Autodesk Inventor Engineer s Handbook

هندبوک مهندسی نرم افزار Autodesk Inventor

انجمن اینونتور ایران

www.irinventor.com

Email: irinventor@chmail.ir
irinventor@hotmail.com

Tel: 09352191813 &

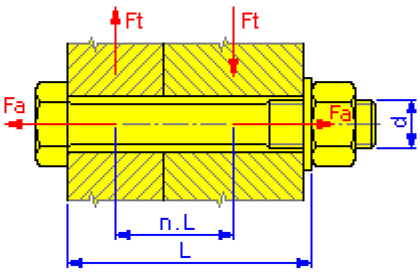
021-46088862

Joints / Movable Joints

Bolted Connection Generator

Basic Calculation of Bolted Connection

Calculation of a bolted connection with prestress. Loading by axial or tangential force. The calculation is carried out in metric or English units. With the ANSI standard set, the calculation is performed in English units, with corresponding bolt dimensions also included.



Input Parameters

ψ Tightness factor - With a prestressed bolted connection, the distance between materials is undesirable (due to the bad quality of surface, for example) and this safety factor is introduced to prevent it. Tightness factor k = 1 + Ψ (additional tightness factorΨ = 0.5 - 1.5). Recommended minimum value is 1.2.

F_a maximum operation axial force

n force input factor

F_t maximum operation tangential force

f joint friction factor (between the connected materials)

z number of bolts

d thread diameter

p thread pitch

d_s mean bolt diameter

d_{min} minimum bolt diameter

S_y Yield strength

k_s safety factor (The value is selected according to the required safety level of the joint.)

p_A allowable thread pressure (nut)

E_1 elasticity module of bolt

f_1 thread friction factor between the nut and the bolt

f_2 friction factor in the contact surface of the nut or bolt

L width of connected material

E_2 elasticity module of connected material

Calculated Parameters

According to the following calculation formulas, the program calculates geometric dimensions of the bolt from the specified nominal bolt diameter:

Minimum diameter of the nut thread

$D_1 = d - 1.082531\ p$

Pitch diameter of the thread

$d_2 = d - 0.649519\ p$

Calculation of Bolted Connection:

Working force in the joint - determined by the axial force, has to secure the transfer of tangential force by friction of connected materials. Also affected by the requirement on tightness expressed by the factor of joint tightness.

$$F_{max} = \frac{\psi}{z} \cdot \left(Fa + \frac{Ft}{f}\right)$$

Prestress force - based on the working force of the joint, takes into account the elastic yielding of bolts and flanges by using the c_n yielding constants.

$$Fo = F_{max} - \left(\frac{c_2}{c_1 + c_2}\right) \cdot \frac{Fa}{z}$$

where:

$c_1 = c_{10} + (1 - n)\ c_{20}$

$c_2 = n\ c_{20}$

$$c_{10} = \frac{L + 0{,}8d}{E_1 \cdot \frac{\pi \cdot ds^2}{4}}$$

$$c_{20} = \frac{L}{E_2 \cdot \frac{\pi}{4}\left(\left(1{,}5d + \frac{L}{a}\right)^2 - 1{,}05d^2\right)}$$

for steel a = 10

for cast iron a = 8

for aluminum and its alloys a = 6

Required tightening moment - determined by the prestress force and affected by the friction factor in threads between the nut and bolt, and by the friction factor in the contact surface of the nut or bolt.

$$Mu = Fo\left[\frac{d_2}{2} \cdot \tan\left(\frac{p}{\pi \cdot d_2} + \frac{f_1}{\cos 30°}\right) + 0{,}7d \cdot f_2\right]$$

Calculated tensile stress in the bolt

$$\sigma_t = \frac{4 \cdot F_o}{\pi \cdot {d_{min}}^2}$$

Calculated torsion stress in the bolt

$$\tau_k = \frac{16 \cdot Mu}{\pi \cdot {d_{min}}^3}$$

Reduced stress in the bolt

$$\sigma_{red} = \sqrt{{\sigma_t}^2 + 3 \cdot {\tau_k}^2}$$

Stress caused by maximum force loading the bolt

$$\sigma_{max} = \frac{4 \cdot F\,max}{\pi \cdot {d_{min}}^2}$$

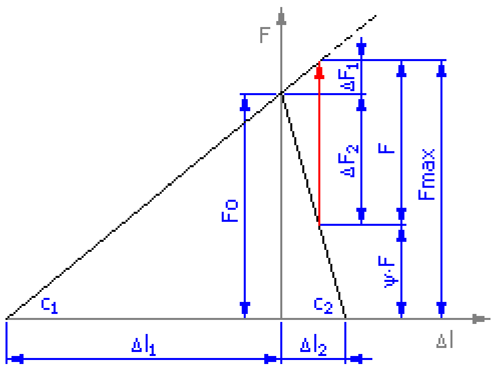
Calculated pressure in the thread

$$p_c = \frac{4F_{max}}{\pi\left(d^2 - {D_1}^2\right)\dfrac{0.8d}{p}}$$

Calculation check - stress in the bolt during tightening the joint and during the operation (respecting the specified joint safety), and the check of allowable pressure in threads.

$\sigma_{red} \leq S_y / k_s$ and $\sigma_{max} \leq S_y / k_s$ and $p_c \leq p_A$

Diagram of prestress joint



where:

F operation force

Ψ factor of joint tightness

F_o prestress force

F_{max} maximum operation force in the bolt

ΔF_1 increasing of prestress in the bolt due to the operation force

ΔF_2 reduction of clamping force in the joint due to the operating force

Δl_1 bolt elongation

Δl_2 compression of connected material

c_1 bolt spring constant

c_2 connected material spring constant

Friction factor

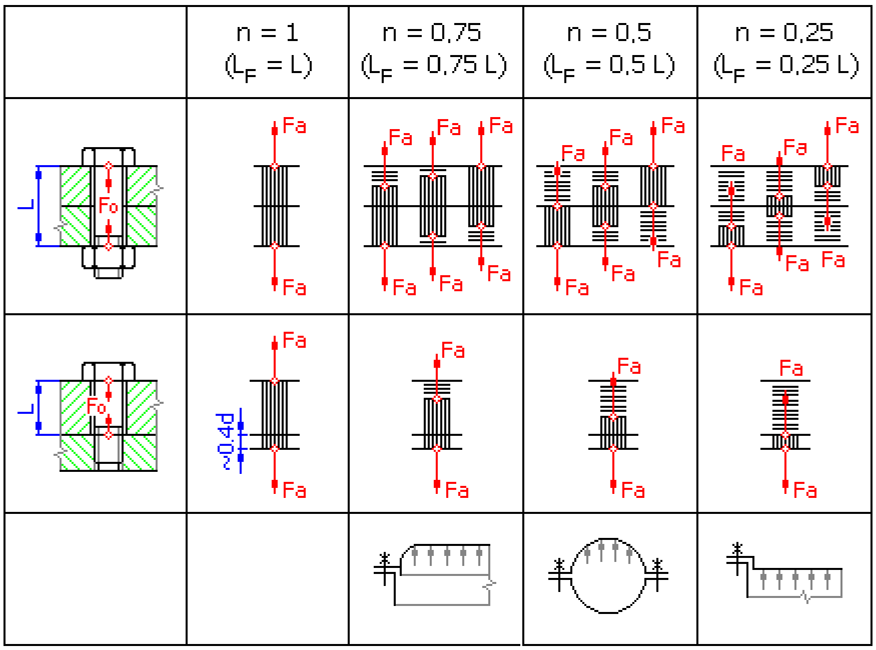
Material	*non-lubricated*	*lubricated*
steel - steel	0.8	0.16
steel - cast iron	0.4	0.21
steel - brass	0.35	0.19
steel - brass	0.13	0.16
cast iron - cast iron	1	0.15 - 0.20
cast iron - bronze	0.25	0.08
bronze - bronze	0.25	0.10
aluminum - aluminum	1.35	0.30
copper - copper	1	0.08
steel - plexiglas	0.4 - 0.5	0.4 - 0.5
plexiglas - plexiglas	0.8	0.8

Friction factor in thread f1

Thread surface	*non-lubricated*	*lubricated*
black or phosphate coating	0.14 to 0.21	0.12 to 0.15
galvanic zinc coating	0.13 to 0.18	0.12 to 0.17
cadmium plating	0.08 to 0.12	0.08 to 0.11

Force input factor n

Examples of force loading



where: L_F ... width of the material loaded by the operation force

Allowable pressure in threads

Allowable pressure in threads of connection bolts.

Nut material	Strength class of bolt material according to the CSN and ISO standards									
	4A	4D	4S	5D	5S	6S	6G	8G, 8E	10K, 10G	12K
	3.6	4.6	4.8	5.6	5.8	6.8	6.9	8.8	10.9	12.9
	pA [MPa]									
steel	40	50	75	70	90	110	120	150	200	250K
gray cast iron	25	30	45	40	55	70	80	90	125	150
light alloys	18	20	30	27	35	45	50	60	80	90

Fatigue strength of bolted connection

Conventional check procedures at fatigue loaded bolted connection (based on the ultimate or yield strength of material) do not provide sufficient guaranty of safe joint design. Consequently, the fatigue strength of joint is used in check of fatigue loaded joints. The description of fatigue loaded bolted connection joints checking follows. This description follows step by step the implementation in the program:

1. Specifying an endurance limit

In the first step the calculation determines the endurance limit at constant strength σ_C for the specified type, design, loading, and material of bolted connection.

2. Specifying finite-life fatigue limit

The finite-life fatigue limit σ_f is calculated for the specified joint life that is in the ($N< 10^6$ cycles) range of timed strength. Calculation continues with this finite-life fatigue limit.

3. Calculation of parameters of particular fatigue loadings

Mean values for given upper and lower cycle loadings are calculated their mean values according to the following formulas. It is done for all specified loadings.

$$F_m = \frac{F_h + F_n}{2}, F_a = \frac{F_h - F_n}{2}$$

4. Effect of strokes

If strokes affect the joint besides the fatigue loading, their influence must be included into the calculation. This is implemented by using the dynamic stroke factor in the formula for determining the maximum calculated loading:

$$F_{max} = F_m + \eta F_a$$

5. Calculation of actuating stress in the bolted connection joint

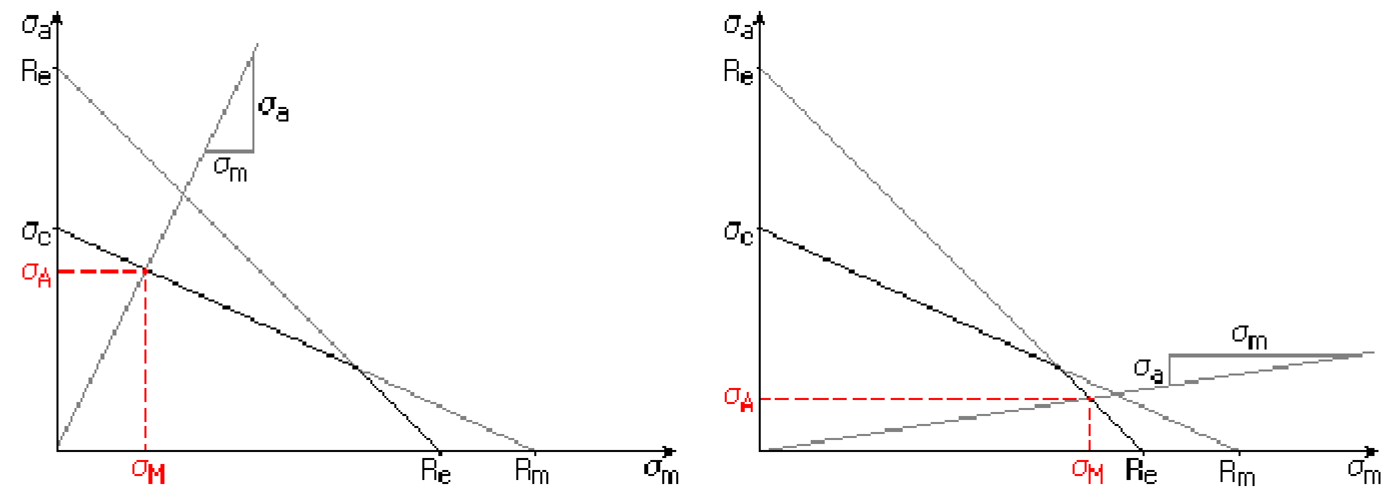
Mean cycle stress σ_m and upper cycle stress σ_h are calculated for the specified mean cycle loading F_m and maximum calculated loading F_{max} with the formulas used in static calculation. These stresses are used for calculation of cycle amplitude according to the formula:

$\sigma_a = \sigma_h - \sigma_m$

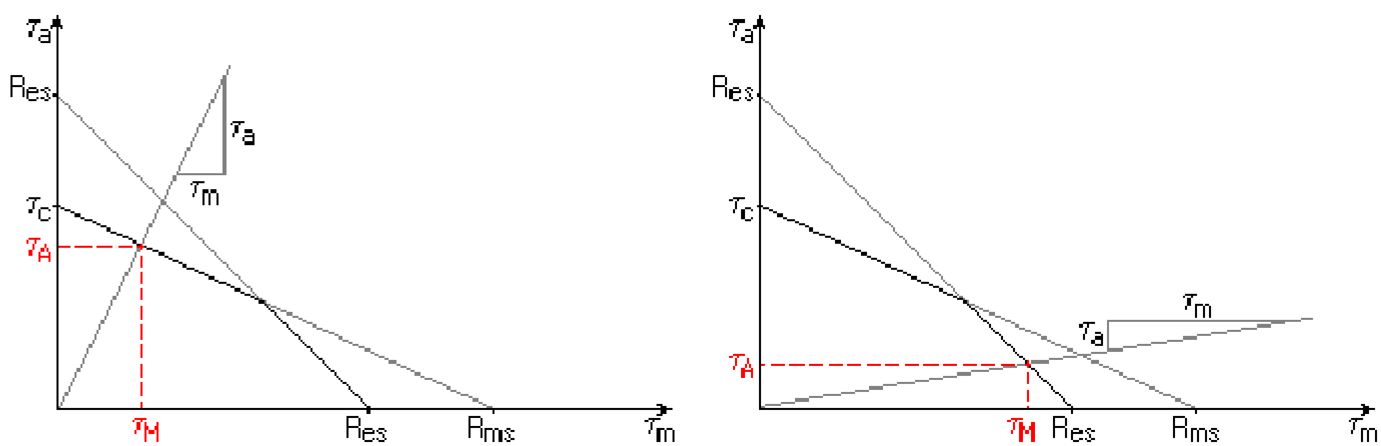
6. Specifying fatigue strength of joint

For calculated stress and known endurance limit, the resulting strength of fatigue joint is easily determined according to the selected fatigue curve. The procedure of fatigue strength determination for both normal and shear stresses is obvious from the following pictures.

Haigh charts of normal stress for different σ_a / σ_m ratio (modified Godman fatigue curve is used):



Haigh charts of normal stress for different τ_a / τ_m ratio (modified Godman fatigue curve is used):



7. Joint check

In the last step, the program calculates the joint safety factor $n_C = \sigma_A / \sigma_a$ and compares it with the required safety degree. For convenient bolted connection the condition $n_f \leq n_C$ must be satisfied.

Bolted connection endurance limit determination

Corrected endurance limit at the constant strength σ_e of the bolted connection is determined for the selected type, design, material, and joint loading from the formula:

$\sigma_e = \sigma'_e k_e k_f$ [MPa, psi]

where:

σ'_e basic endurance limit of a test bar from the selected material [MPa, psi]

k_e modified factor of stress concentration [-]

k_f factor of miscellaneous effects [-]

1. Basic endurance limit σ'_e

If you do not have available results of material tests of the selected bolted connection material and do not know the exact value of basic endurance limit, its value can be estimated by the program. In this case, the calculation designs the basic endurance limit according to the reversed traction - pressure formula:

$\sigma'_e \approx 0.4 S_U$ - for reversed traction - pressure

S_u ultimate tensile strength [MPa, psi]

2. Modified factor of stress concentration k_e

High local stress concentrations originate in a joint when the bolted connection is fatigue loaded because of bolted connection notch effect. These concentrations considerably reduce the joint fatigue strength. Modified factor of stress concentration is determined from the ke = 1/K formula, where the fatigue-strength reduction factor K depends on the bolted connection type, shape, design, bolted connection quality, and the bolted connection loading.

3. Factor of miscellaneous effects k_f

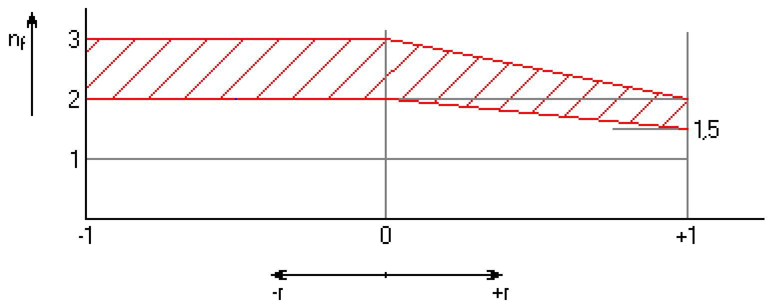
All other effects that can reduce or increase the fatigue strength of bolted connection (the influence of corrosion, for example) are included in this factor.

afety factor of fatigue loaded bolted connection

The required minimum safety factor of bolted connection during fatigue loading nf represents a ratio of fatigue loading and the calculated stress of bolted connection, that is, $n_f \leq \sigma_A / \sigma_a$ or $n_f \leq \tau_A / \tau_a$.

The recommended minimum value of safety factor at fatigue loading is indicated in the n_f = <1.5...3> range and it depends on the fatigue loading pattern. In general, the reversed loading is less favorable than fluctuating loading when the fatigue loading of bolted connection is considered.

The following picture displays the effect of loading course to bolted connection safety. The range of recommended minimum values of safety factor, which depends on the value of cycle asymmetry factor $r = \sigma_n / \sigma_h$, is hatched.



Fatigue curves

For determining the fatigue strength of bolted connection the method of virtual mean stress can be used.

$$\left(\frac{\sigma_a}{\sigma_e}\right) + \left(\frac{\sigma_m}{\sigma_F}\right) = 1, \qquad \left(\frac{\tau_a}{\tau_e}\right) + \left(\frac{\tau_m}{\tau_F}\right) = 1$$

where:

σ_a, τ_a amplitude of normal (shear) stress [MPa, psi].

σ_e, τ_e endurance limit at the constant strength [MPa, psi]

σ_m, τ_m mean cycle stress [MPa, psi].

virtual mean stress [MPa, psi]

σ_F, τ_F $\sigma_F = \frac{\sigma_e}{\psi}, \tau_F = \frac{\tau_e}{\psi}$

Ψ factor of Haigh diagram narrowing [-]

depends on the joint material - recommended values - for traction and bending Ψ <0.15...0.3>

- for shear Ψ <0.1...0.25>.