Approximate values for static coefficient of friction μ_T in the separation joint

according to VDI 2230, edition 2015

Material pairing (Normal case: state following machining)	Coefficient of static friction μ_T when dry	lubricated
Steel – steel / cast steel (general)	0,1 to 0,3	0,07 to 0,12
Steel – steel; cleaned	0,15 to 0,40	–
Steel – steel; case-hardened	0,04 to 0,15	–
Steel – GJL	0,11 to 0,24	0,06 to 0,1
Steel – GJL; cleaned	0,26 to 0,31	–
Steel – GJS	0,1 to 0,23	–
Steel – GJS; cleaned	0,2 to 0,26	–
GJL – GJL	0,15 to 0,3	0,06 to 0,2
GJL – GJL; cleaned / degreased	0,09 to 0,36	–
GJS – GJS	0,25 to 0,52	0,08 to 0,12
GJS – GJS; cleaned / degreased	0,08 to 0,25	–
GJL – GJS	0,13 to 0,26	–
Steel – bronze	0,12 to 0,28	0,18
GJL – bronze	0,28	0,15 to 0,2
Steel – copper alloy	0,07 to 0,25	–
Steel – aluminum alloy	0,07 to 0,28	0,05 to 0,18
Aluminum – aluminum	0,19 to 0,41	0,07 to 0,12
Aluminum – aluminum; cleaned / degreased	0,10 to 0,32	–

Note: Due to the large number of quantities affecting the coefficient of friction it is only possible to give typical ranges here. In the specific instance the minimum coefficient of friction need not correspond to the lower limit of the range in question and it may be necessary to carry out experimental investigations. These are also to be recommended in the case of measures to raise the coefficient of friction.

Guideline values for the tightening factor α_A and the resulting preload forces in assembly

according to VDI 2230, edition 2015

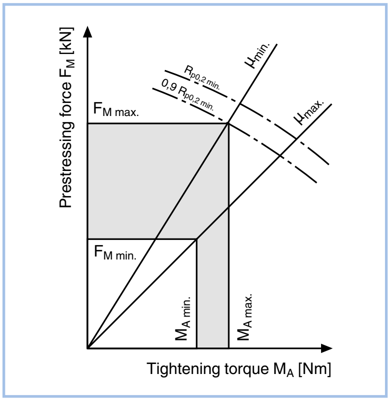
The tightening factor α_A (a factor of uncertainty in assembly) allows for errors in estimating the friction coefficients, scatter of the coefficients of friction, the tightening method, the equipment tolerances, operational failures, and inaccuracies in reading off values.

α_A therefore covers the variation in the desired preload force in assembly between $F_{M\,max}$ and $F_{M\,min}$. The design of the screw is based on the maximum tightening torque $M_{A\,max}$, so that the screw will not be overloaded during assembly.
The tightening factor α_A is then defined as:

$$\alpha_A = \frac{\text{max. possible preload in assembly } F_{M\,max}}{\text{min. required preload in assembly } F_{M\,min}}$$

Today, even simple modern torque screwdrivers are able to provide torques to very close tolerances. Maximum variations in torque over a range of ±2% are typical values quoted by manufacturers.
Nevertheless the resulting preload forces in assembly, depending on the tightening factor, vary from ±9% to as much as ±60%.

- tightening method with measurement of extension – hydraulic tightening methods are practically independent of friction. Their α_A factors are low.
- torque controlled tightening methods react to the effects of friction. The α_A factors are generally higher:
  Smaller variations and so smaller α_A factors occur for friction coefficients which have been derived from preliminary field trials. The same applies to cases involving hard screws with short grip lengths and for quick tightening methods.
  Higher α_A factors arise where friction coefficients are estimated, for cases involving soft screws and in tightening methods which are slower, as e.g. for impact screwdrivers and in hand assembly.



<table>
<tr><th>Tightening factor
α_A</th><th>Scatter
$\frac{\Delta F_M}{2 \cdot F_{Mm}} = \frac{\alpha_A - 1}{\alpha_A + 1}$</th><th>Tightening method</th><th>Setting procedure</th><th colspan="2">Comments</th></tr>
<tr><td>1,1 to 1,2</td><td>±5% to ±9%</td><td>Tightening with elongation control or monitoring by ultrasound</td><td>Sound travel time</td><td colspan="2">– calibration values required
– when $l_K/d < 2$ progressive increase in error to be taken into account
– smaller error with direct mechanical coupling, larger with indirect coupling</td></tr>
<tr><td>1,1 to 1,3</td><td>±5% to ±13%</td><td>Mechanical elongation by means of pressure screws located in the nut or the bolt head</td><td>Prespecified elongation of the bolt, setting via forcing torque of the pressure screws</td><td colspan="2">– hardened washer for supporting the pressure screws
– from approx. M24</td></tr>
<tr><td>1,2 to 1,5</td><td>±9% to ±20%</td><td>Mechanical elongation by means of multipartite nuts with threaded bushing</td><td>Torque of the tightening tool</td><td colspan="2">– largely torsion-free tightening
– from approx. M30</td></tr>
<tr><td>1,1 to 1,5</td><td>±5% to ±20%</td><td>Tightening with mechanical elongation measurement or monitoring</td><td>Direct method: setting via elongation measurement
Indirect method: axial play at monitoring pin used up</td><td colspan="2">– required: precise determination of the proportional axial elastic resiliences of the bolt
– the scatter depends to a considerable extent on the accuracy of the measurement method
– for low values, calibration is necessary
– when $l_K/d < 2$ progressive increase in error to be taken into account</td></tr>
<tr><td>1,1 to 1,4</td><td>±5% to ±17%</td><td>Hydraulic frictionless and torsion-free tightening</td><td>Setting via pressure or length measurement or further rotation angle of the nut</td><td colspan="2">– when $l_K/d \geq 5$ lower values achievable, with mechanically machined bolts and plates $\alpha_A = 1{,}05$ is possible
– with standard bolts and nuts $\alpha_A \geq 1{,}2$
– smaller clamping length values result in higher α_A values
– recovery losses occur which are not taken into account in the tightening factor.
– application from M20 upwards</td></tr>
<tr><td>1,2 to 2,0</td><td>±9% to ±33%</td><td>Impulse driver with hydraulic impulse generator, torque- and/or rotation-angle-controlled</td><td>Setting via angle of rotation or further torque</td><td colspan="2">– small values only in the case of presetting to the bolting case via rotation angle, compressed air servo valve and impulse counting
– in special cases, even assembly up to the yield strength point is possible</td></tr>
<tr><td>1,2 to 1,4</td><td>±9% to ±17%</td><td>Yield-point controlled tightening, motorized or manual</td><td>Presetting of the relative torque-rotation angle coefficient</td><td colspan="2" rowspan="2">The preload scatter is determined to a considerable extent by the scatter of the yield point in the installed bolt batch. Here the bolts are dimensioned for $F_{M\,min}$ a design of the bolts for $F_{M\,max}$ with the tightening factor α_A does not therefore apply with these tightening methods.</td></tr>
<tr><td>1,2 to 1,4</td><td>±9% to ±17%</td><td>Rotation-angle controlled tightening, motorized or manual</td><td>Experimental determination of preliminary tightening moment and rotation angle (stages)</td></tr>
<tr><td>1,4 to 1,6</td><td>±17% to ±23%</td><td>Torque-controlled tightening with hydraulic tool</td><td>Setting via pressure measurement</td><td colspan="2">– from approx. M30</td></tr>
<tr><td>1,4 to 1,6</td><td>±17% to ±23%</td><td>Torque-controlled tightening with torque wrench, signalling wrench or motorized nut-runner with dynamic torque measurement</td><td>Experimental determination of the setpoint torques at the original joint member, for example, by elongation measurement of the bolt</td><td>Low values:
large number of setting or monitoring attempts required (20, for example); low scatter of the output moment (for example, ±5%) required</td><td rowspan="3">Low values for:
– small rotation angles, in other words, relatively stiff joints
– relatively low hardness of the countersurfac [a]
– countersurfaces which do not have a «galling» tendency, for example, phosphated or adequately lubricated
High values for:
– large rotation angle, in other words, relatively resilient joints as well as fine thread
– great hardness of the countersurface, combined with a rough surface</td></tr>
<tr><td>1,6 to 2,0
(coefficient of friction class B)</td><td>±23% to ±33%</td><td rowspan="2">Torque-controlled tightening with torque wrench, signalling wrench or motorized nut-runner with dynamic torque measurement</td><td rowspan="2">Determination of the setpoint tightening moment by estimating the coefficient of friction (surface and lubrication conditions are a great influence)</td><td rowspan="2">Low values for:
measuring torque wrenches with even tightening and for precision nutrunners
High values for:
signalling or buckling torque wrenches</td></tr>
<tr><td>1,7 to 2,5
(coefficient of friction class A)</td><td>±26% to ±43%</td></tr>
<tr><td>2,5 to 4</td><td>±43% to ±60%</td><td>Tightening with impact wrench, «stalling driver» or impulse driver; tightening by hand</td><td>Setting the driver via retightening moment, which is formed from the required tightening moment (for the estimated coefficient of friction) plus a supplement; manual tightening based on subjective assessment</td><td colspan="2">Low values for:
– large number of setting attempts (retightening moment)
– on horizontal branch of the driver characteristic
– backlash-free impulse transmission
Method only suitable for preliminary tightening, in the case of tightening by hand risk of overstretching with M10 and smaller</td></tr>
</table>

[a] Countersurface: clamped joint member whose surface is in contact with the tightening element of the joint (bolt head or nut)

Note: Smaller tightening factors are possible in the specific case. They call for more effort in the setting process, a higher quality of the tool and/or the fasteners and components.