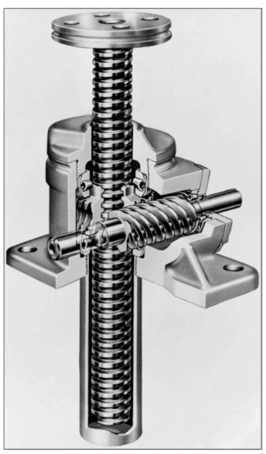
In machine design, a **Power Screw** (or lead screw) is a device that converts **rotary motion** into **linear motion**. Unlike standard fasteners (bolts and screw), which are designed to clamp parts together permanently or semi-permanently, a power screw is a motion transmitter used to lift loads or position components with high precision, such as in car jacks, lathe machines, and 3D printers.

POWER SCREWS

Power screws are translation screws that are used to transfer power and motion in a smooth and uniform manner. Power screws are generally Square thread and ACME thread.

A power screw is a mechanical device that transforms rotational movement into linear movement. It is commonly used in applications requiring precise control of movement and the ability to transmit significant force. Examples include:

- **Lead Screws** in machinery like lathes, where they guide cutting tools.
- **Vise Screws** for clamping.
- **Screws for presses and jacks** used to lift heavy loads or apply force.



In the setup, a worm gear interacts with the power screw to facilitate power transfer from a rotary source. The worm gear system includes a worm, a horizontal helical gear that meshes with the worm gear's teeth. As the worm rotates, it drives the worm gear, which subsequently rotates the power screw. This mechanism allows for precise control over the screw's movement, providing a high mechanical advantage for transmitting torque smoothly. Additionally, the design of the worm and worm gear system inherently prevents back-driving, ensuring that the load will remain in position unless the system is intentionally rotated, enhancing safety and control in lifting operations.

Applications:

1. Raising Loads: Screw jacks for lifting heavy loads.
2. Accurate Motion: Lead screws for precision in machining.
3. Clamping Workpieces: Used in C-clamps or vices.
4. Applying Load to Specimens: Universal testing machines.

Advantages:

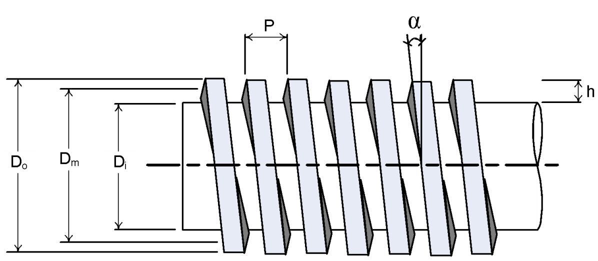
- High load-carrying capacity.
- Simple and cost-effective design.
- Large mechanical advantage (up to 1:40).
- Smooth and maintenance-free operation.
- Self-locking capability for safety.

Limitations:

- Low efficiency (~40%).
- High wear due to friction in threads.
- Not suitable for continuous power transmission.

SQUARE THREAD:

Square thread is a type of power screw thread with a square-shaped cross-section. It is designed for maximum efficiency in transmitting power with minimal friction because the sides of the thread are perpendicular to the axis of the screw. Square threads are commonly used in applications like lead screws, jacks, and presses, where high load-carrying capacity and precision are important. However, they are harder to manufacture compared to other thread forms due to their shape.



P = pitch, is the distance between adjacent threads, inches

$$P = \frac{1}{thread/inch}$$

D_m = mean diameter or pitch diameter

$$D_m = D_o - h$$

$$D_m = \frac{D_o + D_i}{2} = \left(r_o + r_i\right)$$

Where:
D_i = inside diameter
r_i = inside radius
D_o = outside diameter
R_o = outside radius
h = height of the thread = $\frac{1}{2}P$

Lead, L = axial distance traveled by a thread or nut per revolution

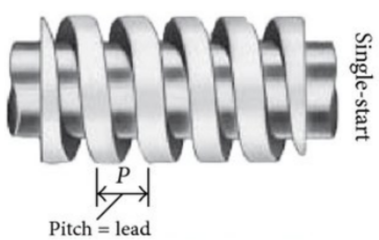
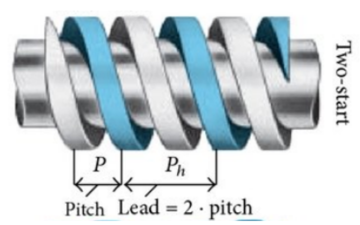
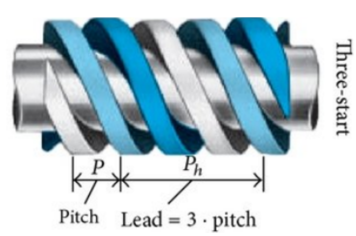
L = P (for single thread)
L = 2P (for double thread)
L = 3P (for triple thread)

If the number of threads is not given, assume it to be a single thread.

Lead angle: $$\alpha = tan^{-1}\left(\frac{L}{\pi D_m}\right)$$

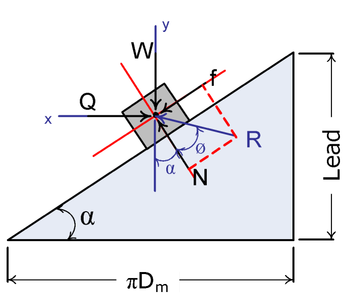
Pitch and Lead

The axial pitch (P) is defined as the linear distance measured parallel to the screw's axis from a point on one thread to the corresponding point on the adjacent thread. While pitch describes the distance between individual threads, the lead (L) refers to the actual distance the nut moves axially along the screw in one complete 360◦ turn.

Single Thread	Double Thread	Triple Thread
		

Torque Required to Overcome Friction

a. For Raising the Load

	Where: Q = tangential force causing rotation W = weight to be lifted or axial load F = frictional force N = normal force f = coefficient of friction α = lead angle

$$[\Sigma F_x = 0]$$

$$Q = N\sin\alpha + fN\cos\alpha \qquad \text{eq. (1)}$$

$$\left[\Sigma F_y = 0\right]$$

$$W = N\cos\alpha - fN\sin\alpha \qquad \text{eq. (2)}$$

Dividing eq. (1) and eq. (2):

$$\frac{Q}{W} = \frac{N\sin\alpha + fN\cos\alpha}{N\cos\alpha - fN\sin\alpha}$$

$$\frac{Q}{W} = \frac{N\sin\alpha + fN\cos\alpha}{N\cos\alpha - fN\sin\alpha} \cdot \frac{\frac{1}{\cos\alpha}}{\frac{1}{\cos\alpha}}$$

$$\frac{Q}{W} = \frac{\tan\alpha + f}{1 - f\tan\alpha}$$

Coefficient of friction: $f = \tan\phi$

$$\frac{Q}{W} = \frac{\tan\alpha + \tan\phi}{1 - \tan\phi\tan\alpha}$$

Recall: From identity $\tan(A + B) = \frac{\tan A + \tan B}{1 - \tan A \tan B}$

$$\frac{Q}{W} = \tan(\alpha + \phi)$$

$$Q = W\tan(\alpha + \phi)$$

The torque T, required to raise the load:

$$T = Q\left(\frac{D_m}{2}\right) = W\tan(\alpha + \phi)\left(\frac{D_m}{2}\right)$$

$$T = W\frac{D_m}{2}\tan(\alpha + \phi)$$

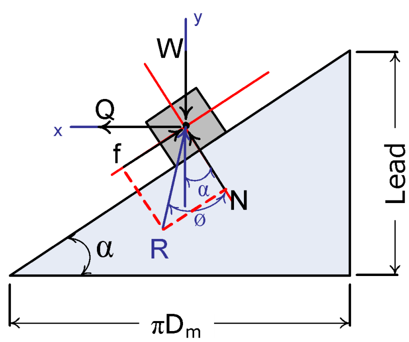
The Relationship Between Coefficient of Friction and Power Screw Performance

The decision to lubricate depends on the design intent. If the component is meant to hold a load or maintain a tight, secure position, friction is required and lubrication is a hazard. In **power screws** like scissor jacks, the engineering goal is not to eliminate lubrication, but to **select a specific type of high-viscosity or heavy-duty grease** that protects the threads from wear without causing the friction angle (ϕ) to drop below the lead angle (α).

If the component is meant to move, rotate, or transmit power efficiently, friction is a liability that must be managed through proper lubrication. A prime example is the **main power shaft of an industrial gearbox or a conveyor system**. In these systems, the goal is to transmit torque with maximum efficiency and minimal power loss. Without constant lubrication, the sliding contact between the gear teeth or within the bearings would generate excessive heat and lead to rapid surface fatigue and galling.

Because power screws are often used in critical lifting or positioning, monitoring the **thread pitch wear** is a standard maintenance procedure. Excessive wear changes the geometry, reduces the load-carrying capacity, and compromises safety.

b. For Lowering the Load



$$T = W\frac{D_m}{2}tan(\alpha - \phi)$$

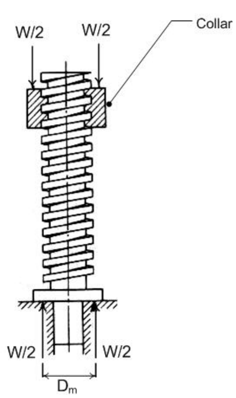
Note: For lowering of load, the screw must be self-locking, $\phi > \alpha$.

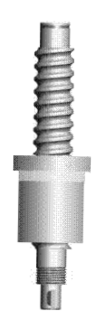
Friction angle, $\phi = tan^{-1}f$

Coefficient of friction, f for power screws:

- f = 0.10 for smooth and well lubricated thread surfaces
- f = 0.125 for materials and workmanship of average quality
- f = 0.15 for doubtful workmanship

Torque required to move without friction: $T' = W\frac{D_m}{2}tan\,\alpha$





Torque required to overcome collar friction: $T_c = W\frac{D_c}{2}f_c$

Where: f_c = coefficient of collar friction
D_c = collar mean diameter

Torque required to overcome thread and collar friction: $T_T = T + T_C$

Efficiency of the screw: $\varepsilon = \frac{T'}{T} * 100\%$

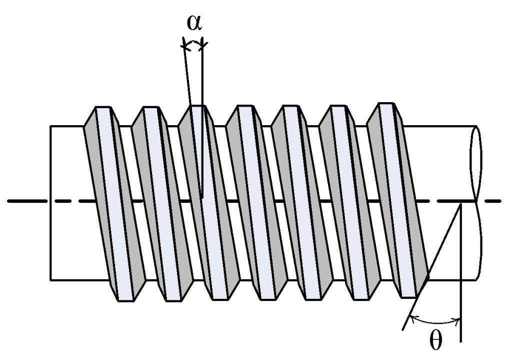
This tells us how much of the applied torque, T' goes into useful lifting, versus being lost to friction, T.

Combined efficiency (Screw and collar): $\varepsilon = \frac{\tan\alpha(1 - f\tan\alpha)}{\tan\alpha + f + \left[\frac{f_c D_c}{D_m}\right](1 - f\tan\alpha)} * 100\%$

Power Input: $P = \frac{2\pi T_T N}{60}$

ACME THREAD:

ACME thread is a modified version of the square thread, featuring a trapezoidal profile. This thread type is stronger and easier to manufacture than square threads while still maintaining good power transmission efficiency. ACME threads are often used in machine tools, clamps, and valves, and are preferred for applications where both load-bearing and ease of production are essential. Additionally, the ACME thread's trapezoidal shape provides better wear resistance and easier engagement and disengagement compared to square threads.



Normal Angle, θ

θ = 14.5° for single thread and double thread
θ = 29° for triple thread

Torque Required to Overcome Friction

a. For Raising the Load: $T = W\frac{D_m}{2}\left[\frac{\tan\alpha + \frac{\tan\phi}{\cos\theta}}{1 - \tan\alpha\left(\frac{\tan\phi}{\cos\theta}\right)}\right]$

b. For Lowering the Load: $T = W\frac{D_m}{2}\left[\frac{\tan\alpha - \frac{\tan\phi}{\cos\theta}}{1 + \tan\alpha\left(\frac{\tan\phi}{\cos\theta}\right)}\right]$

c. Combined efficiency for Acme Thread (θ = 14.5°):

$$\varepsilon = \frac{\tan\alpha(\cos\theta - f\sin\alpha)}{\tan\alpha + f\cos\alpha + \left[\frac{f_c D_c}{D_m}\right](\cos\theta - f\sin\alpha)} * 100\%$$

In general, to increase the efficiency (ε) of a power screw

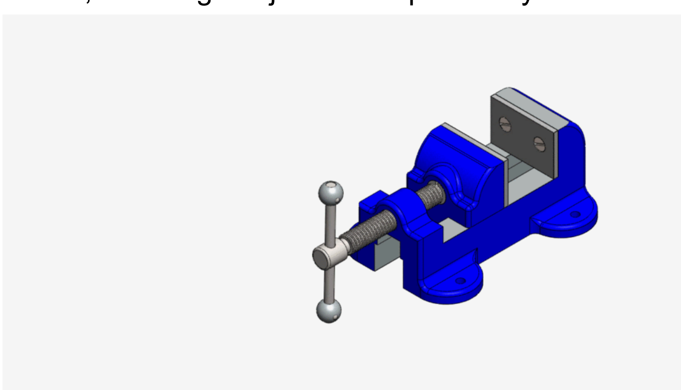
1. **Increase the Lead Angle (α):** By increasing the lead (the axial distance the nut travels per turn), you effectively increase the "slope" of the thread. This results in less sliding distance relative to the axial movement.
2. **Reduce the Coefficient of Thread Friction (f):** use high-quality extreme-pressure (EP) lubricants or greases (e.g., Molybdenum Disulfide) to maintain a low f value.

3. **Minimize Collar Friction (f_c and D_c):** Instead of allowing the screw collar to slide directly against a flat housing surface, use a ball or roller thrust bearing. This replaces sliding friction with rolling friction, which is significantly lower. Keep the collar diameter as small as possible.

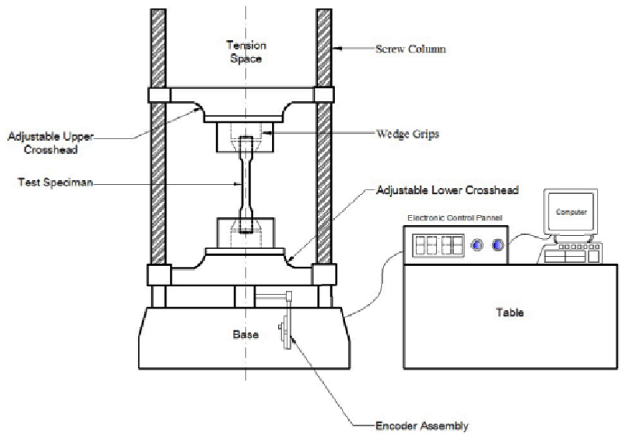
As you increase efficiency, you decrease the system's ability to "self-lock." If you design a power screw that is 90% efficient, it **will not** hold a load when the torque is removed; the load will cause the screw to back-drive or spin down on its own. If your application (like a jack) must hold a load, you must accept lower efficiency to ensure the system is self-locking.

Power Screw Applications and Mechanisms:

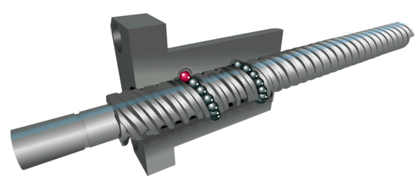
1. **Bench vice** is a mechanical tool used to securely hold jobs for operations such as filing and cutting. It operates by applying torque through a handle, which rotates a screw to generate axial thrust, ensuring the job is clamped firmly.



2. **Crosshead lead screw** is commonly found in Universal Testing Machines and is designed to convert rotational motion into linear movement, maintaining a uniform axial force. The system relies on gears to evenly distribute power across the lead screws for balanced operation.

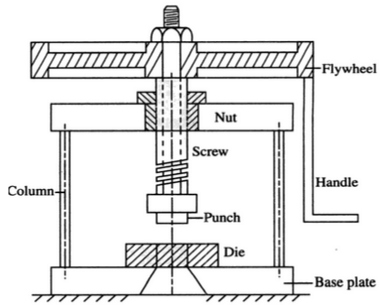


3. **Ball screw** improves efficiency by reducing friction through rolling contact with ball bearings, achieving approximately 90% efficiency. This mechanism eliminates backlash, making it suitable for applications requiring precision, such as CNC machines and automotive steering mechanisms.

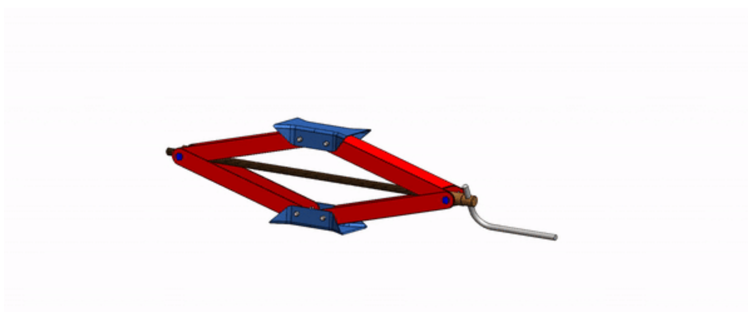
	

4. **Screw clamp** is another tool designed for clamping jobs on machine tables or during woodworking tasks. It applies torque to a handle, which rotates the screw to generate clamping force.

5. **Flypress** is used for punching and pressing operations. It utilizes a high-lead screw for efficient force transfer with minimal rotations, with its efficiency determined by the helix angle and resistance due to friction.



6. **Mechanical screw jack** or **Scissor Jack** is a classic engineering application of a power screw (specifically an Acme or square-threaded screw) designed to convert rotational torque into linear force. In this assembly, the power screw acts as the primary input component; as the handle is turned, the screw rotates through a threaded nut, drawing the two ends of the "scissor" linkages together.



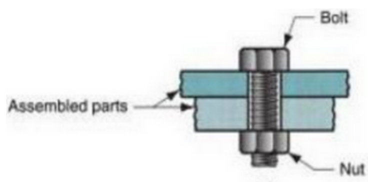
COMPARISON BETWEEN SQUARE AND ACME THREAD

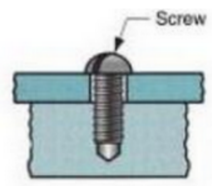
Feature	Square Thread	Acme Thread
Efficiency	Higher	Lower (due to wedging)
Self-Locking	Excellent	Good (but needs more friction)
Manufacturing	Very Difficult	Moderate/Standard
Maintenance	Poor (no wear adjustment)	Excellent (allows for split nuts)
Industry Use	Rare (niche applications)	Standard for most power screws

In machine design, we generally prioritize the use of threaded fasteners (bolts and screws) over welding whenever possible. While welding offers high joint efficiency and creates a permanent bond, it complicates repairs and maintenance. Bolted joints are essential for Design for Serviceability—they allow us to replace standardized parts easily and perform routine maintenance without destroying the assembly. We should only reserve welding for structures requiring permanent rigidity, weight reduction, or leak-proof seals where disassembly is never expected.

BOLTS AND SCREWS

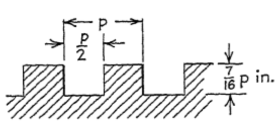
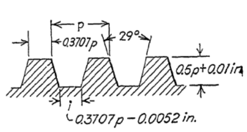
Bolts and screws are cylindrical members with continuous spiral ribs, known as threads and used as fasteners which hold parts of machine members that require easy dismantling. Generally, bolts are designed to be used in combination with a nut and screws are used without nuts.

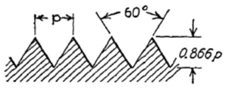
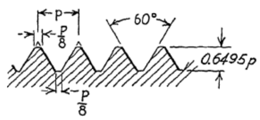
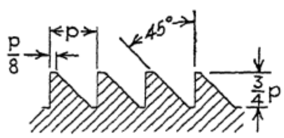




Bolts and screws are used to hold the removable heads of cylinders, machine members that must be readily disassembled, and parts of large machines that must be built in small units for ease in manufacturing, assembling, or shipping. Screws are also used for the transmission of power; examples are lead screws on machine tools and screws on presses.

Types of Treads

Square thread 	The Square thread is a highly efficient power transmission thread where the crests and roots are flat and parallel to the shaft axis. Its profile geometry features a thread thickness and space exactly equal to half the pitch (P/2), resulting in a 90◦ flank angle that eliminates radial (bursting) pressure on the nut. While it offers the lowest friction, it is difficult to machine and cannot be easily used with split nuts to compensate for wear.
ACME thread 	The ACME thread is a rugged trapezoidal profile with a 29◦ included angle, designed to provide greater strength and easier manufacturability than the square thread. It is the industry standard for power screws used in lifting and traversing mechanisms, such as lathe lead screws and jack stands. Its tapered flanks allow for the use of a split nut to take up backlash caused by wear over time.

V thread 	The V-thread features a sharp, 60◦ triangular profile that creates significant friction due to its large surface area. This high friction makes it ideal for permanent fastening applications where vibration might otherwise cause a bolt to loosen. However, because the sharp roots create high stress concentrations and the sharp crests are easily damaged, it is rarely used in modern precision machinery compared to truncated versions.
Sellers Screw thread 	The Sellers Screw thread, also known as the American National Standard, is a 60◦ V-thread that has been modified for better durability and manufacturing. Both the crests and roots are flattened (truncated) by 1/8 of the pitch (P/8), which reduces stress concentrations and prevents the "binding" common in sharp V-threads. This profile serves as the fundamental design for the modern Unified National (UNC/UNF) fastener series used across North America.
Buttress thread 	The Buttress thread is a specialized asymmetric profile designed to transmit exceptionally high power in only one direction. It combines the high efficiency of a square thread on the vertical (load-bearing) face with the structural strength of a V-thread on the 45◦ angled back. You will typically see this on artillery breech blocks, screw presses, or airplane landing gear where heavy loads are applied in a single axial direction.

Thread Series

1. Coarse Thread Series (UNC or NC)
   In this series the pitch is relatively large. This series is used for general fastening applications.

2. Fine-thread Series (UNF or NF)
   In this series, the pitch is smaller (there are more threads per inch) than in the coarse-thread series (UNC or NC). This series is used where a finer thread is needed, as in automobiles, pumps, compressors and aircraft works.

3. Extra-fine-thread Series (UNEF or NEF)
   In this series, the pitch is even smaller than in the fine-thread series (UNF or NF). This series is used where the thread depth must be very small, as on aeronautical equipment.

Reading a Thread Notes
For Imperial System that uses threads per inch (TPI)

1. 1 1/4-7 UNC-1A
   Meaning: 1-¼" diameter, 7 threads per inch, Unified thread series, class 1 fit, external threads.
   Class 1 fit is screw threads with loose fit (large allowance) tolerances.

2. 7/8-14 UNF-2B
   Meaning: 7/8” diameter, 14 threads per inch, Fine-thread series, class 2 fit, internal threads.
   Class 2 fit is screw threads used for general purposes.

3. 1 5/8-18 UNEF-3B-LH
   Meaning: 1-5/8” diameter, 18 threads per inch, Extra-fine-thread series, class 3 fit, internal threads, left hand threads.
   Class 3 fit is screw thread that has tighter fitting and stricter standards for tolerances.

For Metric Threads

1. M10 x 1.5 - 6g
   Meaning: 10mm nominal diameter, 1.5mm pitch, Coarse thread series, Class 6 tolerance, external threads.
   - M: Designates it is a Metric thread.
   - 10: The major (outer) diameter in millimeters.
   - 1.5: The Pitch (the distance from one thread peak to the next).
   - 6g: The tolerance class (similar to "Class 2" in UNC). Lowercase letters (g, h) indicate external threads (bolts).
2. M8 x 1.0 - 5H
   Meaning: 8mm nominal diameter, 1.0mm pitch, Fine thread series, Class 5 tolerance, internal threads.
   - 1.0: Since the standard coarse pitch for M8 is 1.25, a 1.0 pitch indicates a Fine-thread series.
   - 5H: The tolerance class. Uppercase letters (H, G) indicate internal threads (nuts or tapped holes).
   - Note: If the note only says "M8," it automatically implies the standard coarse pitch (1.25 mm).
3. M20 x 2 - 7H - LH
   Meaning: 20mm nominal diameter, 2mm pitch, Class 7 tolerance, internal threads, left-hand threads.
   - 2: The pitch in millimeters.
   - 7H: A "loose" fit tolerance, similar to Class 1 in the Unified system.
   - LH: Stands for Left-Hand threads (tightens counter-clockwise). If "LH" is missing, it is always assumed to be Right-Hand (RH).

Useful formula for bolts from Design of Machine Members:
By Venton Levy Doughtie, Page 135

1. Tensile stress
   The allowable stress in tension bolts is determined by the initial load applied when tightening the nut. For a standard ½-inch National Coarse (NC) bolt, this initial load is approximately 8,000 pounds. The resulting stress at the thread root is calculated as:

$$S_w = C\left(A_r\right)^{0.418}$$

$$F_a = C\left(A_r\right)^{1.418}$$

Where: S_w = permissible working stress, psi
F_a = applied load, lb
A_r = stress area or the root area of the thread, in^2
C = material-dependent constant

For carbon-steel bolts with a 60,000 psi ultimate tensile strength, C is approximately 5,000. Alloy steel bolts, which can have ultimate tensile strengths up to 150,000 psi, use higher values of C, while bronze bolts typically have a lower value of C, around 1,000.

Useful formula for bolts from Design of Machine Elements 4th Edition:
By Virgil Moring Faires Page 159:

1. Tensile stress

   The design tensile strength of a bolt is determined based on the material's yield strength and the stress area of the thread. The equation for the design tensile strength is given by:

$$S_d = \frac{S_y}{6}\left(A_s\right)^{0.50}$$

   By substituting this into the force equation $F = S_d A$, the safe external tensile load is obtained as:

$$F_e = \frac{S_y}{6}\left(A_s\right)^{1.50}$$

   Where: S_d = design tensile stress, psi
   F_e = safe external tensile load, lb
   A_s = stress area, in^2

This equation is used to determine the required nominal size of a bolt for a given application. The constant 6 in the equation is not a factor of safety but rather a parameter derived from empirical studies.

2. Depth of tap

   1.50D for cast iron
   1.25D for steel and wrought iron

   Where: D = nominal diameter, in

3. Initial applied torque

   The initial tension (F_i) in a bolt is the stress induced during tightening. This tension is influenced by factors such as the length of the wrench used, the worker's technique, and the surface condition of the bolt. To achieve consistency, torque wrenches are used. The relationship between the applied torque (T) and initial tension is given by:

$$T = CDF_i$$

Where: T = Applied torque, in-lb
D = nominal diameter, in
C = Torque coefficient, dependent on lubrication
F_i = initial tension, lb

For bolts in **"as received" (unlubricated) condition**, C=0.20, whereas for **lubricated bolts**, C=0.15. These values account for friction between the bolt and nut or under the bolt head, which affects the final clamping force. Proper torque control ensures the correct preload in the bolt to prevent loosening or failure in mechanical assemblies.

Note that these empirical formulas are **unit-dependent**. It is specifically calibrated for English units (lb, psi, in^2). Using Newtons or mm in this specific formula would yield an incorrect answer.

To determine the safe working strength of bolts, an empirical formula was developed for situations where the elasticity of a gasket is greater than that of the bolt or stud. The formula is given by:

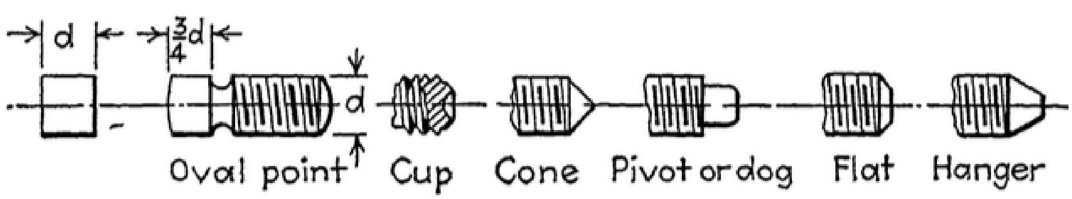
$$W = S_t\left(0.55D^2 - 0.25D\right)$$

Where: W = permissible load, lbs
S_t = allowable working stress in tension , psi
D = is the nominal outside diameter of the bolt, in

This equation helps engineers assess the strength of bolts in practical applications, ensuring that they are not subjected to excessive loads that could lead to failure. In general, thicker bolts can handle greater forces, while smaller bolts require careful consideration to avoid breakage under normal tightening conditions.

Power or Torque Transmitted by a Single Set-screw from Machinery's Handbook 29th Edition:
By Erik Oberg, Franklin D. Jones, Horlbrook L. Horton, and Henry H. Ryffel, Page 1700

Set Screws are fasteners used to prevent relative motion between two parts, such as a shaft and a hub. They work by applying pressure at their pointed end, securing one component to another.



Forms of setscrew points.

The holding power of set-screws depends on factors such as the physical properties of both the screw and the shaft, as well as the size of the set-screw itself. Experiments have established safe holding forces for different set-screw diameters.

The power or torque that a set-screw can safely transmit is determined using the formulas:

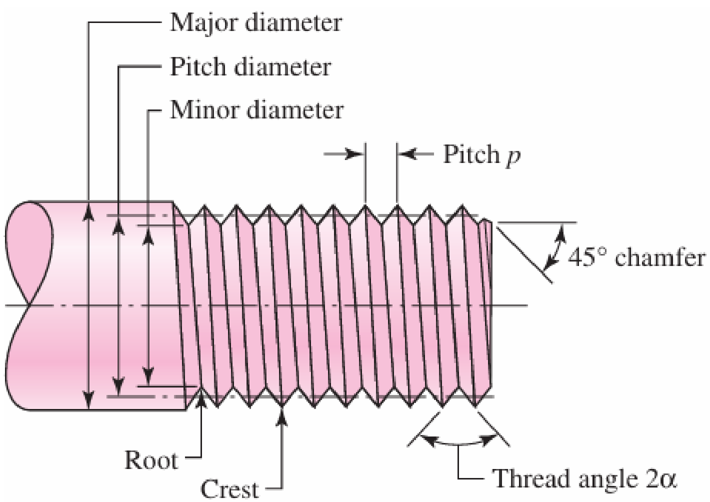
$$P = \frac{DNd^{2.3}}{50} \quad \text{or} \quad T = 1250Dd^{3.3}$$

Where:
P = horsepower transmitted, in hp
T = torque, in-lbs
D = shaft diameter, in
N = speed, in rpm
d = set-screw diameter, in

A ¼-inch (6.35 mm) set-screw can safely hold 100 pounds (445 N), while a ⅜-inch (9.5 mm) set-screw can hold 250 pounds (1112 N). For larger sizes, a ½-inch (12.7 mm) set-screw has a safe holding force of 500 pounds (2224 N), a ¾-inch (19 mm) set-screw can hold 1300 pounds (5783 N), and a 1-inch (25.4 mm) set-screw has a holding force of 2500 pounds (11121 N).

Thread Standards and Terminology

Threaded fasteners follow specific standards to ensure compatibility and performance. Key terms include:

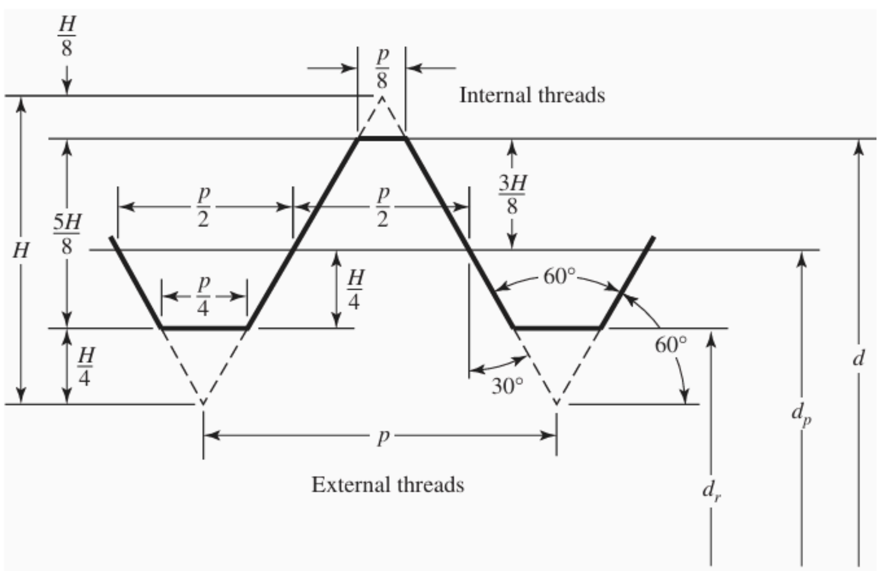


- **Major Diameter**: This is the largest diameter of the thread, measured from crest to crest. It represents the outermost dimension of the threaded part.
- **Minor Diameter**: The smallest diameter of the thread, measured at the root (the bottom part between threads).

- **Pitch Diameter**): The theoretical diameter located between the major and minor diameters, often used to define the thread's fit. It represents the point where the thread thickness is approximately half the depth.
- **Pitch**: The distance between two adjacent crests (or threads) measured parallel to the axis. It indicates the spacing between threads.
- **Root**: The base of the thread cut, which forms the smallest diameter (minor diameter).
- **Crest**: The top surface of the thread. This is the prominent part of the screw thread that makes contact when engaged with a nut or other component.
- **Thread Angle(2α)**: The angle formed between the sides of two adjacent threads. For standard threads, the angle is typically 60° (as seen in metric and unified threads).
- **Chamfer**: The beveled edge at the start of the thread, angled at 45°, which helps in guiding the thread into a mating part.

Multiple-threaded products, such as **double-threaded** or **triple-threaded** screws, have threads that move faster when turned, as the lead increases with the number of threads. This type of screw is useful when faster assembly is required. Most threads follow the **right-hand rule**, meaning the bolt advances when turned clockwise.

Detailed Thread Geometry



Height (H): Represents the depth of the thread, from the crest to the root. This dimension impacts the thread's engagement strength.

- For external threads, **H = 0.866 * p**, where ppp is the pitch.

Thread Pitch (p): Reiterated as the distance from one thread crest to the next.
Angles:

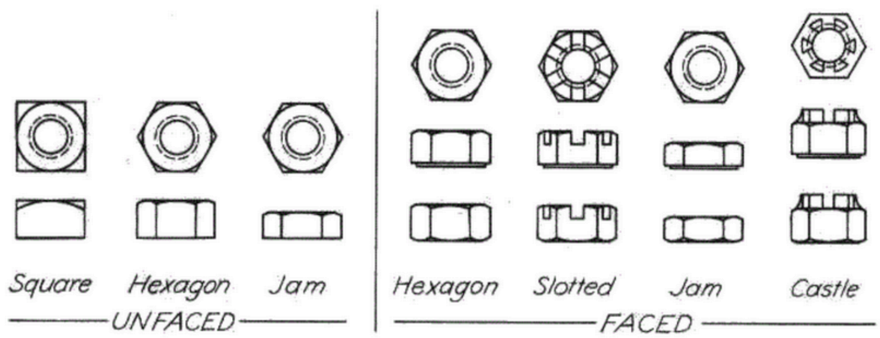
- **60° Angle**: This is the standard flank angle for most metric and unified threads.
- **30° Angle**: Represents the slope found in some parts of the thread profile.

Segments and Measurements:

- The thread's geometry is divided into sections:
  - **H/8, 3H/8, 5H/8** represent divisions that help in understanding thread depth and dimensions.
  - The thread profile consists of multiple sections to define both external and internal fits.
- **p/2**: Represents half the pitch, indicating the spacing within thread divisions.

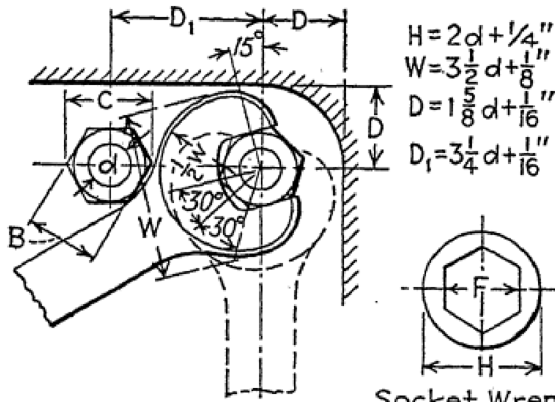
Proper fastening is vital for the safety and functionality of mechanical systems. Threads must be carefully selected and standardized to maintain performance across various conditions. Engineers must consider thread geometry, material properties, and installation techniques to prevent failures, especially in critical applications like aerospace or heavy machinery.

Nuts are used with bolts and studs. These are available in two wrench-type styles: square and hexagonal. Together with plain form usually associated with bolts.



Bolt Spacing

When designing bolted joints, engineers must consider Bolt Spacing to ensure that there is sufficient clearance for assembly and maintenance tools, such as wrenches and sockets. According to the provided technical diagram, the spacing between bolts, as well as the distance from walls or corners, is governed by specific empirical formulas based on the bolt diameter (d). These clearances—represented by variables like H for socket wrench heads and W for open-end wrenches—ensure that a technician can effectively grip and turn the hardware without interference from adjacent bolts or structural obstructions. While special "thin-wall" wrenches may allow for slightly tighter spacing, standard design practice relies on these established ratios to prevent assembly errors.

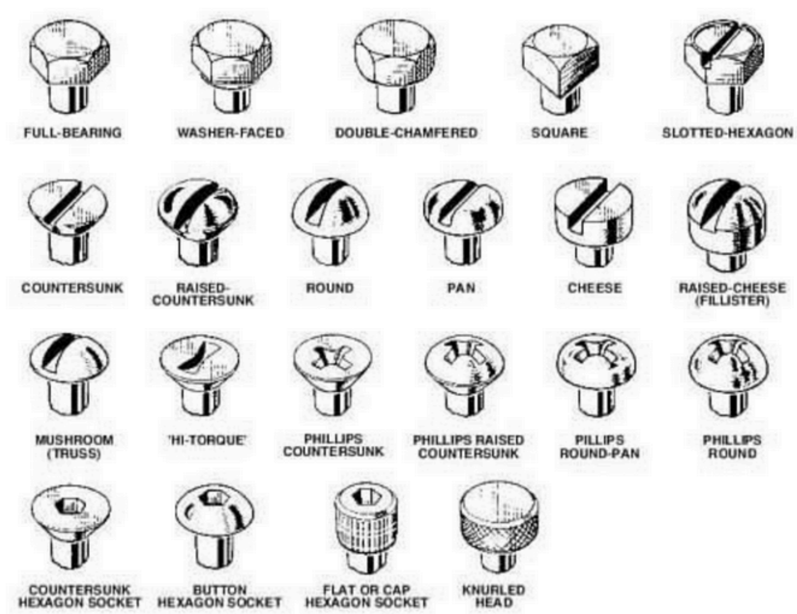


Spacing of Bolts with Hex. Nuts and Wrench Clearance

Socket Wrench Head

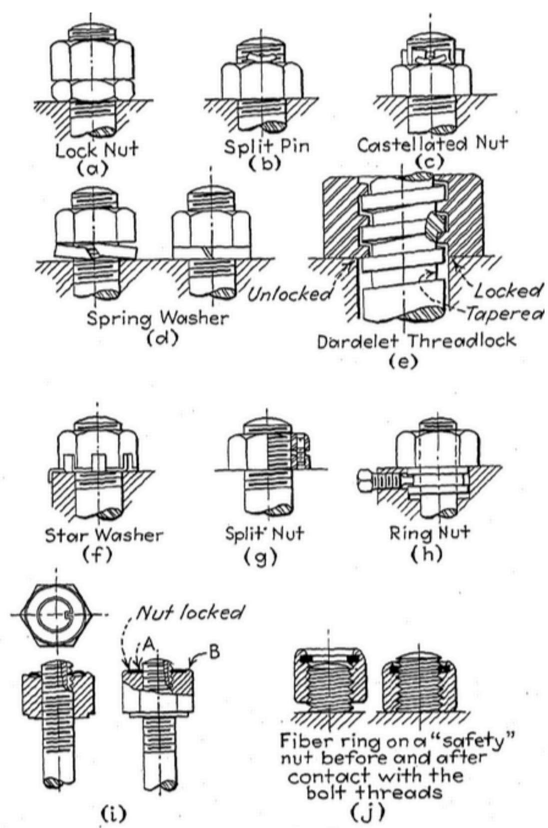
In addition to tool clearance, the spacing (or pitch) between bolts is critical for the integrity of the joint itself, particularly in gasketed applications. To maintain uniform contact pressure across a gasket and prevent leaks, the pitch should not be excessive; a common rule of thumb is to keep the spacing between five to six bolt diameters. Balancing these two requirements—providing enough room for a wrench to operate while keeping bolts close enough to ensure a tight seal—is a fundamental task in mechanical design to ensure both the functionality and serviceability of the machine component.

A **machine screw** is a small fastener used in the same manner as a bolt or a cap screw.



Studs are fasteners threaded on both ends, used where through bolts aren't suitable. One end is screwed into a tapped hole, and the other holds a nut. They're preferred over cap screws because they offer better alignment, reduce wear during disassembly, and provide consistent clamping. In brittle materials, studs should be inserted at least 1.5 times their diameter for strength.

To prevent nuts from loosening due to vibration, various **locking devices** are used. These include lock nuts, split pins, castellated nuts, spring and star washers, split and ring nuts, and fiber ring or safety nuts. Each type increases friction or provides a mechanical stop to keep the nut secure.



Locking devices.