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Design, Development and Analysis of Press Tool for an Industrial Part

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Abstract: **A progressive die performs a number of operations like piercing, blanking, punching, etc in a single die at each workstation. At each stroke of press machine, finished part is obtained. This work deals with design of progressive tool having four workstations by using solidWorks 2013 for modeling the parts and 3dQuick press which is an add on software on soloidWorks2013. Tool involves blanking, piercing and bending operations.**

Keywords: **progressive die, solidWorks 2013 3dQuick press, piercing, blanking, punching.**

I. INTRODUCTION

Progressive die is a die which performs two or more operations subsequently in a single stroke. Finished part can be produced in a single stroke. In a Progressive die the strip is feed from one end and final part is collected from the other end. In this paper, the progressive die has four workstations. Cropping and piercing, piercing, bending 1 and bending 2 are the operations performed respectively at workstations one, two, three and four.

II. MATERIAL FOR DIE COMPONENTS

Selecting appropriate tool steel is crucial for achieving good productivity, tooling economy and quality of part. Whole tool is not required high strength material, because all parts of tool does not involve in operation. More important members are die, punch and hitting pad.

The main principle while selecting the material for that part is given as,

i. The tool material have more wear, abrasive or adhesive resistance than the part material. Also its friction force is more than part material.

ii. The hardness of material is more than the part material.

iii. Fatigue, shear, compressive strength is more than part material strength and plastic or elastic deformation strength is less than the part material strength.[9]

Here D2 type of steel is used for punch and die. It has more hardness and strength.

III. DESIGN OF PROGRESSIVE DIE

A. Die Clearance

Die clearance is depend on the part material property. If the material is ductile in nature then the clearance is small and for brittle material it is large clearance. If the clearance is given in reverse then there for ductile material it pass through die means here it draw from die instead of cutting. And in ductile material it damages the cutting edges of punch and die. The die clearance for mild steel is 2.5% or 5% of thickness per side.

C = 2.5 % of thickness

= (2.5/100) x 0.5 = 0.0125 mm

Or C = 5% of thickness

= (5/100) x 0.5 = 0.025 mm

Large clearance increases the tool life. So here take 5% of thickness per side.

B. Force Analysis

***1) Shear Force**:* The force required to be exerted by the punch in order to shear out the stock can be estimated from the actual shear area and shear strength of the material by using formula,

$$F = fs \, X \, Ls \, X \, t$$

Where, fs = shear strength of the blank material [N/mm^2]

Ls = shear length [mm]

t = thickness of the blank material [mm]

Shear force at station one (F1)

$$L_1 = fs \, X \, L_{S1} \, X \, t$$

LS1 = 228.79

F1 = 378.5 X 228.79 X 0.5

= 43327.10 N

Shear force at station two (F2)

$$L_2 = fs \, X \, L_{S2} \, X \, t$$

LS2 = 36.86 F2

= 378.5 X 36.86 X 0.5

= 6981.49 N

Shear force at station four (F3)

$$L_3 = fs \, X \, L_{S3} \, X \, t$$

LS2 = 32

F2 = 378.5 X 32 X 0.5

= 6060 N

The total shear force is the sum of shear force on each station

F Total shearing = F1 + F2 + F3

= 43327.10 + 6981.49 + 6060

= 56368.60 N

2) Bending Force: Bending force required to bend a work piece depends upon the thickness of the work piece. The bending force will be calculated from the knowledge of material properties and the die characteristics. Bending force can be calculated using formula,

$$B.F = \frac{c \, X \, W \, X \, Su \, X \, t^2}{L}$$

Where, c = die opening factor, 0.33

L = width of die opening in mm

W = width of sheet at bend in mm

Su= tensile strength in kg/mm^2

Bending force at station three (BF1)

$$BF_1 = \frac{0.33 \text{ X } 40 \text{ X } 505 \text{ X } 0.5^2}{8.5}$$

BF1 = 196 N

Bending force at station four (BF2)

$$BF_1 = \frac{0.33 \text{ X } 3.4 \text{ X } 505 \text{ X } 0.5^2}{7.5}$$

BF2 = 18.88 N

The total bending force is the sum of bending force at each station

F Total bending = BF1 + BF2

= 196 + 18.88

= 214.88 N

C. Press Tonnage Required

The capacity of the press is the ability to deliver enough force necessary to perform the metal working operation. And the press machine should be capable of delivering about 33% more force than the required for consistent performance. The plan is to design a progressive die for the multiple operation in a single stroke of the ram, the individual values for shearing and bending should be added.

Total Force per component = F Total bending + F Total shearing

= 67642.32 + 214.88

= 67857.20 N

= 6.91 Tone

Therefore, total tonnage required considering factor of safety is 10 Tone

D. Design of Die Parts

1) Die plate. The die assembly including the stripper and all bottom elements are mounted on the bottom plate. The bottom plate gives cushioning effect to the die and provides enough space for the tool to be clamped to the press bed. There may be an opening in the base plate, which allows the blank, or slug to fall and clear off from the tool.

It is usually made from D2 tool steel material and is hardened to 60-62 HRC. It provides cutting edge. When the cutting action is over, the punch withdraws from the die but the stock strip will also move along with the punch. So for next operation, the strip cannot be moved forward. To facilitate this function one plate is fixed above the die plate. This removes the strip from the punch by the unit called stripper. A good stock guide design always allows for staggering the entryway so that the work piece will not snag; a good design also allows for the stock guide to be removable from the die without components having to be disassembled [3]. The die opening has different designs and the design is selected after looking in the requirements and facilities available. The most common die section has straight line and angular clearance. The angular clearance is given in order to allow easy fall of components and slugs. And the land of the die is 1.5t = 0.75 mm die land. First die block for station one and two the cutting perimeter is 265.65 mm and the shearing force is 68751.59 N (7010.71 kg).

Thickness:

The thickness of die block is given by the formula;

$$T_d = \sqrt[3]{F_{sh}}$$

Where, Td = Thickness of die plate in mm

Fsh= Shear force in kg

For first die plate:

$$T_d = \sqrt[3]{7010.71}$$

Td = 19.14 mm ≈ 20 mm

For second die plate:

$$T_d = \sqrt[3]{917.73}$$

Td = 9.71 mm ≈ 10 mm

Deflection and stress:

Deflection:

It was assumed that the die block (die plate) to be fixed beam. The recommended deflection of the die block should be less than 0.025mm. [2]

$$\text{Deflection, } \delta = \frac{FL^3}{192EI}$$

$$I = \frac{Bh^3}{12}$$

Where; F = 80% of shearing (cutting) force act on the vertical direction [7].

E = modulus of elasticity = 2.1 X 105 N/mm^2

I = moment of inertia of the die block

For first die Block:

Assumption: The force is uniformly distributed load

F = 0.8 x 68751.59 N

= 55001 N

Where, L is the distance between the successive screw = 110 mm

b = 110 mm and h = 20 mm, I = 73333.33 mm4

$$\text{Deflection, } \delta = \frac{55001 \text{ X } 110^3}{192 \text{ X } 2.1 \text{ X } 10^5 \text{ X } 73333.33}$$

= 0.024 mm < 0.025

Hence, deflection of die plate is within allowable limit.

For second die block:

F = 0.8 x 8999.85N

= 7199.88 N

Where, L is the distance between the successive screw = 125 mm

b = 80 mm and h = 10 mm, I = 6666.66 mm^4

Deflection, $\delta = \frac{7199 \times 125^3}{192 \times 2.1 \times 10^5 \times 6666.66}$

= 0.052 mm > 0.025

Since the calculated deflection (0.052) value is above the recommended deflection (0.025) value it required to increase the thickness of die block to reduce the deflection. After iteration the proper thickness of the die block is 20 mm, hence the deflection will be below the recommended value

I = 22500 mm^4

δ= 0.015 mm

Hence, deflection of die plate is within allowable limit.

Stress:

For first die block:

$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

$$\sigma = \frac{55001}{2200}$$

σ = 25 N/mm^2

The stress induced 25 N/mm^2 which is much less than the allowable strength 2,200 N/mm^2, hence it is safe design.

For second die block:

$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

$$\sigma = \frac{7199.85}{1200}$$

σ = 5.99 N/mm^2

The stress induced 5.99 N/mm^2 which is much less than the allowable strength 2,200 N/mm^2, hence it is safe design.

2) Bottom Plate. The bottom plate gives cushioning effect to the die and provides enough space for the tool to be clamped to the press bed. There may be an opening in the base plate, which allows the blank, or slug to fall and clear off from the tool. The die assembly all bottom elements are mounted on the bottom plate. The material selected for the top plate is St-42.

Thickness:

Thickness of the bottom plate is given by,

Tb = 1.5 x Td

= 1.5 x 23.3 mm

= 34.95 mm ≈ 35mm

Deflection and stress:

Deflection:

Bottom plate is considered to be on parallels, the recommended deflection of the die bottom bolster (die shoe) should be less than 0.025 mm by controlling the span between the parallel blocks, or by increasing the bottom bolster thickness in the lower tool. The lower tool can be considered as a simply supported beam with a uniformly distributed load. For the system it is used seven parallel blocks to support the bottom plate.

Deflection,

$$\delta = \frac{5FL^3}{354EI}$$

F = 0.8 x 67642.32N

= 54113.85 N

Where, L is the distance between the successive

screw = 180 mm

b = 260 mm and h = 35 mm

I = 928958.33 mm^4

$$\delta = \frac{5 \times 54113.85 \times 180^3}{354 \times 2.1 \times 10^5 \times 928958.33}$$

= 0.022 mm < 0.025

Hence, deflection of die plate is within allowable limit.

Stress:

$$\sigma = \frac{54113.85}{9100}$$

σ = 5.94 N/mm^2

The stress induced 5.94 N/mm^2 which is much less than the allowable strength 240 N/mm^2, hence it is safe design.

3) Top Plate: The upper working member of the tool is called the top plate. The punch assembly including the punch holder and thrust plate is mounted on the top plate. The tool shank, which locates the whole tool centrally with the press ram, is also screwed into the top plate. Material chosen for the top plate is St-42.

Thickness:

Thickness of the bottom plate is given by,

Tt = 1.25 x Td

= 1.25 x 23.3 mm

= 29.12 mm ≈ 30mm

4) Punch plate: The punch is usually fitted to a plate with a light press fit. Punch holder holds all types of cutting and guiding parts to ensure alignment between punch and die made of St-42.

Thickness:

Thickness of the punch plate is given by,

Tp = 0.5 x Td

= 0.5 x 23.3 mm

= 11.65 mm ≈ 12mm

5) Stripper plate: The primary purpose of a stripper is to remove the stock from the punch after a blanking or piercing operation. However the stripper serves two other secondary functions also. Firstly it guides the strip if fixed to the die block surfaces. Secondly, it holds the blank under pressure before the punch descends fully if the stripper is of spring loaded type.

Thickness:

Thickness of the bottom plate is given by,

Ts = 0.75 x Td

= 0.75 x 23.3 mm

= 17.47 mm ≈ 18mm

Deflection and stress for Top Half:

Deflection:

It can be considered as a simply supported beam loaded at the center and the deflection is given by;

Deflection,

$$\delta = \frac{FL^3}{48EI}$$

F = 0.8 x 67642.32N

= 54113.85 N

Where, L is the distance between the successive screw = 160 mm

b = 260 mm and h = 30 mm, I = 585000 mm^4

$$\delta = \frac{54113.85 \text{ X } 160^3}{48 \text{ X } 2.1 \text{ X } 10^5 \text{ X } 585000}$$

= 0.037 mm > 0.025

Since the calculated deflection (0.037) value is above the recommended deflection (0.025) value it required to increase the thickness of die block to reduce the deflection. After iteration the proper thickness of the die block is 35 mm, hence the deflection will be below the recommended value

I = 928958.33 mm^4

δ= 0.023 mm

Hence, deflection of die plate is within allowable limit.

Stress:

$$\sigma = \frac{54113.85}{9100}$$

σ = 5.94 N/mm^2

The stress induced 5.94 N/mm^2 which is much less than the allowable strength 240 N/mm^2, hence it is safe design.

6) Guide Pillar and Guide Bush: Guide pillar and guide bush are very important elements in press-tool. Pillar and bush guide the moving and fixed half of the tool in the press and they are also used to ensure accurate alignment between the punches and die. These are made of case hardened St-42. Pillar and bushes are hardened and tempered to 56-58 HRC.

Buckling for guide pillar:

Guide pillar material, St-42 with a compressive strength of 330 N/mm^2 and E = 2.1 x 105 N/mm^2

Where, Le = 2L for one end fixed and other end free

l = 142

$I = \frac{\pi \text{X } D^4}{64}$ = 51445.76 mm^4

D= 32 mm

A= 804.24 mm^2

$r_g = \sqrt{\frac{I}{A}}$ = 8

$SR = \frac{L_e}{r_g}$ = 35.5

$$TSR = \sqrt{\frac{2\pi^2 E}{s_{yc}}} = 112$$

Where, rg = radius of gyration

S.R = slenderness ratio

T.S.R.= transition slenderness ratio

Johnson's equation will be used to calculate the critical buckling load because of the slenderness ratio (S.R) is less than the transition slenderness ratio (T.S.R).

$$F_{cri} = A(S_y - \frac{S_y{}^2}{4\pi^2 E}(\frac{L_g}{r_g})2)$$

$$F_{cri} = 804.24(240 - \frac{240^2}{4\pi^2 E}(8)2)$$

$= 264725.40$ N > 16964.30 N

The applying load is less than the critical load carrying capacity of the guide pillar (264725.40 N), therefore the structure is safe.

Load per pillar $= \frac{67857.20}{4}$

$= 16964.30$ N

F = 80 % of 16934.30

= 13571.44 N

Deflection, $\delta = \frac{FL}{AE}$

$$= \frac{13571.44 \text{ X } 142}{804.24 \text{ X } 2.1 \text{ X } 10^5}$$

$= 0.011$ mm

Stress, $\sigma = \frac{13571.44}{804.24}$

$= 16.87$ N/mm^2

The stress induced 16.87 N/mm2 which is less than the allowable strength 240 N/mm^2 hence, the structure is safe.

7) Punch: A punch is the male member of a press tool to get a component from the strip. The shank should be running fit and the length of the shank should be 1 to 2 mm less than shank hole depth to ensure full contact of the ram face with the top bolster of the tool. The shank clamping screw should be almost at the center of the tapered part of the shank. It is made out of good quality alloy steel called HCHCr (D2) material and hardened to 58-62 HRC. The proper length of a punch has a considerable effect on the overall performance of the die. With too long punches, the compressive stress on them may be excessive, resulting in frequent breakages. The maximum length of a punch may be calculated with the aid of Euler's formula, for punch fixed at one end and guided at the other end the critical force computed by the formula.

$$F_{cri} = \frac{2\pi^2 EI_{min}}{L^2}$$

If critical force Fcri equals punch force, then the maximum length of the punch may be calculated by the following formula;

$$L_{max} = \sqrt{\frac{2\pi^2 EI_{min}}{P}}$$

For cylindrical Punch: D = 5mm,

E = 2.1 x 105 N/mm^2, P = 2973.18 N

Critical max Length =

$$L_{max} = \sqrt{\frac{2\pi^2 EI_{min}}{P}} = \sqrt{\frac{2\pi^2 \times 2.1 \times 10^5 \times 30.67}{2973.18}}$$

= 206.68mm

This is the safe maximum length that can perform without failure.

$$I = \frac{\pi X D^4}{64} = \frac{\pi X 5^4}{64}$$

= 30.67 mm^4

Buckling for Punch:

Punch material, D2 with a compressive strength of 2200 N/mm^2 and E = 2.1 x 105 N/mm^2

Where, Le = 2L for one end fixed and other end free

l = 62

A= 20 mm^2

$$r_g = \sqrt{\frac{I}{A}} = 1.23$$

$$SR = \frac{L_e}{r_g} = 100$$

$$TSR = \sqrt{\frac{2\pi^2 E}{s_{yc}}} = 43.38$$

Where, rg = radius of gyration

S.R = slenderness ratio

T.S.R.= transition slenderness ratio

Euler's equation will be in use to calculate the critical buckling load because the slenderness ratio is greater than the transition slenderness ratio.

$$F_{cri} = \frac{\pi^2 EI}{L^2}$$

$$F_{cri} = \frac{\pi^2 \times 2.1 \times 10^5 \times 30.67}{62^2}$$

= 16519 > 2973.18

The applying load is less than buckling/crippling load; it is safe load.

Assuming the piercing punch as one end is fixed and compressive force is acting on other end. For cutting operation (piercing operation) 80% of cutting force is acting on punch as compressive nature [7].

F = 80 % of 2973.18

= 2378.54 N

Deflection, $\delta = \frac{FL}{AE}$

$$= \frac{2378.54 X 62}{20 X 2.1 X 10^5}$$

= 0.035 <0.25 mm

Stress, $\sigma = \frac{2378.54}{20}$

= 118.95 N/mm2

The stress induced 118.95 N/mm2 which is less than the allowable strength 2200 N/mm2.

IV. FEM ANALYSIS

In the preceding section critical parts of the die is designed by consulting different die hand book, the validation of this design is preferred to perform on software. The critical parts of the die is modeled and the simulation has been done on solidwork2013, during the analysis the boundary condition are appropriately given to the model and the material properties are specified as per the selection for each component.

A. Material Properties

TABLE I: MATERIAL PROPERTIES OF DIE PARTS>

Sr. No.	Part Name	Modulus of elasticity [N/mm^{2}]	Ultimate compressive strength [N/mm^2]	Poisson's ratio	Density [Kg/mm^3]
1	Piercing and bending punches	2.1X 10^5	2200	0.394	7600
2	Piercing and bending die	2.1X 10^5	2200	0.394	7600
3	Top, bottom, stripper and punch plate	2.1X 10^5	240	0.3	7800
4	Guide pillar	2.1X 10^5	240	0.3	7800

B. Loads

Load for some function elements like top half; bottom plate and die plate are applied on Fz positive direction of magnitude as 80% of cutting force as vertical. And for punches like piercing punch, bending piercing punch, notching punch and blanking punch are applied on Fz positive direction of magnitude as calculated cutting force of that operation as compressive load on surface. And also for guide pillar load applied is on Fx positive direction of magnitude as 10 to 20% of cutting force as thrust load and Fz positive direction of magnitude of 80 to 90% of cutting force as vertical load

C. Analysis

Load for some function elements like top half; bottom plate and die plate are applied on Fz positive direction of magnitude as 80% of cutting force as vertical. And for punches like piercing punch, bending piercing punch, notching punch and blanking punch are applied on Fz positive direction of magnitude as calculated cutting force of that operation as compressive load on surface. And also for guide pillar load applied is on Fx positive direction of magnitude as 10 to 20% of cutting force as thrust load and Fz positive direction of magnitude of 80 to 90% of cutting force as vertical load

***1) Punch1*:** Material: D2; Yield strength 2,200MPa; F (applied load): 80% of the cutting force = 2379.75N

Table II: Stress plots and resultant displacement for punch 1

Part Name	Von Misses Stress		Resultant Displacement	
	Min (N/M2)	Max (N/M2)	Min (mm)	Max (mm)
Punch 1	2,362,757.8	131,122,688.0	0.0	0.0097

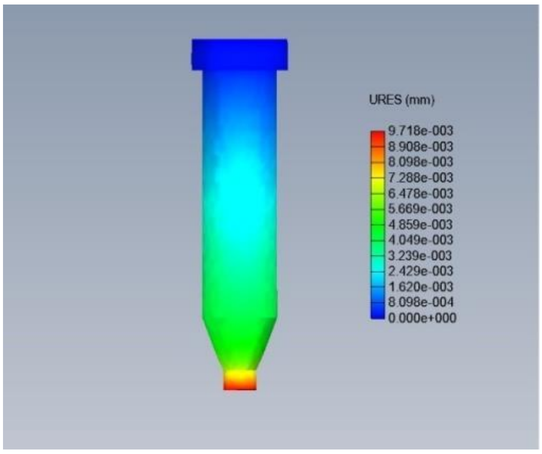

Fig.1 Displacement plot of punch 1

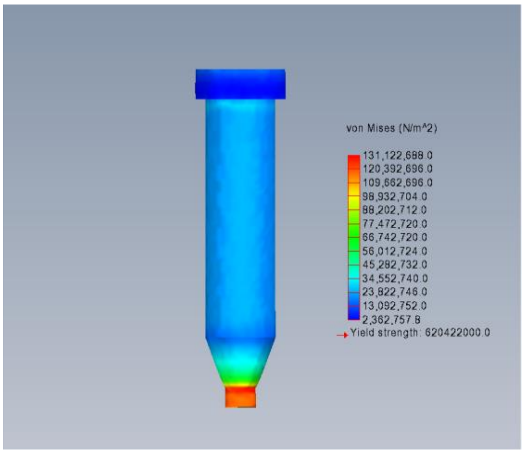

Fig.2 Stress plot of punch 1

***2) Guiding Pillar**:* Material: St-42; Yield strength 240 MPa; F(applied load): 80% of the cutting force = 13571.44 N

Table III: Stress plots and resultant displacement for guide pillar

Part Name	Von Misses Stress		Resultant Displacement	
	Min (N/M^2)	Max (N/M^2)	Min (mm)	Max (mm)
Guide pillar	4,501.1	14,535,453.0	0.0	0.0095

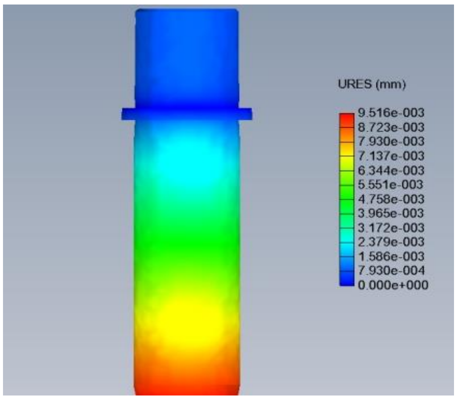

Fig. 3 Displacement plot of guide pillar

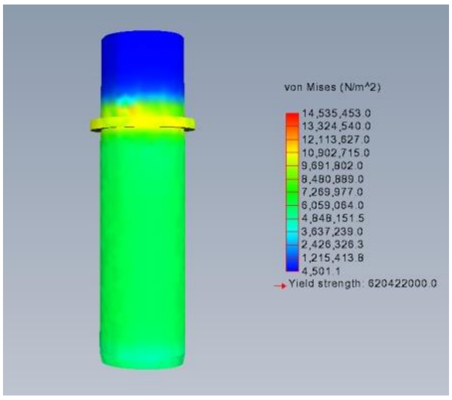

Fig. 4 Stress plot of guide pillar

Table IV: FEM simulation and calculated results

Sr. No.	Part Name	FEM Simulation Results		Calculated Results	
		Deflection (mm)	Stress (MPa)	Deflection (mm)	Stress (MPa)
1	Punch 1	0.0097	132	0.035	119
2	Punch 2	0.047	85	0.008	26
3	Punch 3	0.023	58	0.008	26
4	Punch 4	0.014	95	0.011	40
5	Punch 5	0.00042	2	$9.48x10^{-5}$	1
6	Punch 6	0.0011	2	$5.8x10^{-5}$	1
7	Die Block1	0.017	32	0.024	25
8	Die Block2	0.0083	24	0.015	6
9	Bottom plate	0.0079	20	0.022	6
10	Top Plate	0.0041	16	0.023	6
11	Punch plate	0.0045	31	0.023	20
12	Stripper plate 1	0.0032	25	0.022	17
13	Stripper plate 2	0.0023	25	0.022	17
14	Guide Pillar	0.0095	15	0.011	17

V. CONCLUSION

Progressive die is an economical way to form metal components with variety of characteristics, including strength, durability and wear resistance. In this research work, four stage progressive die has been designed for manufacturing of given industrial part.

Finite element method (FEM) analysis is done for piercing punches, bending punches, piercing block, bending block, bottom plate, top half plate and pillars. The analytical and FEM result of critical components of the die is sound and the percentage of error is within the acceptable range.

All the results of stress and displacement which were used as a parameter to check the appropriateness of the design of each component shows that it is within the allowable limit. The results obtained from Solid-works simulation, the stress values for all parts are less than the respective yield stress value of the material. So, the designed progressive die parts are safe under the given loading conditions. The tools which are exposed to wear will work in optimum condition by satisfying structural stability; furthermore parts which are not directly in contact with the blank material give their required function without any difficulty of structural integrity and stability. The deflections of all the parts during operation are kept below 0.025mm as per the recommendation of die manufacturer.

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