Flyball Press Design for Sheet Metal Punching

Design of Machine Components Project 2

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I. PROBLEM STATEMENT

Design a suitable mechanical system for a manually operated punch press machine to punch rectangular holes of specified size in sheet metal.
Specifications:
Load: 6000 N
Space constraints: 0.5 m X 0.5 m X 0.5 m

II. SOLUTION

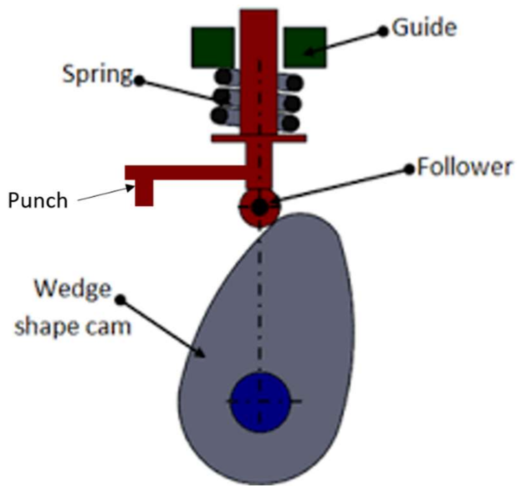
Application: Punch square hole in sheet metal
Capacity: 6000 N
Space constraints: 0.5 m X 0.5 m X 0.5 m
Working condition: Hand operated punching machine
Human effort assumption: 125 N

III. THEORY

A. Possible Design Solutions

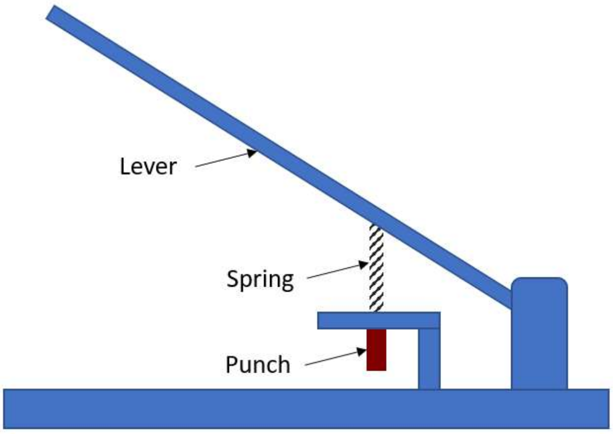
Cam Follower Mechanism

The mechanism uses the cam can be rotated by hand (prime mover), which lifts the follower pushing the punch out of the hole and compressing the spring at the same time. In the second half of cam's rotation, the follower moves downwards with a force equal to its weight and the spring force.This mechanism can be employed to punch successive holes in sheet metal.



Lever with attached spring Mechanism

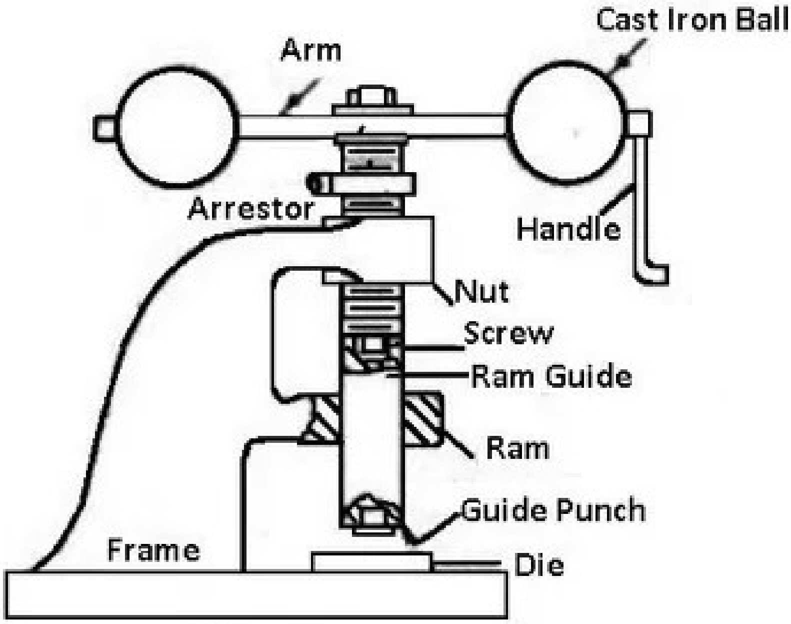
A lever is pivoted on the work table with sufficient leverage is provided to the operator for punching applies force onto a vertical push rod is pinned to the lever. The mechanism returns to the original position due to spring action.



Rack and Pinion Mechanism
The torque applied to the pinion drives the rack and hence the punch attached to the rack. The punch translates and punches hole in sheet metal placed on the base of the frame.

B. Proposed Solution

Fly Press Mechanism
A Fly Press is a machine tool used to shape sheet metal by deforming it or cutting it with punches and dies. The punch is at placed at the top and the die at the bottom. The two heavy cast iron balls are mounted at the two ends of the flyball rod and provide high moment of inertia. The flyball rod is attached to the power screw which translates within the nut when rotary motion is provided. The ram attached to the power screw slides along with the power screw and punches hole in sheet metal placed at the bottom on the die. The press is operated by a sharp, partial revolution of the arm by pulling the handle and the kinetic energy is stored up in the two heavy balls mounted on the arm.



Fly press

Advantages:

1. A power screw has large load carrying Capacity.
2. The overall dimensions of the power screw are small, resulting in compact construction.
3. A power screw is simple to design and manufacture on a lathe
4. The manufacturing of a power screw is easy without requiring specilised machinery.
5. A power screw provides large mechanical advantage. A load of 15 kN can be raised by applying an effort as small as 400 N.
6. A power screw provides precisely controlled and highly accurate linear motion required
7. A power screw gives smooth and noiseless service without much maintenance.
8. A non-self-locking power screw can reduce the required punching load.

Disadvantages:

1. A power screw has very poor efficiency, of about 40%.
2. High friction in threads causes rapid wear of the screw or the nut.
3. The nut is usually made of soft material and needs replacement when worn out.

IV. DESIGN PROCEDURE

A. Sheet Metal – Material and Size Selection

The sheet thickness selected is 0.5 mm. Following materials with given shear strength are taken into consideration for the design calculations.

Material	Shear Strength (S_{us}) (MPa)
Brass	240
Low carbon steel	345
Aluminium	400

Minimum size of rectangular hole that can be punched in the metal sheets with thickness 2 mm. is –

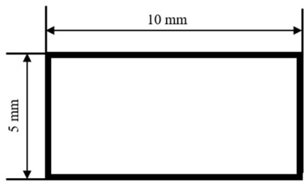
$$Perimeter * t * S_{us} = Area * S_{uc}$$

where, S_{us} - shear strength
S_{uc} – compressive strength

Considering $S_{uc} = 2S_{us}$

$$t = \frac{2\ Area}{Perimeter}$$

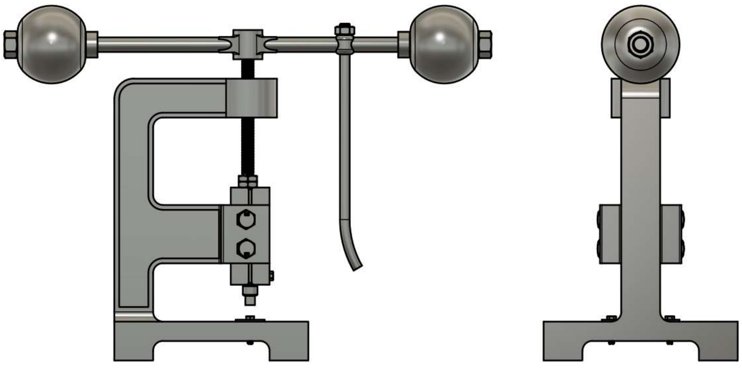
A rectangular hole of size 5 mm x 10 mm is selected as the punch size.



Perimeter (P) = 30 mm.
Thickness (t) = 0.5 mm.

Punching force requirements for different materials –
For Brass,
$Punch\ Force = S_{us} * P * t = 240 * 0.5 * 30 = 3600\ N$
For Low carbon steel,
$Punch\ Force = S_{us} * P * t = 345 * 0.5 * 30 = 5175\ N$
For Aluminium,
$Punch\ Force = S_{us} * P * t = 400 * 0.5 * 30 = 6000\ N$

B. Orthographic views

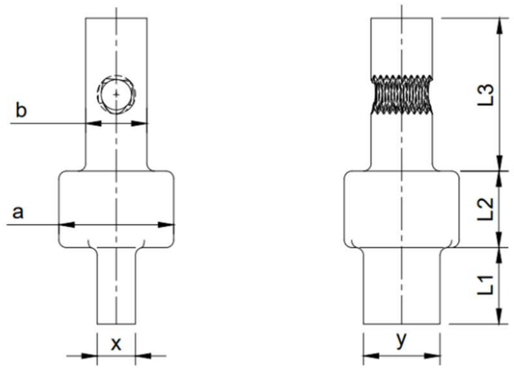


FRONT VIEW L.H.S.V

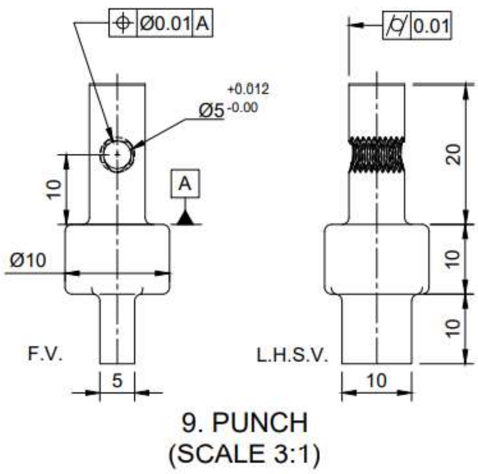
V. PART DESIGN

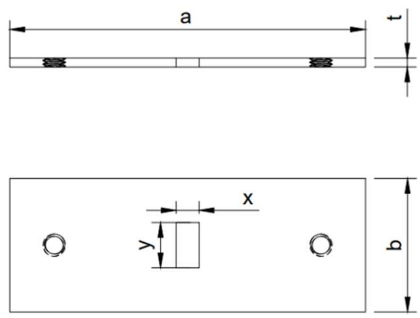
A. Punch (9) and Die (10)

Function:
To apply force and cause shear of sheet metal for punching action.

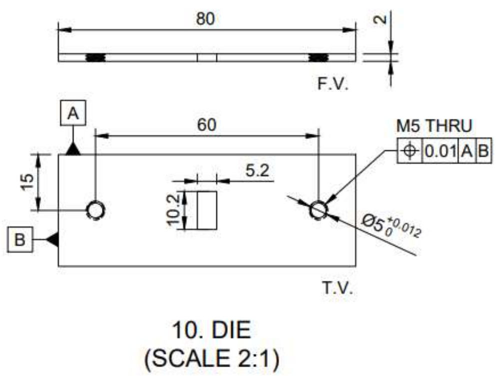


Design parameters





Design parameters



Orthographic view

Material Selection:
Carbon tool steel T65, T70
Tool steels are selected as they offer high resistance to abrasion, high hardness and have the ability to withstand high pressures.

Punch dimensions – 5 mm x 10 mm

Die Clearance $c = 0.0032\, t \sqrt{f_s}$

For t = 0.5 mm,

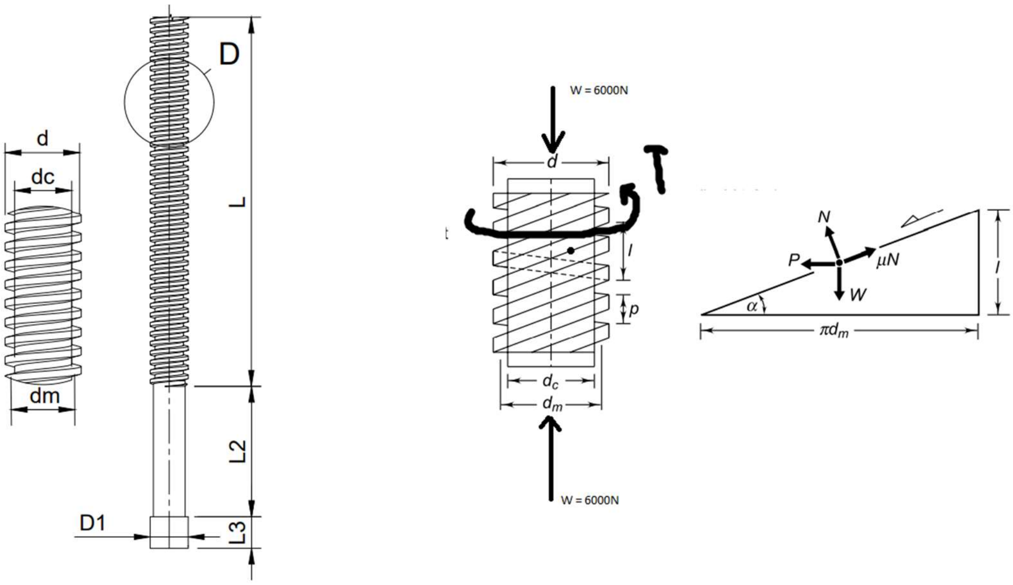
c = 0.032 mm

Die dimensions – 5.032 mm x 10.032 mm

B. *Power Screw (4)*

Function:
Linear and rotary motion of the screw in the nut generates the force required to shear the sheet metal.

Critical Mode of Failure:
Crushing failure due to compressive force.



Design parameters

Material Selection:
Steel 30C8
Steel is chosen as it is the recommended material for power screws.
The grade is chosen after various trials.

Material Properties:
Tensile Yield Strength (S_{yt}) = 400 N/mm^2.

Factor of Safety:
Screw is subjected to torque, axial compressive load and bending moment also, sometimes. Screws are generally made of C30 or C40 steel. As the failure of power screws may lead to serious accident, higher factor of safety of more than 5 is taken.

Design Calculations

Diameter, pitch, and number of starts of screw-

Compressive stress experienced by lower portion of screw,

$$S_{yc} = S_{yt} = 400\ N/mm^2$$

$$\sigma_c = \frac{S_{yc}}{f_s} = \frac{400}{3} = 133.33\ N/mm^2$$

Core diameter of the screw d_c,

$$d_c = \sqrt{\frac{4W}{\pi\sigma_c}} = 7.57\ mm$$

To account for the torsional shear stress along with compressive stress, a screw with an increased nominal diameter is considered by trial-and-error method,

A fine square threaded power screw of nominal diameter (d) of 24 mm, pitch (p) of 5 mm and triple start thread is selected. A pair of case-hardened steel screw and bronze nut is suggested for hand press.

Standard size of power screw selected – Sq 24 x 15 (P5)

Lead of screw,

$$l = 3p = 15\ mm$$

Mean diameter of screw,

$$d_m = d - 0.5p = 21.5\ mm$$

Torque required to lift load-

Helix angle,

$$\alpha = \tan^{-1}\frac{l}{\pi d_m} = 12.519°$$

Considering average friction coefficient between steel screw and bronze nut = 0.15,

Friction angle,

$$\varphi = \tan^{-1}\mu = \tan^{-1}(0.15) = 8.531°$$

Since friction angle (φ) < helix angle (α),

The power screw is non-self-locking. Thus, no force is required to lower the load.

The torque required to lift the load,

$$M_t = \frac{Wd_m}{2}\tan(\varphi + \alpha) = 24823.902\ Nmm$$

Stresses in power screw-

Core diameter,

$$d_c = d - p = 19\ mm$$

Compressive stress,

$$\sigma_c = \frac{W}{\frac{\pi}{4}d_c^2} = 21.159\frac{N}{mm^2}$$

Torsional stress,

$$\tau = \frac{16M_t}{\pi d_c^3} = 18.430\ N/mm^2$$

Total stress,

$$\tau_{max} = \sqrt{(\frac{\sigma_c}{2})^2 + \tau^2} = 21.251\ N/mm^2$$

According to maximum shear stress theory,

$$S_{sy} = 0.5\ S_{yt} = 200\ N/mm^2$$

$$f_s = \frac{S_{sy}}{\tau_{max}} = 9.411$$

Efficiency of the power screw-

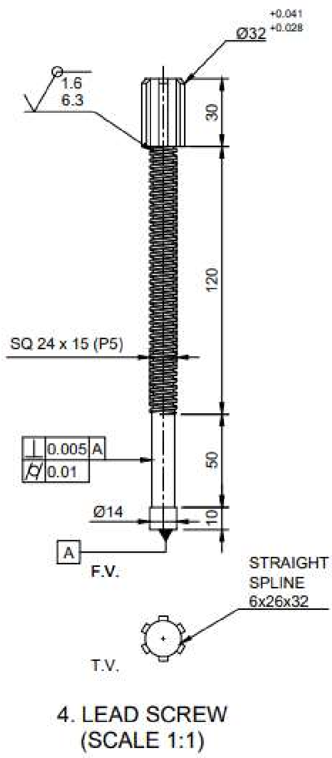
$$\eta = \frac{\tan\alpha}{\tan(\alpha + \varphi)} = 57.69\%$$

Torque required to lower the load-

$$M_t = \frac{Wd_m}{2}\tan(\varphi - \alpha) = -81454.21\ Nmm$$

Negative sign indicates that torque is not required to lower the screw (Overhauling)

Standard size: Sq 24 x 15 (P5)
Material: Steel 30C8

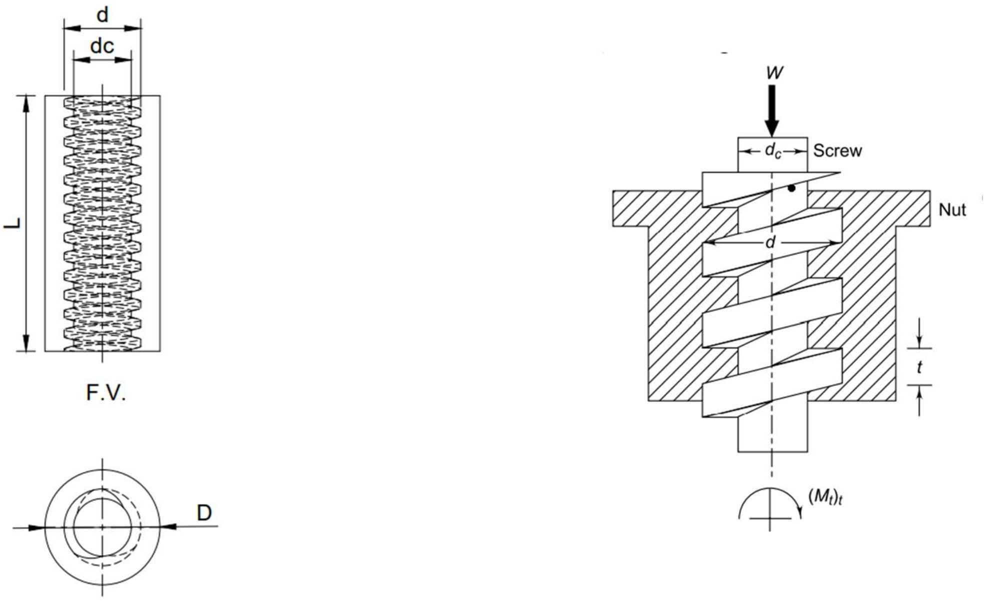


Orthographic view

C. Power Screw Nut (5)

Function:
The power screw engages its threads in the nut, also as a support to the screw.

Critical Mode of Failure:
Crushing failure due to compressive force.



Design parameters

Material Selection:
Bronze is selected as it is recommended nut material for steel screws.

Length of nut-

Unit bearing pressure (S_b) for steel screw and bronze nut is 18 N/mm^2
Number of threads,

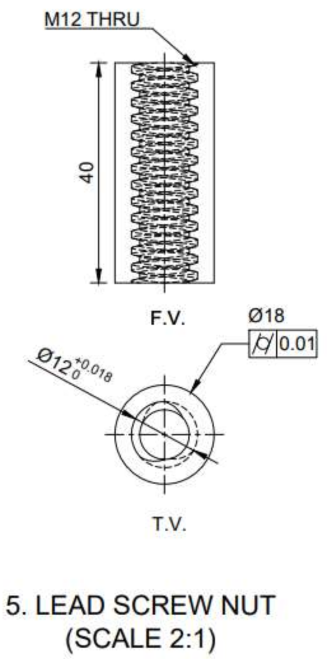
$$z = \frac{4W}{\pi\, S_b (d^2 - d_c^2)} = 1.97 \;\approx 2\; threads$$

Length of nut,
$L = zp = 10\; mm$

Shear stresses in screw nut-

$$\tau_s = \frac{2W}{\pi d_c p z} = 20.101\; N/mm^2$$

$$\tau_n = \frac{2W}{\pi d p z} = 15.9\; N13/mm^2$$

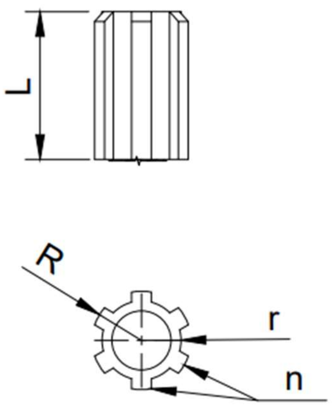


Orthographic view

D. Spline Design (4)

Function:
Fixation of power screw with rotating flyball rod.

Critical Mode of Failure:
Crushing failure due to compressive force.



Design parameters

Material Selection:
Steel 30C8
The spline is a part of the upper end of power screw and hence is of the same material as that of the screw.

Material Properties:
Tensile Yield Strength 400 N/mm^2.

Factor of Safety:
The screw is subjected to torque, axial compressive load. A spline is used to fix the power screw and the flyball rod and hence must not fail under high torque. As the failure of spline may lead to serious accident, a higher factor of safety is considered.

Major Diameter (D) = 32 mm

Minor Diameter (d) = 26 mm

Length (l) = 20 mm

No of spline (n) = 6

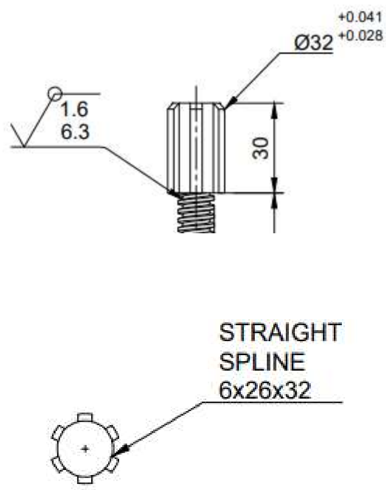
Torque transmitted (M_t) = 24825.9 Nmm

Pressure acting on spline $(P_m) = \frac{8\,M_t}{l * n\,(D^2 - d^2)} = 4.75$ N/mm^2

< 6.5 N/mm^2 (Permissible pressure)

Standard size (Straight sided spline) – 6 x 26 x 32 Medium duty series

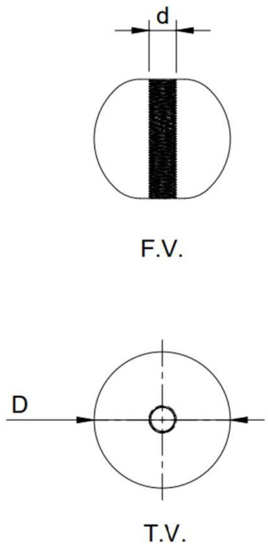
Material: Steel 30C8



Orthographic view

E. *Flyball (3)*

Function: Two heavy metal spheres placed at a distance from lead screw in order to provide greater moment of inertia for rotating the lead screw.



Design parameters

Design dimensions are selected after various iterations of calculations.

Work done in punching the hole (E) is given by,

$E \;=\; Punch\ Force * Sheet\ Thickness * 0.5$

$E = \; 1.5\ Nm\ or\ J$

The efficiency of the screw is 48.4 %, therefore, the work done by the balls is given by,

$E_i = 3.1\,J$

The Kinetic Energy of the Flywheel is given by,

$E_k = \frac{1}{2}mr^2\omega^2$ where, m = total mass of two balls

r = radius of gyration

ω = angular acceleration

The proposed operation consists of moving the flyball by a quarter turn in 1 second.
This leads to an average angular velocity of,

$$\omega_{avg} = \frac{\pi}{2}\ rad/s$$

The maximum angular velocity is given by,

$$\omega_{avg} = \frac{\omega_{max} \quad \omega_{intial}}{2}$$

$$\omega_{max} = \pi \, rad/s$$

Using the Kinetic Energy Equation, the total mass of the balls,
m = 10.04 ≈ 10 kg

Mass of each cylinder,
M = 5.02 kg ≈ 5 kg

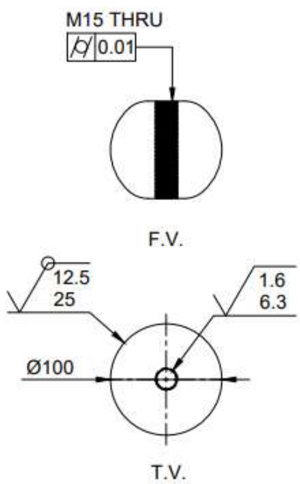
Considering material of cylinder to be Cast Iron with density 7840 kg/m^3
Diameter of each ball,
d = 100 mm

The force to be applied by the human (F) is given by

$$F = \frac{E_i}{r * \theta} = \frac{55.007 * 2}{0.3 * \pi} = 16.23 \, N$$

This force is well within the max intermittent force of 125 N as recommended by ergonomists.

Size: d = 100 mm
Material: CI (Density = 7840 kg/m^3)



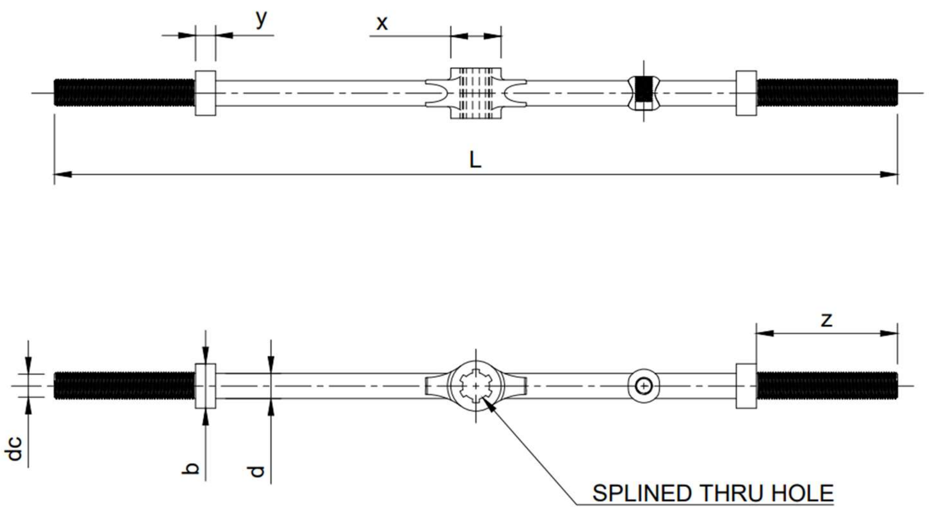
3. FLYBALL
(SCALE 1:2)

Orthographic view

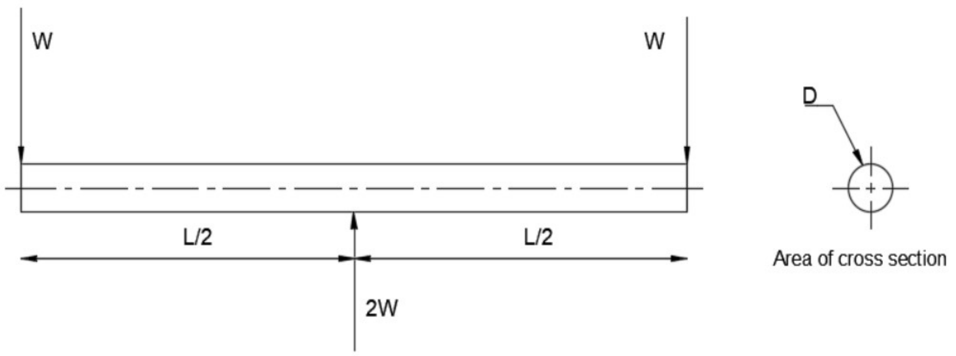
F. *Flyball Rod Design (2)*

Function:
Supports the flyballs at the ends in order to provide larger moment of inertia when rotated about the lead screw.

Critical Mode of Failure:
Bending failure due to loads on rod ends.



Design parameters



Free Body Diagram

Material Selection:
FG 150
The flyball rod needs high strength in order to sustain the heavy flyball loads on the ends.

Material Properties:
Tensile Yield Strength 150 N/mm^2.

Factor of Safety:
The rod is subjected to heavy loads on the ends and hence undergoes bending. Failure of flyball rod would cause harm to the used and hence a high factor of safety of 3 is considered.

According to Bending stress theory in beams,

$$\frac{M}{I} = \frac{\sigma_{max}}{y}$$ where, M – Maximum bending moment

W is the weight of Cast iron balls attached to the ends of the rod which is simply supported at the center.

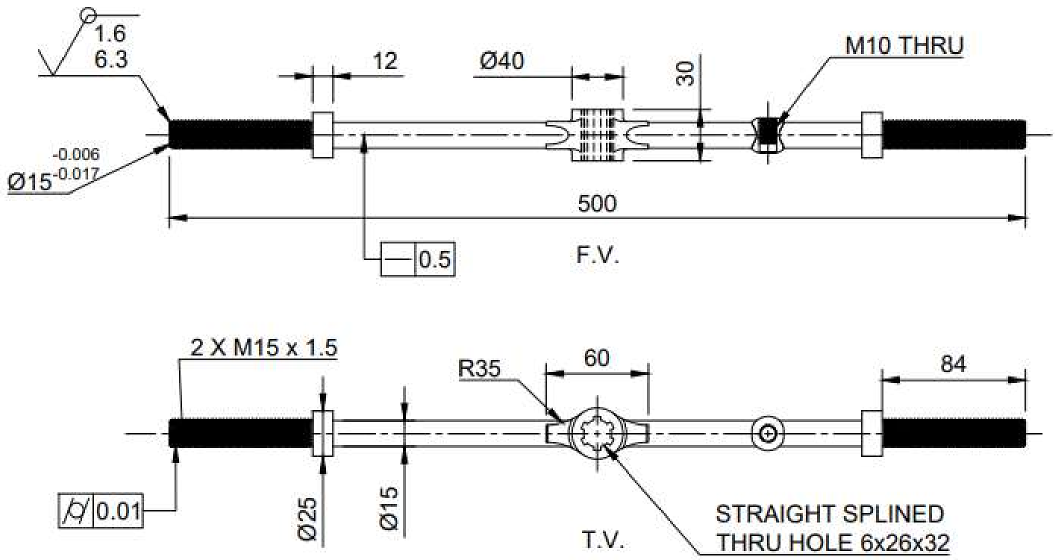
Considering road material to be FG 150 with S_{yt} = 150 N/mm^2 and Factor of safety = 3,
Maximum permissible stress,
$\sigma_{max} = 50 \text{ N}/mm^2$

Maximum deflection occurs at surface, ∴ y = D/2

Maximum bending moment occurs at center,
M = $\frac{WL}{4}$ = 12262.5 Nmm

From bending moment equation,
Diameter of solid circular section (D) = 13.57 mm

Standard size: d = 15 mm, M15 threaded ends
Material: FG 150, S_{yt} = 150 N/mm^2

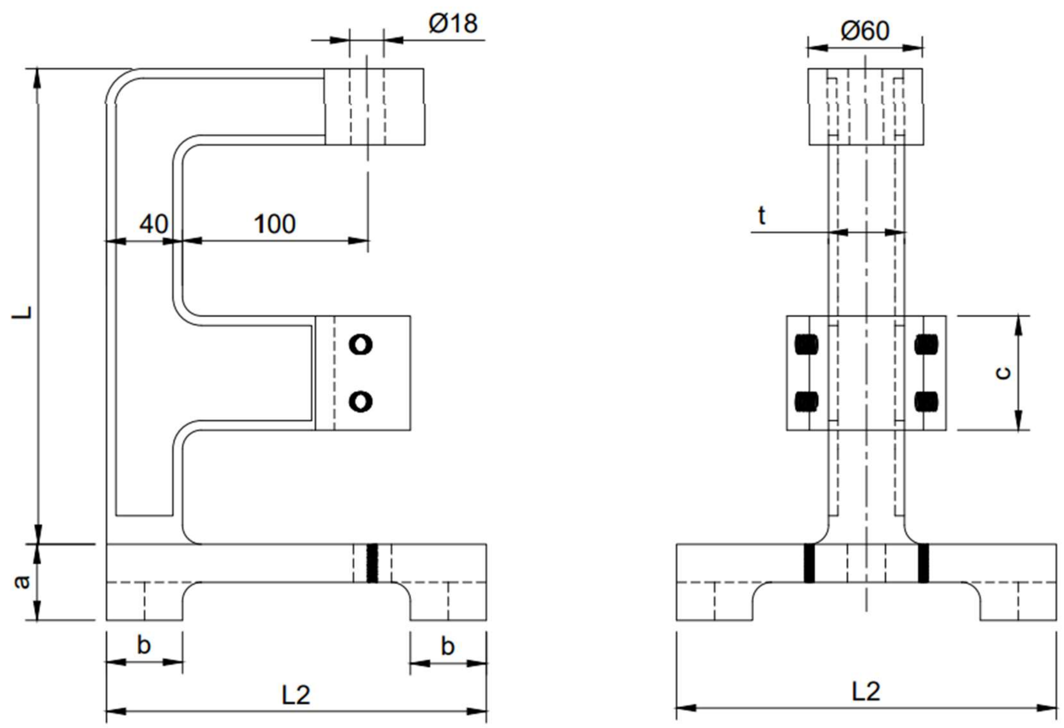


Orthographic view

G. Frame (1)

Function: Supports the entire structure and provides a path for ram attached to the lead screw and supports the sheet to be punched.

Critical Modes of Failure: Bending failure, Tensile failure



Design parameters

Material Selection:
FG 200
A sturdy frame is necessary in order to support the heavy mechanism. Hence material with high tensile yield strength is chosen.

Material Properties:
Tensile Yield Strength 200 N/mm^2.

Factor of Safety:
The failure of frame does not occur easily and the frame can be replaced being cheaper than other components. Also, frame does not form an integral part of the mechanism. Hence a lower factor of safety of 2.5 is considered.

The basic C shaped Cast iron structure is proposed for the frame of the punching press.
The dimensions have been arrived upon by considering eccentric loading for a C section after various iterations,

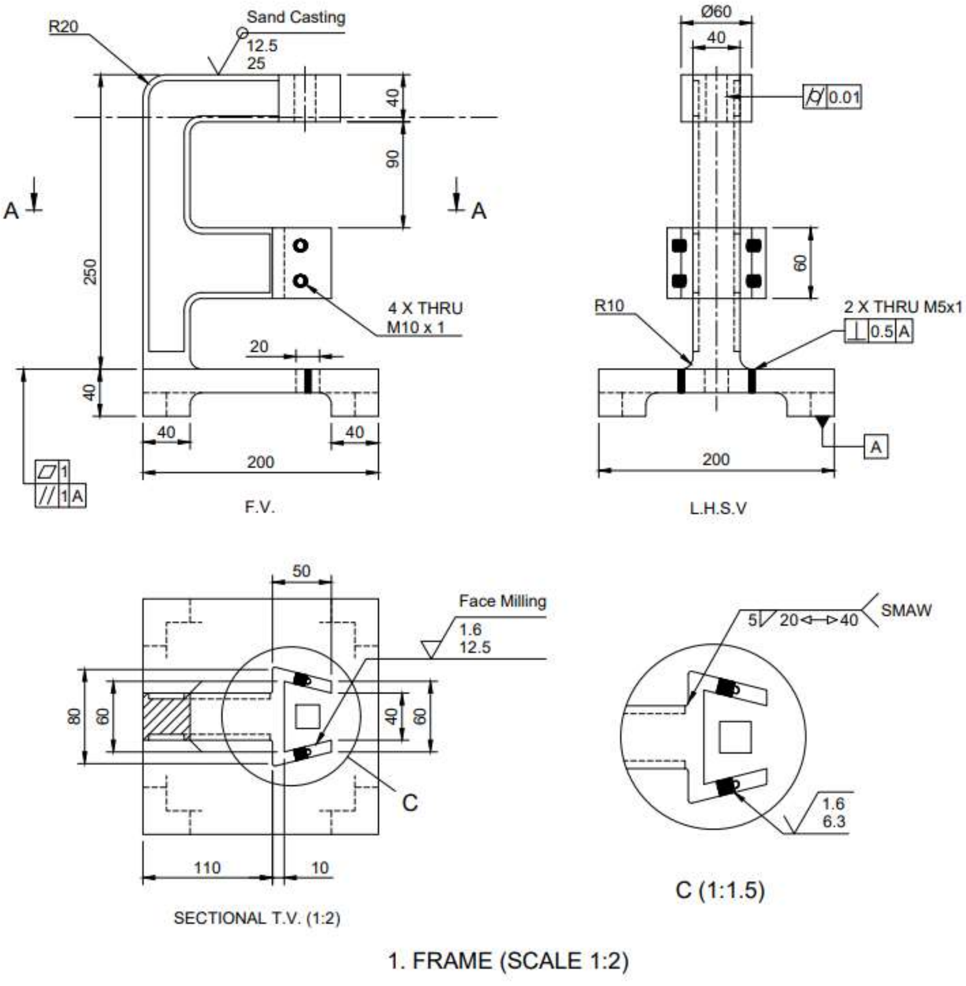
Considering material of structure as FG 200 with S_{yt} = 200 N/mm^2 and f_s = 2.5,
Permissible stress σ_t = 80 N/mm^2

Considering the parameters,
Gap between power screw and body = 100 mm
Width of C section of structure = 40 mm

The structure experiences direct tensile stress and bending stress,
Total stress $\sigma_t = \frac{P}{A} + \frac{M_b * y}{I} = \frac{6000}{40t} + \frac{6000\ (100+20)(20)}{\frac{1}{12} t\ (40)^3}$

Thickness of C section (t) = 35.63 mm ≈ 40 mm

Size: 40X40 mm cross section
Material: FG 200, S_{yt} = 200 N/mm^2



Orthographic view

VI. RESULTS

Standard Components

Part Name	Description	Material
Lead screw nut	SQ 14x6 (P2)	Phosphor Bronze (IS: 28 – 1975)
Hexagonal nut	M10 (IS: 2389 - P - 4D)	Steel
Hexagonal nut	M12 (IS: 2389 - P - 4D)	Steel
Hexagonal nut	M15 (IS: 2389 - P - 4D)	Steel
Hexagonal bolt	M10x16 (IS: 2389 - P - 4D)	Steel
Hexagonal bolt	M5 (IS: 2389 - P - 4D)	Steel
Hexagonal split bolt	M12x40 (IS: 2389 - P - 4D)	Steel

Customized Components

Part Name	Description	Material
Lead screw	SQ 14x6 (P2), Straight splined end - 6x26x32 (IS: 2327 - 1963)	Steel 30C8
Flyball	Ø100, Threaded through hole - M15	Grey cast iron FG 150 (IS: 210 - 1978)
Flyball rod	Straight splined center -6x26x32 (IS: 2327 - 1963) Threaded ends - M15x100 (IS: 2389)	Grey cast iron FG 150 (IS: 210 - 1978)
Frame	Casted C frame, 40x40 c/s	Grey cast iron FG 200 (IS: 210 - 1978)
Ram	Threaded blind hole -M12x50 (IS: 2389)	Grey cast iron FG 150 (IS: 210 - 1978)
Ram guideway	60x40x10, high surface finish	Mild steel (IS: 2389-P-4D)
Handle	Ø10, Threaded end M10	Steel
Punch	10x5	Carbon tool steel T70
Die	10x5	Carbon tool steel T65

Fits Table

Part Name	Description	Fit
Flyball rod - Flyball	Loose running fit	H7g6
Splined screw – Flyball rod	Interference fit	H7r6
Lead screw – Screw nut	Normal running fit	H7f7
Lead screw – Hex split bolt	Force fit	H7m6
Hex split bolt – Ram hole	Force fit	H7m6
Die – Hex bolt	Force fit	H7m6
Punch – Hex bolt	Force fit	H7m6
Handle – Hex nut	Force fit	H7m6

Rendered Image

VII. REFERENCES

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