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DESIGN OF DRAW DIE FOR CYLINDRICAL CUP FORMATION

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***Abstract*—**

For production of sheet metal parts we need various dies (press tools) which will convert flat sheet metal into desired product. The traditional techniques for design of dies for sheet metal operations used in industry are experimental and expensive methods. Using analytical methods we can calculate various design parameters and forces required for the sheet metal operation and can be verified using computer aided design and finite element analysis, which will reduce the time for the development of dies. For the design of dies designer requires inputs from method planning personnel which include simulation report, press data, blank size, work strokes, die faces ,loading height of component , shut height of die, methods of loading and unloading the component ,various forces required for the operations etc. based on this data, dies are designed. In this paper, various forces for cylindrical cup formation, elements of draw die, design layout of draw die, working mechanism of die, design of elements of draw die are discussed.

Key words- **blank-holder, cupping strain factor, deep drawing, die ring, shut height**

I. INTRODUCTION

The traditional techniques for design of dies for sheet metal operations used in industry are experimental and expensive methods. Using analytical methods we can calculate various design parameters and forces required for the sheet metal operation and can be verified using computer aided design and finite element analysis which will reduce the time for the development of dies.

Drawing is a metal forming process during which a flat piece of sheet-metal material (that is blank) is transformed into a hollow, three-dimensional object. Such transformation can be produced either in a single step, or in a sequence of operations, each of them changing the shape but partially. During the process of drawing, the material is forced to follow the movement of a punch, which pulls it along, on its way through the die. In the process, shape of the part and sometimes even the thickness of it are altered. At first, the drawn material has to overcome its own elastic limit, succumbing to plastic deformation right afterwards. Various forces are acting upon the drawn cup (Fig.1) are blank-holder's pressure, the friction between the drawn shell and other components of tooling.

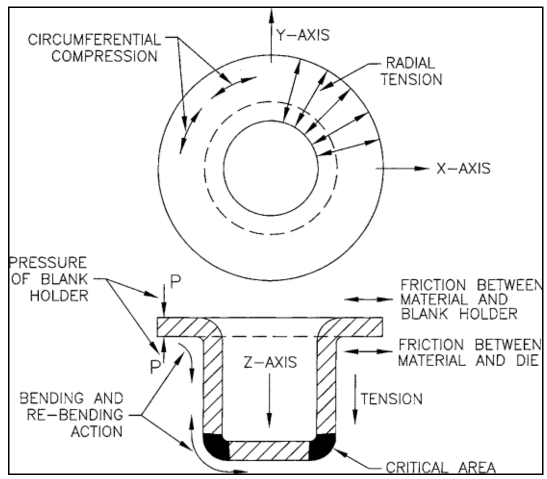

Fig.1 various forces acting upon the drawn cup [6]

II. LITERATURE REVIEW

Susila Candra [1] did the research on prediction of maximum variable blank holder force, over the punch stroke to avoid crack formation on sheet metal during deep drawing operation and gave empirical formulae for blank holder force.

A.Pourkamali Anaraki [2] conducted the study on deep drawing process with the help of finite element simulation and compared the experimental results with the analytical and simulation results and gave the formula for draw force.

Amir Mostafapur [3] conducted study on the effect of a pulsating blank-holder system for improving the formability of aluminium 1050 alloy, during each pulsating cycle, first the metal was easily flowed into the die through removing the blank-holder force, and then the blank-holder force applied by springs to prevent excessive metal flow and wrinkling. In this study he gave formula for variable blank holder force depending on frequency of stroke of press.

Z. Marciniak [4] studied mechanics of sheet metal forming and gave the analytical formulae for limiting drawing ratio which relate blank size and punch size.

Vukota Boljanovic [5] conducted study on important design parameters and various forces required for deep drawing operation of sheet metal and given important empirical formulae for design of die for deep draw operation.

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Ivana Suchy [6] has studied industrial die design and derived various analytical formulae for cylindrical deep drawing operation which include severity of draw and number of drawing passes, cupping strain factor, blank size of drawn shell etc. these formulae play vital role in design of die. David A. Smith [7] has studied die design processes for various operation which also include deep drawing of cylindrical cup, he has given analytical formulae for tool design , criteria for various part selection such as size, material, tolerance values etc.

III. OBJECTIVES

- Design a draw die to produce cylindrical cup shaped output component from flat metal sheet as input, by taking inputs from the process engineering department. Fig.2 and Fig.3 shows the input and output part of the die respectively. The input part is metal sheet of 110mm X 110mm X 0.8mm.

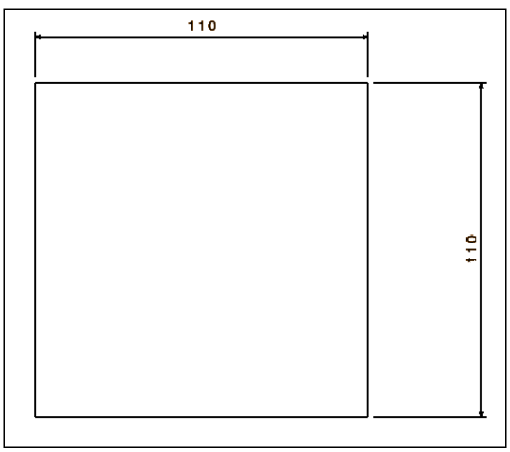

Fig.2 Input part for die

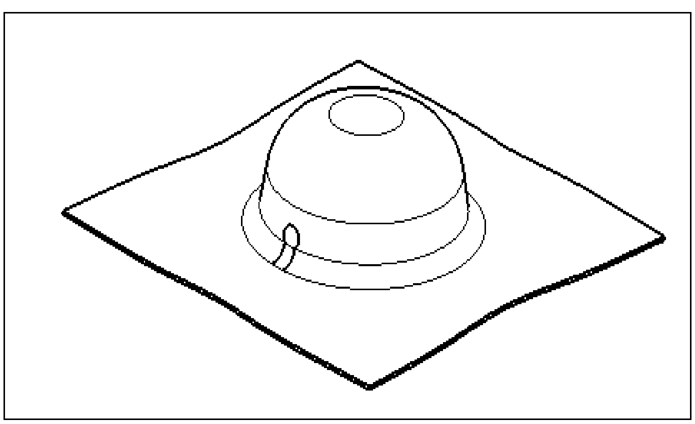

Fig.3 Output part from die

- To design a draw die for minimum weight.
- To design a draw die, which will be feasible to manufacture.
- To carry out production of component and test it on coordinate measuring machine for its accuracy.

IV.ELEMENTS AND DESIGN PARAMETERS OF DRAW DIE

A.ELEMENTS OF DRAW DIE

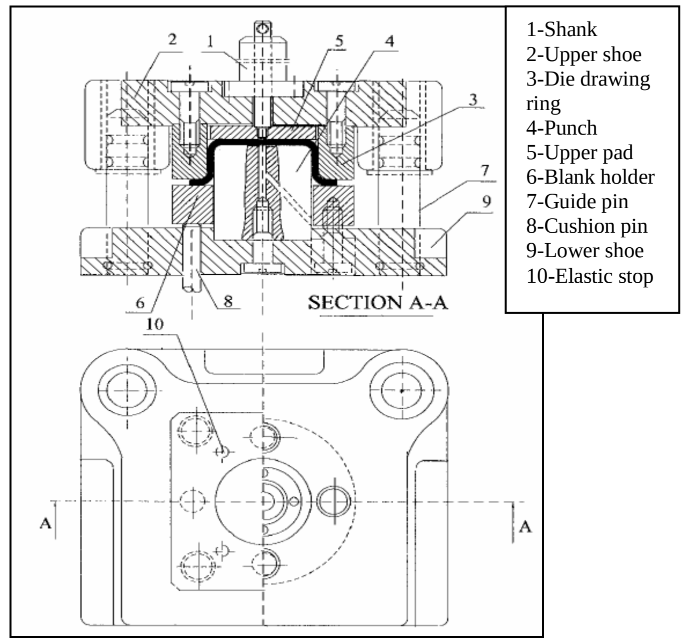

Fig.4 Layout of draw die [5]

- Shank- Shank is mounted on upper shoe for mechanical press to connect upper shoe with ram.
- Upper shoe **-** It is a part of the die, fixed to ram of the press with the help of clamping screw. It moves along the ram and guided by guide pillar or wear plates mounted on lower shoe. It has cavity shape, as of the output component.
- Die drawing ring **–** It is fixed on upper shoe with the help of screw and dowel. It has same shape of punch maintaining clearance; the clearance value depends on sheet metal thickness and material of sheet.
- Punch **-** Punch has same shape of output component required from the die. It is mounted on lower shoe with help of screw and dowel. It is a rigid part. It forces sheet metal to flow in to cavity of die draw ring.
- Upper pad **–** It is mounted on upper shoe with help of side pin or safety screw or both. It has only one degree freedom along vertical direction; other degrees of freedom are locked by guide pin or wear plate. It has pressure source such as gas spring, coil spring or elastic rubber. It holds the sheet metal before the start of operation by the force provided by pressure source.
- Blank holder – This part of the die is mounted on lower shoe of the die. It has single degree of freedom in vertical direction. Its function is to hold the blank and provide necessary holding force for the drawing of the sheet metal. The force is provided to the blank-holder by coil springs or gas springs or cushions in

the press. It is moves along the upper shoe, due to force of upper shoe.

- Guide pin – It is the guiding component used for the alignment of upper shoe and lower shoe during the operation. It is also used for the guiding of blank holder in the lower shoe.
- Cushion pin – It is the source of force for the blank-holder. The selection of cushion pin is based on force required for blank-holder, travel of the blank-holder and space available.
- Lower shoe **-** It is a part of the die, fixed to bolster of the press with the help of clamping screw. Lower shoe may be made by casting or made up of steel plate based on the requirement of the design. Various elements are mounted on the lower shoe like guide pins and wear plate for upper shoe , guide pins and wear plate for blank-holder, blank-holder, coil springs or gas springs for blank-holder, punch for drawing operation.
- Elastic stop **–** It is a pressure source of upper pad which provides force to hold the sheet metal at proper location before the start of deformation of sheet metal, and it limits the displacement of upper pad in vertical direction.

B.PARAMETERS OF DRAW DIE

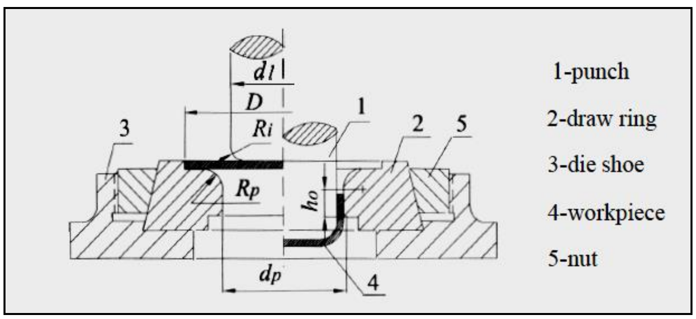

Fig.5[5]

Where
D =Blank diameter
d_1=Inside work piece diameter after the first drawing operation
T = Material thickness
R_p=Draw ring
R_i=Punch radius
d_p=Outside work piece diameter after the first drawing operation

- The radius of draw ring

$$R_p= 0.8[(D-d_1) X T]^{0.5} \ldots\ldots.(1)[5]$$

- The height of the cylindrical part of the draw ring (h_0)

$$h_0= (3/5) X T \ldots\ldots\ldots\ldots\ldots.(3)[5]$$

- The clearance between the walls of the punch and the die

$$C = T + k (10T)^{0.5} \ldots\ldots.... (4)[5]$$

Where:
C = clearance
T = material thickness
k = coefficient

Material	Coefficient k
Steel sheet	0.07
Aluminum sheet	0.02
Other metal sheet	0.04

Table 1[5]

- Blank Holder Pressure (Pd_1) - The value of blank-holder pressure is decided on the basis of sheet metal material which is to be deformed.

Material	Pressure	
	lb/in^2	MPa
Deep-drawing steel	300–450	1-3
Low-carbon steel	500	3-5
Aluminum and aluminum alloys	120-200	0.85-1.4
Aluminum alloys, special	500	3.5
Stainless steel, general	300-750	2-5
Stainless steel, austenitic	1000	7
Copper	175-250	1.25-1.75
Brass	200-300	1.40-2.0

Table 2[5]

- The blank holder force can be calculated by the following formula:

$$Fd_1= (\pi/4) [D^2-d_1^2] Pd_1 \ldots\ldots\ldots\ldots\ldots.. (5)[5]$$

- Draw force – draw force required for the operation is given by

$$P_{draw} = A\ S_t\ n_c \ln(Ec)\ldots\ldots\ldots\ldots\ldots...(6)[6]$$

Where
$A = \pi\ d_1\ T$
A-area of cross section of a shell
T- Thickness of sheet metal
S_t- Ultimate tensile strength of material
E- Cupping strain factor
n_c - Deformation efficiency of drawing process

The cupping strain factor E gives us the actual strain in the metal created by its elongation during the deep-drawing process, it is calculated by

$$E = [(D/d_1) +1] X 0.5\ldots\ldots\ldots\ldots\ldots\ldots(7)[6]$$

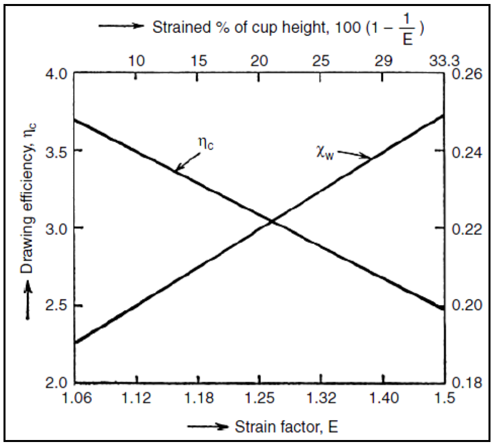

Fig.6 [6] Deformation efficiency of drawing process (n_c)

Deformation efficiency of drawing process (n_c) is selected based on the cupping strain factor using graph from Fig.6

V. DESIGN CALCULATIONS-

A. Input parameters-

- Sheet metal (Input part) details-

Material specification	EDD-513
Dimension	110mmX110mmX0.8mm thick
Ultimate tensile strength (S_t)	260 MPa
Yield strength (S_y)	165 MPa

- Press data –
  - Shut height -340mm
  - Clamping slot dimension-50mm (thick) X 30mm (width) X45mm (depth) for M28 clamping bolt,pitch of clamp slots from center of press is 75 mm.
  - Front to back maximum size -650mm
  - Left to right maximum size-550mm
  - Number of strokes per minute-20
  - Make-union
  - Maximum capacity-160 ton
  - No cushion pins for blank-holder

- Travel of blank-holder as per shape of output component.

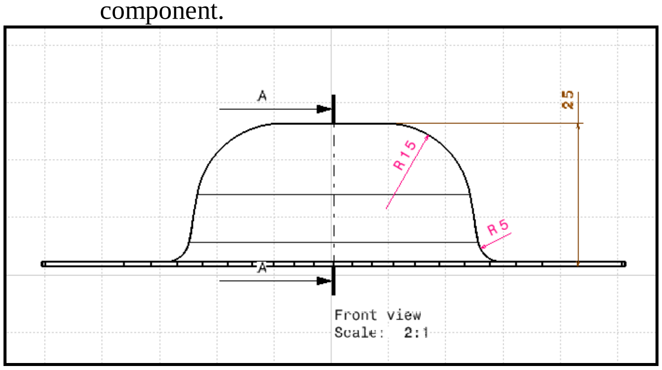

Fig.7 Output part

As the depth of drawn component is 25mm, blank-holder travel is kept 26mm for proper holding 1mm before the start of operation.

- Various parameters
  - Blank Diameter (D)-110 mm
  - Punch diameter (d_1)-59 mm
  - Thickness of sheet (T)-0.8 mm

- Draw ring radius (R_p) –

  $R_p = 0.8 \text{ X } [(D-d_1) \text{ X } T]^{0.5}$

  $=5.10$ mm

  ≈ 5 mm
- Clearance value between punch and cavity (C)-

  $C = T + k \sqrt{(10 \text{ X } T)}$

  $= 0.99$ mm

  ≈ 1 mm
- Cavity diameter (d_0)-

  $D_0= 59+0.99$

  $= 59.99$ mm

  ≈ 60 mm
- Blank-holder pressure (P) is decided based on the finite element analysis of metal flow. From method plan report and table 2 the value is selected as 1.17MPa

- Blank-holder force (Pd_1) –

  $Pd_1 = P$ X area of sheet metal holding

  $=1.17 \text{ X } [110^2 - (\pi/4) \text{ X } 59^2]$

  $=10.958$ kN
- Draw Force (F) –

  $F= A \text{ X } S_t \text{ X } n_c \text{ X } \ln(E)$

  $A= \pi \text{ X } d_1 \text{ X } T$

  $=148.28 \text{ mm}^2$

- Cupping strain factor (E)

  $E = [(D/d_1) + 1] / (2d_1)$

  $= 1.43$

  From fig.6, $n_c=2.3$

  $F=148.28 \text{ X } 260 \text{ X } 2.3 \text{ X } \ln(1.43)$

  $= 39.035$ kN

- Total ram force required (T) = Draw force + Blank-holder force

  $= F + Pd_1$

  $= 39.035 + 10.958$

  $= 49.993$

  ≈ 50 kN

VI. LAYOUT OF DRAW DIE

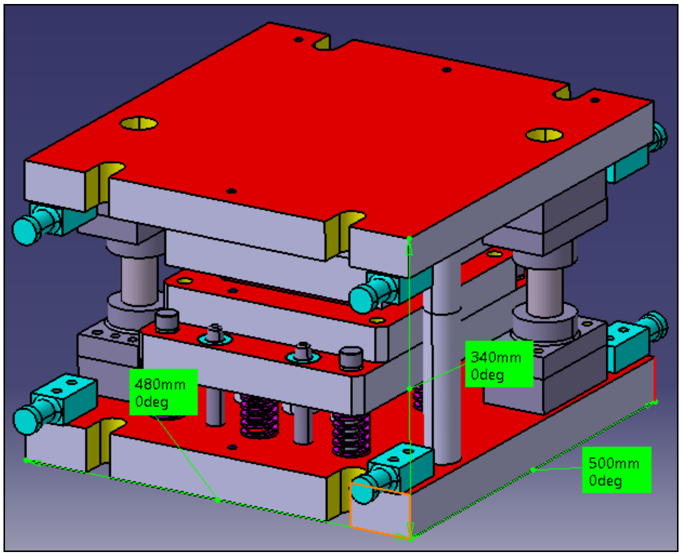

Fig.8 Draw tool

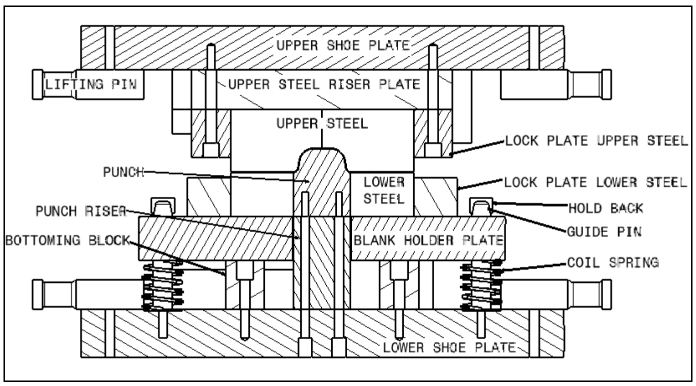

Fig.9 Sectional view of tool

The elements of die are designed based on the maximum draw force 50kN. The load coming on the components is compressive. The elements used in the die are

- Lifting pin
- Upper shoe plate
- Upper riser plate
- Upper steel
- Lock plate for upper steel
- Punch
- Lower steel
- Punch riser
- Hold back
- Guide pin
- Coil spring
- Bottoming block
- Lower shoe plate
- Blank holder plate
- Lock plate for lower steel

The design of the tool is carried out using CAD (CATIA V5 R21), the design is checked for its working mechanism using CATIA kinemeatic simulation tool.

VII.EXPERIMENTATION

The tool is manufactured based on the CAD design .Fig.10 shows the actual draw tool manufactured based on design.

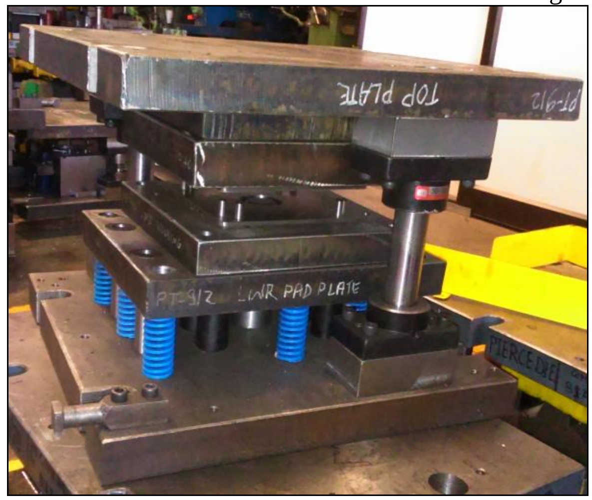

Fig.10 Manufactured draw tool

For testing of tool the try-out is carried out on the tool.

Fig.11 Testing of tool

The draw die is tested on press, for production of component.Fig.11 shows the actual testing of draw tool.

VIII. RESULTS AND DISCUSSION

The fig.12 shows the actual in-put part fed to the draw die.

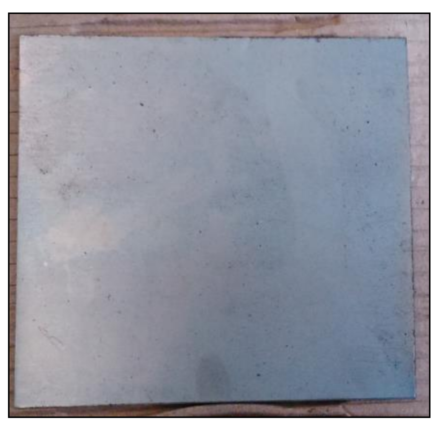

Fig.12 Input part

Fig.13 shows the output from the tool. This produced output is tested on co-ordinate measuring machine for checking its shape. Various points on part were measured and they were checked against the standard reference part geometry, prepared from CAD data.

Fig.13 Output part

The C.M.M. report indicates the part produced is within the tolerance limits which are decided by quality control department.

IX. CONCLUSION

Based on the results of design and experiment following conclusions are drawn

- Instead of using the traditional techniques for design of dies for sheet metal operations which are experimental and expensive, we can use analytical methods, CAD and FEA tools.
- Analytical tools help us to find out the various design parameters, forces, and key inputs for the design and same can be verified using CAD and FEA tools.
- Use of analytical methods, CAD and FEA tools reduce the errors, time for development of dies and increase the accuracy and reliability of design.
- The mechanism of tool can be decided and analyzed easily if the inputs from method planning department are proper.
- The working of tool can be visualized using CAD tools.
- Analytical and FEA tools help designer for design of elements and material selection.
- The travel of blank-holder is decided based on the draw depth of the output component.
- The size and the weight of upper die decide the type of guide elements to be used, their dimensions.
- Based on the report obtained from the CMM we can say that the design of the tool is correct.

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