Steel and Single action die is used	Drawing speed[m/sec] = 0.3
4	Sheet material is Steel and Double action die is used	Drawing speed[m/sec] = 0.15- 0.25
5	100 mm < Punch diameter < 200 mm	7<Air vent hole diameter[mm]<8
6	Sheet material is Aluminum	0.03 < Blank holder pressure[N/mm^2] <0.07
7	Sheet material is Copper	0.08<Blank holder pressure[N/mm^2] <0.14
8	Sheet Material is Soft steel and sheet thickness < 0.5 mm	Lubricant = Mineral oil; SP -Emulsion
9	Punch diameter < 25 mm	Air vent hole diameter[mm]=4.7

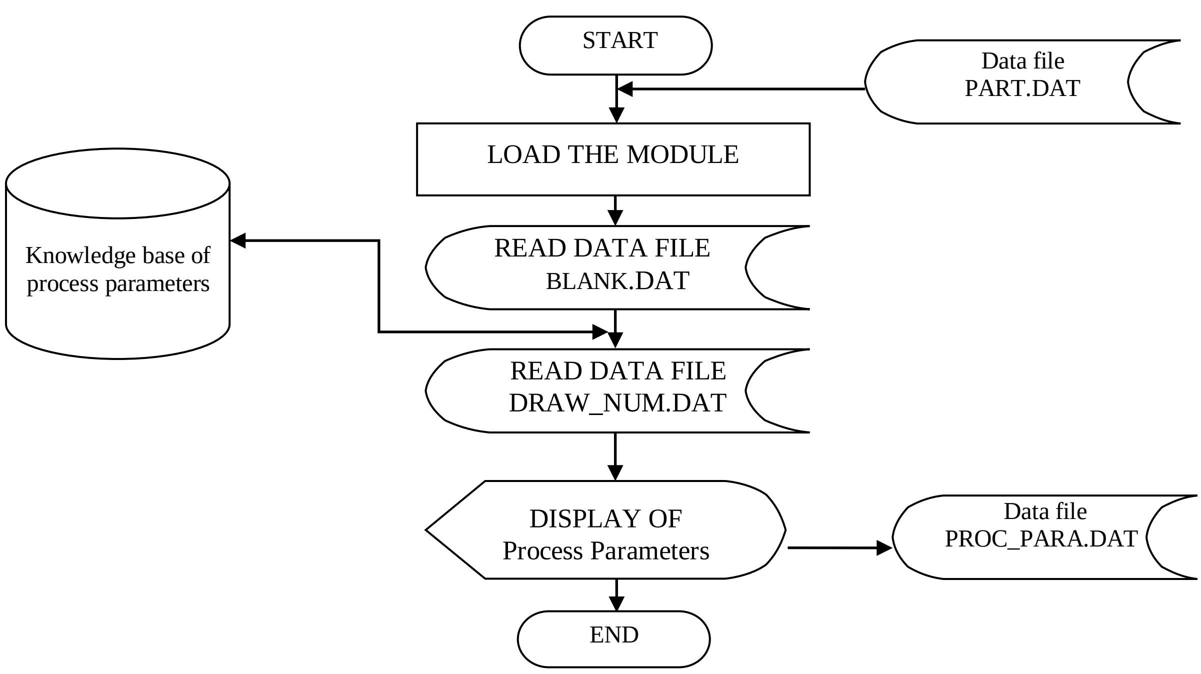

Fig. 1 Execution of the Proposed System


```
(defun c:aaa()
 (C:ppses)
)
(defun C:ppses ()
  (Prompt "\n Welcome to the system PPSES developed for process parameter selection of deep drawing
process") (TERPRI)
-----------------
-----------------
;ViewProcessParameters
  (close fp)
  (setq Draw_cnt 0 )
      (setq ProcessparamFileName (strcat ProjectPath  "ProcessParam.dat"))
      (setq fp (open ProcessparamFileName "w"))
     (repeat (length Procparam_lst)
     (setq eachStage (cadr(nth Draw_cnt Procparam_lst)))
     (setq MatName (nth 0 eachStage))
     (setq Sheetthk_val (atof (nth 1 eachStage) ))
     (setq final_blanck (atof (nth 2 eachStage) ))
     (setq EachstageDia (atof (nth 3 eachStage) ) )
     (setq DrawratioB (atof (nth 04 eachStage)))
     (setq Uts_val (atof (nth 06 eachStage)))
     (setq Uts_val (nth 06 eachStage))
    ;;;if draw is first
    (if (= Draw_cnt 0)(progn
       (if (= MatName "Stainless steel")(progn
           (setq Clearence_val (* 1.25 Sheetthk_val))
      ))
     (if (= MatName "Mild Steel")(prong
          (setq Clearence_val (* 1.4 Sheetthk_val))
     ))
-----------------
-----------------
;;condition for drawing  speed
;;;  (if (= die_type1 "DoubleAction") (setq die_type "Double Action" ))
;;;       (if (= die_type1 "SignleAction") (setq die_type "Single Action" ))
     (if (= die_type "Single Action")(progn
           (if (= MatName "Stainless steel")(progn
             (setq DrawSpeedmax 0.2)
           ))
      (if (= MatName "Mild Steel")(progn
          (setq DrawSpeedmax 0.3)
                  ))
--------------------
-------------------
;; punch force calculation
   (setq CalcPF (*  (* 3.14 EachstageDia Sheetthk_val Uts_val)  (- ( / final_blanck  EachstageDia) 0.7 )))
--------------------
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```

Fig. 2 Few Lines of AutoLISP Coding of the Proposed System

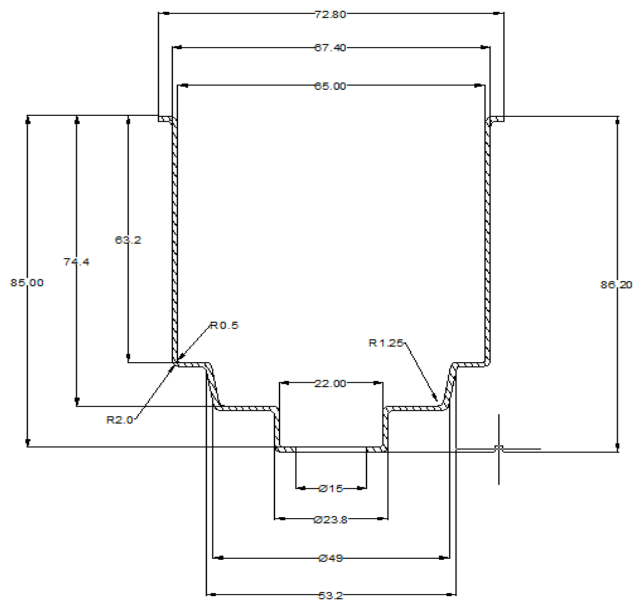

Fig.3 Example Component (Sheet material-M.S EDD, Dimensions in mm. Sheet thickness: 2.40 mm)

Table 2: Typical Prompts, User Responses and Expert Advices Imparted during execution of the Proposed System

S. No	Prompt	Example Data Entry	Advice to the User
1	(Load "C:/PPSES.LSP")		Welcome to the system PPSES developed for selection of appropriate process parameters for deep drawing process
2	Please enter part name	SSK	-------
3	Please enter sheet material	M.S EDD	Max permissible strain rate = 1.44 Lubricant = EP-MO;EP MO-EM-EM
4	Please enter sheet thickness [mm]	2.40	
5	Please select type of die	Double action Die	Draw Speed[m/s]= 0.15 -0.25
6	Please select draw ratio for first draw	1.95	Punch Force [N]=495 ; Blankholder pressure [N/mm^2] = 580; Punch radius[mm]= 5 ; Die radius [mm]= 8; Clearance[mm]= 1.40
7	Please select draw ratio for second draw	1.30	Punch Force [N]=380.23; Blankholder pressure [N/mm^2]= 510; Punch radius[mm]= 5 ; Die radius [mm]= 8 ;Clearance[mm]= 1.25
8	Please select draw ratio for third draw	1.10	Punch Force [N]=300.45; Blankholder pressure [N/mm^2]=; 470; Punch radius[mm]= 5; Die radius [mm]= 8 ;Clearance[mm]= 1.25
9	Please select draw ratio for fourth draw	1.18	Punch Force [N]= 221.45; Blankholder pressure [N/mm^2] = 380; Punch radius[mm]= 5 ; Die radius [mm]= 8 ;Clearance[mm]= 1.25
10	Please select draw ratio for fifth draw	1.18	Punch Force [N]= 77.14; Blankholder pressure [N/mm^2]= 260; Punch radius[mm]= 5; Die radius [mm]= 8 ; Clearance[mm]= 1.25
11	Please select draw ratio for sixth draw	1.18	Punch Force [N]=64.3; Blankholder pressure [N/mm^2]= 210; Punch radius[mm]= 2; Die radius [mm]= 5 ; Clearance[mm]= 1.05

6. Conclusion

The present investigation proposes an automated process parameters selection for design of deep drawing die. The system outputs include recommendations for appropriate values of process parameters along with its appropriate recommendations of selection of lubricant. The data stored in output file of the system can further be utilize for generation of process sequence and design of deep drawing die using AutoCAD and AutoLISP routines. Application of the proposed system is illustrated through real industrial example component. The system is sufficiently flexible, as its knowledge base can be extended and modified, as old manufacturing facilities are discarded and newer ones are installed. The low cost of implementing the system makes it affordable for die designers working in small and medium-sized metal stamping industries

References

1. *Potocinik D, Pesan B, Balic J and Ulbin M (2011), "Intelligent System for the Automatic Calculation of Stamping Parameters", Advances in Production Engineering and Management, Vol. 6, 129 - 137.*

2. *Kumar S (2007), "A Contribution to the Development of Knowledge Based System for Intelligent Design of Progressive Dies", Ph.D. Thesis, Maharshi Dayanand Univerity, Rohatak, Haryana, India.*

3. *Chaturvedi S and Allada V (1999), "Integrated Manufacturing System for Precision Press Tooling", International Journal Of Advanced Manufacturing Technology, Vol. 15, 356 – 365.*

4. *Eshel G, Barash M and Chang T (1986), "Rule-Based System for Automatic Generation of Deep Drawing Process Outlines", Computer Aided Intelligent Process Plan, Vol. 14, 1- 115.*

5. *Tisza M (1987), "A CAD/CAM System for Deep Drawing Processes", Advance Technology of Plasticity, Vol. 1, 145 - 152.*

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

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

8. *Park S, Cho Y, Kim B and Choi J (1998), "A Study on the Computer-Aided Process Design System of Axisymmetric Deep Drawing Products", International Journal of Materials Processing Technology, Vol. 75, 17–26.*

9. *Singh W and Rao K (1997), "Knowledge-Based Process Layout System for Axisymmetrical Deep Drawing Using Decision Tables", International Journal of Computers & Industrial Engineering, Vol. 32, 299 - 319.*

10. *Choi J, Kim C, Choi Y, Kim J and Park J (2000), "An Integrated Design System for Deep Drawing of Blanking Products", International Journal of Advanced Manufacturing Technology, Vol. 6, 803-813.*

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

12. *Babu V, Narayanan G and Kumar S (2010), "An Expert System for Predicting the Deep Drawing Behavior of Tailor Welded Blanks", Expert System with Applications, Vol. 37, 7802 - 7812.*

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

14. *Early D and Reed E (1958), "Techniques of Pressworking sheet metal", Second Edition, Prentice Hall, Englewood Cliffs. New Jersey.*

15. *Suchy I (2006), "Die Design Handbook", McGraw-Hill, Second edition, New York.*

16. *Avitzur B (l983), "Handbook of Metal Forming Processes", John Wiley, New York.*

17. *Ostergard D (1967), "Advanced Die Making", McGraw-Hill, New York.*

18. *Wifi A, Gomaa A and Magied R (2006), "Deep Drawing Process Design and CAPP System for Axisyemmetric Complex Shells", Cairo Univ. Conf. on Mechanical Design and Production, Cairo, Egypt, 1089 - 1100.*

19. *Naranje Vishal and Kumar Shailendra (2011), "Design of Deep Drawing Die: An Expert System Approach", Journal of Manufacturing Engineering, Vol. 6, 99-105.*

