Expert Systems with Applications 41 (2014) 1419–1431

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

A knowledge based system for automated design of deep drawing die for axisymmetric parts

V. Naranje [a], S. Kumar [b,*]

[a] Department of Technology, University of Pune, Pune, India
[b] Department of Mechanical Engineering, S.V. National Institute of Technology, Surat, India

ARTICLE INFO

Keywords:
Knowledge based system
Automated design
Deep drawing die
AutoCAD

ABSTRACT

This paper presents the research work involved in the development of a knowledge based system (KBS) for automated design of deep drawing die for axisymmetric parts. The production rule based KBS approach of artificial intelligence (AI) is utilized for development of the proposed system. The overall system is organized in 27 modules. System modules are coded in AutoLISP language and user interface is created using Visual Basic 6.0 and AutoCAD software. The proposed system is capable to automate all major activities of design of deep drawing die such as manufacturability assessment of deep drawn parts, design of strip-layout, process planning, selection of die components, and modeling of die components and die assembly. The system is user interactive, flexible and has low cost of implementation.

1. Introduction

Deep drawing is one of the typical sheet metal forming process used to produce axisymmetric and irregular hollow shapes through combined action of tensile and compressive deformation. Design of deep drawing die is a highly specialized task. It includes number of important activities that sequential start with determination of blank size, manufacturability assessment of deep drawn parts, selection of process parameters, determination of process sequence, selection/design of die components, and modeling of die components and die assembly. Traditionally, these tasks are carried out by skilled die designers and process planners using experience-based trial-and-error procedure (Sitaraman, Kinzel, & Altan, 1991; Tisza & Racz, 1991). Traditional design process of a deep drawing die is manual, tedious, time consuming and error-prone, which results in high cost and long manufacturing lead time of deep drawn parts (Sing & Rao, 1997). Therefore automated design of deep drawing die has become a challenge for researchers.

From early 1970s to mid 1980s, the first generation CAD/CAM systems for die design were developed to reduce time, cost and to minimize the trail-and-error adjustments in die design process. Schaffer (1971) was probably the pioneers in use of computer in die design. The system labeled as PDDC (Progressive Die Design by Computer) was developed to identify projections of the part which may subject the die to undue stresses during cutting operation. Later on, Fogg and Jaimeson (1975) proposed an improved PDDC system by considering other factors which influence the die design. Nakahara et al. (1978) proposed a CAD/CAM system for automation of progressive die design. A progressive die design system was also developed by Shirai and Murakami (1985). System is capable to automate strip-layout planning, die layouts, and other activities of design of progressive dies. Altan (1987) described some of the interactive CAD/CAM systems for die design and manufacturing. These CAD/CAM systems are developed for forging, extrusion, rolling, forming of shells and sheet metal forming. Bergstrom, Kivivuori, Osenius, and Korhonen (1988) reported to develop a CAD/CAM system for automation of progressive die. This system includes functions like calculation of springback, die clearance, bending radius, forces and flat pattern generation. Prasad and Somasundaram (1992) developed a computer aided die design system labeled as CADDS. This system consists of modules for calculation of bend allowance, nesting, strip layout design and die design. Nee (1994) presented a CAD system for automation of progressive die design. Choudhary and Allada (1999) developed an integrated PC-based CAD/CAM system for design of precision punches and dies for small scale manufacturers. The system deals with only blanking and piercing operations.

With the advancement in the area of computer graphics, CAD/CAM and AI, worldwide researchers started to apply various AI techniques along with suitable CAD systems for die design. Karima and Richardson (1987) pioneered the idea of knowledge based system (KBS) in sheet metal forming. Karima (1989) presented a hybrid system for process planning in sheet metal forming. Eshel, Barash, and Chang (1986) developed a rule based expert system for generation of process plan for axisymmetric and monotone parts produced by deep drawing process. They suggested G & TR (Generate & Test and Rectify) strategy for the process planning of

* Corresponding author. Tel.: +91 9824590088.
E-mail address: skbudhwar@med.svnit.ac.in (S. Kumar).

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http://dx.doi.org/10.1016/j.eswa.2013.08.041

axisymmetric deep drawing products. Tisza (1995) developed an expert system for sheet metal forming applications. AutoCAD software and AutoLISP language are used to develop this system. Esche, Khamitkar, Kinzel, and Altan (1996) developed an expert system to generate process sequences for multi-stage drawing of round cups and tool geometry for each station of the sequence. Sing and Rao (1997) constructed a knowledge based CAPP system using decision tables for axi-symmetrical deep drawn cup. Park, Choi, Kim, and Choi (1998) developed a rule based computer aided process planning design system for generation of process sequence with intermediate object geometry and also to determine process parameters. Choi, Choi, Naa, Baeb, and Chung (2002) used case based reasoning (CBR) approach to develop a modular design support system for production of circular cup. Kang and Park (2002) constructed a rule based expert system for process planning of multi-stage non-axisymmetric deep drawn parts having elliptical cross-sectional shape. Park and Prasad (2004) and Park and Prasad (2005) developed surface area calculating system and CAPP system for non-axisymmetric deep drawn parts with elliptical shape. Wifi, Gomaa, and Abdel-Magied (2004), Wifi, Gomaa, and Abdel-Magied (2005) reported to develop a CAPP system using rule-base technique for complex axisymmetric circular and rectangular deep drawn parts. This system is coded using Visual Basic (VB) and interfaced with AutoCAD software. Zhang, Tor, and Britton (2006) developed a CAPP system for multi-stage non-axisymmetric sheet metal deep drawing parts using CBR approach. Abbassi and Zghal (2007) proposed a CAPP system based on the experimental results and empirical knowledge of experts for axisymmetric deep drawn parts. Researchers (Lin, Chan, & Wang 2008; Lin, Chang, Huang, & Liu 2008; Lin & Hsu 2008) from Department of Mechanical and Automation Engineering, National Kaohsiung First University of Science and Technology, China developed a knowledge-based parametric design system to automate the design of main components of a drawing die. Researchers at Indian Institute of Technology, Guwahati, India (Babu, Narayanan, & Kumar 2010) developed an artificial neural network (ANN) based expert system for predicting forming behavior of tailor welded blank (TWB) for varied weld and blank conditions. Lin and Kuo (2011) proposed a method to explore multi-objective optimization in the structural design of ribs for drawing dies by combining finite element analysis and the fuzzy-based taguchi method. Hernandez, Kremer, Schmidt, and Herrera (2012) developed a sustainability tool and method adviser to assist engineers in the selection of design for environment methods and tools. Treviño, Salazar, Ortíz, and Alejo (2013) proposed an expert system to assist machining processes users in order to generate a set of machining parameters that improves the process considering the minimization of surface roughness. Some other researchers (Cheok, Foong, Nee, & Teng, 1994; Chu, Tor, & Britton, 2004; George-Christophe, Segredou, & Giannakakis, 2005; Ghatrehnaby & Arezoo, 2009; Giannakakis & George-Christopher, 2008; Hussein 2006; Hwang, Han, Bae, & Kim, 2009; Ismail, Chen, & Hon, 1996; Ismail, Hon, & Huang, 1995; Kim, Park, Kim, & Choi, 2002; Kumar & Singh, 2007a; Kumar & Singh, 2007b; Kumar & Singh, 2007c; Kumar & Singh, 2008; Kumar & Singh, 2011; Kumar, Singh, & Sekhon, 2006; Lin, Hsu, & Yao, 1989; Nee & Foong, 1992; Potocnik, Ulbin, & Dolsak, 2012; Singh & Sekhon, 1996; Singh & Sekhon, 1998; Tor, Britton, & Zhang, 2005; Tsai, You, Lin, & Liu, 2010) developed KBSs for design of single operation dies (shearing, blanking, bending etc.) and progressive dies.

Today, some commercial software packages (UG, CATIA, SolidWorks etc.) having special die design modules are available in the market. Also there are some dedicated CAD applications available in the market developed on platform of commercial software, like 3D-QuickStrip, Logopress3 developed on SolidWorks platform, and VAMOS CAA V5 progressive die on CATIA platform. Experienced die designers are using these softwares for various activities of die design process such as flat pattern development, nesting of parts, blank layout and generation of drawing of strip layout, mainly for shearing and bending operations. However, most of these softwares provide a vertical solution for die design and their applicability is also restricted to limited part geometries. Hence, users are not satisfied with these existing solutions. Further, die designers have to use multiple software packages for various activities of die design process and connectivity between these softwares is mostly non-existent. Well trained, competent and experienced persons are required to operate these softwares and interpret the results. Also, small scale industries are not able to afford these systems because of their high costs.

Therefore, there is stern need to develop an intelligent system for design of deep drawing dies by combining suitable AI technique and CAD system. The system should have rich knowledge-base comprising knowledge of experienced die designers and process planners, must be user friendly, has low cost of implementation and capable to perform all major tasks related to die design. This paper presents a KBS for automated design of deep drawing die for axisymmetric parts. The proposed system is capable to automate all major activities of design of deep drawing die; and flexible and has low cost of implementation.

2. Considerations for design of deep drawing die

2.1. Manufacturability assessments

Manufacturability assessment of deep drawn parts is the first important activity of design of deep drawing die. It should be in concurrent with product development, since it helps to identify and resolve potential problems on the part such as splitting and excessive thinning or wrinkling at initial die design process. Higher thickness to diameter ratio is good and it should be at least 1.0 percent. If it is less, then wrinkling may occur. Depth and length of the deep drawn parts must be greater than one half of their diameter. Plastic deformation during deep drawing process must be kept below the strain at the ultimate strength of the material. Sharp radius (inside radius or flange radius) should be avoided. Draw and punch radii should be at least four times of sheet thickness. With a large radius of the drawing die ranging from 8 to 15 times of sheet thickness, smaller values of the severity of the draw coefficient may be used. Subsequently, with smaller drawing die radii such as those ranging from 4 to 8 times of sheet thickness, larger draw coefficient is recommended. When the draw radius is too small, excessive thinning or fracture results at the bottom of a shell and at any stage of the operation. This can be corrected by increasing die radius or blank diameter to allow easier metal flow.

2.2. Process planning

During the process planning, the die designer or process planner has to determine various process parameters such as limiting draw ratio, die radius, punch radius, clearance, punch velocity, type of lubricant etc. These process parameters depend on sheet material, sheet thickness, type of die, accuracy requirement and complexity of part geometry etc. Generally the limiting draw ratio (blank diameter to cup diameter) is taken as 1.8 for aluminum; 1.9 for steel and 2.0 for stainless steel sheet material. Die radius should be four to six times of material thickness for steel and five to ten times for stainless steel and aluminum. Punch radius should be at least four to eight times of material thickness for steel, and eight to ten times for aluminum sheet material. Generally it is recommended that punch-die clearance should be at least 1.10 times of sheet thickness. Experienced process planners recommend that