Application of Expert System for Non-Axisymmetric Deep Drawing Products

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ABSTRACT

An expert system for rotationally symmetric deep drawing products has been developed. The application for non-axisymmetric components, however, has not been reported yet. This study constructs an expert system for non-axisymmetric motor frame which shape is classified into ellipse in deep drawing process and investigates process sequence design with elliptical shape. The developed system consists of four modules. The first is recognition of input shape module to recognize geometries of the product. The second is three dimensional modeling module to calculate surface area for non-axisymmetric products. The third is a blank design module that creates an oval-shaped blank with the same surface area. The fourth is a process planning module based on production rules that play the best important roles in an expert system for manufacturing. The production rules are generated and upgraded by interviewing field engineers. Especially, drawing coefficient, punch and die radii for elliptical shape products are considered as main design parameters. The constructed system for elliptical deep drawing product would be very useful to reduce lead time and improve accuracy for products.

Keywords: Expert system, production rules, process sequence design, preform, drawing coefficient, elliptical shape products

1. Introduction

In general, deep drawing products have various cross-section shapes. For example, there are rotationally symmetric shapes what we called cylindrical and square. Many researches have been carried out for cylindrical products considered as the fundamentals of deep drawing process.

Recently, researches of expert system for deep drawing process have been widely reported. Park et al. [1] constructed an automated process planning system for axisymmetric deep drawing products. Eshel et al. [2] developed the Automatic Generation of Forming Process Outlines(AGFPO) system for axisymmetric deep drawing product. They suggested G&TR(Generate & Test, Rectify) strategy for the process planning of axisymmetric deep drawing products. The system relies on experience-based die-design guidelines for its process sequence design. Altan et al. [3] developed a knowledge-based system in axisymmetric sheet metal. Tisza [4] presented a group technology and modularity in an expert system The expert systems for deep drawing process developed are mostly applications for axisymmetric products up to now, but research for non-axisymmetric products has not been reported. Therefore, it is necessary that application of the expert system for non-axisymmetric products must be performed.

This study makes researches of process sequence design and constructs an expert system for non-axisymmetric product with elliptical shape. The cross-section of product body consisting of a round in the major axis and a straight line in the minor axis is defined as elliptical. This study presents new recognition scheme, three dimensional modeling technique, a modified Entity_List used to create three dimensional part model and accumulated production rules for non-axisymmetric products The system was written in AutoLISP on

AutoCAD software environment.

2. Production Rules

The expert system can be constructed on experienced knowledge of field engineers. By interviewing field engineers, production rules are generated and developed. In addition, plasticity theories, handbooks, and experimental results were referred, too. Especially, characteristic of process sequence in elliptical deep drawing products was scientifically investigated. The cross-section of the product body, drawing coefficient, punch radius (Rp), and die radius (Rd) considered as main design parameters [7, 8]. Production rules that are distinguished from those of rotationally symmetric deep drawing products are given here.

Rule 1. If the cross-section of deep drawing products is constituted a round in the major axis and a straight line in the minor axis, then the product is defined as elliptical deep drawing product.

Rule 2. The total surface area of the product is calculated by use of three dimensional model of the product based on neutral axis of the thickness.

Rule 3. If the input geometry is elliptical, then blank shape is basically oval.

Rule 4. In computing blank size, trimming allowance is 1.25 times the thickness of the blank.

Rule 5. Process sequence consists of cylindrical drawing, preform, and top-drawing process.

Rule 6. If a process is first drawing, then drawing coefficient must be applied to be in 0.54-0.58.

Rule 7. If a process is the last cylindrical drawing, then next process is defined as preform.

Rule 8. If a process is preform, then drawing coefficient must be applied to be in 0.87-0.9 with the body dimension of the major axis.

Rule 9. If a process is preform, then the punch radius between cup wall and top-part must be applied to be in 8R-10R.

Rule 10. If a process is preform, then the product height is determined by surface area constancy.

Rule 11 If a process is first process in top-part drawing, then the process is called bottoming and drawing coefficient is applied to be in 0.64-0.7 with the body dimension of the major axis. After the bottoming process, redrawing coefficient is used.

Rule 12. If a process is the last process in top-part drawing, then drawing coefficient must be applied to be 0.95.

Rule 13. If a process is first drawing, then Rp and Rd are Cfd (coefficient) times the thickness.

$$R_d = C_{fd} \times t_o\ ,\ where\ C_{fd} = 4.0$$

$$R_p = C_{fd} \times t_o\ ,\ where\ C_{fd} = 6.0$$

, here t_0 : material thickness

Rule 14. If a process is redrawing in cylindrical drawing, then Rp and Rd are Crd times the reduction of the diameter.

$$R_d = \frac{(D_{n-1} - D_n)}{2} \times C_{rd}$$

$$R_p = \frac{(D_{n-1} - D_n)}{2} \times C_{rd}$$

, here D_n : a present cup diameter
D_{n-1} : a previous cup diameter

Rule 15. If a process is preform, then Rp and Rd are Cpr times the reduction of the diameter in the major axis and minor axes.

$$R_d = \frac{(D_{Cyl} - D_{mL})}{2} \times C_{pr}\ (\text{for } Major\ Axis)$$

$$R_p = \frac{(D_{Cyl} - D_{mS})}{2} \times C_{pr}\ (\text{for } Major\ Axis)$$

$$R_d = \frac{(D_{Cyl} - D_{mS})}{2} \times C_{pr}\ (\text{for } Minor\ Axis)$$

$$R_p = \frac{(D_{mL} - D_{mS})}{2} \times C_{pr}\ (\text{for } Minor\ Axis)$$

, here D_{mL} : body diameter of the major axis
D_{mS} : body dimension of the minor axis
D_{cyl} : diameter of the last cylindrical cup

Rule 16. Draft of process sequence for elliptical shape products on AutoCAD represents side view of the product in orthogonal axes. Description shows geometry of the major axis on the left side and that of the minor axis on the right side.

3. Constitution of the System

The input of the constructed expert system is only a final product geometry which model was performed on AutoCAD software along the major and minor axes of the appearance. It is convenient to construct, modify, and extend with the aid of the modularity. Fig. 1 represents procedures of the expert system for elliptical deep drawing products. The system is composed of shape reading, recognition of shape, three dimensional model to calculate the surface area, blank design, and process planning module. The following section presents the function and characteristics of each module briefly.

3.1 Recognition of input shape

Fig. 2 shows the input modeling, side view, and cross-section of motor frame product with elliptical shape, and defines important variables. For example, DmL is a body diameter in the major axis, and DmS is a body dimension in the minor axis. DF is a diameter of top-part. Owing to the differences of shape characteristics, process planning expert systems for cylindrical products developed until now could not recognize non-axisymmetric geometry. In this study, however, it is possible to read geometries of the product in the major and minor axes by drafting them in another two layers on AutoCAD. Therefore, properties in each layer can be recognized respectively. It would be an useful method to recognize the properties in application of non-axisymmetric shape products. In this study, geometry of the major and minor axes in each layer is read, arranged, and translated into alphanumeric terms which are said Entity_List in the study. Constitutions and contents of Entity_List are given in Table 1.

3.2 three dimensional modeling module

To calculate the surface area of product is a main procedure to determine blank dimension. For axisymmetric product, the surface area is calculated by means of deep drawn component formula [9] and graphical method. However, the surface area of non-axisymmetric products can't help being calculated as separated components with errors because there is

no concrete method. Thus, this system uses a three dimensional modeling technique. This can be carried out directly in a similarly real product by means of Entity_List. The total surface area can be automatically computed by use of command designated as "area" on AutoCAD. Fig. 3 shows the result of three dimensional model of the elliptical shape product.

Table 1 Definition of Entity_List

(Entity_name, Entity_type, T, OD, ID, H, N, FR)	
Entity_name	Feature of the entity
Entity_type	Class of entity (e. g. HL, VL. TL)
T	Thickness
OD	Outside Diameter of entity
ID	Inside Diameter of entity
H	Height
N	Not used in the system
FR	Fillet Radius of entity

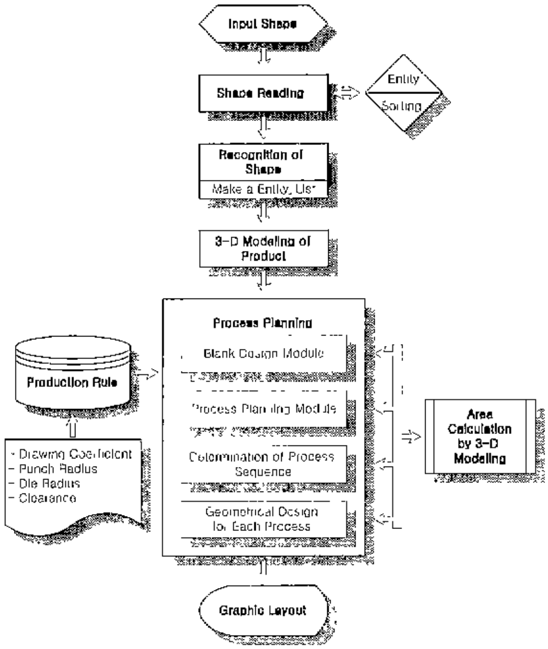


Fig. 1 Procedures of the expert system for elliptical deep drawing products

3.3 Blank design module

There is no formulated blank shape for elliptical deep drawing product. In a practical process, the accumulated know-how and trial-and-error procedures are known as the best ways to determine blank shape and dimension. Generally, a circular blank is designed for cylindrical and square deep drawing.

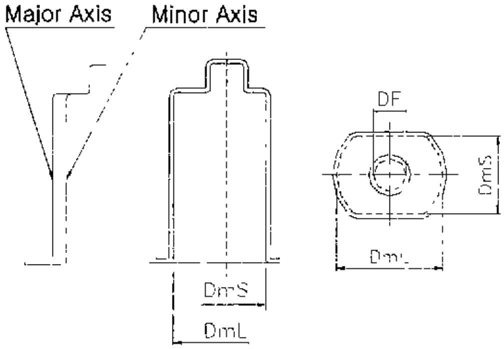


Fig. 2 Characteristics of the product with elliptical shape

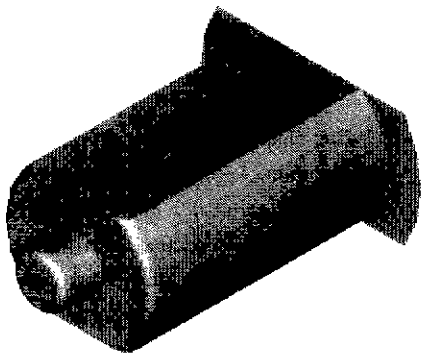


Fig. 3 3-D Modeling to calculate total surface area

For a rectangular deep drawing, the configuration of the blank is obtained by spreading out the geometrical elements and by means of numerical formulas. Based on the finite element results of material flow during the forming, an optimal blank shape was determined [5, 6].

This study presents an oval-shaped blank for production of elliptical shape deep drawing product. The proposed blank geometry is given in Fig. 4. The blank dimension was determined by the same area, which was acquired in three dimensional modeling module.

3.4 Process planning module

In the practical production, The total process of the product consists of cylindrical drawing, preform, and top-part deep drawing. A key process in the production of this motor frame is preform, which makes a straight wall in a circular cup, because metal flow differs from each direction during the forming [10].

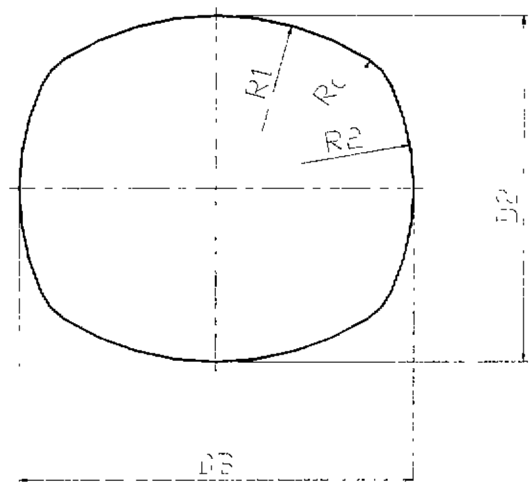


Fig. 4 Oval blank for elliptical deep drawing products

In method (Ⅰ), inverse design was performed from the body diameter to the blank diameter in the major axis Then the design was rectified from the blank diameter to the body diameter in the major axis Fig. 5 shows flow chart to determine drawing coefficient in cylindrical deep drawing process and Fig. 6 shows it in top-part deep drawing.

In method (Ⅱ), the study modified the drawing coefficient table of Romanowski's based on the characteristics of elliptically shaped deep drawing products. Table 2 shows the modified drawing coefficient table of cylindrical cup with the ratio of the body diameter of the major axis to the blank diameter.

Table 2 Modified drawing coefficient for cylindrical deep drawing in Method (Ⅱ)

Drawing Coefficient	D_{mL} / D_B		
	0.27~0.31	0.31~0.335	0.335~0.35
m1	0.53~0.55	0.55~0.58	0.58~0.60
m2	0.76~0.78	0.78~0.79	0.79~0.80
m3	0.79~0.80	0.80~0.81	0.81~0.82
m4	0.81~0.82	0.82~0.83	0.83~0.85
m5	0.84~0.85	0.85~0.86	0.86~0.87

Table 3 shows the constructed table in top drawing coefficient with the ratio of the top-part diameter to the body dimension of the minor axis. m1 as given in Table 3 is the drawing coefficient of bottoming process, which is about 1.2 times the first drawing coefficient.

Table 3 Modified drawing coefficient for top-part deep drawing in Method (Ⅱ)

Drawing Coefficient	D_F / D_{mS}		
	0.39～0.42	0.42～0.47	0.47～0.55
m1	0.64～0.65	0.65～0.67	0.67～0.70
m2	0.76～0.78	0.78～0.79	0.79～0.80
m3	0.79～0.80	0.80～0.81	0.81～0.82
m4	0.81～0.82	0.82～0.84	0.84～0.85
m5	0.84～0.85	0.85～0.86	0.86～0.87

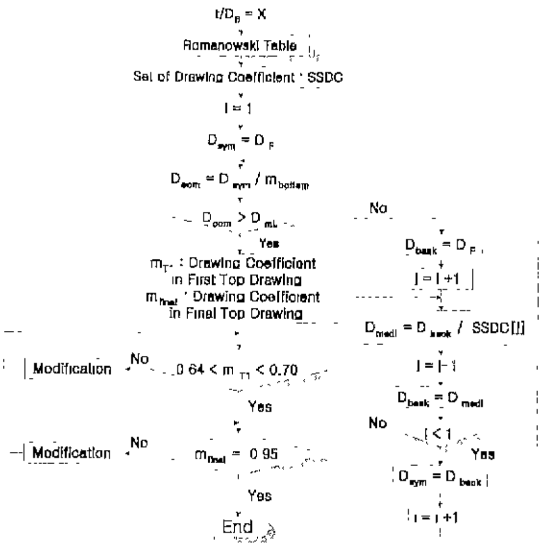


Fig. 6 Determination of drawing coefficient for top-part drawing in Method (Ⅰ)

4. Application and Discussions

4.1 The example of applied products

The applied product in the system is a motor frame with elliptical shape, which is completely produced by multistage deep drawing and secondary operations such as piercing and trimming. The last deep drawing process is used as an input shape to the system. There is a input model as given in Fig. 2.

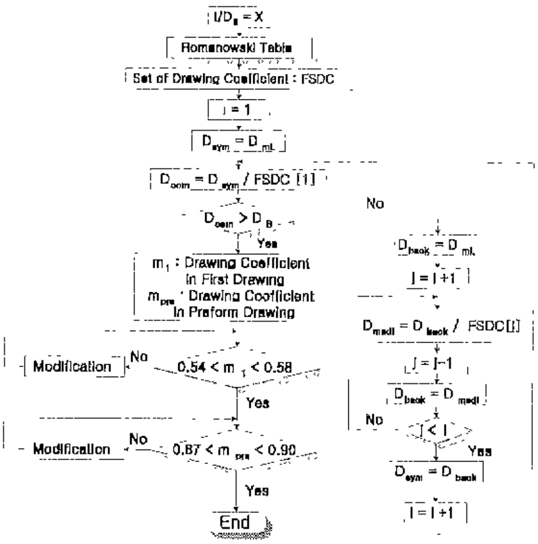


Fig. 5 Determination of drawing coefficient for cylindrical deep drawing in Method (Ⅰ)

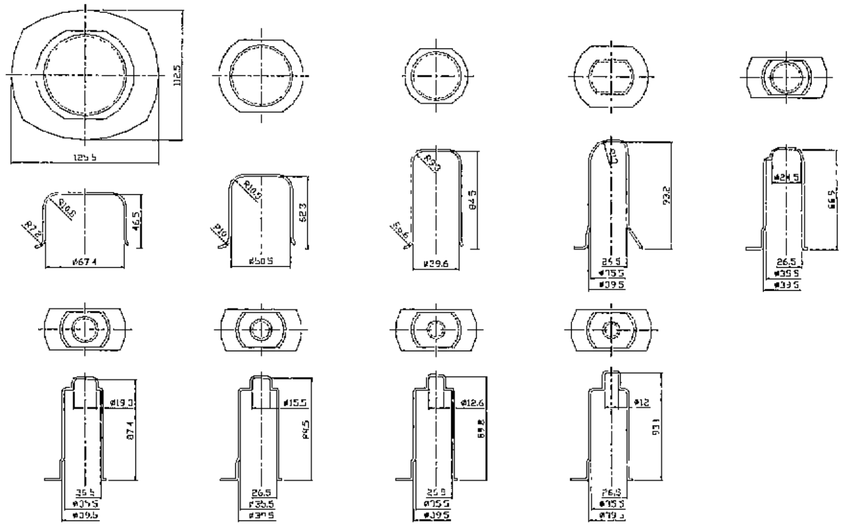
To produce a net-shape product, the stability of preform process is very important. Appropriate drawing coefficient must be maintained as about 0.9 in preform process to prevent a locally thickness reduction, and the height of the product must be designed by surface area constancy. If the rules are not kept, defects like tearing and folding can be expected in top-part of product In the system, three dimensional model of top-part is used determine an accurate height.

4.2 Results of the system and discussions

There are no cases found in die design handbooks and references for elliptical deep drawing products. Thus, the system only was tested against two cases found in industrial brochures. Process sequences for deformation zone as given in Table 4, show two results for elliptical deep drawing product. The results of model YZ show process sequence of the system. After comparing the process sequences, the system results of method (Ⅰ) and method (Ⅱ) are examined. Process sequence for model YZ is shown in Table 4 The blank diameter suggested by the system is about 6.5mm larger than diameter used in an industrial practice for the major axis. It is seemed that the difference results from calculation of the surface area.

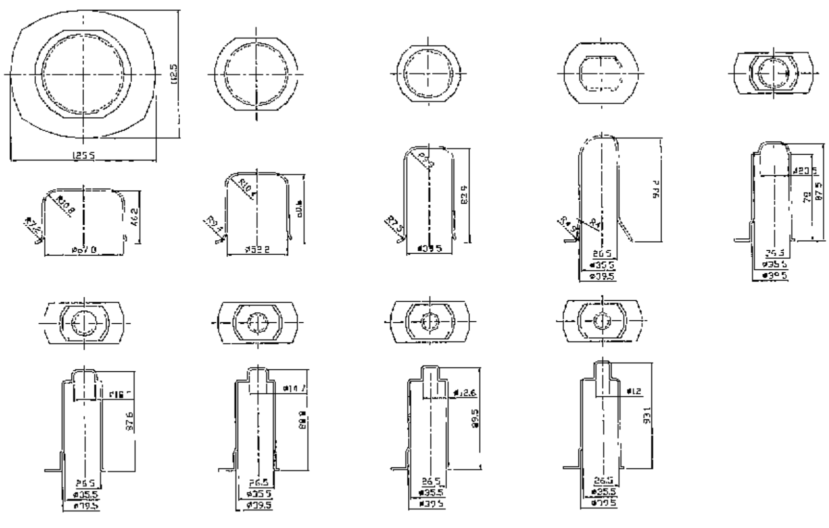
In cylindrical deep drawing process, method (Ⅰ) and method (Ⅱ) present the same stage number. The preform process is designed stable both method (I) and method (II).

This is why drawing coefficient is used in the preform process is 0.9. Fig. 7 and 8 show the system output of process sequence for model YZ. Although top-part drawing of the preform process was in stretching mode, the result of the system must be required modification of the height and punch radius. Top-part drawing of the 5th process was performed by hemispherical forming. It is desirable that cylindrical and tapered component was employed because top-part drawing was deformed severely in the preform process. In the last process of top-part drawing, drawing coefficient was applied 0.95.



Process	1	2	3	4(L)	4(S)	5	6	7	8	9
Draw Coeff	0.537	0.75	0.784	0.9	0.67	0.69	0.787	0.80	0.813	0.95

Fig. 7 Process sequence of method (I) for model YZ



Process	1	2	3	4(L)	4(S)	5	6	7	8	9
Draw Coeff.	0.54	0.77	0.757	0.9	0.67	0.66	0.78	0.80	0.857	0.95

Fig. 8 Process sequence of method (II) for model YZ

Table 4 Process sequence of the expert system for model YZ

Process	No.	Blank (DB)	1	2	3	4-0 (D_{mL})	4-1 (D_{nS})	5	6	7	8	9
Method (I)	Dimension	125.5	67.4	50.5	39.6	35.5	26.5	24.5	19.3	15.5	12.6	12
	Drawing coefficient		0.537	0.75	0.784	0.9	0.67	0.69	0.787	0.8	0.813	0.95
Method (II)	Dimension	125.5	67.8	52.2	39.5	35.5	26.5	23.5	18.3	14.7	12.6	12
	Drawing coefficient		0.54	0.77	0.757	0.9	0.67	0.66	0.78	0.80	0.857	0.95

5. Conclusions

This study expanded a domain of process planning expert system, which definitely used in axisymmetric to non-axisymmetric products. a three dimensional modeling for non-axisymmetric products was used to calculate the total surface area. And this study presents a modified Entity_List to make a part modeling for non-axisymmetric products. The oval-shaped blank was designed by use of the same area calculated in three dimensional modeling module. The designed blank was applied without defects in this process. Preform design is important to succeed in forming the elliptical deep drawing products. Therefore, drawing coefficient for the preform process was suggested about 0.9, because the body of the product consisting of a round in the major axis and a straight wall in the minor axis was formed simultaneously. The process planning expert system based on industrial practice has been developed on production rules. The results of the system in method (I) and method (II) had a good agreement with the industrial practice.

Acknowledgement

This study was supported by the Engineering Research Center for Net Shape and Die Manufacturing (ERC/NSDM) at Pusan National University.

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