TURNITIN Design and efficiency optimization

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Design and efficiency optimization of deep drawing for sustainable electric pole cap application

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A B S T R A C T

Deep drawing is one of the most frequently used plate-forming methods. This process forms materials by a cold working system. Like other press tool processes, the deep drawing process is also assisted by press tools, press machines, and other components that are tailored to accommodate the desired product being produced. Electric pole products consist of several pipes and a cover in the form of a semicircular plate of a certain size which is then assembled using electric arc welding. This part of the electric pole cover is made using deep drawing and blanking processes. Making products using the deep drawing method must be done with proper analysis and planning. For this reason, the dimensions of the product, the type of material, and the required strength need to be determined. The electric pole cover is made using ST37 material which is equivalent to AISI 1045 with a thickness of 2 mm and a tensile strength of 370 N/mm^2.

Selection and peer-review under responsibility of the scientific committee of the 2023 International Conference on Advanced Technologies in Chemical, Construction and Mechanical Sciences.

1. Introduction

In this current industrial development, there has been an increasing need for metal products. There are various metal objects, such as spoons, electric poles, motorized vehicles, and more. A high number of requests for these products also requires a faster and more accurate production process. Metal producers make efforts to produce better products. Using a press tool is a way to increase the production rate. It is because it can produce objects with the same dimensions and high precision [1,2].

A press tool cuts or forms plate sheets into finished or semi-finished products. There are many processes in making a metal product [3]. One of the stages is deep drawing. It is a process in various fields related to metal production in automotive and household appliances. Usually, the product is shaped like a bowl or has a concave part. To make the desired products, there must be different calculations because deep drawing is prone to production defects [4–7]. This includes making an electrical pole cap with a diameter of 4 in..

The electrical pole cap is made using a press tool through a deep drawing and blanking process [8]. These two steps take place on the same press tool so that the electric pole cap, punch, and die to stay on the same axis. A deviation in the axis will result in the electric pole's dimensions not aligning with the specifications, preventing the installation of the cap. The caps designed for power poles, specifically those with a diameter of 4 in. or 101.6 mm, are manufactured using ST 37 steel material with a thickness of 2 mm. These caps will be assembled onto the pipe using the electric arc welding method. Fig. 1 shows the position of the pipe cap installed on a power pole. Accurate calculations are essential for the production of the deep drawing press tool to ensure its effectiveness. Inaccurate processes can lead to defects during the deep drawing process [9–12]. Additionally, the capacity of the machine also plays a crucial role in preventing such defects.

2. Research methodology

An electric pole cap with a diameter of 101.6 mm is used which is made in the shape of a half ball or made to resemble a bowl made of a 2 mm thick plate. Fig. 2 shows a circular stretch. The punch and die will press the stretched form (shell) until it forms as shown in Fig. 3. The thickness of the product should not be less than 2.8 mm to facilitate the assembly process on the pipe.(See Fig. 4).

This 101.6 mm electric pole cap uses ST37 material included in low carbon steel called mild steel. ST37 is a low-carbon steel numbering system using the DIN standard (*Deutsches Institut fur Nor-*

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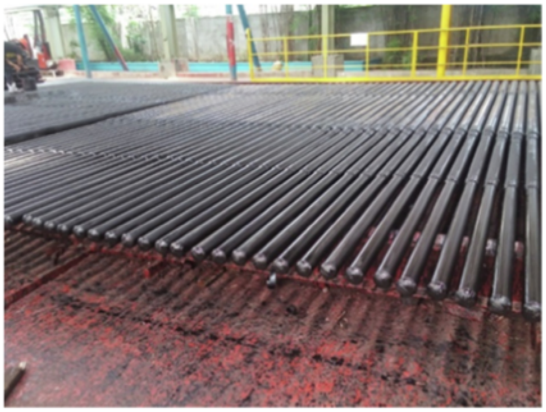


Fig. 1. Electrical Poles.

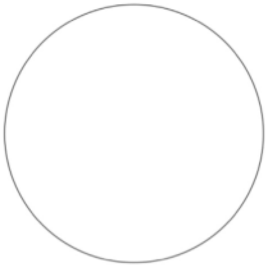


Fig. 2. Exposition.

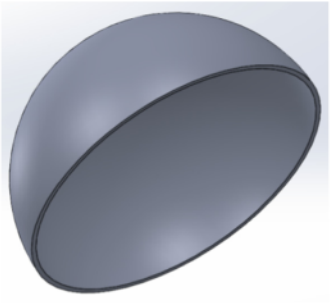


Fig. 3. Electrical pole cap with 101.6 mm diameter.

mung) from Germany. ST stands for *Stahl* which means steel. Meanwhile, 37 is the tensile strength of the steel at 37 kg/mm^2. ST37 is selected as the material due to its high tensile strength, which facilitates the forming and cutting processes.

2.1. Layout selection

The electric pole cap with a diameter of 101.6 mm is circular. It has some alternative layouts for the raw material. Layout 1 offers the advantage of a simple press tool design, but it has the disadvantage of being uncentered in the drawing process and requiring a separate press tool for the blanking process. On the other hand, Layout 2 has the advantages of symmetrical formability, faster processing, and the ability to use the same press tool for drawing and blanking, despite having a more complex design shape. While Layout 3 is somewhat similar to Layout 1 in terms of a simple and smaller press tool design, its disadvantage is that the material needs to be cut into a square shape, resulting in longer processing time. Therefore, there must be alternative layouts so that the design press tool has a comparison, as shown in Table 1. The layouts can affect the design of the press tool, so there must be an assessment first for each alternative. The following table presents some alternatives that the authors have defined.

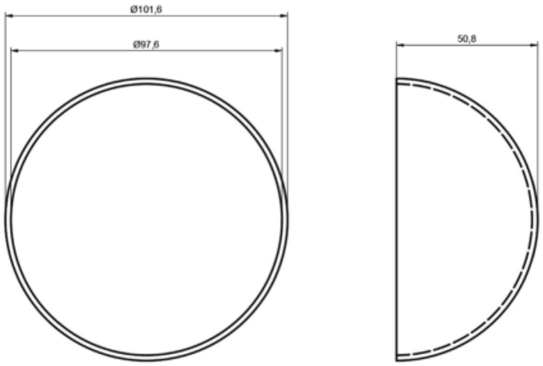


Fig. 4. Dimension of the electric pole cap with a diameter of 101.6 mm.

Based on the three alternative layout options above, the authors make an assessment based on each advantage and disadvantage by setting the following assessment parameters. The best assessment parameter for the alternative layout is layout 2. This is because layout 2 allows for the symmetric formation of the material, saves processing time, and enables the execution of both the drawing and blanking processes using a single press tool.

2.2. Press tool and press machine material

The choice of material for the press tool depends on the specific functions of its components. Steel tools are commonly selected for punches and dies as they are responsible for cutting and shaping plate materials. On the other hand, tool steel is preferred for the thrust plate and guide pillar to withstand the cutting forces that occur during the process. The design of the press tool should consider the slightly different part composition for the 101.6 mm diameter pipe cap, requiring adjustments in the material selection. For the design process of the electric pole caps, the AIDA supporting instrument machine is used as a reference.

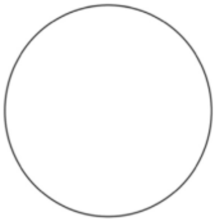
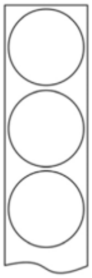
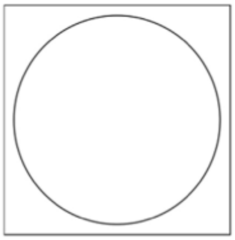
2.3. Engineering software and press tool calculation

AutoCAD is software used for designing in the world of engineering. AutoCAD can create 2D or 3D drawings, but it is usually for making 2D designs because it has more complete features than similar software. The design of the press tool in two dimensions also uses AutoCAD. SOLIDWORKS functions to make a 3-dimensional design. It can create 3-dimensional images using more complete features. Each part can be distinguished using a different color, and there are also assembly processes and a work simulation. The design calculations of this press tool include calculations of stretch, drawing force, cutting force, clearance between punch and dies, selection of springs, and machine capacity.

3. Results and discussion

To produce electrical pole caps that meet the specifications, there must be an analysis of the technical aspects of tool design

Table 1
Alternative raw material layouts.

Layout 1	Layout 2	Layout 3
		

that can affect the formation results. The calculation results will be a reference for selecting the press machine. To calculate the forming factor for a pipe cap with a diameter of 101.6 mm, there must be some blank dimensions. The blank diameter, which is obtained from Equation [1], is 142 mm. This is calculated using the radius R_b, which is 71 mm.

$$D = R_b \times 2 \tag{1}$$

To achieve the optimal process, the initial drawing process should be able to meet the largest constraint. The drawing ratio (m) is determined by comparing the product diameter (D) and blank diameter (d) through direct measurement. The constraint calculation is based on the blank diameter, with a benchmark m = 0.7. The product diameter is also calculated using Equation [2]. The result of the product diameter benchmark is 1.4, which is less than or equal to 1.8 as defined in Equation [3]. According to the constraint standards, a pipe cap with a diameter of 101.6 mm can be formed in a single process.

$$\beta_{act} = \frac{D}{d} \tag{2}$$

$$\beta_{act} \leq \beta \tag{3}$$

The blank and drawing forces can be calculated using Equations [4] and [5], respectively. In these equations, D represents the blank diameter, d represents the drawing diameter, and t represents the thickness. The results of blank force F_b is 264.1 kN and drawing force F_{dr} is 141.7 kN.

$$F_b = 0.8 \times \pi \times d \times t \times R_m \tag{4}$$

$$F_{dr} = \pi \times d \times t \times R_m \times \alpha \tag{5}$$

The blank holder force is determined based on the forming force (deep drawing force). The calculation of the blank holder force is divided into two parts: the surface pressure and the material thickness. The blank holder force based on the surface pressure can be calculated using Equations [6] - [8], while the blank holder force based on the material thickness and type can be calculated using Equations [9] and [10].

$$p = 0,25 \times [(\beta - 1)^2 + \frac{0,5 \times d}{100 \times t}] \times R_m \tag{6}$$

$$R_d = 0,035 \times [50 + (D - d)] \times \sqrt{s} \tag{7}$$

$$F_{BH} = p \times A_{BH} \tag{8}$$

$$F_{BH} = 0.25 \times Fd \tag{9}$$

$$F_{BH} = P_b \times A_{BH} \tag{10}$$

The calculation result of surface pressure p is 38.295 kg/mm^2, the surface area of the blank holder A_{BH} is 5416.25 mm2, the blank holder force F_{BH} is 207424.87 N. Furthermore, the blank holder force F_{BH} based on material thickness is 35429.63 N, and the blank holder force F_{BH} based on material type is 9532.6 N.

The total clearance is calculated by the amount of clearance for each side in Equations [11] and [12]. The calculation of the deep drawing clearance for mild steel with a thickness of 2 mm can be done using the Oehler and Kaiser formulas, as shown in Equation [13]. The spring selection relies on the force in the blank holder because the spring is attached to the part in Equation [14]. The deflection comes from the sum of the initial deflection height at the installation conditions and the spring deflection height just before cutting to maximum penetration, as calculated by Equations [15] – [18].

$$\frac{C}{2} = 0,01 \times 2 \times \sqrt{370 \times 0,8} \tag{11}$$

$$C = 2 \times 0,344 \tag{12}$$

$$U_c = s + 0,07\sqrt{10s} \tag{13}$$

$$Fperspring = \frac{F_{BH}}{n} \tag{14}$$

$$deflection = f_a + f_{k2} \tag{15}$$

$$k_{spring} = \frac{f_{spring}}{deflection} \tag{16}$$

$$f_{tot} = drawingforce + blankcuttingforce \tag{17}$$

$$Machinecapacity = 120\% \times f_{tot} \tag{18}$$

The result of clearance for each side is 0.344 mm and the total clearance C is 0.688 mm. The clearance of deep drawing U_c is 2.313 mm. The force F per spring is 25928.1 N, where the deflection is 63 and k_{spring} is 411.6 N/mm. MISUMI SWG20-25 spring is chosen based on the calculation results. The total force f_{tot} is 613.2 kN. The machine capacity is 735.84 kN. Fig. 5 shows the design of deep drawing applied for electric pole cap with 101.6 mm diameter.

The results obtained from the press tool utilization for four hours of work are able to produce 500 pcs of products with 0 NG product. The calculation of Return on Investment (ROI) and Payback Period (PP) can be performed for electric pole caps with a diameter of 101.6 mm, considering a production volume of 150

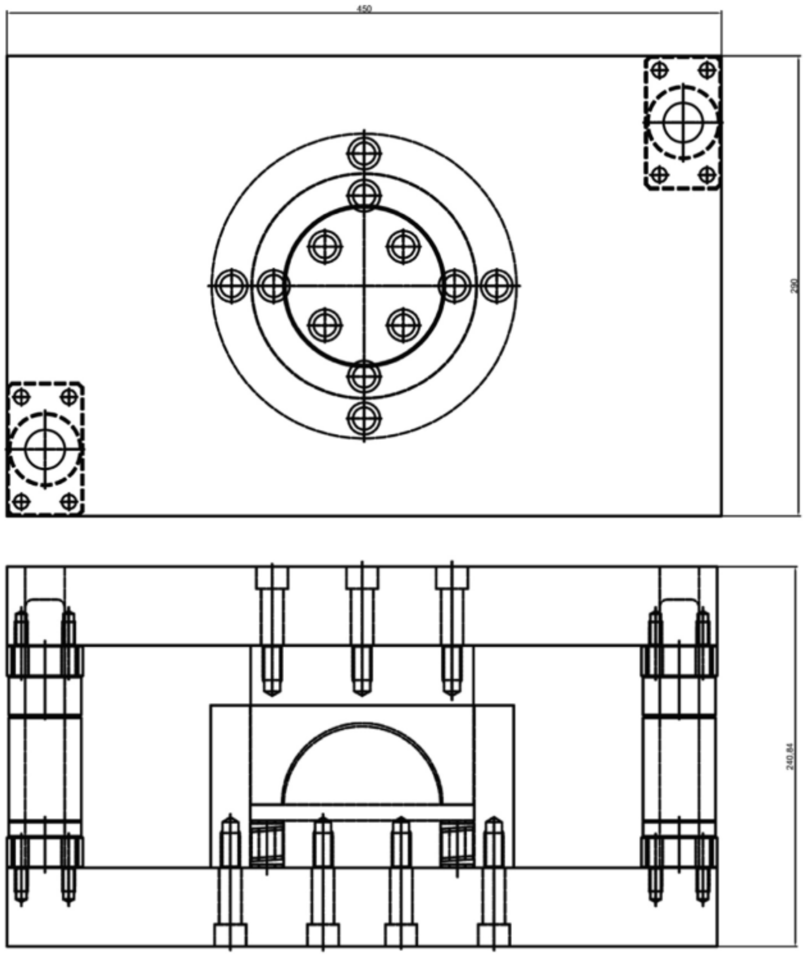


Fig. 5. Two dimensional design of the electric pole cap with a diameter of 101.6 mm.

pieces per day. It is important to note that the total trial product was higher than the production target, with 500 pieces produced. The number of trial products exceeded the daily target by approximately 3.33 times, and there were no defective (NG) products during production. Based on these results, it was determined that the press tool can be used in the subsequent production process.

Electrical pole caps with a diameter of 101.6 mm are produced at a rate of 150 pieces per day. Assuming a profit of IDR 5,000 per product, and considering five working days in a week, the annual profit can be calculated. With 49 weeks in one year, the annual profit amounts to IDR 183,750,000. The price of the die used in the production process is IDR 120,000,000. Over a five-year period of depreciation, the annual depreciation cost can be calculated using Equation [19], resulting in a depreciation cost of IDR 24,000,000 per year. Additionally, there is a maintenance cost of IDR 15,000,000. By applying Equation [20], the investment cost is determined to be IDR 39,000,000.

$$Costofdepreciation = \frac{Thevalueofinvestmentassets}{Usefullifeoftheassets} \tag{19}$$

$$\text{Cost of investment} = \text{Cost of depreciation} + \text{Cost of maintenance} \tag{20}$$

Furthermore, return on investment (ROI) and payback period (PP) are calculated by Equations [21] and [22], respectively. The results of the calculations obtained for ROI of 370% and PP for 0.8 years.

$$ReturnonInvestment(ROI) = \left[\frac{(Netprofitaftertax)}{Totalassets}\right] \times 100\% \tag{21}$$

$$PP = \frac{Totalcashinflowofinvestment}{Initialcashoutflowforinvestment} \times 1year \tag{22}$$

4. Conclusions

The design results of deep drawing die for a 4-inch electric pole cap conclude the following points. The required blank diameter to make the pipe cap is 142 mm. The required deep drawing force is 141718.5 N. The clearance between the punch and dies for the deep drawing process is 2.313 mm, while the blanking process is 0.688 mm. The blanking force to make a blank is 264094.8 N.

The calculations on the blank holder force generate some different results. These results choose the surface pressure because it has the highest value (207424.87 N). The spring selected to withstand the blank holder force is MISUMI SWG20-25. The required capacity of the press machine for carrying out the deep drawing and blanking process is 80 tons. Therefore, this design is appropriate for the electric pipe application.

The engine capacity used in the production process is confirmed to be greater than the required capacity, ensuring its safety and suitability for the task. During a trial period of four working hours, a total of 500 pieces of pipe caps with a diameter of 101.6 mm were successfully produced without any defective (NG) products. This indicates that the press tool is capable of being used for mass production. Considering a total investment of IDR 120,000,000, the ROI is calculated to be 370% within 0.8 years.

CRediT authorship contribution statement

Lydia Anggraini: Writing – original draft, Formal analysis. **Fikri Aulia:** Resources, Visualization.

Data availability

No data was used for the research described in the article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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