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Screw Jack Mechanism for Reducing Effort

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Abstract:- This report delineates the design parameters for a mechanical screw jack engineered to hoist a 300kg load. Emphasizing structural robustness, operational efficiency, and user safety as primary objectives, the design framework integrates various considerations.

A sturdy framework, constructed from high-strength materials, forms the backbone of the design, engineered to endure the imposed load. Critical components, notably the threaded screw and supporting structure, undergo meticulous analysis to ascertain their load-bearing capacity, with safety margins incorporated to avert structural failure.

To enhance operational efficiency, the design meticulously selects materials and geometries to minimize frictional losses and optimize mechanical advantage. Furthermore, the screw jack integrates a mechanical locking mechanism to secure the lifted load, preventing inadvertent descent.

Safety features are integral, encompassing overload protection mechanisms to forestall exceeding the rated capacity and a user-friendly control system to facilitate straightforward operation. Moreover, ergonomic considerations are factored in to ensure user comfort and operational ease.

In summary, this abstract encapsulates the core principles of a mechanical screw jack engineered to handle a 300kg load, prioritizing structural integrity, operational efficiency, and user safety in its design ethos.+

Keywords:- *Screwjack, Pitch, Worm, Worm Gear, Mild Steel.*

I. INTRODUCTION

A jackscrew, also known as a screw jack, is operated by turning leadscrew and is normally used to lift moderate to heavy loads, such as vehicles, adjusting the horizontal stabilizers of aircraft, and providing adjustable support for substantial weights, including house foundations.

Fig 1: Simple Screw Jack

Typically, a screw jack comprises a robust vertical screw supporting a load table at its apex, which threads into a threaded hole within a stationary support frame with a wide base resting on the ground. A rotating collar positioned on the screw's head features holes for inserting a handle, usually a metal bar. By turning the handle clockwise, the screw extends further out of the base, thereby raising the load on the table. To withstand significant load forces, the screw often employs Acme threads.

One advantage of jackscrews over certain other jack types lies in their self-locking mechanism. Upon removal of rotational force on the screw, it remains stationary at its position and does not revert backward, irrespective of the load it supports. This inherent self-locking feature renders jackscrews safer than hydraulic jacks, which may retract under load if the force on the hydraulic actuator is inadvertently released.

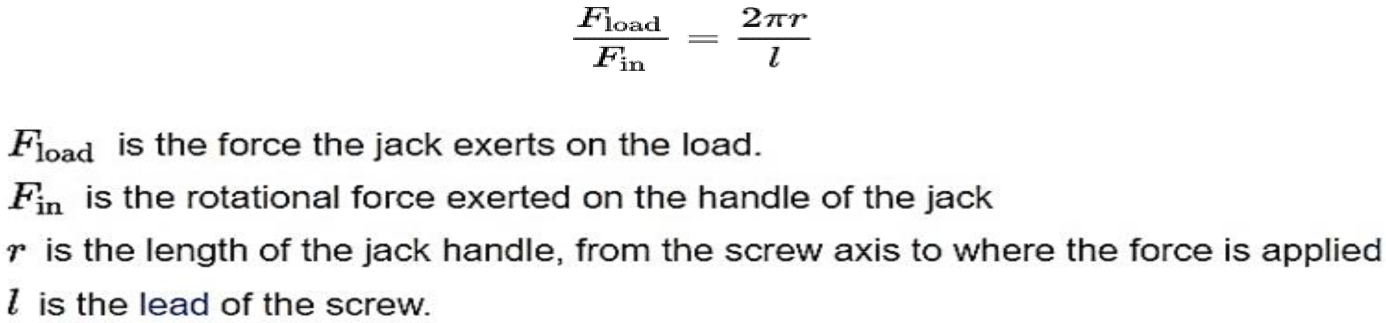
A. *Mechanical Advantage*

The ideal mechanical advantage of screw jack, which is defined as the ratio of the force exerted by the jack on the load to the input force applied on the lever, is influenced by its design features.

In a screw jack, two simple machines operate in series: the long operating handle acts as a lever, converting input force into rotational force to turn the screw. Therefore, the mechanical advantage is augmented by utilizing a longer handle and incorporating a finer screw thread.

However, practical screw jacks encounter significant friction, necessitating increased input force. Consequently, the actual mechanical advantage typically falls within the range of 30% to 50% of the theoretical value due to these frictional losses.

B. *Limitations:*



$$\frac{F_{\text{load}}}{F_{\text{in}}} = \frac{2\pi r}{l}$$

F_{load} is the force the jack exerts on the load.

F_{in} is the rotational force exerted on the handle of the jack

r is the length of the jack handle, from the screw axis to where the force is applied

l is the lead of the screw.

- Screw jacks face limitations in lifting capacity due to increased friction in screw threads with load increase.
- Fine pitch threads could enhance screw's advantage but decrease jack's operating speed.
- Lengthening the operating lever reaches a threshold where bending may occur, further limiting lifting capacity.
- Hydraulic jacks gained traction in 1858 when Tangye company applied Bramah's concept to launch Brunel's SS Great Eastern successfully.
- Hydraulic jacks offer greater mechanical advantage without mechanical limitations.
- Post-World War II advancements in hydraulic ram grinding and O-ring seals lowered hydraulic jack costs, leading to widespread use, especially in domestic cars.
- Screw jacks still find use in cost-sensitive scenarios like basic car tire-changing jacks or where self-locking is crucial, such as aircraft horizontal stabilizers.

C. *Applications:*

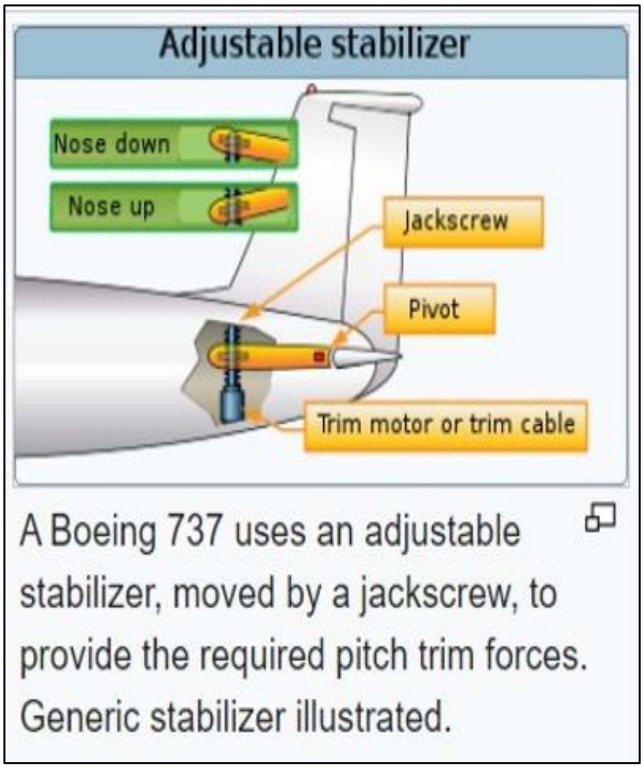
- Jackscrews have extensive sliding contact area between screw threads, resulting in high friction and relatively low efficiency (typically 30% to 50%).
- They are not commonly used for continuous transmission of high power due to their inefficiency.
- Jackscrews are more commonly employed in intermittent positioning applications.
- In heavy-duty applications like screw jacks, square thread or buttress thread is used due to their lower friction and wear.

Fig 2: Antique Screw Jacks

D. Industrial and Technical Applications:

- Acme threads are commonly used in technical applications, particularly in actuators, despite higher friction levels.
- Acme threads are chosen for their ease of manufacturing, ability to compensate for wear, superior strength compared to square threads, and smoother engagement.
- To address friction and prolong screw thread life, more advanced leadscrew types like ball screws are used.
- Ball screws incorporate a recirculating-ball nut mechanism to minimize friction and enhance screw thread longevity.
- Ball screws feature a thread profile approximately semicircular, often called a "gothic arch" profile, ensuring proper mating with bearing balls.
- One drawback of ball screws is their lack of self-locking capability.
- Despite this, ball screws are extensively used in powered leadscrew actuators due to efficiency and reliability.

E. Aviation:



A Boeing 737 uses an adjustable stabilizer, moved by a jackscrew, to provide the required pitch trim forces. Generic stabilizer illustrated.

Fig 3: Use of Screw Jack in Aviation

- Jackscrews are extensively used in aviation, particularly for adjusting horizontal stabilizers.
- Notable incidents highlight the critical importance of proper maintenance and design integrity in their usage.
- In 1982, a jackscrew failure on a Yakovlev Yak-42 airliner, attributed to design flaws, led to the crash of Aeroflot Flight 8641.
- In 2000, a jackscrew failure on a McDonnell Douglas MD-80, caused by a lack of grease, resulted in the fatal crash of Alaska Airlines Flight 261.
- In 2013, the destruction of a jackscrew on a Boeing 747-400BCF caused the crash of National Airlines Flight 102. The incident occurred after takeoff from Bagram Airfield when a MRAP armored vehicle broke loose, breached the rear bulkhead, severed hydraulic lines, and destroyed the jackscrew.
- These incidents emphasize the importance of proper maintenance, lubrication, and design reliability for safe operation of jackscrews in aviation applications.

II. EQUIPMENTS USED

A. Manufacturing Equipment

Fig 4: Vertical Boring Machine

B. Vertical Drilling Machine

Fig 5: Vertical Drilling Machine

C. *Surface Grinding Machine*

Fig 6: Surface Grinding Machine

D. *Universal Milling Machine*

Fig 7: Universal Milling Machine

E. *Welding Machine*

Fig 8: Welding Machine

F. *Quality Control Equipment*

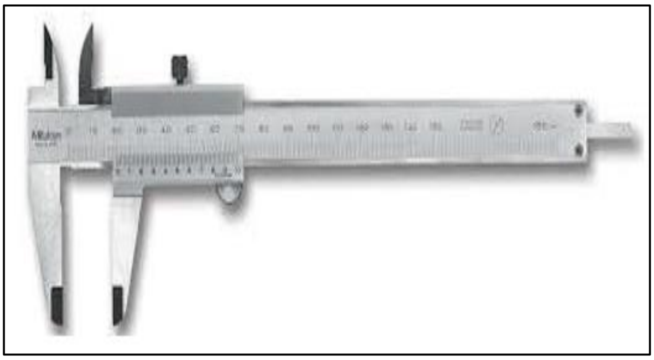


Fig 9: Vernier Caliper

Fig 10: Micrometer

G. *Surface Roughness Tester*

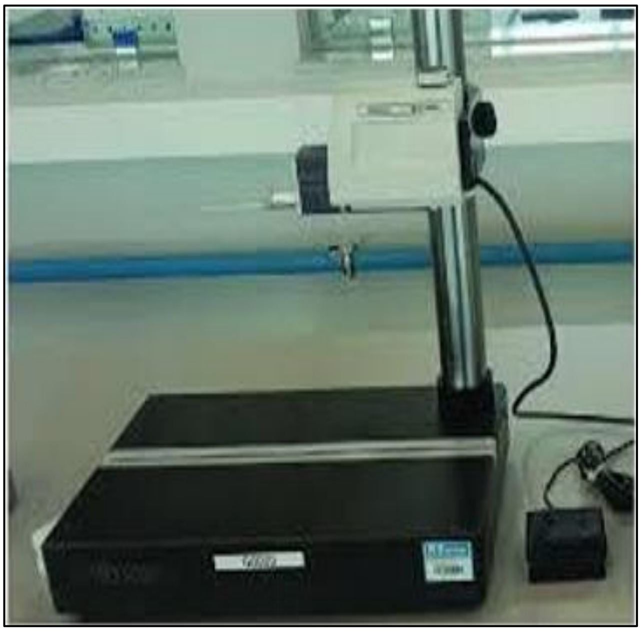


Fig 11: Surface Roughness Tester

III. DESIGN OF SCREW JACK

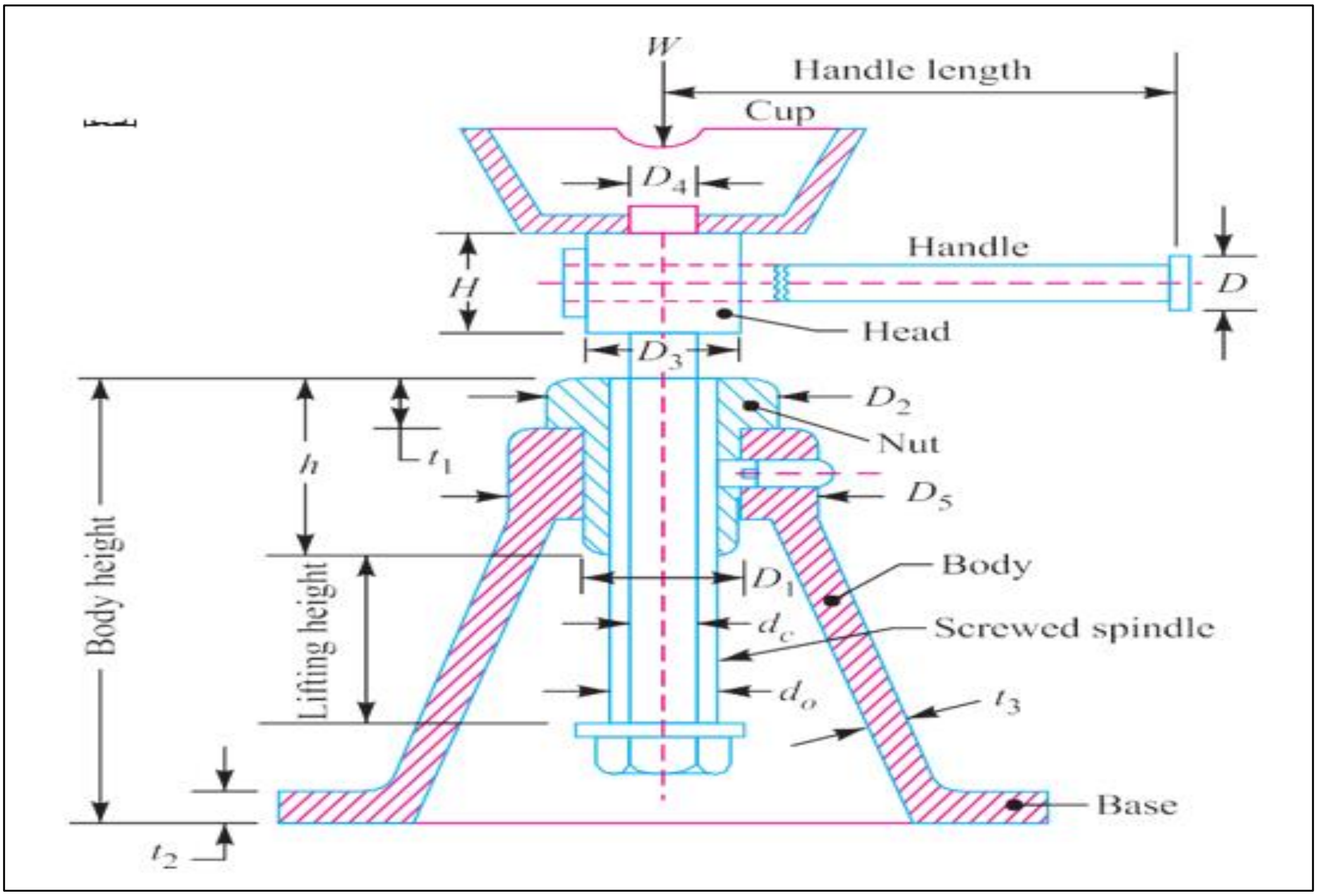


Fig 12: Dimensions of Screw Jack

In order to design a screw jack for a load *W*, the following procedure may be adopted:

- *First of all, Find the Core Diameter (DC)*

$$W = \sigma_c x \frac{\pi}{4}(d_c)^2$$

- *Find the Torque (T1) Required to Rotate the Screw and the Shear Stress (τ) because of this Torque.*

$$T_1 = W x \tan(\phi + \alpha)\frac{d}{2}$$

Where,
P = Effort required at the circumference of the screw, and
d = Mean diameter of the screw.

- *Shear Stress due to Torque T_1,*

$$\tau = \frac{16T_1}{\pi(d_c)^3}$$

Also find direct compressive stress (σ_c) because of axial load, i.e

$$\sigma_c = \frac{W}{\frac{\pi}{4}(d_c)^2}$$

- *Find the Principal Stresses as Follows:*

Maximum principal stress (tensile or compressive),

$$\sigma_{c\,max} = \frac{1}{2}\left[\sigma_c + \sqrt{(\sigma_c)^2 + (4\tau)^2}\right]$$

and maximum shear stress,

$$\tau_{max} = \frac{1}{2}\left[\sqrt{(\sigma_c)^2 + (4\tau)^2}\right]$$

These stresses should be less than the permissible stresses.

- *Find the Height of Nut (h),*

$$p_b = \frac{W}{\frac{\pi}{4}[(d_o)^2 - (d_c)^2]n}$$

Where n = Number of threads in contact with screwed spindle.

∴ Height of nut,

$h = n \times p$

where p = Pitch of threads.

- *Check the Stresses in the Screw and Nut as Follows,*

$$\tau_{(screw)} = \frac{W}{\pi n d_c t}$$

$$\tau_{(nut)} = \frac{W}{\pi n d_o t}$$

where t = Thickness of screw = p / 2

- *Find Inner Diameter (D_1), Outer Diameter (D_2) and Thickness (t_1) of the Nut Collar.*

The inner diameter (D_1) is found by the following method,

We know that,

$$\sigma_t = \frac{W}{\frac{\pi}{4}[(D_1)^2 - (d_o)^2]}$$

The outer diameter (D2) is found by the following formula,

$$\sigma_c = \frac{W}{\frac{\pi}{4}[(D_2)^2 - (D_1)^2]}$$

The thickness (t 1) of the nut collar is found by the following method,

$W = \pi D_1 . t_1 . \tau$

- *Fix the Dimensions for the Diameter of Head (D_3) and for the Cup. Take,*

$D_3 = 1.75$ do.
$D_4 = D_3 / 4$ approximately.

- *Find the Torque Required (T_2) to Overcome Friction at the Top of Screw. We Know that,*

$$T_2 = \frac{2}{3} \times \mu_1 W \left[\frac{(R_3)^3 - (R_4)^3}{(R_3)^2 - (R_4)^2} \right]$$

$$= \mu_1 W \left[\frac{R_3 + R_4}{2} \right] = \mu_1 \; W \; R$$

Considering Uniform Pressure and Uniform Wear conditions respectively.

Where,
R_3 = Radius of head,
R_4 = Radius of pin.

- *Now the Total Torque to which the Handle will be Subjected is Given by,*

$$T = T_1 + T_2$$

- *Assume that a Person Can Apply a Force of 300 to 400 N Intermittently,*

The length of handle required = T / 300

- *The Diameter of Handle (D) May be Obtained by the Following Method,*

$$M = \sigma_b x \frac{\pi}{32} (D)^3$$

- *The Height of Head (H) is Usually taken as Twice the Diameter of Handle, i.e. H = 2D.*

L = Lift of screw + 1/2 Height of nut

We know that buckling or critical load,

$$W_{cr} = A_c . \sigma_y \left[1 - \frac{\sigma_y}{4 \, C \, \pi^2 \, E} \left(\frac{L}{k} \right)^2 \right]$$

Where,
W_{cr} = Buckling load,
σ_y = Yield stress
k = Radius of Gyration

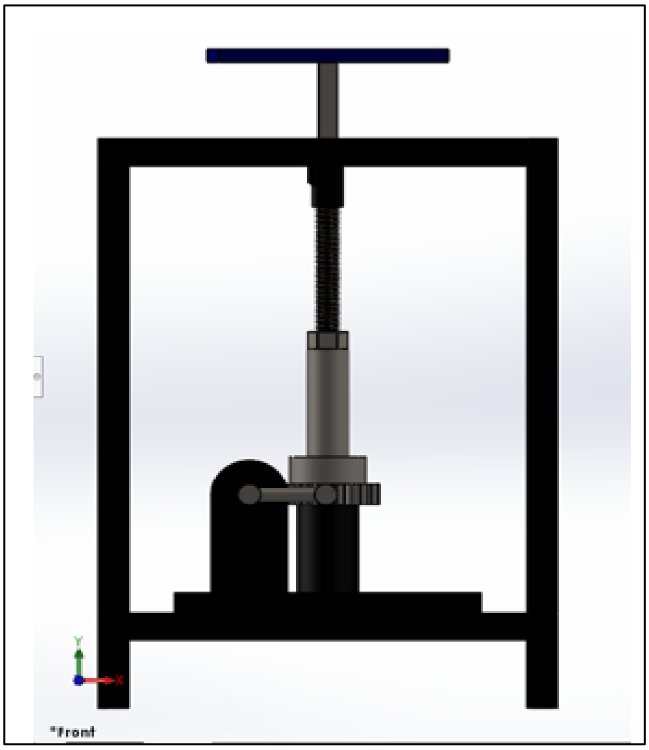


Fig 13: Front View of Screwjack

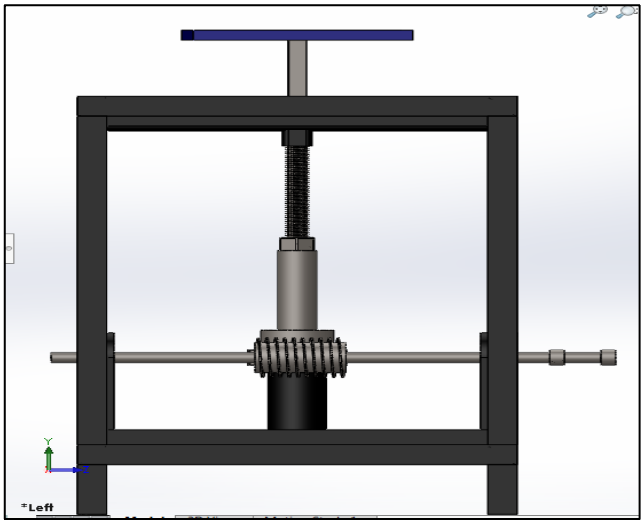


Fig 14: LH Side View of Screwjack

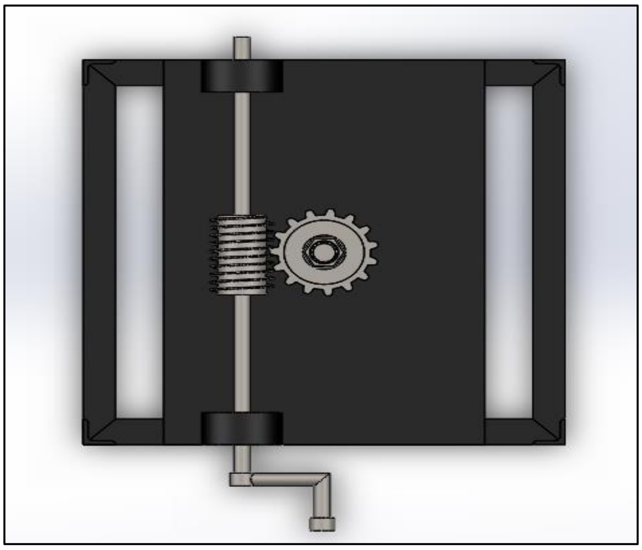


Fig 15: Sectional Top View of Screwjack

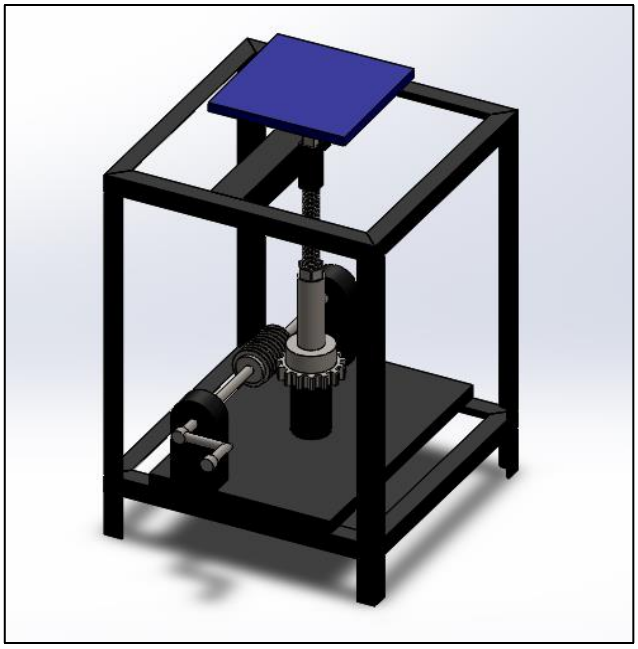


Fig 16: Trimetric View of Screwjack

IV. PARTS OF SCREW JACK

A. Worm Gear Set

Fig 17: Worm Gear Set

B. Main Frame (Acting Frame)

Fig 18: Main Frame

C. Processed Master Gear (Spacer, Bearing, Hollow Tube and Nut)

Fig 19: Processed Master Gear

D. *Processed Worm Gear (Vertical Alignment Fixtures, Driving Shaft with Key Slotted in Gear, Base Plate):*

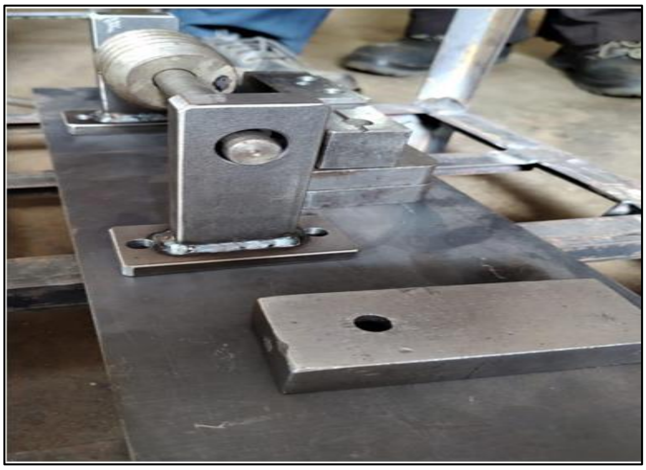


Fig 20: Processed Worm Gear

E. *Bearing*

Fig 21: Ball Bearing

F. *Nylon Wheels*

Fig 22: Nylon Wheels

G. *Gear Assembly*

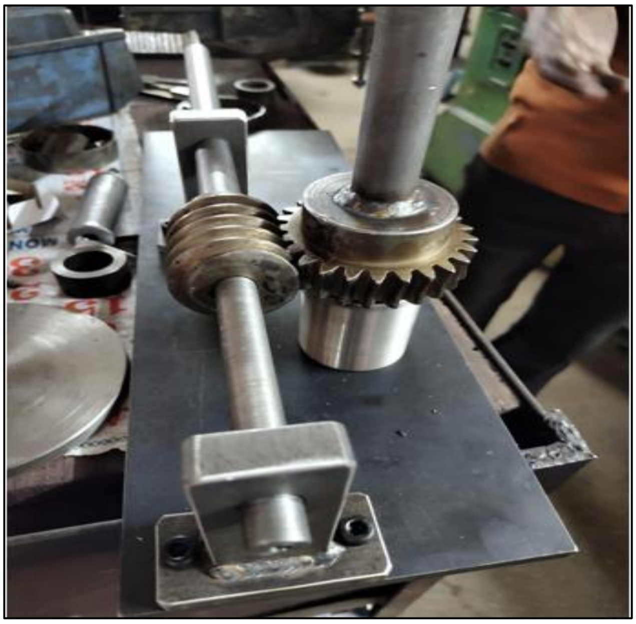


Fig 23: Worm and Worm Gear Assembly

H. *Master Assembly*

Fig 24: Master Assembly

V. PROCESS CHART

- PART NAME: **FRAME**
- MATERIAL SIZE: 500mm x 25mm x 3mm
  400mm x 25mm x 3mm
- MATERIAL: Mild Steel (MS)
- QUANTITY: 500mm – 4 nos.
  400mm – 10 nos.

Table 1: Frame

SR NO.	OPERATION	MACHINE	TIME
1	Cutting the material – 25 x 3 x 500 – 4, 25 x 3 x 400 – 10	Hand Grinder	30 min
2	Welding – Arc Welding	Welding Machine	45 min

- PART NAME: **WHEEL PLATES**
- MATERIAL SIZE: 100mm x 60mm x 10mm
- MATERIAL: Mild Steel (MS)
- QUANTITY: 4 nos.

Table 2: Wheel Plates

SR NO.	OPERATION	MACHINE	TIME
1	Drilling – 6.8(through) x 4 nos.	Drilling machine	80 min
2	Tapping – M8	Tap Wrench	45 min
3	Welding		

- PART NAME: **BASE PLATE**
- MATERIAL SIZE: 300mm x 160mm x 10mm
- MATERIAL: Mild Steel (MS)
- QUANTITY: 1

Table 3: Base Plate

SR NO.	OPERATION	MACHINE	TIME
1	Sides Milling	Universal Milling Machine	20 min
2	Drilling - Dia.8.5mm x 4nos Dia.20mm x 1nos	Drilling Machine	30 min

- PART NAME: **SHAFT SUPPORTING BRACKET (HORIZONTAL SUPPORT)**
- MATERIAL SIZE: 80mm x 35mm x 10mm
- MATERIAL: Mild Steel (MS)
- QUANTITY: 2

Table 4: Shaft Supporting Bracket (Horizontal Support)

SR NO.	OPERATION	MACHINE	TIME
1	Drilling – Dia.8.5mm x 4 nos.	Drilling Machine	30 min

- PART NAME: **SHAFT SUPPORTING BRACKET (VERTICAL SUPPORT)**
- MATERIAL SIZE: 100mm x 40mm x 10mm
- MATERIAL: Mild Steel (MS)
- QUANTITY: 2

Table 5: Shaft Supporting Bracket (Vertical Support)

SR NO.	OPERATION	MACHINE	TIME
1	Drilling – Dia.20mm x 1 nos. Dia.16mm x 1 nos.	Drilling Machine	20 min

- PART NAME: **SPACER WORM WHEEL**
- MATERIAL SIZE: Dia.58mm x 95mm
- MATERIAL: Mild Steel (MS)
- QUANTITY: 1

Table 6: Spacer Worm Wheel

SR NO.	OPERATION	MACHINE	TIME
1	Step Turning – Dia.30mm x 16mm Dia.16mm x 12.5mm	Universal Milling Machine	45 min
2	Tapping – M6 x 12mm deep on the face of Dia. 16mm	Tap Wrench	10 min

- PART NAME: **BEARING**
- MATERIAL SIZE: Inner Diameter -30 mm
- Outer Diameter - 52 mm
- MATERIAL: Mild Steel (MS)
- QUANTITY: 1

Table 7: Bearing

SR NO.	OPERATION	MACHINE	TIME
1	Press fitting on spacer worm wheel	Hand press	10 min

- PART NAME: **PIPE**
- MATERIAL SIZE: Inner Diameter - 18mm
- Outer Diameter - 25 mm
- MATERIAL: Mild Steel (MS)
- QUANTITY: 1

Table 8: Pipe

SR NO.	OPERATION	MACHINE	TIME
1	Press fitting into worm wheel	Hand Press	10 min
2	Welding to M16 Nut	Welding	15 min

Table 9: Bill of Material

SR NO.	PART NAME	QUANTITY	COST (Rs.)
1	Frame Strips	14	1000
2	Wheel Mounts	4	325
3	Shaft Supporting Brackets	4	708
4	Base Plate	1	520
5	Spacer Worm Wheel and Shaft	1	847
6	Nylon Wheels	4	600
7	Worm Gear Set	1	2000
TOTAL			**6000**

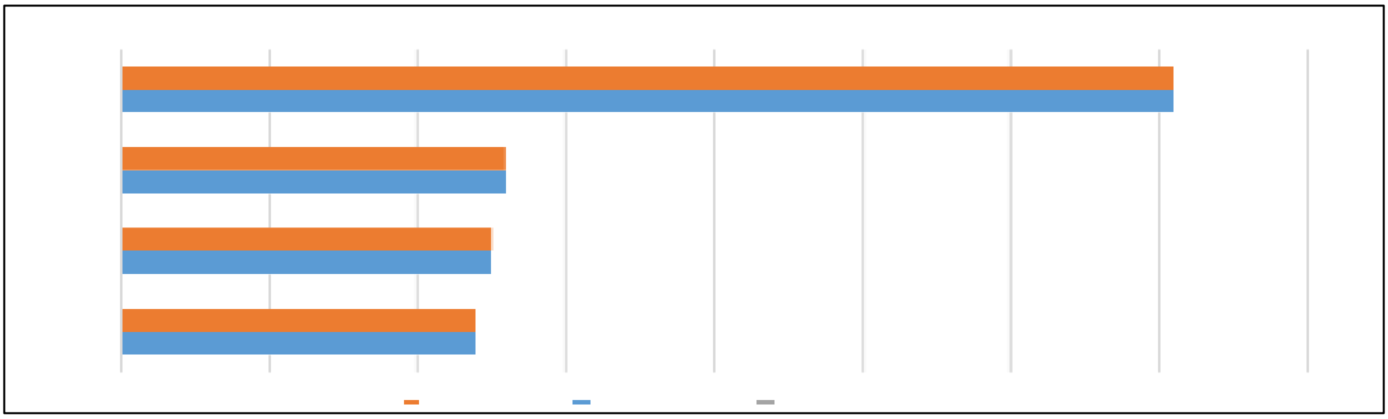


Fig 25: Gantt Chart

VI. FUTURE SCOPE

The mechanical screw jack has long served as a reliable tool for lifting and lowering heavy loads across various applications. Despite the emergence of alternative lifting methods driven by technological advancements, mechanical screw jacks still hold potential for future applications and enhancements. Here are several areas where they could continue to excel:

- Industrial Machinery: Mechanical screw jacks remain valuable in industrial settings where precise vertical positioning is essential. They find utility in assembly lines, manufacturing processes, and other industrial applications requiring controlled lifting and lowering of heavy equipment.
- Construction and Infrastructure: Screw jacks can contribute to construction projects by providing temporary support, leveling, and adjustment of structures. They are beneficial for aligning precast concrete elements, adjusting formwork, and facilitating temporary lifting during construction activities.
- Maintenance and Repair: Screw jacks offer practical solutions for maintenance and repair tasks, particularly when hydraulic or electric alternatives are impractical. They assist in lifting heavy machinery or equipment for inspection, repair, or component replacement.
- Automotive Industry: In the automotive sector, screw jacks serve various purposes such as vehicle repairs, tire changing, and lifting heavy vehicle parts during assembly or disassembly. They provide stability and controlled lifting in diverse automotive applications.
- Customized Applications: Mechanical screw jacks can be tailored to meet specific requirements in niche industries or specialized applications. They can be integrated into unique equipment or machinery setups, addressing challenges like space constraints, environmental conditions, or specific load demands.

While mechanical screw jacks offer distinct advantages, it's essential to acknowledge that other lifting technologies, such as hydraulic, pneumatic, or electric systems, may outperform them in terms of speed, efficiency, and automation. Consequently, the future scope of mechanical screw jacks might be somewhat constrained compared to these alternatives. Nonetheless, they retain relevance in specific scenarios where their unique features and characteristics are advantageous.

VII. CONCLUSION

In conclusion, the mechanical screw jack stands as a versatile and indispensable device vital for lifting, lowering, or holding heavy loads across diverse applications. Its core mechanism comprises a threaded screw that converts rotary motion into linear motion, offering mechanical advantage to lift loads with minimal exertion.

Throughout our exploration, we delved into the working principles, components, and design considerations of the mechanical screw jack. We examined crucial features such as the screw thread profile, load capacity, lifting speed, and safety mechanisms. Additionally, we explored various types of screw jacks, including worm gear screw jacks and ball screw jacks, each with distinct advantages and limitations.

Furthermore, we emphasized the significance of proper maintenance and lubrication to ensure the smooth operation and longevity of screw jacks. Regular inspection, cleaning, and lubrication are imperative to prevent issues such as wear, corrosion, or jamming.

Safety precautions associated with screw jack usage were also discussed, stressing the importance of accurate load calculations, stability, and the implementation of additional safety measures like limit switches, overload protection, and emergency stop mechanisms.

In summary, the mechanical screw jack stands as a reliable and efficient tool indispensable in industries such as automotive, construction, and manufacturing. Its straightforward yet robust design, coupled with diligent maintenance and safety measures, enables efficient load handling while ensuring a secure working environment.

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