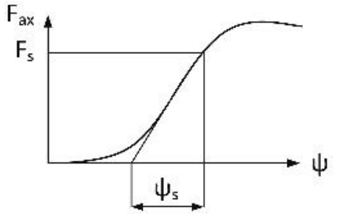
Tighten to correct pretension

Theory

Traditionally we tighten a bolted joint by turning bolt/screw or nut with the aim of reaching an axial force F_{ax} in the bolt/screw of 85-90% of yield force F_s. In modern screw/bolted joints we often tighten to full plasticity. For a class 8.8 screw onset of yield corresponds to a strain of

$$\varepsilon_s = \frac{\Delta L}{L} = \frac{\sigma_S}{E} = \frac{640}{210} \cdot 10^{-3} = 0{,}00305$$



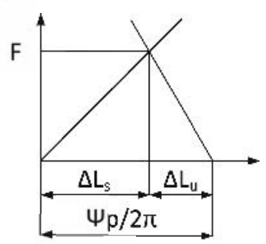
Through experiments we know that $F_{ax}(\psi)$ behaves as shown in the figure.

First there is an elastic deformation removing play in the joint. Then F_{ax} increases linearly until onset of yield F_s.

With compressed parts taken to be rigid, the angle ψ will be underestimated because in a real joint the compressed part, being elastic, will deflect while the screw is elongated. Further, there is deformation of screw head, nut, and threads.

The screw is elongated ΔL_s and the clamped joint is compressed ΔL_u. These deformations are caused by pitch p and by the turning of screw/nut angle ψ. We have

$$\psi \frac{p}{2\pi} = \Delta L_s + \Delta L_u$$



From the figure

$$F = k_s \Delta L_s = k_u \Delta L_u$$
$$L_u = \frac{k_s}{k_u} \Delta L_s$$

which yields

$$\frac{\psi}{2\pi} p = \Delta L_s + \frac{k_s}{k_u} \Delta L_s = \left(1 + \frac{k_s}{k_u}\right) \Delta L_s\,, \quad \Delta L = \varepsilon L$$

$$\psi_s = \frac{2\pi}{p}\left(1 + \frac{k_s}{k_u}\right) L\varepsilon$$

Angle in radians. Converted to number of hex sections, m, we get

$$m = \frac{\psi_s \cdot 180}{60\pi} = \psi_s \frac{3}{\pi} = \frac{6}{p}\left(1 + \frac{k_s}{k_u}\right) L\varepsilon = K\left(1 + \frac{k_s}{k_u}\right) L$$

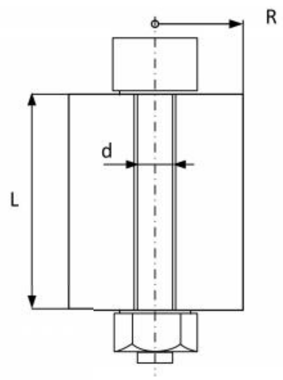
The factor $K = 6\varepsilon \,/\, p$ for tightening to full plasticity has been calculated and is shown in table 1.

Table 1. Factor K for different screws

M-thread		K for different screw classes		
d [mm]	p [mm]	8.8	10.9	12.9
6	1	0.01829	0.02571	0.03086
8	1.25	0.01463	0.02057	0.02469
10	1.5	0.01219	0.01714	0.02057
12	1.75	0.01045	0.01469	0.01763
16	2	0.00914	0.01286	0.01543
20	2.5	0.00731	0.01029	0.01234
24	3	0.00610	0.00857	0.01029
Elongation at yield [%]		12	9	8

Method

For M-thread and the same material in all parts. (In order to reduce stress due to torque, **the thread must be lubricated**.)



1. Read K from table 1
2. calculate L/d and R/d
3. read $\frac{k_s}{k_u}$ from curves
4. calculate $m = K\left(1 + \frac{k_s}{k_u}\right) L$, (L in mm)
5. tighten screw/nut in order to remove play
6. loosen screw/nut
7. tighten again until all play is removed (”finger tight”)
8. turn number of hex sections, m.

Example. A M10, class 8.8, hex screw & nut shall be tightened. Length L=35 mm, R=14 mm. From table 1: K=0.01219. Fig1 with L/d=3.5 and R/d=1.4 yields ks/ku=0.17. With the formula for m, we get m=0.01219*1.17*35=0.50 number of hex sections.

Commentaries

Screw in threaded hole differs marginally from screw in nut if L is taken from head to first engaged thread and L/d>1.

For R>2.5d, ks/ku no longer varies with R, because the deformation of the clamped parts is mainly locally at head and nut.

The elastic deformation of the screw head is surprisingly large. If Young’s modulus of the clamped part is reduced, e.g. Al instead of steel (70GPa instead of 210GPa) deformation of the clamped part increase strongly, ks/ku will be nearly three times larger, and the deformation of the head is increased, figure 4.

Screw stem diameter can be from 3-5% (M6) to 1.7-2.6% (M20) less than nominal diameter, depending on production class.

As shown in table 1, screws have large elongation at break. They therefor can sustain large plastic deformation. Take note that the thread must be well lubricated, preferably with solid lubricants.

In the threaded part the screw becomes thinner and the nut expands radially outwards. This works against pitch error due to axial screw elongation and nut compression. Conditions in the thread are very complicated and have been extensively simplified.

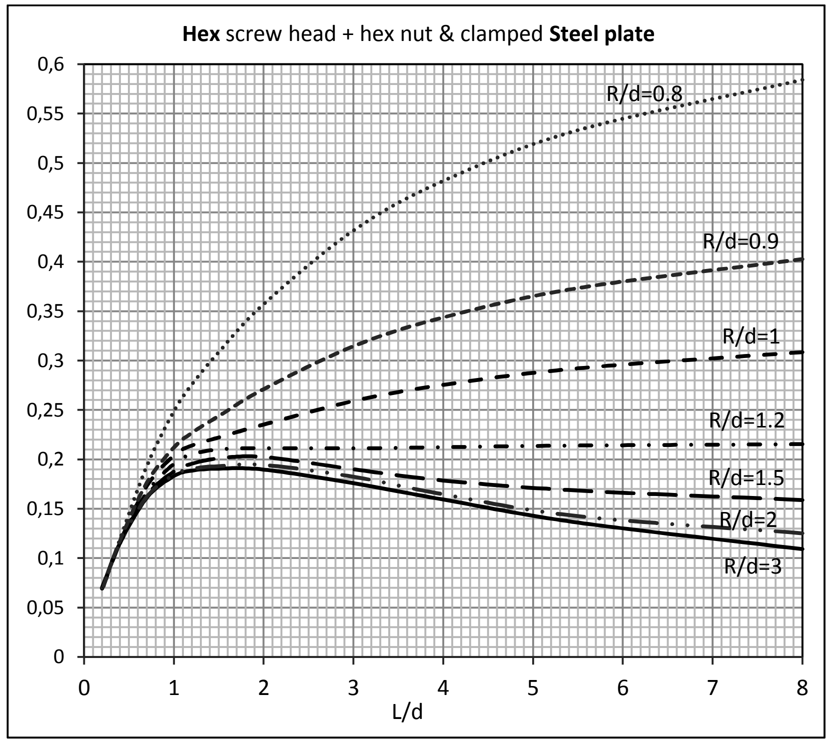


Figure 1. Factor ks/ku for different L/d and R/d. Hex screw, hex nut, same material in all parts and screw hole is 1.1d

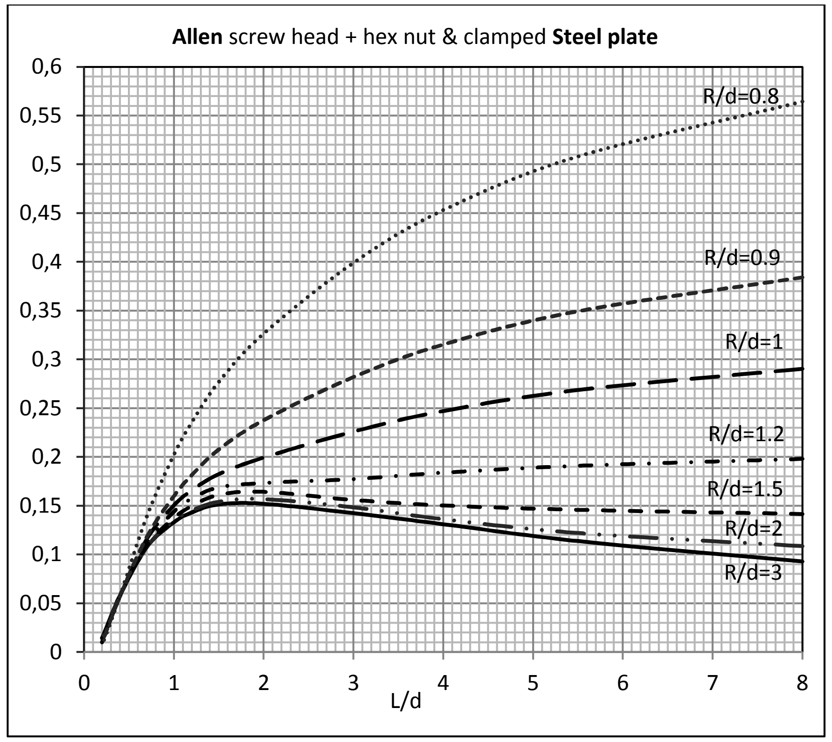


Figure 2. Factor ks/ku for different L/d and R/d. Allen screw, hex nut, same material in all parts and screw hole is 1.1d

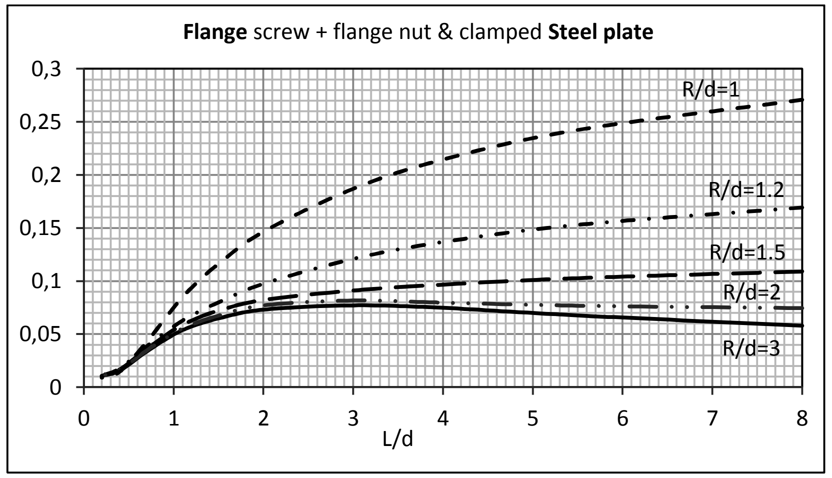


Figure 3. Factor ks/ku for different L/d and R/d. Flange screw, flange nut, same material in all parts and screw hole is 1.1d

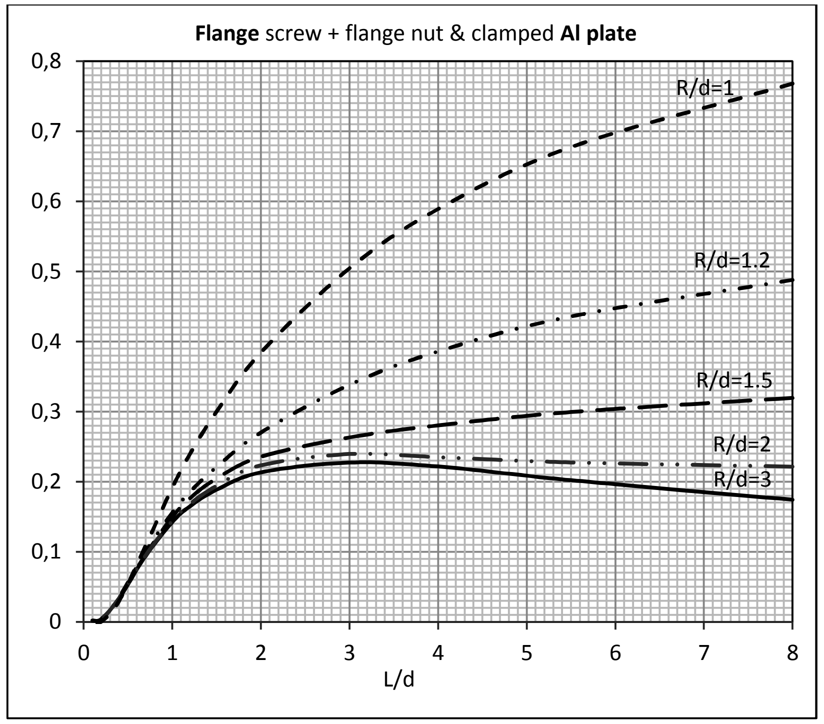


Figure 4. Factor ks/ku for different L/d and R/d. Flange screw and flange nut in steel. Clamped part in aluminium parts and screw hole is 1.1d