Design and Analysis of Seven Stage Progressive Tool for Automobile Engine Starter Key

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***Abstract*: Sheet metal operations are carried out in press machine. Mainly, the types of tools are simple tool, compound tool and progressive tool. Progressive tools have high productivity, maximum stock strip utilization and have low cost as well. Close tolerances can also be achieved in a progressive tool. This paper describes the design of a seven stage progressive tool for irregular-shaped sheet metal automobile engine starter key of brass alloy material. The software used for modeling and assembling is CATIA V5. Finite element analysis using ANSYS 14.0 is performed on the punches to ensure the working condition of the tool well within the limit.**

***Index Terms*: Strip layout, progressive tool, press capacity**

I. Introduction

Metal stamping process is popular because of high productivity, ease in manufacturing, production of intricate shape and low cost [1].

Progressive die design is an important component of tool engineering. It consists of two or more dies and can perform multiple operations in single stroke of the press machine. The work is carried forward to next station at each press stroke. Products made by progressive tool can be found in almost all household or industrial appliances which are made by sheet metal [2]. Waller identified four factors which are quite essential to execute first class presswork which are good operation planning, excellent tool design, accurate tool making and knowledgeable press setting [3].

Design of right tool is the foremost aspect of tooling as it holds a considerable portion on overall cost of the manufactured component. It’s important to keep the tooling cost low without compromising the longevity of the tool as well [4].

In most industries, progressive die design is an art rather than a science. The tooling, the design sequence is decided based on individual designer’s skill and knowledge which are accumulated primarily through working experience [5].

In this paper, a seven stage progressive tool for automobile engine starter key is designed and finite element analysis is conducted over the punches. The 3D CAD model of the automobile engine starter key is shown in figure 1.

II. Component Details

The progressive die is to be designed for an automobile engine key starter of brass alloy. The details of the alloy and other properties such as thickness of the stock strip, shear strength, area of the component (obtained through CAD model), volume and weight of the component are tabulated in table 1.

TABLE I.
COMPONENT DETAILS

Material	ISO CuZn35Pb1 Brass
Thickness	2 mm
Shear strength (kg/mm2)	24 kg/mm2
Area of the component	525.735 mm2
Volume of the component	1051.47 mm3
Weight of component	8.8401047 g

Figure 1. 3D CAD model of the key

III. Strip Layout Development And Shear Force Calculation And Press Capacity

The first step of designing a progressive tool is development of the strip layout. It represents the sequence of operations to be carried out in each stages (or stations) [6].

A. Strip Layout

A = Back scrap = Front scrap = 2mm
B = Bridge scrap = 2mm
Width of the stock = 80mm
Pitch = B + L = 51.52 mm

Equation 1 shows the percentage utilization of the stock strip. The development of strip layout is shown in figure 2.

DOI:10.32377/cvrjst1208

% Stock strip utilization (n)

$$n = \frac{Area\ of\ blanks\ from\ the\ strip}{Area\ of\ strip\ before\ blanking} \times 100 \quad (1)$$

= 74.1 %

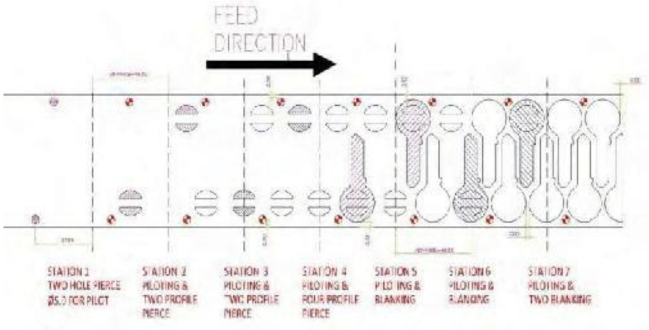

Figure 2. Development of the strip layout

As shown in figure 2, from the left hand side, at station 1 two holes for piloting are pierced. At stage 2 and 3 piloting on the sheet is done along with piercing two profile holes respectively.At station 4 four profile holes are pierced and at station 5 blanking of the outer profile of the key is performed. At station 6 and station 7, two blanking of two key profiles are performed in zigzag orientatation to have maximum stock utilization.

B. Shear Force calculation in Tons (T)

Equation 2 shows the shear force for cutting in tons (T) [7].

Stock Thickness, t = 2mm

Total cutting perimeter, L = 824 mm (Obtained from CAD model)

Shear force, $F_{sh} = \frac{K \times L \times t \times S_{sh}}{1000}$ T (2)

K= Factor of safety = 1.35

S_{sh}= Shear strength of the stock material = 24 kg/mm^2

Therefore, F_{sh} = 53.3952 ≈ 54 T

C. Ejection force (F_{ej}) & Press Capacity (P_c) in tons (T)

The sheet metal after shearing gets stuck in the land provided in the die hole. Therefore, it is required to push the slug out of the die hole by applying ejection force or push through force. Press capacity is the capacity of the press machine in which the progressive tool has to be installed. Equation 3 and equation 4 shows the calculation for ejection force and press capacity respectively [7].

Ejection force, $F_{ej} = 0.1 \times F_{sh}$ (3)

= 0.1 × 54 = 21.6 T

Press Capacity, $P_c = 1.5 \times F_{sh}$ (4)

= 1.5 × 54 = 81 T

IV. Development Of The Progressive Tool

A. Clearance (C)

Equation 5 shows the calculation for clearance to be given between die and the punch for shearing [7].

$$C = 0.005 \times t \times \sqrt{F_{sh}} \quad (5)$$

= 0.063 mm per side

B. Die Block Design

Equation 6 shows the thickness of the die which is also known as the female member of the tool [7].

a) Thickness of the die (T_D) in mm

$$T_D = \sqrt[3]{F_{sh}} \times 10 \quad (6)$$

= 37.7 ≈ 38 mm

b) Land and draft

If draft is not given, internal stress in the punch will cause crack in the die block. The standard value of land is 8 mm and draft angle is 1/2°.

c) Thickness of Bottom and Top Bolster

Equation 7 and equation 8 show the calculation for calculating the thickness of the bottom bolster and top bolster of the die set respectively [7].

Thickness of bottom bolster = 1.75×T_D (7)

= 66.5 ≈ 67 mm

Thickness of Top bolster = 1.25×T_D (8)

= 47.5 ≈ 48mm

d) Stripper plate design

During return stroke the scrap material adheres to the punch and causes interference. Stripper plate is used to strip the scrap material from the die block.

There are two types of stripper plate i.e fixed stripper plate and floating stripper plate. The later is used when the stock thickness is less than 1 mm, number of stations is more and various operations are present.

Equation 9 shows the calculation of the thickness of the stripper plate.

Thickness of the stripper plate, T_{ST}= 0.5×T_D (9)

T_{ST} = 19mm

e) Spring Design

When floating stripper plate is used, it is essential to use spring followed by shouldered pin. Mostly, helical springs are used for the floating stripper.

The two important parameters of spring design are maximum force (F_{max}) exerted by the spring shown in equation 10 and total deflection (Y_{max}) [8].

Stroke length or travel of the stripper in mm = Y_{st}

Y_{st} = (t+2) = 4 mm

Deflection of the spring = Y_{1max}

Y_{1max} = 4 times Y_{st} = 16 mm

Considering resharpening allowance, s = 2mm

Y_{max}= Y_{1max} + s = 18 mm

Now,

$$F_{max} = \left(1 + \frac{s}{Y_{1max}}\right) \times F_2 \quad (10)$$

F_2= Force exerted by the spring in fully compressed position.

F_c= Cutting force

F_{st}= Stripping force

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Equation 11 and equation 12 show the equation for force exerted by the spring in fully compressed position and stripping force respectively [8].

$F_2 = \frac{1.5 \times F_{st}}{i}$ (11)

$F_c = L \times t \times S_{sh}$

= 39552 kgf

i= Number of springs = 23

$F_{st} = 8\%\ of\ F_c$ (12)

= 3164.16 kgf

Equation 13 and equation 14 show the calculation for wire diameter and deflection of one free coil respectively [8].

$F_2 = \frac{1.5 \times 3164.16}{23} = 206.35$ kgf

Therefore, F_{max} = 232.143 kgf

Wire diameter, $d = \left[\frac{k \times 8 \times F_{max}}{\pi \times S} \times C\right]^{\frac{1}{2}}$ (13)

Where, k = 1.36 (Wahl's factor which is calculated from graph between C and k)

S = Permissible shear strength of the spring material = 70 kg/mm^2

$C = \frac{D}{d}$ = spring index = 4

D = Coil diameter

Therefore, d = 6.75≈ 7 mm

Deflection of one free coil, $Y_1 = \frac{8 \times F_{max}}{G} \times \frac{D^3}{d^4}$ (14)

G = Modulus of rigidity of the spring = 8300 kg/mm^2

D= C × d = 4 × 7 = 28mm

Therefore, Y_1 = 2.04 mm

Equation 15, 16, 17 and 18 show the calculation for number of coils, compressed length of the spring, free length of the spring and pre-compressed length on assembly respectively [8].

Number of coils, $n = \frac{Y_{max}}{Y_1}$ (15)

= 8.82 ≈ 9 coils

Compressed length, $L_{min} = (1.1 \times n \times d) + d$ (16)

= 76.3 mm

Free length of the spring, $L_0 = L_{min} + Y_{max}$ (17)

= 94.3 mm

Pre-compressed length on assembly,

$L_1 = L_{min} + Y_{st} + s$ (18)

= 82.3 mm

V. Finite Element Analysis Of The Punches

A. Results for Piloting punch

The CAD models of the punches are imported to ANSYS 14.0 for validating the working of the tool. The type of element chosen is tetrahedron (10 nodes) shown in figure 3.

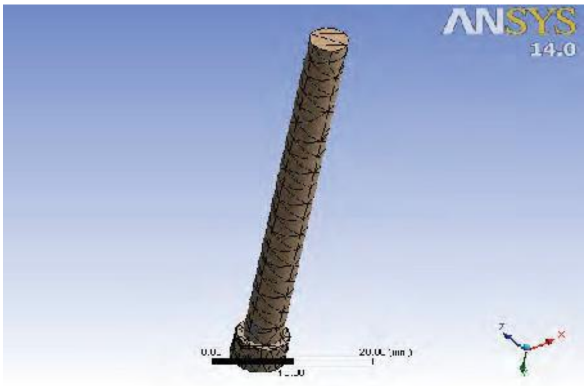

Figure 3. Meshing of the piloting punch (Tetrahedron 10-nodes)

Force required for piloting punch = $\frac{L_p \times t \times S_{sh1}}{1000}$ Tons

L_p= Length of cut by the piloting punch $= \pi D_p$

D_p= Diameter of the piloting punch = 5 mm

L_p= 15.71 mm

S_{sh1}= 24 kg/mm^2

Area of the piloting punch = $\frac{\pi}{4} \times D_p^2$ = 19.634 mm^2

Therefore, force required for piloting punch = 0.754 T or 7396.7 N

The results for maximum Von-Mises stress and total deformation after applying a load of 7396.7 N on the piloting punch are shown in figure 4 and figure 5.

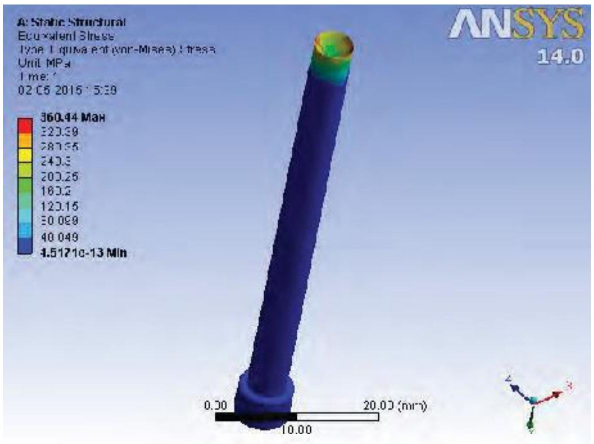

Figure 4. Von-Mises stress developed in the piloting punch

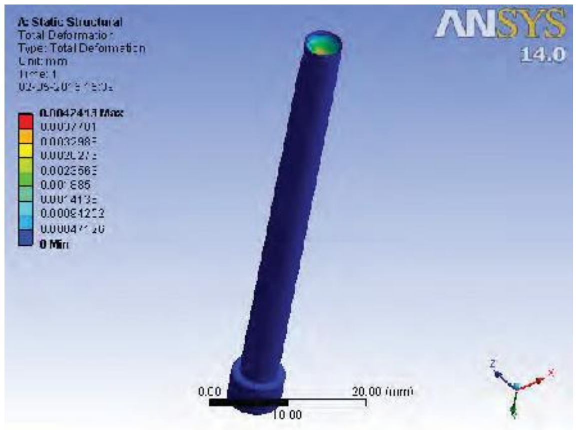

Figure 5. Total deformation occurred in the piloting punch

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It is required to calculate the stress develop in the piloting punch analytically.

Stress developed (σ_1) in piloting punch in N/mm^2

$$\sigma_1 = \frac{Force\ required\ for\ piloting\ punch}{Area\ of\ the\ piloting\ punch} = 376.63 \text{ N/mm}^2$$

B. Results for piercing profile punch

Force required for piercing profile punch = $\frac{L_{p1} \times t \times S_{sh1}}{1000}$ Tons

L_{p1}= Length of cut by the piloting punch = 34.6 mm (Obtained by CAD model)

S_{sh1}= 24 kg/mm^2

Area of the profile punch = 37.79 mm^2

Therefore, force required the profile punch = 16294.4 N

The type of meshing for the profile punch is similar to the meshing for the piloting punch.

The results for maximum Von-Mises stress and total deformation after applying a load of 16294.4 N on the profile punch are shown in figure 6 and figure 7.

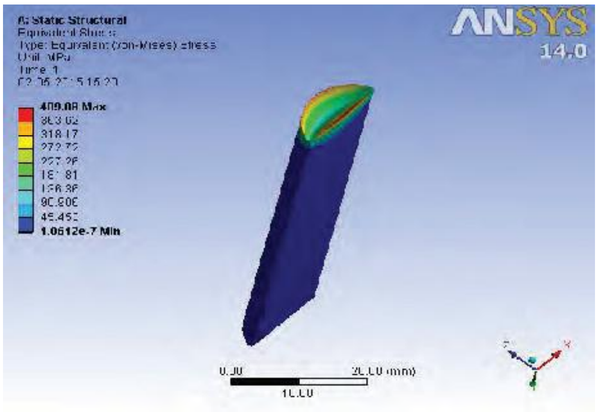

Figure 6. Von-Mises stress developed in the profile punch

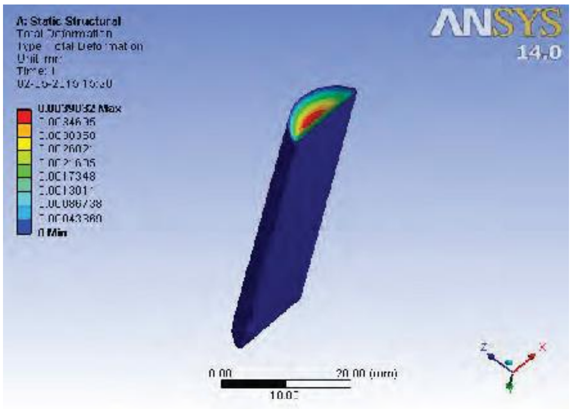

Figure 7. Total deformation occurred in the profile punch

It is required to calculate the stress develop in the profile punch analytically.

Stress developed (σ_2) in profile punch in N/mm^2

$$\sigma_2 = \frac{Force\ required\ for\ profile\ punch}{Area\ of\ the\ profile\ punch} = 431.11 \text{ N/mm}^2$$

C. Results for blanking punch

Force required for piercing profile punch = $\frac{L_{p2} \times t \times S_{sh1}}{1000}$ Tons

L_{p2}= Length of cut by the piloting punch = 128.8 mm (Obtained by CAD model)

S_{sh1}= 24 kg/mm^2

Area of the blanking punch = 161.05 mm^2

Therefore, force required the profile punch = 60822 N

The type of meshing for the blanking punch is similar to the meshing for the piloting punch.

The results for maximum Von-Mises stress and total deformation after applying a load of 60822 N on the blanking punch are shown in figure 8 and figure 9.

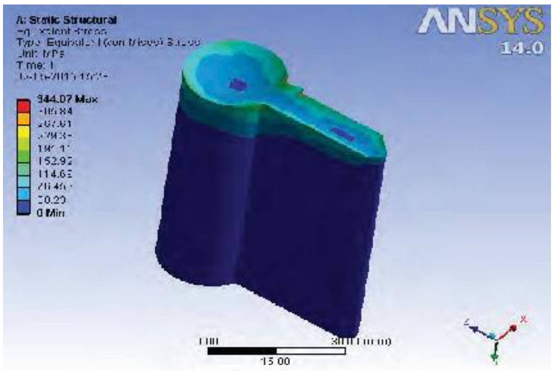

Figure 8. Von-Mises stress developed in the blanking punch

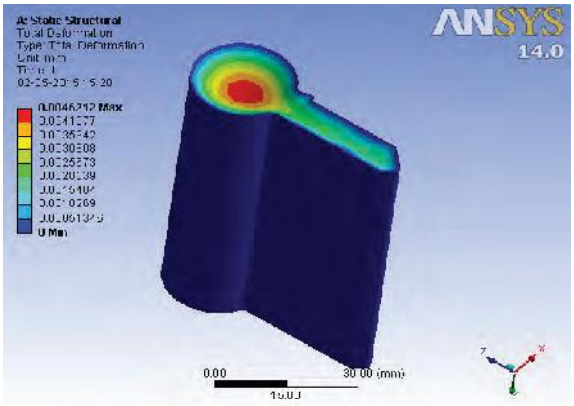

Figure 9. Total deformation occurred in the blanking punch.

It is required to calculate the stress develop in the blanking punch analytically.

Stress developed (σ_3) in blanking punch in N/mm^2

$$\sigma_3 = \frac{Force\ required\ for\ blanking\ punch}{Area\ of\ the\ blanking\ punch} = 377.64 \text{ N/mm}^2$$

VI. RESULTS AND DISCUSSIONS

The results of obtained from finite element analysis and analytical method is tabulated in table II.

DOI:10.32377/cvrjst1208

TABLE II.
RESULTS AND REMARKS

Serial number	Punches	Maximum Stress developed obtained through ANSYS	Stress developed analytically	Remarks
1.	Piloting Punch	360.44 MPa	376.63 MPa	Safe
2.	Profile Punch	409.08 MPa	431.11 MPa	Safe
3.	Blanking punch	344.07 MPa	377.64 MPa	Safe

The material of all the three punches is high carbon high chromium steel (D2 steel). Yield strength of D2 steel is 1476 N/mm^2 and the results obtained from both ANSYS and analytical method are less than the yield strength of the material. Hence, the material will not fail in the required working condition.

VII. FINAL ASSEMBLY

The final assembly consists of bottom bolster, stripper plate, punch plate and punches. The top assembly and bottom assembly are shown in figure 10 and figure 11 respectively.

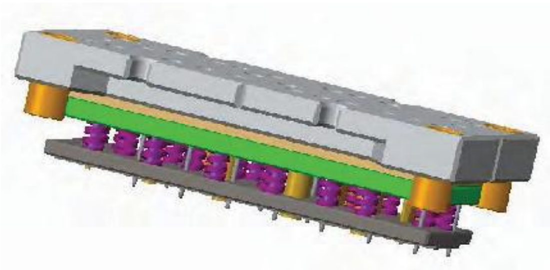

Figure 10. Top Assembly of the progressive tool

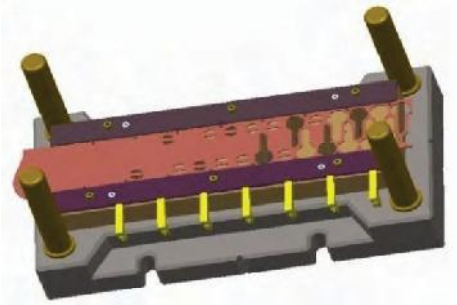

Figure 11. Bottom assembly of the progressive tool

VIII. CONCLUSIONS

In this paper, a seven stage progressive tool for automobile engine starter key is designed and modeled. Strip layout for maximum stock strip utilization is developed. Stock strip utilization achieved is 74.1 %. Three punches i.e. piloting punch, profile punch and blanking punch and the die elements are designed and assembled in CATIA V5. Further, finite element analysis for maximum Von-Mises stress and deformation is carried out on the punches using ANSYS 14.0 for validating the design. The results obtained are well within the limit. The press capacity obtained is of 81 T.

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DOI:10.32377/cvrjst1208