5.1 SCREWS AND NUTS

Definitions

Figure 5.1 Helix curve

One can consider a screw and a bolt as a combination of two wedges. One wedge is obtained from opening the helical treads of the screw and the other will come from opening the helical threads of the bolt. For example, if one opens one revolution of the thread of a screw having a lead of \( h \) and mean thread diameter \( 2r \), one gets the following wedge where \( \alpha \) is the lead angle.

Screw thread can be defined as a ridge of uniform section in the form of a helix on the external or internal surface of a cylinder or hole. The primary terms useful in defining screw threads are:

2. Internal thread (nut): A thread on the internal surface of a cylinder.
3. Right-hand thread: A thread that when viewed axially winds in a clockwise and receding direction. Threads are always right-hand unless otherwise specified.
4. Left-hand thread: A thread that when viewed axially winds in a counterclockwise and receding direction. All left-hand threads are designated LH.
5. Major diameter (nominal diameter), \( d \): The largest diameter of a screw thread
6. Minor diameter (tap drill diameter), \( d_2 \): The smallest diameter of a screw thread.
7. Pitch diameter, \( d_1 \): average diameter
8. Pitch (hatve) (P) (h): The axial distance between corresponding points on adjacent threads
A **screw**, or **bolt**, is a type of fastener characterized by a helical ridge, known as an external thread or just thread, wrapped around a cylinder.

A **nut** is a type of fastener with a threaded hole. Nuts are almost always used opposite a mating **bolt** to fasten a stack of parts together. The two partners are kept together by a combination of their threads’ friction, a slight stretch of the bolt, and compression of the parts. The most common shape is **hexagonal**.

**A bolt** is an externally threaded fastener designed for insertion through holes in assembled parts, and is normally intended to be tightened or released by **torquing a nut**.

**A screw** is an externally threaded fastener capable of being inserted into holes in assembled parts, of mating with a preformed internal thread or forming its own thread, and of being tightened or released by **torquing the head**.

**Thread Profiles:** triangle, square, trapezoid and round
Standardized threads

a) Metric Screw: Thread angle is $\beta = 60^\circ$. Profile of the thread is equilateral triangle

- Pitch: $P(h)$
- Major diameter (Anma çapı): $d$
- Pitch diameter (Ortalama çap): $d_2$
- Minor diameter (Diş dibi çapı): $d_1$
- Thread height (Diş yüksekliği): $h$

M16, M20

b) Whitworth Screw: Angle of thread is $\beta = 55^\circ$. It was formerly the standard in Great Britain.

- $W \times$ Major Diameter x Pitch

W 2” x 5.645

c) Trapezoid (Trapez Vida): Profile is trapezoid (angle is $30^\circ$)

- $Tr \times$ Major Diameter x Pitch

Tr 20

d) Buttress screw (Testere vida):

Square profile: not standard

APPLICATIONS AREAS

a) Bolt and screws are used to fasten the various parts of an assembly together. Metric and Whitworth screws are used for that purpose. Self-locking is important in this connections.
b) Translation screws (Hareket ve kuvvet iletiminde): Power screws sometimes called linear actuators or translation screws, are used to convert rotary motion of either the nut or the screw to relatively slow linear motion of the mating member along the screw axis (lifting weights, screw jack). Screws with square and trapezoid profile are used for that purpose.

**FASTENER MATERIALS**

Materials for screws, nuts and bolts are normally selected on the basis of strength (at the operating temperatures involved), weight, corrosion resistance, life expectancy and cost.

Symbols to show material:
Such as
4.6 6.8  
4.8 8.8  
5.6 9.8  
5.8 10.9  

Example (4.6): Ultimate strength, \( \sigma_k = 40 \text{ daN/mm}^2 \),  
Yield stress of the material, \( \sigma_A = 24 \text{ daN/mm}^2 \).

<table>
<thead>
<tr>
<th>Mechanical Prop.</th>
<th>Groups</th>
<th>3.6</th>
<th>4.6</th>
<th>4.8</th>
<th>5.6</th>
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<th>6.6</th>
<th>6.8</th>
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<tr>
<td>Rm (min) (( \sigma_k )) N/mm^2</td>
<td></td>
<td>340</td>
<td>400</td>
<td>400</td>
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<td>600</td>
<td>600</td>
<td>600</td>
<td>800</td>
<td>1000</td>
<td>1200</td>
<td>1400</td>
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<tr>
<td>R_eH (min) (( \sigma_A )) N/mm^2</td>
<td></td>
<td>200</td>
<td>240</td>
<td>320</td>
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<td>400</td>
<td>480</td>
<td>540</td>
<td>540</td>
<td>640</td>
<td>900</td>
<td>1080</td>
<td>1260</td>
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<tr>
<td>A5 (min) %</td>
<td></td>
<td>30</td>
<td>25</td>
<td>14</td>
<td>22</td>
<td>10</td>
<td>-</td>
<td>12</td>
<td>8</td>
<td>12</td>
<td>8</td>
<td>8</td>
<td>-</td>
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<tr>
<td>BSD 30 daN/mm^2 (min)</td>
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<td>90</td>
<td>120</td>
<td>120</td>
<td>140</td>
<td>140</td>
<td>170</td>
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<td>170</td>
<td>225</td>
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<td>390</td>
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<tr>
<td>KU3 J/cm^2</td>
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<td>-</td>
<td>-</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>40</td>
<td>-</td>
<td>70</td>
<td>50</td>
<td>40</td>
<td>-</td>
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Heading is done cold for diameters up to 15 mm and heated for larger sizes. Threads are usually formed by rolling between dies that force the material to cold form into threaded contour of the die grooves. The threads thus formed are stronger than cut or ground threads in fatigue and impact because of cold working.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Manufacturing type</th>
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<td></td>
<td>Hot</td>
<td>Cold</td>
<td>Cut Talaş kaldirarak</td>
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<td></td>
<td>Civatalar</td>
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<td>Fe 34</td>
<td>Fe 34KG</td>
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<td>Fe 34;Fe 37; MuFe 34; QFe 34</td>
<td>Fe 37KG, 9C20KG</td>
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<tr>
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<td>Chemical compound %</td>
<td>Appl. Temp.</td>
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<tr>
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<td>-</td>
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<tr>
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<td>1.1191</td>
<td>0.42-0.5</td>
<td>0.25</td>
<td>0.65</td>
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<td>0.25</td>
<td>0.65</td>
<td>1.05</td>
<td>0.25</td>
</tr>
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<td>1.35</td>
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<td>0.17-0.25</td>
<td>0.45</td>
<td>0.4</td>
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</table>

**Forces in screw and nut connections**

Two types of connections are present:

1. **Preloaded**
2. **Without preload**

![Figure 5.2 Forces in screw-nut connections](attachment:image.png)
The purpose of a bolt is to clamp two or more parts together. The clamping load stretches or elongates the bolt: The load is obtained by twisting the nut until the bolt has elongated almost to the elastic limit.

If the nut does not loosen, this bolt tension remains as the preload or clamping load.

It exists in the connection after the nut has been properly tightened no matter whether the external tensile load (Fış) is exerted or not.

Since the members are being clamped together, the clamping force which produces tension in the bolt induces compression in the members.

**Tightening and disassembly under preload (Ön yükleme altında sıkma – çözme):**

Imagine that a single thread of the bolt is unrolled for exactly the single turn.

To raise the load, the force acts to the right. Friction force acts to oppose the motion. The system is in equilibrium.

![Figure 5.3 Loads in thread](image)

- \( F_h \) : Force during tightening (Sıkma kuvveti)
- \( r_2 = d_2 / 2 \) : Pitch radius (Ortalama yarıçap)
- \( F_o \) : Preload (Ön yükleme kuvveti)
- \( R_s \) : Average radius under nut (Somun altı ortalama yarıçapı)
- \( \alpha \) : Thread helix angle (Vida eğim açısı)
- \( M_s = M_1 + M_2 \) : Torque (Sıkma moment)
- \( \rho \) : \( \arctg \mu \) : Friction angle
- \( \beta \) : Thread angle (Vida profili tepe açısı)

If there is no friction
\[
F_h = F_o \cdot \tan \alpha
\]

With friction
\[
F_h = F_o \cdot \tan (\alpha + \rho)
\]

Force for disassembly
\[
F_h = F_o \cdot \tan (\alpha - \rho)
\]
Torque is required for two purposes: To overcome thread friction and to raise the load,

\[ M_1 = F_h r_2 = F_o r_2 \tan(\alpha + \rho) \]

Friction under the nut,  
Total torque (moment) for assembly,  
Total torque (moment) for disassembly,  

For triangle shaped profile,

\[ \mu' = \frac{\mu \cos \beta/2}{\cos \beta/2} \]
\[ \tan \rho' = \tan \rho / \cos \beta/2 \]
\[ M_{\text{sk-clo}} = F_o [\pm \mu_s R_s + r_2 \tan(\alpha \pm \rho')] \]

For disassembly (-)
\[ \beta = 60 ^\circ, \quad \mu' = 1.15 \mu \quad \text{(metric)} \]
\[ \beta = 55 ^\circ, \quad \mu' = 1.12 \mu \quad \text{(Whitworth)} \]

For practical applications, \( \alpha \leq 3 ^\circ, \rho' = (6.5) ^\circ \) can be taken.

**Autoblockage (Self-locking)**

\[ M_\xi = F_o r_2 \tan(\alpha - \rho') \leq 0 \quad \alpha \leq \rho' \]

Self-locking is obtained whenever the coefficient of thread friction is equal to or greater than the tangent of the thread angle.
5.1.2 - Dimensioning

1- Connections without preload (Ön yüklemesiz bağlantılar):

If the force (F) is in the form of tension or compression

\[ \sigma = \frac{F}{A_1} = \frac{4F}{\pi d_1^2} \leq \sigma_{em} \]

\[ \sigma_{em} = 0.6 \sigma_{Ak} \]

d_1 (d_3): minor diameter of the screw.
\( \sigma_{Ak} \): yield stress of the screw material

2- Tightening of nut under preload (Ön yükleme altında somunun sıkılması):

Tension stress due to \( F_0 \),

\[ \sigma = \frac{F_0}{A_1} = \frac{4F_0}{\pi d_1^2} \]

Torsional stress during tightening:

\[ \tau = \frac{M}{W_b} = \frac{F_0 r_2 \tan(\alpha + \beta)}{\pi d_1^3 / 16} \]

Effective stress:

\[ \sigma_{es} = \sqrt{\sigma^2 + 3.7^2} \leq \sigma_{em} \]

3- Tension joints - The external load (İşletmede toplam kuvvet)

Let us now consider what happens when an external tensile load is applied to a bolted connection.

Nomenclature:

\( F_0 \) : Preload

Figure 5.7. Deformation triangle

Prof. Dr. Özgen Ü. Çolak
\( F_{i\phi} \) : External tension load
\( F_{\text{max}} \) : Max. force on the bolt after \( F_{i\phi} \) (resultant bolt load)
\( F_a \) : Decrease in preload, Portion of \( F_{i\phi} \) taken by members
\( F_k \) : Resultant load on members
\( F_z \) : Portion of \( F_{i\phi} \) taken by bolt.

\( x \) : Extension, elongation in screw due to preload (\( F_0 \))
\( x' \) : Compression on the members
\( k_c \) : Stiffness of screw
\( k_p \) : Stiffness of members
\( E_1, E_2 \) : Elasticity modulus of bolt and members
\( A_1, A_2 \) : Cross section of bolt and members

Before external tension load is applied

\[
F_0 = k_c x = k_p x' \\
x = \frac{F_a l_1}{A_1 E_1} \quad \text{or} \quad k_c = \frac{A_1 E_1}{l_1}
\]

\( A_1 \) : minor diameter area

\( l_v \): Length of threaded portion of bolt.
\( l_s \): Length of unthreaded portion of bolt.

\[
x = \frac{F_0}{E_1} \left( \frac{l_v}{A_1} + \frac{l_s}{A} \right) \quad \text{ve} \quad \frac{1}{k_c} = \frac{1}{k_v} + \frac{1}{k_s}
\]

Stiffness of the members (\( k_p \)) are calculated approximately.

![Figure 5.8 Compression of a member with the equivalent elastic properties represented by a frustum of hollow cone.](image)

\[
k_p = \frac{A_2 E_2}{l} \quad \text{, According to Rötscher’s approach (pressure cone method for stiffness calculations)}
\]
A_2 = \frac{\pi}{4} (D^2 - d^2) \quad \text{and equivalent cone diameter (D)} \quad D = e + k \cdot (l_2 / 2) \quad \text{dir.}

e : anahtar ağzı genişliği olup \quad k : 0,25 for cast iron and 0,2 for steel.

After Fiş is applied,

Additional elongation in bolt: \Delta x

Decrease in compression on members:

\[ |\Delta x'| \]
and \[ \Delta x = |\Delta x'| \]

\[ F_{\text{max}} = (x + \Delta x)k_c = F_\theta + F_z \]
\[ F_a = F_\theta - F_k \]
\[ F_{\text{max}} = F_\text{is} + F_k \]
\[ F_\text{is} = F_a + F_z \]

If \( F_\text{is} \) is dynamic,

a) If there is preload (\( F_\theta \)), \( F_z = F_{\text{max}} - F_\theta \) and change in load will be between \( F_\theta \) and \( F_{\text{max}} \)
b) If there is no preload (\( F_\theta \)), \( F_z = F_{\text{max}} = F_\text{is} \) and change in load will be between zero and \( F_\text{is} \)

Load which cause additional elongation, \( F_z = k_c \Delta x \)

Decrease in preload (\( \Delta x' \)) \( F_a = k_p \Delta x' \) since \( \Delta x = |\Delta x'| \)

\[ \frac{F_z}{F_a} = \frac{k_c}{k_p} \quad F_{\text{is}} = (k_c + k_p)\Delta x \]

To decrease effect of dynamic external load, the ratio \( k_p / k_c \) (or \( x / x' \) ) should be increased.

( Elastic bolt application)

To prevent leakage in the system, \( F_k > 0 \).
Maximum Stress

\[ \sigma_{\text{max}} = \frac{F_{\text{max}}}{A_1} = \frac{4 \cdot F_{\text{max}}}{\pi d_1^2} \leq \sigma_{\text{em}} \quad \sigma_{\text{em}} \cong 0,6 \cdot \sigma_{\text{Ak}} \cdot \frac{F_s}{F_{\text{max}}} \]

If external load is dynamic,

\[ \sigma_{\text{max}} = \frac{F_{\text{max}}}{A_1}, \quad \sigma_{\text{min}} = \frac{F_{\text{S}}}{A_1}, \quad \sigma_g = \frac{\sigma_{\text{max}} - \sigma_{\text{min}}}{2} \]

Stress amplitude \[ \sigma_g = \frac{F_z/2}{A_1} \]

Mean stress \[ \sigma_m = \frac{F_{\text{max}} + F_{\text{S}}}{2 \cdot A_1} \quad [F_m = (F_{\text{max}} + F_{\text{min}})/2] \]

\[ \sigma_g \leq \sigma_{\text{gem}}, \quad \sigma_{\text{gem}} \cong 0,7 \sigma_s \]