Bolt and Screw Compendium

KAMAX

Introduction

"Who invented the bolt, where, when and to what purpose it was invented, remains entirely in the darkness of history" (S. Kellermann/Treue: "Die Kulturgeschichte der Schraube" ("The cultural history of bolts"); 2nd Ed. Munich, Bruckmann 1962).

"Today, in a slightly exaggerated sense, bolts hold together our entire civilization. Billions of bolts are manufactured throughout the year for the widest variety of uses. Hence it could be impulsively concluded that this omnipresent machine element does not pose any problem to science and technology any more. But the fact that it is far from being so is shown by the abundance of works published on the subject of bolts in the last two decades."

This quote, from the introduction to the first Bolt and Screw Compendium, in the beginning of the eighties, has not lost any of its relevance even today. Even though the standard topics have been processed to the point of saturation, there are and have always been new fields of requirement. In order to allow for the awareness in the areas of materials and surface finishes as well as the changes in the computational regulations, KAMAX has revised the Bolt and Screw Compendium, maintaining the usual compact form.

We hope that this booklet, like its predecessor is carried in numerous pockets, and is helpful to its user.

Troy, MI – September, 2006

KAMAX

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1. Fastener Materials and Standards

1.1 Mechanical and physical characteristics of fasteners (at room temperature) (Abstract from DIN EN ISO 898-1; Edition 11/99)

Mechanical and physical characteristics		3.6	4.6	4.8	5.6	5.8	6.8	8.8[a] d ≤ 16 mm[c]	8.8[a] d > 16 mm[c]	9.8[b]	10.9	12.9
Nominal tensile strength $R_{m\,nom}$	N/mm²	300	400		500		600	800	800	900	1000	1200
Minimum tensile strength $R_{m\,min}$ [d e]	N/mm²	330	400	420	500	520	600	800	830	900	1040	1220
Vickers hardness HV	min.	95	120	130	155	160	190	250	255	290	320	385
F ≥ 98 N	max.	220[f]					250	320	335	360	380	435
Brinell hardness HB	min.	90	114	124	147	152	181	238	242	276	304	366
F = 30 (D^2)	max.	209[f]					238	304	318	342	361	414
Rockwell hardness	HRB min.	52	67	71	79	82	89	–	–	–	–	–
	HRC min.	–	–	–	–	–	–	22	23	28	32	39
	HRB max.	95.0[f]					99.5	–	–	–	–	–
	HRC max.	–					–	32	34	37	39	44
Surface hardness HV 0.3		–						–[g]				
Lower yield stress	nominal	180	240	320	300	400	480	–	–	–	–	–
R_{eL} [h] in N/mm²	min.	190	240	340	300	420	480	–	–	–	–	–
Stress at 0.2 % non-proportional elongation	nominal	–						640	640	720	900	1080
$R_{p\,0.2}$ [i] in N/mm²	min.	–						640	660	720	940	1100
Stress under	S_p/R_{eL} o. $S_P/R_{p\,0.2}$	0.94	0.94	0.91	0.93	0.90	0.92	0.91	0.91	0.90	0.88	0.88
proof load S_p	N/mm²	180	225	310	280	380	440	580	600	650	830	970
Breaking torque M_B	Nm min.	–						see ISO 898-7				

Elongation after fracture A % min.	25	22	–	20	–	–	12	12	10	9	8
Reduction area after fracture Z % min.	–						52		48	48	44
Strength under wedge loading	The value for the entire bolt (not stud bolts) under bevel tensile strain must not fall below the minimum tensile strengths given above										
Impact strength, KU J min.	–			25	–		30	30	25	20	15
Head soundness	No rupture										
Minimum height of non-decarb. thread area E							$^1/_2\ H_1$			$^2/_3\ H_1$	$^3/_4\ H_1$
Max. depth of (complete decarburization) mm	–						0.015				
Hardness after re-tempering	–						Max. 20 HV drop in hardness				
Surface integrity	In conformance with ISO 6157-1 or ISO 6157-3, wherever applicable										

[a] For bolts of property class 8.8 in diameters d ≤ 16 mm, there is an increased risk of nut stripping in the case of inadvertent over-tightening inducing a load excess of proof load. Reference to ISO 898-2 is recommended.

[b] Applies only to nominal thread diameters d ≤ 16 mm.

[c] For structural bolting the limit is 12 mm.

[d] Minimum tensile properties apply to products of nominal length l ≥ 2,5 d. Minimum hardness applies to products of length l < 2,5 d and other products which cannot be tensile-tested (e.g. due to head configuration).

[e] When testing full-size bolts, screws and studs, the tensile loads, which are to be applied for the calculation of R_m shall meet the values given in tables 6 and 8.

[f] A hardness reacting at the end of bolts, screws and studs shall be 250 HV, 283 HB or 99.5 HRB maximum.

[g] Surface hardness shall not be more than 30 Vickers points above the measured core hardness on the product when reactings of both surface and core are carried out at HV 0,3. For property class 10.9, any increase in hardness at the surface which indicates that the surface hardness exceeds 390 HV is not acceptable.

[h] In cases where the lower yield stress R_{eL} cannot be determined, it is permissible to measure the stress at 0.2% non-proportional elongation $R_{p\,0,2}$. For the property classes 4.8, 5.8 and 6.8 the values for R_{eL} are given for calculation purposes only, they are not test values.

[i] The yield stress ratio according to the designation of the property class and the minimum stress at 0,2% non-proportiopnal elongation $R_{p\,0,2}$ apply to machined test specimens. These values if received from test of full size bolts and screws will vary because of processing method and size effects.

1.2 Materials and Tempering Temperatures for Various Property Classes of fasteners. (DIN EN ISO 898-1; Edition 11/99)

Property Classes	Materials and Treatment	Chemical Composition (check analysis) C min.	C max.	P max.	S max.	B[a] max.	Tempering Temperature °C min.
3.6[b]	Carbon steel	–	0.20	0.05	0.06	0.003	–
4.6[b]		–	0.55	0.05	0.06	0.003	–
4.8[b]		–	0.55	0.05	0.06	0.003	–
5.6		0.13	0.55	0.05	0.06	0.003	–
5.8[b]		–	0.55	0.05	0.06	0.003	–
6.8[b]		–	0.55	0.05	0.06	0.003	–
8.8[c]	Carbon steel with additives (e.g. Boron, Mn or Cr) quenched and tempered	0.15[d]	0.40	0.035	0.035	0.003	425
	Carbon steel, quenched and tempered	0.25	0.55	0.035	0.035	0.003	
9.8	Carbon steel with additives (e.g. Boron, Mn or Cr) quenched and tempered	0.15[d]	0.35	0.035	0.035	0.003	425
	Carbon steel, quenched and tempered	0.25	0.55	0.035	0.035	0.003	
10.9[e f] (underlined)	Carbon steel with additives (e.g. Boron, Mn or Cr) quenched and tempered	0.15[d]	0.35	0.035	0.035	0.003	340
10.9[f]	Carbon steel, quenched and tempered	0.25	0.55	0.035	0.035	0.003	
	Carbon steel with additives (e.g. Boron, Mn or Cr) quenched and tempered	0.20[d]	0.55	0.035	0.035	0.003	425
	Alloyed steel, quenched and tempered [g]	0.20	0.55	0.035	0.035	0.003	
12.9[f h i]	Alloyed steel, quenched and tempered [g]	0.28	0.50	0.035	0.035	0.003	380

[a] Boron content can reach 0.005%, provided that non-effective boron is controlled by addition of titanium and/or aluminium.

[b] Free cutting steel is allowed for these property classes with the following maximum sulfur, phosphorus and lead contents: sulfur: 0.34%; phosphorus: 0.11%; lead: 0.35%.

[c] For nominal diameters above 20 mm the steels specified for property classes 10.9 may be necessary in order to achieve sufficient hardenability.

[d] In case of plain carbon boron steel with a carbon content below 0.25% (ladle analysis), the minimum manganese content shall be 0.6% for property class 8.8 and 0.7% for 9.8, 10.9 and <u>10.9</u>.

[e] Products shall be additionally identified by underlining the symbol of the property class (see clause 9). All properties of 10.9 as specified in table 3 shall be met by <u>10.9</u>, however, its lower tempering temperature gives it different stress relaxation characteristics at elevated temperatures (see annex A).

[f] For the materials of these property classes, it is intended that there should be a sufficient hardenability to ensure a structure consisting of approximately 90% martensite in the core of threaded sections for the fasteners in the "as-hardened" condition before tempering.

[g] This alloy steel shall contain at least one of the following elements in the minimum quantity given: chromium 0.30%, nickel 0.30%, molybdenum 0.20%, vandium 0.10%. Where elements are specified in combinations of two, three or four and have alloy contents less than those given above, the limit value to be applied for class determination is 70% of the sum of the individual limit values shown above for the two, three or four elements concerned.

[h] A metallographically detectable white phosphorous enriched layer is not permitted for property class 12.9 on surfaces subjected to tensile stress.

[i] The chemical composition and tempering temperature are under investigation.

1.3 Material for high-tensile bolts (DIN EN ISO 898-1)

Tensile Strength Classes	Material
8.8	19 MnB 4 / 23MnB 3 28 B 2 / 35 B 2
10.9	19 MnB 4 / 23MnB 3 28 B 2 32 CrB 4
12.9	32 CrB 4 34 CrMo 4

1.4 Material for high temperature resistant bolts (DIN EN 10 269)

Working Temperature*	Tensile Strength R_m	Material	Head Marking
≤ 500 °C	1040 – 1200 N/mm²	40 CrMoV 4-7	GB
≤ 540 °C	800 – 1000 N/mm²	21 CrMoV 5-7	GA
≤ 580 °C	800 – 1050 N/mm²	X 22 CrMoV 12-1	V (for $R_{p0,2}$ ≥ 600 MPa)
≤ 650 °C	900 – 1150 N/mm²	X6NiCrTiMo VB25-15-2 / A 286	SD
≤ 700 °C	1000 – 1300 N/mm²	Nimonic 80 A	SB

* Unit Temperature

1.5 Material for corrosion resistant fasteners

Tensile Strength R_m	Type of Steel*	Material	Material-№
> 700 N/mm²	A2 – 70	X 5 CrNi 18 12	1.4303
> 800 N/mm²	A2 – 80		
> 700 N/mm²	A4 – 70	X 5 CrNiMo 17 12 2	1.4401
> 800 N/mm²	A4 – 80		

* as per DIN EN ISO 3506-1

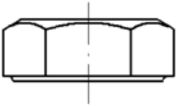
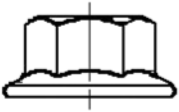
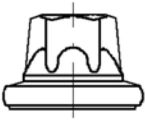
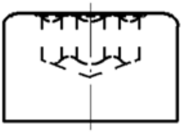
1.6 Materials for high-tensile bolts without heat treatment after cold forming

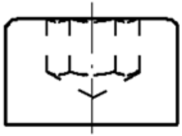
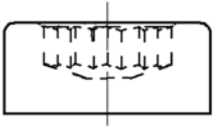
Tensile Strength R_m	Material	Annotation
800 – 1000 N/mm^2 Tensile Strength Classes 800K	10 MnSi 7 17 MnV 7	Micro-alloyed Steels
800 – 1000 N/mm^2	34 Cr 4	Pre heat treated material

1.7 Materials for Fasteners made from Aluminum Alloys

Tensile Strength R_m	Material	Field of Application
R_m > 320 N/mm^2 $R_{p0,2}$ > 290N/mm^2 Without heat treatment after cold working	EN AW 6082 AlSi1MgMn	Magnesium bolting Temperature load < 100 °C High corrosion load
R_m > 380 N/mm^2 $R_{p0.2}$ > 350 N/mm^2 With heat treatment after cold working	EN AW 6056 AlSi6MgCuMn EN AW 6013 AlMg1Si0,8CuMn	Magnesium bolting Aluminum bolting Temperature load < 150 °C High corrosion load

1.8 Types of Bolts and Associated Product Standards

Type of Bolt	**Product Standard**	
Hexagon bolt 	DIN EN ISO 4014 DIN EN ISO 4017 DIN EN ISO 8676 DIN EN ISO 8765	Hexagon head bolts Hexagon head screws Hexagon head screws, with fine pitch thread Hexagon head bolts with fine pitch threads
Hexagon bolt with flange 	DIN EN 1662 DIN EN 1665 ISO 4162	Hexagon bolt with flange – small Hexagon bolt with flange – large Hexagon flange bolts – small
Hexalobular bolt with flange 	KN 7210 DIN 34 800 DIN 34 801	Kamax Spec. KARUND – external drive Hexalobular bolts with small flange Hexalobular bolts with large flange
Hexalobular with internal drive 	KN 7230 KN 7240 DIN EN ISO 14 579 DIN EN ISO 14 580 DIN 34 802	Kamax Spec. KARUND – socket cap screws Cylindrical bolt for overelastic tightening with large KARUND (Fig.) Hexalobular socket head cap screws (Fig.) Hexalobular socket cheese head screws Hexalobular bolts with large internal drive

Type of Bolt	Product Standard	
Hexagon socket head screws 	DIN EN ISO 4762 DIN 6912 DIN 7984	Hexagon socket head cap screws Hexagon socket thin head cap screws with pilot recess Hexagon socket thin head cap screws
Internal multipoint socket 	KN 7300 KN 7310	Kamax Spec. for internal drive – multipoint socket head Cylindrical bolts for overelastic tightening with internal multipoint socket head

2. Calculation of Bolted Joints

Generally a load carrying bolted joint is designed so that:

- the forces occurring during tightening and operation of the joint do not overstrain the components of the joint
- a minimal clamping force will be maintained during service which will guarantee the function of the joint regarding the necessary sealing force or a prevention of the opening of the joint
- the fatigue strength of the bolt will be exceeded by the cyclic load

without over sizing of the joint.

During assembly, in principle, the bolts are elongated (f_{SM}) and the bolted parts are compressed (f_{PM}). The load of both partners is equal in magnitude (action = reaction = FM = FSM = FPM), but the elongation/comression of the bolts and bolted components are dependent on the stiffness, and thus unequal.

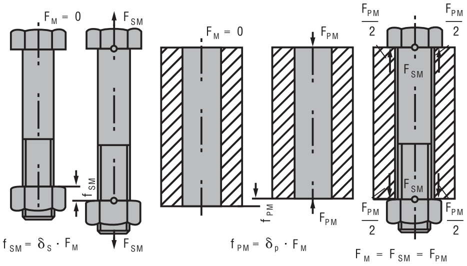


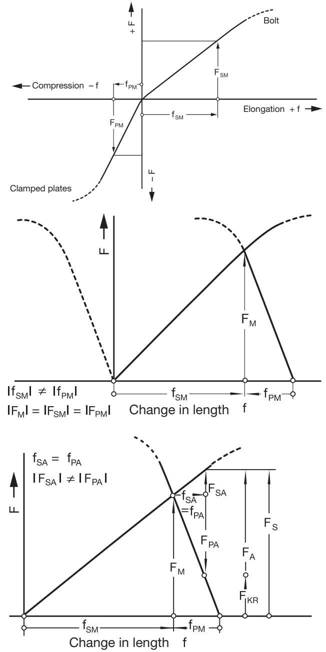
Fig. 2.1 Elongation/Compression
Components of a bolted joint before and after loading

The basic relations of load and elongation alterations of a bolted joint are clearly shown in the joint diagram.

2.1 Joint Diagram

The classical form of the joint diagram, originally introduced by Roetscher, will be used here. However, through various modifications, it can also be applied to complex joints.

Fig. 2.2 Joint Diagram



The relationship between the assembly preload and the elongation of the bolt is shown in the bolt curve, which is none other than the spring characteristic of the bolt. This analogy is valid for the joint components which experience a compression.

The slope of the curve is dependent on the material and geometry. The typical joint diagram is now developed by reflecting the component displacement curve on the same coordinate system as the bolt elongation curve and bringing the two curves to the point of intersection of the clamp load.

When a work load is applied to the joint the internal load balance will be altered.

The load on the bolt increases, that on the components decreases. The bolt is thus further elongated, and the components somewhat expand because of the release. It should be noted that the alteration of the displacement for the bolt and the joint component is the same, whereas depending on the relation of the slope (equals the

ratio of the stiffness) of the curves the work load will be carried unequally. The requirement of a minimal clamp load during operation therefore borders the bearable work load as well as the upper limit of the load capacity of the bolt.

2.2 Mechanics of Calculation

The fundamental pre-requisites for the calculation of a bolted joint according to the nominal diameter and tensile strength (PC) are:

- External forces and torques
- Stiffness and load introduction conditions
- Minimal clamping force
- Embedding
- Tightening factors

First, the diameter of the bolt is estimated from tables and approximate formulae, and from these estimated measures the actual calculation in carried out. If the results do not lie within the permissible range of stress, the diameter should be changed and the calculation should be carried out all over again.
The systematic of calculation given below refers exclusively to the linear calculation approach according to VDI2230 (10/2001).
The core point of the calculation is the principle dimensioning formula (calculation step 6) which is shown graphically as well as a formula in the force-elongation diagram below:

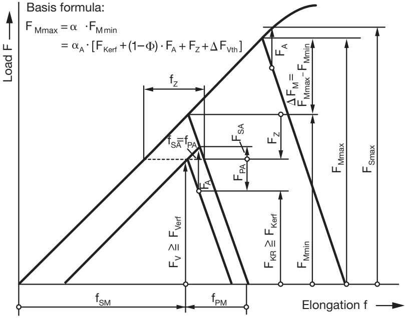


Fig. 2.3
Principle dimensioning formula

Step 0
At the beginning of the calculation, the required bolt diameter d and the property class as well as the applicability of the calculation rules for eccentrically deformed and/or loaded joints has to be evaluated on the basis of tables or simple formula.

Step 1
A tightening method should be determined. Its accuracy is reflected through the factor α_A attributed to it. The method of assembly has huge influence on the assembly preload and consequently the designing of the bolted joint.

Step 2
A minimal clamping force of the joint F_{Kerf} , not to be under-run at any time during operation is to be estimated from the working conditions. This can be deduced from the requirements regarding the sealing force of the joint, the friction, or the prevention of an opening under work load.

Step 3
The load ratio ϕ is to be calculated in order to determine the distribution of axial working load F_A between the bolt and the joint components. Smaller the ratio ϕ, lesser additional force will be carried by the bolt. Thus ϕ defines itself from the elastic resilience of the bolt δ_S and the joint parts δ_P, as well as the load introduction level (denoted by the factor **n**) and the eccentricities of the joint and work load. In general, the value of ϕ decreases with the increase in the resilience of the bolt, as opposed to that of the deformed parts. The factor n is dependent on the given geometry, the level of load introduction level and the type of joint. It can be defined according to VDI2230 or from a table.

Step 4
Through the embedment of surfaces, the system looses partly its elastic deformation. This is reducing the assembly preload. Under consideration of the stiffness F_Z, the loss of preload as a result of the embedding, will be determined and used for the calculation. Furthermore a change in the preload F_{Vth} will occur under thermal load when the components of the bolted joint do have different thermal expansion coefficients.

Steps 5 and 6

By using the main dimensioning formula $\mathbf{F_{Max} = \alpha_A{}^* [F_{Kerf} + (1 - \phi)^* F_A + F_Z + F_{Vth}]}$, the maximum assembly preload as well the minimum required assembly preload $\mathbf{F_{Min} = F_{Max} / \alpha_A}$ of the bolted joint will be calculated.

Step 7

The result is to be compared against the table values for the bolt stress ($\mathbf{F_M}$)) at a utilisation of the yield strength of 90% and the given friction factors.
The condition $\mathbf{F_{Mzul} \geq F_{Mmax}}$ **or** $\mathbf{F_{MTab} \geq F_{Mmax}}$, must be fulfilled. The reference value must be calculated for specially designed bolts.
Should the result lead to a necessary change in the bolt geometry or the ratio of grip length, the calculation is to be repeated right from step 2.

Step 8

It should be calculated whether the allowable bolt load during operation is not exceeded through the total bolt load of $\mathbf{F_{Smax} = F_{Mzul} + \phi_{en}{}^* F_{Amax} - \Delta F_{Vth}}$. The condition $\mathbf{\sigma_{red,\,B} < R_{p0.2min}}$ should be fulfilled, where $\mathbf{\sigma_{red,\,B}}$ represents the comparative stress from maximum tensile stress and torsional stress obtained from the smallest cross-sectional area of the bolt. The simplified formula $\mathbf{F_{Smax} \leq R_{p0.2min}{}^* A_0}$ is acceptable for torsion-free joints. Furthermore, a safety factor can be incorporated for $\mathbf{\sigma_{red}, B < R_{p0.2min} / S_F}$.

Step 9

The acceptable alternating stress $\mathbf{\sigma_A}$ is relatively low for bolts as compared to the unthreaded wire. In case there is continious alternating stress, the joint should be checked for the condition $\mathbf{\sigma_a \leq \sigma_{AS}}$ where $\mathbf{\sigma_{AS}}$ depends on whether the bolt has had thread rolling before or after heat treatment. The existing alternating stress $\mathbf{\sigma_a}$ is determined with respect to the tensile stress area of the bolt.

Step 10

In general, the surface pressure in the joints should not exceed the allowable surface pressure of the components concerned in either the assembly state $\mathbf{p_{Mmax}}$ or during operation $\mathbf{p_{Bmax}}$ in order to avoid a decrease in the preload by creep processes. A safety factor can be included for $\mathbf{p_G \geq p_{M,\,Bmax}}$.

Step 11
The length of full thread engagement available has to be determined in order to avoid stripping of the thread(s). Related to nominal diameter and strength the minimum values can be gathered from the VDI 2230 standard.

Step 12
The transverse loads working in the joint are generally transmitted by static friction in the interfaces of the preloaded joint. Considering the number of interfaces and the friction coefficients of the interfaces, a comparison has to be carried out between the minimal residual clamp load $\mathbf{F_{KRmin}}$ and the clamp load required for the transmission of the transverse loads $\mathbf{F_{KQerf}}$. A safety factor $\mathbf{F_{KQerf} < F_{KRmin} / S_F}$ may also be included. If it comes to overloading of the joint, or also for the use of fitting bolts, one should avoid shearing the bolt. For that, $\boldsymbol{\tau_{max} = F_{Qmax} / A_{\tau} \leq \tau_B}$ should be valid.

Step 13
The assembly torque required for the tightening of the bolts can be read from corresponding tables for 90 % bolt utilization, or can be calculated through $\mathbf{M_A = F_{Mzul} * [0.16 * P + 0.58 * d_2 * \mu_{Gmin} + D_{Km} / 2 * \mu_{Kmin}]}$. Additional moments in case connecting elements are used to prevent slacking and loosening have to be considered.

3. Self loosening of bolted joints

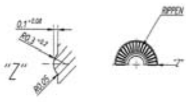
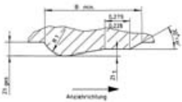
A bolted joint with a mechanically sound design and reliable assembly does not need a locking device in most cases. In these cases, the applied clamping forces obstruct relative movements on the bolted joint over the entire life.

But under certain conditions, initial stress in the bolted joints can be broken down, reduced for a short time, or nullified.

1. Relaxation of bolted joint through loss of preload as a result of compression or permanent elongations, e.g. creep.

2. Dynamic load normal to the bolt axis can result in complete self-loosening of a bolt. This begins under a full preload when transverse shearing deformation occurs as relative movement between joint components.

Matrix for Securing Elements for Bolted Joints
Mechanical Safety Elements

	Name	Working temp. °C	Safety for dyn. load	Hardness of bearing surface	Installation	Recycle count	Lubrication of bolt / bearing surface	Surface of bearing surface	Shelf-life of product
Karipp®		Upto starting temp.	yes	Must be less than the tensile strength of the bolt	Larger flange diameter and space requirement	multiple	Any lubrication possible	Minor damage, not for lacquer	unlimited
Kalok®	serration	Upto starting temp.	yes	Must be less than the tensile strength of the bolt: max. 40 HRC	Larger flange diameter and space requirement	multiple	Any lubrication possible	Major damage, not for lacquer	unlimited
Kalok II®		Upto starting temp.	yes	Must be less than the tensile strength of the bolt: max. 40 HRC	less space requirement	multiple	Any lubrication possible	Major damage, not for lacquer	unlimited
Plastic Patch PA11	locking coatins	-56 bis 120	conditional	All hardnesses	less space requirements	multiple		no damage	4 Years
Trilobular Threads	locking feature of threadforming area in connection with female thread	Upto starting temp.	conditional	Tensile strength of the drill must be less than the tensile strength of the bolt	Locking effect only in blind hole borings	multiple	Any lubrication possible	no damage	unlimited

Matrix for Securing Elements for Bolted Joints
Mechanical Safety Elements

	Manufacturer, trademark	Working temp. °C	Safety for dyn. Load	Hardness of sealing run	Installation	Recycle count	Lubrication bolt / sealing run	Surface of sealing run	Shelf-life of product
MVK, red	Omni-Technik Precote 80	Upto 150	yes	All hardnesses	No additional space requirements	easy	securing MVK not with SM; nut thread oilfree	No damage	2 – 4 years, lesser at high humidity
MVK, blue	3M Scotch grip 2353	Upto 110	yes	All hardnesses	No additional space requirements	easy	securing MVK not with SM; nut thread oilfree	No damage	2 – 4 years, lesser at high humidity
MVK, turquoise	Omni-Technik Precote 85	Upto 170	yes	All hardnesses	No additional space requirements	easy	securing MVK not with SM; nut thread oilfree	No damage	2 – 4 years, lesser at high humidity
Liquid adhesive			yes	Also suitable for high hardnesses	No additional space requirements	easy		No damage	

4. Tightening joints

The tightening methods used today are not able to measure the assembly preload directly, but only as a function of the tightening torque, the elastic elongation, the tightening angle or the determination of the yield point of the bolt. The variation of the friction coefficients and the inaccuracy of the tightening methods do lead to a need for over dimensioning of the bolted joint, which is expressed by the tightening factor

$$\alpha_A = F_{vmax} / F_{vmin}$$

4.1 Torque Controlled Tightening

By tightening tests on original components, the friction coefficients are first determined, and the required torque is subsequently specified. This torque must be assigned in such a way that the elastic limit of the bolt is not exceeded even in adverse conditions e.g. low friction factor, etc. Pic 4.1. For hexagon bolts acc. DIN EN 24014 and similar, the torque values are shown on table 4.1. These are valid for a stress in the shank of 90 % of the standard minimum yield strenght according to VDI code 2230. The table values represent the maximal torque values. For deviant head-geometry, the initial torque is calculated by

$$M_A = F_M(0.16*P+0.58*d_2*\mu_G+(D_{Km}/2)*\mu_K)$$

For torque-driven tightening, the designing of bolts is based on a α_A of 1.8 .

Monitoring the final angle of rotation along with a given torque is recommended for the control of the assembly process. The tolerance range of the final angle of rotation must be in a defined zone (window), which is established through tests. In case the final angle of rotation lies outside of this window, the driver indicates a failure.

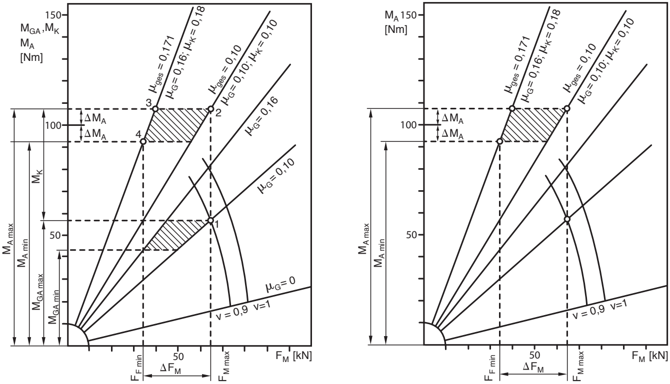


Fig. 4.1 Scatter of ΔF_M for torque controlled tightening of bolted joints

4.2 Angle Controlled Tightening

First the joint is loaded with a snug torque until all interfaces are completely closed. Subsequently a defined angle ϑ_A will be applied, which is measured from the point the snug torque is achieved, with which the bolt will be tightened to or beyond the yield point.

For the control of the tightening process a tolerance range for the final torque has to be specified. The final torque must be in this range.
The big advantage of this tightening process versus torque controlled tightening is that the elongation of the bolt in the plastic area is defined over the given angle. The cut off torque preferably lies above the yield point. The bolt will thus be used to the full. It therefore underlies a tightening factor $\alpha_A = 1.0$.

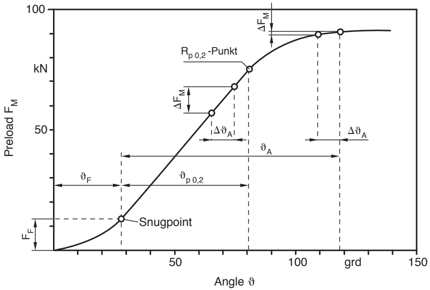


Fig. 4.2
Angle controlled tightening of bolted connections

4.3 Yield Controlled Tightening

Similar to angle controlled tightening, a snug torque will be applied until all interfaces are completely closed. From this point, the angle and the attained torque are dynamically measured, and the respective differential ratio

$$\Delta M_a/\Delta\vartheta$$

is calculated. This differential ratio is constant in the elastic region, and diminishes as it approaches the elastic limit of the bolt; the torque does not increase in proportion to the angle of rotation any more. When the value of the differential ratio declines to a pre determined value,

e.g. $0.5^*(\Delta M_a/\Delta\vartheta)$

the assembly machine will be cut off and the tightening process is completed.

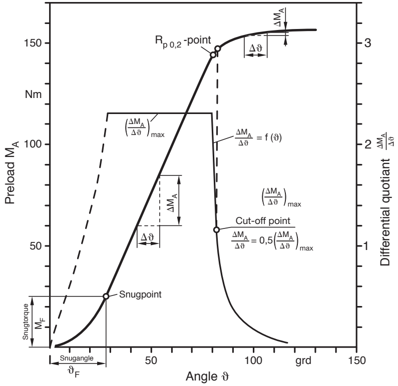


Fig. 4.3
Yield controlled tightening of bolted connections

The position of the cut-off in the diagram Ma/ϑ is essentially determined through the tensile strength of the bolt and the friction. The assembly preload varies with the elastic limit of the bolt and thread friction (Fig. 4.4).

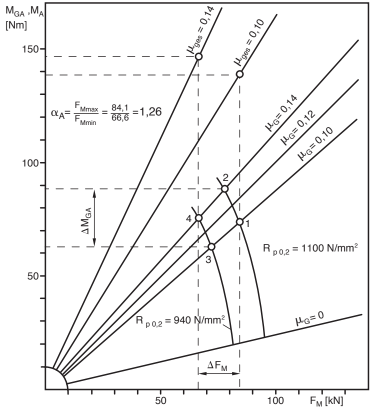
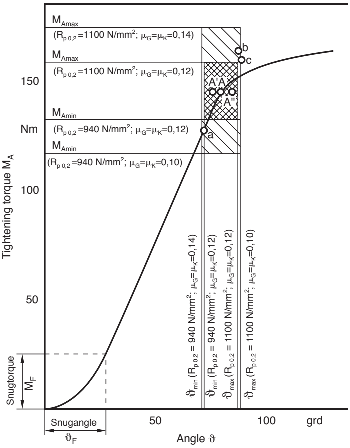


Fig. 4.4
Scatter of clampload due to variances of thread friction and yield point of fastener material during yield controlled tightening of bolted joints

For the control of the tightening, the min. and max. values of tightening torque and rotating angle of tightening are calculated, or established through tests. Recorded in diagram Ma/ϑ, these values define a right angle, which is usually indicated by a green window (Fig. 4.5). If the cut-off points lie within this range, the tightening process is deemed OK.



Point	$R_{p0.2}$ [N/mm²]	F [kN]	m_G	m_K
A	1020	75.3	0.120	0.120
A'	960	70.2	0.125	0.134
A"	1080	82.7	0.100	0.114
a	870	65.4	0.110	0.130
b	1200	85.2	0.140	0.100
c	1000	87.2	0.080	0.140

Fig 4.5 "green window" for yield controlled tightening of bolted joints

As compared to the angle control, there is the advantage that the bolts undergo a smaller plastic elongation; of course the assembly preload level is somewhat lower.

The required torque and the attained assembly preload can be estimated through multiplication of values from Table 4.1 with the following conversion factors:

F_M bzw. M_A = 1.1-1.3* Table value

4.1 Clamp Loads and tightening torques for bolts with metric thread acc DIN 13 and head configuration acc D/E/I 4014 for $\nu = 0.9$

Thread Size	Property Class	Assembly Preload F_M [kN] for μ_g					Tightening Torque M_A [Nm] for $\mu_k = \mu_g$				
		0.08	0.10	0.12	0.16	0.20	0.08	0.10	0.12	0.16	0.20
M6	**8.8**	10.7	10.4	10.2	09.6	09.0	07.7	09.0	10.1	12.3	14.1
A_S = 20.1 mm²	**10.9**	15.7	15.3	14.9	14.1	13.2	11.3	13.2	14.9	18.0	20.7
	12.9	18.4	17.9	17.5	16.5	15.5	13.2	15.4	17.4	21.1	24.2
M7	**8.8**	15.5	15.1	14.8	14.0	13.1	12.6	14.8	16.8	20.5	23.6
A_S = 28.9 mm²	**10.9**	22.7	22.5	21.7	20.5	19.3	18.5	21.7	24.7	30.1	34.7
	12.9	26.6	26.0	25.4	24.0	22.6	21.6	25.4	28.9	35.2	40.6
M8 x 1.0	**8.8**	21.2	20.7	20.2	19.2	18.1	19.3	22.8	26.1	32.0	37.0
A_S = 39.2 mm²	**10.9**	31.1	30.4	29.7	28.1	26.5	28.4	33.5	38.3	47.0	54.3
	12.9	36.4	35.6	34.7	32.9	31.0	33.2	39.2	44.9	55.0	63.6
M8 x 1.25	**8.8**	19.5	19.1	18.6	17.6	16.5	18.5	21.6	24.6	29.8	34.3
A_S =36.6 mm²	**10.9**	28.7	28.0	27.3	25.8	24.3	27.2	31.8	36.1	43.8	50.3
	12.9	33.6	32.8	32.0	30.2	28.4	31.8	37.2	42.2	51.2	58.9
M9 x 1.0	**8.8**	27.7	27.2	26.5	25.2	23.7	28.0	33.2	38.1	46.9	54.4
A_S = 51.0 mm²	**10.9**	40.7	39.9	39.0	37.0	34.9	41.1	48.8	55.9	68.8	79.8
	12.9	47.7	46.7	45.6	43.3	40.8	48.1	57.0	65.4	80.6	93.4
M10 x 1.0	**8.8**	35.2	34.5	33.7	32.0	30.2	39.0	46.0	53.0	66.0	76.0
A_S = 64.5 mm²	**10.9**	51.7	50.6	49.5	47.0	44.4	57.0	68.0	78.0	97.0	112.0
	12.9	60.4	59.2	57.9	55.0	51.9	69.0	80.0	91.0	113.0	131.0
M10 x 1.25	**8.8**	33.1	32.4	31.6	29.9	28.2	38.0	44.0	51.0	62.0	72.0
A_S = 61.2 mm²	**10.9**	48.6	47.5	46.4	44.0	41.4	55.0	65.0	75.0	92.0	106.0
	12.9	56.8	55.6	54.3	51.4	48.5	65.0	76.0	87.0	107.0	124.0

M10 x 1.5	**8.8**	31.0	30.3	29.6	27.9	26.3	36.0	43.0	48.0	59.0	68.0
A_S = 58.0 mm^2	**10.9**	45.6	44.5	43.4	41.0	38.6	53.0	63.0	71.0	87.0	100.0
	12.9	53.3	52.1	50.8	48.0	45.2	62.0	73.0	83.0	101.0	116.0
M12 x 1.25	**8.8**	50.1	49.1	48.0	45.6	43.0	66.0	79.0	90.0	111.0	129.0
A_S = 92.1 mm^2	**10.9**	73.6	72.1	70.5	66.9	63.2	97.0	116.0	133.0	164.0	190.0
	12.9	86.2	84.4	82.5	78.3	73.9	114.0	135.0	155.0	192.0	222.0
M12 x 1.5	**8.8**	47.6	46.6	45.5	43.1	40.6	64.0	76.0	87.0	107.0	123.0
A_S = 88.1 mm^2	**10.9**	70.0	68.5	66.8	63.3	59.7	95.0	112.0	128.0	157.0	181.0
	12.9	81.9	80.1	78.2	74.1	69.8	111.0	131.0	150.0	183.0	212.0
M12 x 1.75	**8.8**	45.2	44.1	43.0	40.7	38.3	63.0	73.0	84.0	102.0	117.0
A_S = 84.3 mm^2	**10.9**	66.3	64.8	63.2	59.8	56.3	92.0	108.0	123.0	149.0	172.0
	12.9	77.6	75.9	74.0	70.0	65.8	108.0	126.0	144.0	175.0	201.0
M14 x 1.5	**8.8**	67.8	66.4	64.8	61.5	58.1	104.0	124.0	142.0	175.0	203.0
A_S = 125 mm^2	**10.9**	99.5	97.5	95.2	90.4	85.3	153.0	182.0	209.0	257.0	299.0
	12.9	116.5	114.1	111.4	105.8	99.8	179.0	213.0	244.0	301.0	349.0
M14 x 2.0	**8.8**	62.0	60.6	59.1	55.9	52.6	100.0	117.0	133.0	162.0	187.0
A_S = 115 mm^2	**10.9**	91.0	88.9	86.7	82.1	77.2	146.0	172.0	195.0	238.0	274.0
	12.9	106.5	104.1	101.5	96.0	90.4	171.0	201.0	229.0	279.0	321.0
M16 x 1.5	**8.8**	91.4	89.6	87.6	83.2	78.6	159.0	189.0	218.0	269.0	314.0
A_S = 167 mm^2	**10.9**	134.2	131.6	128.7	122.3	115.5	233.0	278.0	320.0	396.0	461.0
	12.9	157.1	154.0	150.6	143.1	135.1	273.0	325.0	374.0	463.0	539.0
M16 x 2.0	**8.8**	84.7	82.9	80.9	76.6	72.2	153.0	180.0	206.0	252.0	291.0
A_S = 157 mm^2	**10.9**	124.4	121.7	118.8	112.6	106.1	224.0	264.0	302.0	370.0	428.0
	12.9	145.5	142.4	139.0	131.7	124.1	262.0	309.0	354.0	433.0	501.0
M18 x 1.5	**8.8**	122.0	120.0	117.0	112.0	105.0	237.0	283.0	327.0	406.0	473.0
A_S = 216 mm^2	**10.9**	174.0	171.0	167.0	159.0	150.0	337.0	403.0	465.0	578.0	674.0
	12.9	204.0	200.0	196.0	186.0	176.0	394.0	472.0	544.0	676.0	789.0

Thread Size	Property Class	Assembly Preload F_M [kN] for μ_g					Tightening Torque M_A [Nm] for $\mu_k = \mu_g$				
		0.08	0.10	0.12	0.16	0.20	0.08	0.10	0.12	0.16	0.20
M18 x 2.0	**8.8**	114.0	112.0	109.0	104.0	98.0	229.0	271.0	311.0	383.0	444.0
A_S= 204 mm²	**10.9**	163.0	160.0	156.0	148.0	139.0	326.0	386.0	443.0	545.0	632.0
	12.9	191.0	187.0	182.0	173.0	163.0	381.0	452.0	519.0	638.0	740.0
M18 x 2.5	**8.8**	107.0	104.0	102.0	96.0	91.0	220.0	259.0	295.0	360.0	415.0
A_S= 193 mm²	**10.9**	152.0	149.0	145.0	137.0	129.0	314.0	369.0	421.0	513.0	592.0
	12.9	178.0	174.0	170.0	160.0	151.0	367.0	432.0	492.0	601.0	692.0
M20 x 1.5	**8.8**	154.0	151.0	148.0	141.0	133.0	327.0	392.0	454.0	565.0	660.0
A_S= 272 mm²	**10.9**	219.0	215.0	211.0	200.0	190.0	466.0	558.0	646.0	804.0	90.0
	12.9	257.0	252.0	246.0	234.0	222.0	545.0	653.0	756.0	941.0	1100.0
M20 x 2.5	**8.8**	136.0	134.0	130.0	123.0	116.0	308.0	363.0	415.0	509.0	588.0
A_S= 245 mm²	**10.9**	194.0	190.0	186.0	176.0	166.0	438.0	517.0	592.0	725.0	838.0
	12.9	227.0	223.0	217.0	206.0	194.0	513.0	605.0	692.0	848.0	980.0
M22 x 1.5	**8.8**	189.0	186.0	182.0	173.0	164.0	440.0	529.0	613.0	765.0	896.0
A_S= 333 mm²	**10.9**	269.0	264.0	259.0	247.0	233.0	627.0	754.0	873.0	1090.0	1276.0
	12.9	315.0	309.0	303.0	289.0	273.0	734.0	882.0	1022.0	1275.0	1493.0
M22 x 2.5	**8.8**	170.0	166.0	162.0	154.0	145.0	417.0	495.0	567.0	697.0	808.0
A_S= 303 mm²	**10.9**	242.0	237.0	231.0	213.0	207.0	595.0	704.0	807.0	993.0	1151.0
	12.9	283.0	277.0	271.0	257.0	242.0	696.0	824.0	945.0	1162.0	1347.0
M24 x 1.5	**8.8**	228.0	224.0	219.0	209.0	198.0	570.0	686.0	769.0	995.0	1166.0
A_S= 401 mm²	**10.9**	325.0	319.0	312.0	298.0	282.0	811.0	977.0	1133.0	1417.0	1661.0
	12.9	380.0	373.0	366.0	347.0	330.0	949.0	1143.0	1326.0	1658.0	1943.0
M24 x 2.0	**8.8**	217.0	210.0	209.0	198.0	187.0	557.0	666.0	769.0	955.0	1114.0
A_S= 384 mm²	**10.9**	310.0	304.0	297.0	282.0	267.0	793.0	949.0	1095.0	1360.0	1586.0
	12.9	362.0	355.0	348.0	331.0	312.0	928.0	1110.0	1282.0	1591.0	1856.0

M24 x 3.0	**8.8**	196.0	192.0	188.0	178.0	168.0	529.0	625.0	714.0	875.0	1011.0
A_S= 353 mm^2	**10.9**	280.0	274.0	267.0	253.0	239.0	754.0	890.0	1017.0	1246.0	1440.0
	12.9	327.0	320.0	313.0	296.0	279.0	882.0	1041.0	1190.0	1458.0	1685.0
M27 x 1.5	**8.8**	293.0	288.0	282.0	269.0	255.0	822.0	992.0	1153.0	1445.0	1697.0
A_S= 514 mm^2	**10.9**	418.0	410.0	402.0	383.0	363.0	1171.0	1413.0	1643.0	2059.0	2417.0
	12.9	489.0	480.0	470.0	448.0	425.0	1370.0	1654.0	1922.0	2409.0	2828.0
M27 x 2.0	**8.8**	281.0	276.0	270.0	257.0	243.0	806.0	967.0	1119.0	1394.0	1630.0
A_S= 496mm^2	**10.9**	400.0	393.0	384.0	366.0	346.0	1149.0	1378.0	1594.0	1986.0	2322.0
	12.9	468.0	460.0	450.0	428.0	405.0	1344.0	1612.0	1866.0	2324.0	2717.0
M27 x 3.0	**8.8**	257.0	252.0	246.0	234.0	220.0	772.0	915.0	1050.0	1292.0	1498.0
A_S= 459 mm^2	**10.9**	367.0	359.0	351.0	333.0	314.0	1100.0	1304.0	1496.0	1840.0	2134.0
	12.9	429.0	420.0	410.0	389.0	367.0	1287.0	1526.0	1750.0	2153.0	2497.0

4.5 Tightening Torques for bolt assembly beyond yield point

The snug torques and angles of rotation in the following table are valid for bolt grip lengths from 1d to 4d which are assembled beyond yield (angle controlled and yield controlled tightening). For smaller and larger grip length, the required angle of rotation is to be determined by test on original components. In such cases, by keeping the same initial torques, rotation angles of 45° or 180° should be considered. The reusability of these bolted joints is limited.

Thread	Property Class	Initial Torque [Nm] + Rotation Angle 90°	Preload Force [kN] overelastic angle controlled tightening		Tightening Torque [Nm] overelastic angle controlled tightening	
			F_{Mmin}	F_{Mmax}	M_{Amin}	M_{Amax}
M 6	8.8	8	10.5	14.5	10.0	17
	10.9	10	15.5	20	14.5	23.5
	12.9	10	18.5	22.5	17.0	26.5
M 8	8.8	20	19.5	26	24.0	41
	10.9	20	29	36	35.5	57
	12.9	20	34	41.5	41.5	65
M 10	8.8	40	31	41.5	47.5	81
	10.9	50	45.5	57	70	110
	12.9	50	54	66	81	130
M 12 x 1.5	8.8	60	48	64	85	154
	10.9	90	71	88	125	200
	12.9	90	83	100	145	230
M 14 x 1.5	8.8	100	69	91	140	240
	10.9	150	100	125	205	335
	12.9	150	115	145	235	380
M 16 x 1.5	8.8	120	95	125	215	380
	10.9	180	135	170	310	510
	12.9	180	160	195	360	585
M 18 x 1.5	8.8	140	125	165	315	555
	10.9	210	175	220	450	745
	12.9	210	205	250	525	855

4.6 Recommended Values for Tightening Factors

Tightening process	Tightening factors α_a	Remarks
Yield point controlled, motorized or manual	1.18	
Angle of rotation controlled, motorized or manual	1.18	Snug torque (pre-tightening) and angle of rotation determined through experimentation
Elongation measurement of calibrated bolt	1.2	
Hydraulic tightening	1.2 to 1.6	Long bolts: lower values Short bolts: higher values Established through measurement of elongation length and applied pressure
Torque controlled, with torque wrench or precision screwdriver with dynamic torque control	1.4 to 1.6 1.6 to 1.8	Determination of required torque through measurement of F_M on the joint Nominal torque determined with the estimated friction coefficient of the particular case
Torque controlled, with mechanical screwdriver	1.7 to 2.5	Pre-setting of power screwdriver with post torque, which is established from the required torque plus post torque
Impulse controlled, with impact wrench	2.5 to 4	

4.7 Recommended Minimum Length of Thread Engagement for Blind-hole Threads (VDI 2230)

Tensile Strength of Bolt **Fineness of thread d/P**	**8.8** **< 9**	**8.8** **≥ 9**	**10.9** **< 9**	**10.9** **≥ 9**
AlCuMg1 F 40	1.1 d	1.4 d		–
GG 22	1.0 d	1.2 d		1.4 d
St 37	1.0 d	1.25 d		1.4 d
St 50	0.9 d	1.0 d		1.2 d
C 45 V	0.8 d	0.9 d		1.0 d

5. Corrosion Protection and Lubrication

5.1 Surface Coating System (Optional)

Specifications as known at the time of printing.

Symbol (abbr.)	Basecoat	Passivation	Topcoat / Sealing
Surfaces containing Cr(VI)			
Zn yellow	Galv. Zinc	Yellow	-
Zn + Metex LM	Galv. Zinc (acid)	Yellow	Metex® LM
ZnFe black	Galv. Zinc-Iron	Black	-
ZnNi transparent	Galv. Zinc-Nickel	Transparent	-
ZnNi black	Galv. Zinc-Nickel	Black-	-
DAC 320	DACROMET® 320		-
DAC 500	DACROMET® 500		-
DAC 320 + Plus L	DACROMET® 320		Plus® L
Cr(VI)-free Surfaces			
op thin	Zinc phosphate	-	-
Zn transp. / Zn Thin III	Galv. Zinc	Thin layer Cr(III)	-
Zn Thin III + V	Galv. Zinc	Thin layer Cr(III)	Sealing
Zn Thick III	Galv. Zinc	Thick layer Cr(III)	-
Zn Thick III + V	Galv. Zinc	Thick layer Cr(III)	Sealing
ZnFe Pass III	Galv. Zinc-Iron	Containing Cr(III)	-
ZnFe Pass III + V	Galv. Zinc-Iron	Containing Cr(III), if black	Sealing if black
ZnNi Pass III	Galv. Zinc-Nickel	Containing Cr(III)	-
ZnNi Pass III + V	Galv. Zinc-Nickel	Containing Cr(III), if black	Sealing if black
DS (GZ)	-		DELTA®-Seal (GZ)
GEO 500	GEOMET® 500		-
DT/DP 100 (+ SM)	DELTA®-Tone / DELTA®-Protekt KL 100		-
GEOMET + V	GEOMET® 321		e.g. DACROLUB x
DT / DP 100 + DS GZ	DELTA®-Tone / DELTA®-Protekt KL 100		DELTA®-Seal GZ
DT / DP 100 + Klevercol	DELTA®-Tone / DELTA®-Protekt KL 100		Klevercol®
GEOBLACK	GEOMET® 500		Plus ML black
DP 100 + DP 30x	DELTA®-Protekt KL 100		DELTA®-Protekt VH 30x
GEO + Plus VL	GEOMET® 321		Plus® VL
GEOMET + Plus x	GEOMET® 321		Plus® 10 / L / ML / M
B 46 + B 18 x	MAGNI B 46		MAGNI B 18 x

[1] Reference values for parts in new condition (head and thread ends) to be examined individually / these values can be reduced through subsequent handling operation

Optical characteristics	Layer thickness [µm]	Additional lubricant treatment	NaCl-Test DIN 50 021 RR (WR) [1, 2]	Resistance to chemicals [1, 2] (Rim-cleanser)
Yellow	≥ 8	Necessary	144h (72h)	-
Yellowish	≥ 15	TTF	600h (192h)	-
Black	≥ 8	Necessary	360h (48h)	-
Silver	≥ 8	Necessary	480h (240h)	-
Black	≥ 8	Necessary	480h (120h)	-
Silver	≥ 5 / ≥ 8	Necessary	480h / 720h	No
Silver	≥ 5 / ≥ 8	- (Possible)	480h / 720h	No
Silver	≥ 5	- (Possible)	720h	(Yes)
Dark / black	1 - 4	Oiled	8h	No
Silver	≥ 8	Necessary	96h (6h)	-
Silver	≥ 8	If necessary	144h (48h)	-
Silver (iridescent)	≥ 8	Necessary	168h (72h)	-
Silver	≥ 8	If necessary	240h (96h)	-
(Silver)	≥ 8	Necessary	240h (24h)	-
Silver / black	≥ 8	If necessary	480h (120h)	-
(Silver)	≥ 8	Necessary	480h (120h)	-
Silver / black	≥ 8	If necessary	720h (240h)	-
Silver / black	≥ 10	If necessary	120h	Yes
Silver	≥ 12	- (Possible)	480 / 720h	No
Silver	≥ 8 / ≥ 12	If necessary	240h / 480h	No
Silver	≥ 8 / ≥ 12	- (Possible)	480h	conditional
Silver / black	≥ 12	- (Possible)	480h (120h)	Yes
Black	≥ 12	- (Possible)	480h (240h)	Yes
Black	≥ 12	- (Possible)	720h (120h)	(Yes)
Silver	≥ 12	- (Possible)	480 / 720h	(Yes)
Silver-gray	≥ 12	- (Possible)	480 / 720h	(Yes)
Silver-gray	≥ 12	- (Possible)	480 / 720h	(Yes)
Silver-gray	≥ 12	- (Possible)	480 / 720h	Yes

[2] With Cr(VI)-free surfaces, a considerably stronger scaling should be accounted for, compared to surfaces containing with Cr(VI), as there's no self-healing effect

5.2 Lubrication

The primary task of lubricants is to set up a defined and constant coefficient of friction. Along with this task, lubricants can also fulfill other functions (e.g. Anti-corrosion, chemical resistance, optical characteristics etc.) where applicable.

Specifications VDA 235-101 / DIN 946 / DIN EN ISO 16047
According to VDA 235-101, a total friction coefficient μ_{tot} of 0.09 – 0.14 is required for lubricated bolts (partial friction coefficients μ_K and μ_G between 0.08 and 0.16). The determination of the friction coefficients generally is performed according to DIN 946 and DIN EN ISO 16047 respectively.

Influencing Factors
(To be considered while choosing a suitable lubricant)
The friction coefficients and their range, in practice, are greatly dependant on the following factors:

- **Coating system** of the bolt: Type of coating, thickness of layer etc.
- **Bearing plates:** hard (e.g. hardened steel), middle (e.g. auto-body sheet steel), soft (e.g. Al), uncoated / KTL-coated)
- **Geometry of the bolt-head:** Convex / Concave bearing surface, flange diameter, etc.
- **Nut thread:** un-coated / coated (type of coating), crimped nut, etc.
- **End conditions:** Temperature, dampness, tightening speed, multiple surfaces etc.

Notes
The friction-coefficient window defined in the VDA test sheet 235-101 can generally be obtained by proper lubrication. The process-safe compliance in the serial production with acceptable range of distribution can still be problematic (» Influencing factors). In principle, integrated lubricants are best suited for majority applications.
If required, friction coefficients over 0.14 can be reached through proper lubricant treatment or through a single coating system without additional lubricant treatment. The spread of friction coefficients increases with increase in the coefficients.
Friction coefficients under 0.08 are technically quite difficult to set, and are not desired due to the required safety against self loosening of a joint.

Standard Lubricants with usual areas application (Example)

Product name	Friction Coefficients (DIN 946)	Area of application
Subsequently-applied Lubricants		
Gardorol CP 8006 or similar	0.08 – 0.14	Phosphated bolts (Motor bolts)
Torque N Tension Fluid	0.09 – 0.14	Zinc-plated coats / galv. surface
microGLEIT DF911 / 921	0.09 – 0.14	Zinc-plated coats / galv. surface
Gleitmo® 605	0.07 – 0.14	Galvanic surfaces
Gleitmo® 2332 V	0.09 – 0.14	Application with high temperatures
OKS® 1700	0.09 – 0.14	Aluminum bolts / thread-forming bolts
OKS® 1765	0.08 – 0.14	Thread-forming bolts
Gleitmo® 627	0.09 – 0.14	Austenitic bolts
Integrated Lubricants		
Torque N Tension 11 / 15	0.08 – 0.14 / 0.12 – 0.18	Galvanic surfaces
microGLEIT DCP 9000	0.09 – 0.14	Zinc-plated coats / galv. surface
DACROLUB® 10 / 15	0.10 – 0.14 / 0.15 – 0.20	DACROMET® 320 / GEOMET® 321
Geomet® 500	0.12 – 0.18	-
Plus® VL	0.09 – 0.14	GEOMET® 321
Plus® L / ML / M	0.08 – 0.14 / 0.10 – 0.16 / 0.15 – 0.20	DACROMET® 320 / GEOMET® 321
DELTA®-Seal GZ	0.10 – 0.16	DELTA®-Tone / DELTA®-Protekt KL 100
DP VH 301 GZ / VH 302 GZ	0.09 – 0.14 / 0.10 – 0.16	DELTA®-Tone / DELTA®-Protekt KL 100
B 18 / B 18 N / B 18 T	0.12 – 0.18 / 0.15 – 0.21 / 0.18 – 0.24	MAGNI B 46

6. Durability-compatible Configuration

The fatigue limit of a bolted connection can be raised through the following measures:

a) Rolling of threads after heat treatment;
   Please note: Disassembly of residual stress occurs during a temperature load. Hence it is important to note the working temperature and thermal load during the coating process.

b) Cold worked bolts from annealed raw material or tensile strength class 800 K.

c) The geometery of bolts constructed according to the largest possible elastic resilience. e.g. fully threaded parts, parts, waisted shank or reduced shank, hollow shaft option of the largest possible grip length.

d) Observance of the thermal expansion of bolted parts and fastener. Choosing materials with similar coefficients of expansion if possible.

e) Usage of MJ thread with enlarged core-radius according to DIN ISO 5855 sections 1-3.

f) Equal load distribution in threads:
   1.) Nut materials of smaller E-modules (e.g. cast iron, Aluminum, Titanium)
   2.) Nut materials of lower tensile strength (Note depth of thread!)
   3.) Nuts designed as tensile-nuts

g) Bolt head designed for fatigue endurance (e.g. bigger radius in head-shaft transition).
   Avoiding metal-cutting process, especially under the bolt head.

h) Reduction of setting amount through:
   1.) Reduction of joint faces/clamped parts
   2.) Avoiding over-loading of bearing faces. (Note surface pressure!)
   3.) Usage of the smoothest possible bearing areas

6.1 Estimation of fatigue limits (reference value)

a) Heat treated after thread rolling

$$\pm \delta_{ASV} = 0.75\ (180/d + 52)$$

b) Heat treated before thread rolling

$$\pm \delta_{ASG} = (2 - F_V / F_{0.2})\ \delta_{ASV}$$

7. Miscellaneous

7.1 Conversion tables for hardness and tensile strength

Hardness test and Conversion
Cold forming material and Punching in **untempered** Condition
HB, HV, HRc and Tensile Strength
(according to DIN 50150 Table A.1 – Oct. 2000) – values partly interpolated

Brinell				Conversion		
∅ 2.5 [mm]	∅ 5 [mm]	∅ 10 [mm]	HB	HV	HRc	Rm
1.839 [kN]	7.355 [kN]	29.42 [kN]				[N/mm^2]
0.750	1.50	3.00	415	436	44.0	1407
0.760	1.52	3.04	404	424	43.1	1367
0.770	1.54	3.08	393	413	42.1	1331
0.780	1.56	3.12	383	402	41.0	1295
0.790	1.58	3.16	373	392	40.0	1262
0.800	1.60	3.20	363	381	38.9	1225
0.810	1.62	3.24	354	372	37.9	1195
0.820	1.64	3.28	345	362	36.8	1163
0.830	1.66	3.32	337	354	35.9	1137
0.840	1.68	3.36	329	346	34.9	1111
0.850	1.70	3.40	321	337	34.2	1082
0.860	1.72	3.44	313	329	33.3	1056
0.870	1.74	3.48	306	321	32.4	1031
0.880	1.76	3.52	298	313	31.5	1005
0.890	1.78	3.56	292	307	30.6	986
0.900	1.80	3.60	285	299	29.8	960
0.910	1.82	3.64	278	292	28.9	937
0.920	1.84	3.68	272	286	27.9	918
0.930	1.86	3.72	266	279	27.1	895
0.940	1.88	3.76	260	273	26.2	876
0.950	1.90	3.80	255	268	25.2	860
0.960	1.92	3.84	249	261	24.5	837
0.970	1.94	3.88	244	256	23.4	821

Brinell				Conversion		
∅ 2.5 [mm] 1.839 [kN]	∅ 5 [mm] 7.355 [kN]	∅ 10 [mm] 29.42 [kN]	HB	HV	HRc	Rm [N/mm^2]
0.980	1.96	3.92	239	251	–	805
0.990	1.98	3.96	234	246	–	789
1.000	2.00	4.00	229	240	–	770
1.010	2.02	4.04	224	235	–	754
1.020	2.04	4.08	219	230	–	738
1.030	2.06	4.12	215	226	–	725
1.040	2.08	4.16	211	222	–	712
1.050	2.10	4.20	207	217	–	696
1.060	2.12	4.24	202	212	–	680
1.070	2.14	4.28	198	208	–	667
1.080	2.16	4.32	195	205	–	657
1.090	2.18	4.36	191	201	–	644
1.100	2.20	4.40	187	196	–	631
1.110	2.22	4.44	184	193	–	621
1.120	2.24	4.48	180	189	–	607
1.130	2.26	4.52	177	186	–	597
1.140	2.28	4.56	174	183	–	587
1.150	2.30	4.60	170	179	–	573
1.160	2.32	4.64	167	175	–	563
1.170	2.34	4.68	164	172	–	553
1.180	2.36	4.72	161	169	–	543
1.190	2.38	4.76	158	166	–	533
1.200	2.40	4.80	156	164	–	526
1.210	2.42	4.84	153	161	–	516
1.220	2.44	4.88	150	158	–	506

Hardness test and Conversion
Cold forming material and Punching in **tempered** Condition
HB, HV, HRc and Tensile Strength
(according to DIN 50150 Table B.2 – Oct. 2000) – values partly interpolated

Brinell				Conversion		
∅ 2.5 [mm] 1.839 [kN]	∅ 5 [mm] 7.355 [kN]	∅ 10 [mm] 29.42 [kN]	HBW	HV	HRc	Rm [N/mm^2]
0.720	1.44	2.88	451	458	46.2	1424
0.725	1.45	2.90	444	450	45.7	1401
0.730	1.46	2.92	438	444	45.4	1390
0.735	1.47	2.94	432	438	44.7	1365
0.740	1.48	2.96	426	432	44.3	1347
0.745	1.49	2.98	420	426	43.7	1328
0.750	1.50	3.00	415	421	43.3	1317
0.755	1.51	3.02	409	414	43.0	1294
0.760	1.52	3.04	404	409	42.4	1281
0.765	1.53	3.06	398	403	41.8	1260
0.770	1.54	3.08	393	398	41.3	1244
0.775	1.55	3.10	388	393	40.8	1238
0.780	1.56	3.12	383	388	40.4	1214
0.785	1.57	3.14	378	383	39.9	1198
0.790	1.58	3.16	373	378	39.4	1185
0.795	1.59	3.18	368	373	38.9	1168
0.800	1.60	3.20	363	368	38.4	1152
0.805	1.61	3.22	359	364	38.0	1140
0.810	1.62	3.24	354	359	37.5	1125
0.815	1.63	3.26	350	355	37.1	1113
0.820	1.64	3.28	345	350	36.5	1097
0.825	1.65	3.30	341	346	36.0	1085
0.830	1.66	3.32	337	341	35.5	1073
0.835	1.67	3.34	333	337	35.1	1060
0.840	1.68	3.36	329	333	34.6	1046
0.845	1.69	3.38	325	329	34.2	1033

Brinell				Conversion		
∅ 2.5 [mm] 1.839 [kN]	∅ 5 [mm] 7.355 [kN]	∅ 10 [mm] 29.42 [kN]	HB	HV	HRc	Rm [N/mm^2]
0.850	1.70	3.40	321	325	33.7	1020
0.855	1.71	3.42	317	321	33.2	1006
0.860	1.72	3.44	313	317	32.7	994
0.865	1.73	3.46	309	313	32.2	981
0.870	1.74	3.48	306	310	31.8	972
0.875	1.75	3.50	302	306	31.3	959
0.880	1.76	3.52	298	302	30.8	946
0.885	1.77	3.54	295	299	30.4	937
0.890	1.78	3.56	292	296	29.9	925
0.895	1.79	3.58	288	292	29.3	915
0.900	1.80	3.60	285	289	28.9	906
0.905	1.81	3.62	282	286	28.5	896
0.910	1.82	3.64	278	282	28.0	883
0.915	1.83	3.66	275	279	27.6	874
0.920	1.84	3.68	272	276	27.1	864
0.925	1.85	3.70	269	273	26.7	852
0.930	1.86	3.72	266	270	26.2	845
0.935	1.87	3.74	263	268	26.0	842
0.940	1.88	3.76	260	266	25.6	832
0.945	1.89	3.78	257	262	24.9	819
0.950	1.90	3.80	255	260	24.6	813
0.955	1.91	3.82	252	257	24.1	803

7.2 Size limit for regular (standard) and fine threads

Metric ISO-threads, size limits for **regular threads**, DIN 13 Part 20, Oct 1983

Symbol		max. 4h - 6h	min. 4h	min. 6h	max. 4g-6g	min. 4g	min. 6g	max. 4e-6e	min. 4e	min. 6e
M 3 x 0.5	outerØ=d	3.000	2.933	2.894	2.980	2.913	2.874	2.950	2.883	2.844
	flankØ=d2	2.675	2.627	2.600	2.655	2.607	2.580	2.625	2.577	2.550
	coreØ=d3	2.387	2.320	2.293	2.367	2.299	2.273	2.337	2.270	2.243
M 4 x 0.7	outerØ=d	4.000	3.910	3.860	3.978	3.888	3.838	3.944	3.854	3.804
	flankØ=d2	3.545	3.489	3.455	3.523	3.467	3.433	3.489	3.433	3.399
	coreØ=d3	3.141	3.058	3.024	3.119	3.036	3.002	3.085	3.002	2.968
M 5 x 0.8	outerØ=d	5.000	4.905	4.850	4.976	4.881	4.826	4.940	4.845	4.790
	flankØ=d2	4.480	4.420	4.385	4.456	4.396	4.361	4.420	4.360	4.325
	coreØ=d3	4.019	3.928	3.893	3.995	3.903	3.869	3.959	3.868	3.833
M 6 x 1.0	outerØ=d	6.000	5.888	5.820	5.974	5.862	5.794	5.940	5.828	5.760
	flankØ=d2	5.350	5.279	5.238	5.324	5.253	5.212	5.290	5.219	5.178
	coreØ=d3	4.773	4.663	4.622	4.747	4.637	4.596	4.713	4.603	4.562
M 7 x 1.0	outerØ=d	7.000	6.888	6.820	6.974	6.862	6.794	6.940	6.828	6.760
	flankØ=d2	6.350	6.279	6.238	6.324	6.253	6.212	6.290	6.219	6.178
	coreØ=d3	5.773	5.663	5.622	5.747	5.637	5.596	5.713	5.603	5.562
M 8 x 1.25	outerØ=d	8.000	7.868	7.788	7.972	7.840	7.760	7.937	7.805	7.725
	flankØ=d2	7.188	7.113	7.070	7.160	7.085	7.042	7.125	7.050	7.007
	coreØ=d3	6.466	6.343	6.300	6.438	6.315	6.272	6.403	6.280	6.237
M 9 x 1.25	outerØ=d	9.000	8.868	8.788	8.972	8.840	8.760	8.937	8.805	8.725
	flankØ=d2	8.188	8.113	8.070	8.160	8.085	8.042	8.125	8.050	8.007
	coreØ=d3	7.466	7.343	7.300	7.438	7.315	7.272	7.403	7.280	7.237
M 10 x 1.5	outerØ=d	10.000	9.850	9.764	9.968	9.818	9.732	9.933	9.783	9.697
	flankØ=d2	9.026	8.941	8.894	8.994	8.909	8.862	8.959	8.874	8.827
	coreØ=d3	8.160	8.017	7.970	8.128	7.985	7.938	8.093	7.950	7.903
M 11 x 1.5	outerØ=d	11.000	10.850	10.764	10.968	10.818	10.732	10.933	10.783	10.697
	flankØ=d2	10.026	9.941	9.894	9.994	9.909	9.862	9.959	9.874	9.827
	coreØ=d3	9.160	9.017	8.970	9.128	8.985	8.938	9.093	8.950	8.903

Metric ISO-threads, size limits for **regular threads**, DIN 13 Part 20, Oct 1983

Symbol		max. 4h - 6h	min. 4h	min. 6h	max. 4g-6g	min. 4g	min. 6g	max. 4e-6e	min. 4e	min. 6e
M 12 x 1.75	outerØ=d	12.000	11.830	11.735	11.966	11.796	11.701	11.929	11.759	11.664
	flankØ=d2	10.863	10.768	10.713	10.829	10.734	10.679	10.792	10.697	10.642
	coreØ=d3	9.853	9.691	9.635	9.819	9.656	9.602	9.782	9.619	9.565
M 14 x 2.0	outerØ=d	14.000	13.820	13.720	13.962	13.782	13.682	13.929	13.749	13.649
	flankØ=d2	12.701	12.601	12.541	12.663	12.563	12.503	12.630	12.530	12.470
	coreØ=d3	11.546	11.369	11.309	11.508	11.331	11.271	11.475	11.298	11.238
M 16 x 2.0	outerØ=d	16.000	15.820	15.720	15.962	15.782	15.682	15.929	15.749	15.649
	flankØ=d2	14.701	14.601	14.541	14.663	14.563	14.503	14.630	14.530	14.470
	coreØ=d3	13.546	13.369	13.309	13.508	13.331	13.271	13.475	13.298	13.238
M 18 x 2.5	outerØ=d	18.000	17.788	17.665	17.958	17.746	17.623	17.920	17.708	17.585
	flankØ=d2	16.376	16.270	16.206	16.334	16.228	16.164	16.296	16.190	16.126
	coreØ=d3	14.933	14.731	14.666	14.891	14.688	14.625	14.853	14.650	14.587
M 20 x 2.5	outerØ=d	20.000	19.788	19.665	19.958	19.746	19.623	19.920	19.708	19.585
	flankØ=d2	18.376	18.270	18.206	18.334	18.228	18.164	18.296	18.190	18.126
	coreØ=d3	16.933	16.731	16.666	16.891	16.688	16.625	16.853	16.650	16.587
M 22 x 2.5	outerØ=d	22.000	21.788	21.665	21.958	21.746	21.623	21.920	21.708	21.585
	flankØ=d2	20.376	20.270	20.206	20.334	20.228	20.164	20.296	20.190	20.126
	coreØ=d3	18.933	18.731	18.666	18.891	18.688	18.625	18.853	18.650	18.587
M 24 x 3.0	outerØ=d	24.000	23.764	23.625	23.952	23.716	23.577	23.915	23.679	23.540
	flankØ=d2	22.051	21.926	21.851	22.003	21.878	21.803	21.966	21.841	21.766
	coreØ=d3	20.319	20.078	20.003	20.271	20.030	19.955	20.234	19.993	19.918
M 27 x 3.0	outerØ=d	27.000	26.764	26.625	26.952	26.716	26.577	26.915	26.679	26.540
	flankØ=d2	25.051	24.926	24.851	25.003	24.878	24.803	24.966	24.841	24.766
	coreØ=d3	23.319	23.078	23.003	23.271	23.030	22.955	23.234	22.993	22.918
M 30 x 3.5	outerØ=d	30.000	29.735	20.575	29.947	29.682	29.522	29.910	29.645	29.485
	flankØ=d2	27.727	27.595	27.515	27.674	27.542	27.462	27.637	27.505	27.425
	coreØ=d3	25.706	25.439	25.359	25.653	25.386	25.306	25.616	25.349	25.269

Metric ISO-threads, size limits for **fine pitch threads**, DIN 13 Part 21, Oct 1983

Symbol		max. 4h - 6h	min. 4h	min. 6h	max. 4g-6g	min. 4g	min. 6g	max. 4e-6e	min. 4e	min. 6e
M 8 x 0.75	outerØ=d	8.000	7.910	7.860	7.978	7.888	7.838	7.944	7.854	7.804
	flankØ=d2	7.513	7.450	7.413	7.491	7.428	7.391	7.457	7.394	7.357
	coreØ=d3	7.080	6.988	6.951	7.058	6.968	6.929	7.024	6.932	6.895
M 8 x 1.0	outerØ=d	8.000	7.888	7.820	7.974	7.862	7.794	7.940	7.828	7.760
	flankØ=d2	7.350	7.279	7.238	7.324	7.253	7.212	7.290	7.219	7.178
	coreØ=d3	6.773	6.663	6.622	6.747	6.637	6.596	6.713	6.603	6.562
M 9 x 1.0	outerØ=d	9.000	8.888	8.820	8.974	8.862	8.794	8.940	8.828	8.760
	flankØ=d2	8.350	8.279	8.238	8.324	8.253	8.212	8.290	8.219	8.178
	coreØ=d3	7.773	7.663	7.622	7.747	7.637	7.596	7.713	7.603	7.562
M 10 x 1.0	outerØ=d	10.000	9.888	9.820	9.974	9.862	9.794	9.940	9.828	9.760
	flankØ=d2	9.350	9.279	9.238	9.324	9.253	9.212	9.290	9.219	9.178
	coreØ=d3	8.773	8.663	8.622	8.747	8.637	8.596	8.713	8.603	8.562
M 10 x 1.25	outerØ=d	10.000	9.868	9.788	9.982	9.840	9.760	9.937	9.805	9.725
	flankØ=d2	9.188	9.113	9.070	9.160	9.085	9.042	9.125	9.050	9.007
	coreØ=d3	8.466	8.343	8.300	8.438	8.315	8.272	8.403	8.280	8.237
M 12 x 1.0	outerØ=d	12.000	11.888	11.820	11.974	11.862	11.794	11.940	11.828	11.760
	flankØ=d2	11.350	11.275	11.232	11.324	11.249	11.206	11.290	11.215	11.172
	coreØ=d3	10.773	10.659	10.616	10.747	10.633	10.590	10.713	10.599	10.556
M 12 x 1.25	outerØ=d	12.000	11.868	11.788	11.972	11.840	11.760	11.937	11.805	11.725
	flankØ=d2	11.188	11.103	11.056	11.160	11.075	11.028	11.125	11.040	10.993
	coreØ=d3	10.466	10.333	10.286	10.438	10.305	10.258	10.403	10.270	10.223
M 12 x 1.5	outerØ=d	12.000	11.850	11.764	11.968	11.818	11.732	11.933	11.783	11.697
	flankØ=d2	11.026	10.936	10.886	10.994	10.904	10.854	10.959	10.869	10.819
	coreØ=d3	10.160	10.012	9.962	10.128	9.980	9.930	10.093	9.945	9.895
M 14 x 1.0	outerØ=d	14.000	13.888	13.820	13.974	13.862	13.794	13.940	13.828	13.760
	flankØ=d2	13.350	13.275	13.232	13.324	13.249	13.206	13.290	13.215	13.172
	coreØ=d3	12.773	12.659	12.616	12.747	12.633	12.590	12.713	12.599	12.556
M 14 x 1.5	outerØ=d	14.000	13.850	13.764	13.968	13.818	13.732	13.933	13.783	13.697
	flankØ=d2	13.026	12.936	12.886	12.994	12.904	12.854	12.959	12.869	12.819
	coreØ=d3	12.160	12.012	11.962	12.128	11.980	11.930	12.093	11.945	11.895

Metric ISO-threads, size limits for **fine pitch threads**, DIN 13 Part 21, Oct 1983

Symbol		max. 4h - 6h	min. 4h	min. 6h	max. 4g-6g	min. 4g	min. 6g	max. 4e-6e	min. 4e	min. 6e
M 16 x 1.0	outerØ=d	16.000	15.888	15.820	15.974	15.862	15.794	15.940	15.828	15.760
	flankØ=d2	15.350	15.275	15.232	15.324	15.249	15.206	15.290	15.215	15.172
	coreØ=d3	14.773	14.659	14.616	14.747	14.633	14.590	14.713	14.599	14.556
M 16 x 1.5	outerØ=d	16.000	15.850	15.764	15.968	15.818	15.732	15.933	15.783	15.697
	flankØ=d2	15.026	14.936	14.886	14.994	14.904	14.854	14.959	14.869	14.819
	coreØ=d3	14.160	14.012	13.962	14.128	13.980	13.930	14.093	13.945	13.895
M 18 x 1.5	outerØ=d	18.000	17.850	17.764	17.968	17.818	17.732	17.933	17.783	17.697
	flankØ=d2	17.026	16.936	16.886	16.994	16.904	16.854	16.959	16.869	16.819
	coreØ=d3	16.160	16.012	15.962	16.128	15.980	15.930	16.093	15.945	15.895
M 18 x 2.0	outerØ=d	18.000	17.820	17.720	17.962	17.782	17.682	17.929	17.749	17.649
	flankØ=d2	16.701	16.601	16.541	16.663	16.563	16.503	16.630	16.530	16.470
	coreØ=d3	15.546	15.369	15.309	15.508	15.331	15.271	15.475	15.298	15.238
M 20 x 1.5	outerØ=d	20.000	19.850	19.764	19.968	19.818	19.732	19.933	19.783	19.697
	flankØ=d2	19.026	18.936	18.886	18.994	18.904	18.854	18.959	18.869	18.819
	coreØ=d3	18.160	18.012	17.962	18.128	17.980	17.930	18.093	17.945	17.895
M 20 x 2.0	outerØ=d	20.000	19.820	19.720	19.962	19.782	19.682	19.929	19.749	19.649
	flankØ=d2	18.701	18.601	18.541	18.663	18.563	18.503	18.630	18.530	18.470
	coreØ=d3	17.546	17.369	17.309	17.508	17.331	17.271	17.475	17.298	17.238
M 22 x 1.5	outerØ=d	22.000	21.850	21.764	21.968	21.818	21.732	21.993	21.783	21.697
	flankØ=d2	21.026	20.936	20.886	20.994	20.904	20.854	20.959	20.869	20.819
	coreØ=d3	20.160	20.012	19.962	20.128	19.980	19.930	20.093	19.945	19.895
M 22 x 2.0	outerØ=d	22.000	21.820	21.720	21.962	21.782	21.682	21.929	21.749	21.649
	flankØ=d2	20.701	20.601	20.541	20.663	20.563	20.503	20.630	20.530	20.470
	coreØ=d3	19.546	19.369	19.309	19.508	19.331	19.271	19.475	19.298	19.238
M 24 x 1.5	outerØ=d	24.000	23.850	23.764	23.968	23.818	23.732	23.933	23.783	23.697
	flankØ=d2	23.026	22.931	22.876	22.994	22.899	22.844	22.959	22.864	22.809
	coreØ=d3	22.160	22.007	21.952	22.128	21.975	21.920	22.093	21.940	21.885
M 24 x 2.0	outerØ=d	24.000	23.820	23.720	23.962	23.782	23.682	23.929	23.749	23.649
	flankØ=d2	22.701	22.595	22.531	22.663	22.557	22.493	22.630	22.524	22.460
	coreØ=d3	21.546	21.363	21.299	21.508	21.325	21.261	21.475	21.292	21.228

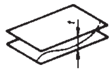
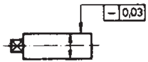
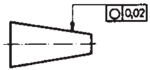
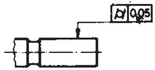
7.3 GO Screw ring gage measurement acc. DIN/ISO 1502 edition 01/12.96

threads	min. outer-Ø	Flank-Ø (tolerance in µm)	Flank-Ø wear limit	Tightening torque Nm max.	ball contact	Test dimensions for wear-limits	
						Test dimension M (tol. in µm)	Test Dimension M worn out	core-Ø (tolerance in µm)
M6 -6h	6.081	5.348 ± 7	5.364	0.22	0.620	5.592 ± 7	5.608	4.917 ± 7
M8 -6h	8.099	7.186 ± 7	7.202	0.51	0.725	7.5416 ± 7	7.5576	6.647 ± 7
M8 x 1.0 -6h	8.081	7.348 ± 7	7.364	0.51	0.620	7.593 ± 7	7.609	6.917 ± 7
M10 -6h	10.1195	9.018 ± 9	9.039	1.0	0.837	9.478 ± 9	9.499	8.376 ± 9
M10 x 1.0 -6h	10.081	9.348 ± 7	9.364	1.0	0.620	9.5934 ± 7	9.6094	8.917 ± 7
M10 x 1.25 -6h	10.099	9.186 ± 7	9.202	1.0	0.725	9.5424 ± 7	9.5584	8.647 ± 7
M12 -6h	12.1375	10.855 ± 9	10.876	1.73	1.10	11.268 ± 9	11.289	10.106 ± 9
M12 x 1.0 -6h	12.081	11.348 ± 7	11.364	1.73	0.620	11.5936 ± 7	11.6096	10.917 ± 7
M12 x 1.25 -6h	12.101	11.180 ± 9	11.201	1.73	0.725	11.5368 ± 9	11.5578	10.647 ± 9
M12 x 1.5 -6h	12.1195	11.018 ± 9	11.039	1.73	0.837	11.4787 ± 9	11.4997	10.376 ± 9
M14 -6h	14.1555	12.693 ± 9	12.714	2.7	1.112	13.3107 ± 9	13.3317	11.835 ± 9
M14 x 1.0 -6h	14.081	13.348 ± 7	13.364	2.7	0.620	13.5937 ± 7	13.6097	12.917 ± 7
M14 x 1.5 -6h	14.1195	13.018 ± 9	13.039	2.7	0.837	12.4791 ± 9	13.5001	12.376 ± 9
M16 -6h	16.1555	14.693 ± 9	14.714	4.1	1.112	15.3113 ± 9	15.3323	13.835 ± 9
M16 x 1.0 -6h	16.081	15.348 ± 7	15.364	4.1	0.620	15.5938 ± 7	15.6098	14.917 ± 7
M16 x 1.5 -6h	16.1195	15.018 ± 9	15.039	4.1	0.837	15.4794 ± 9	15.5004	14.376 ± 9
M18 -6h	18.1915	16.368 ± 9	16.389	5.8	1.350	17.1804 ± 9	17.2014	15.294 ± 9
M18 x 1.5 -6h	18.1195	17.018 ± 9	17.039	5.8	0.837	17.4795 ± 9	17.5005	16.376 ± 9
M18 x 2.0 -6h	18.1555	16.693 ± 9	16.714	5.8	1.112	17.3117 ± 9	17.3327	15.835 ± 9
M20 -6h	20.1915	18.368 ± 9	18.389	8	1.35	19.181 ± 9	19.202	17.294 ± 9
M20 x 1.5 -6h	20.1195	19.018 ± 9	19.039	8	0.837	19.4796 ± 9	19.5006	18.376 ± 9
M20 x 2.0 -6h	20.1555	18.693 ± 9	18.714	8	1.112	19.312 ± 9	19.333	17.835 ± 9
M22 -6h	22.1915	20.368 ± 9	20.389	10.6	1.35	21.1814 ± 9	21.2024	19.294 ± 9
M22 x 1.5 -6h	22.1195	21.018 ± 9	21.039	10.6	0.837	21.4797 ± 9	21.5007	20.376 ± 9
M22 x 2.0 -6h	22.1555	20.693 ± 9	20.714	10.6	1.112	21.3122 ± 9	21.3332	19.835 ± 9
M24 -6h	24.2275	22.043 ± 9	22.064	13.8	1.773	22.8653 ± 9	22.8863	20.752 ± 9
M24 x 1.5 -6h	24.1195	23.018 ± 9	23.039	13.8	0.837	23.4798 ± 9	23.5008	22.376 ± 9
M24 x 2.0 -6h	24.1555	22.693 ± 9	22.714	13.8	1.112	23.3123 ± 9	23.3333	21.835 ± 9

threads	min. outer-Ø	Flank-Ø (tolerance in µm)	Flank-Ø wear limit	Tightening torque Nm max.	Test dimensions for wear-limits: ball contact	Test dimensions for wear-limits: Test dimension M (tol. in µm)	Test dimensions for wear-limits: Test Dimension M worn out	Kern-Ø (Toleranz in µm)
M6 -6g	6.055	5.322 ± 7	5.338	0.22	0.620	5.566 ± 7	5.582	4.891 ± 7
M8 -6g	8.071	7.158 ± 7	7.174	0.51	0.725	7.5136 ± 7	7.5296	6.619 ± 7
M8 x 1.0 -6g	8.055	7.322 ± 7	7.338	0.51	0.620	7.567 ± 7	7.583	6.891 ± 7
M10 -6g	10.0875	8.986 ± 9	9.007	1.0	0.837	9.446 ± 9	9.467	8.344 ± 9
M10 x 1.0 -6g	10.055	9.322 ± 7	9.338	1.0	0.620	9.5674 ± 7	9.5834	8.891 ± 7
M10 x 1.25 -6g	10.071	9.158 ± 7	9.174	1.0	0.725	9.5144 ± 7	9.5304	8.619 ± 7
M12 -6g	12.1035	10.821 ± 9	10.842	1.73	1.10	11.2339 ± 9	11.2549	10.072 ± 9
M12 x 1.0 -6g	12.055	11.322 ± 7	11.338	1.73	0.620	11.5676 ± 7	11.5836	10.891 ± 7
M12 x 1.25 -6g	12.073	11.152 ± 9	11.173	1.73	0.725	11.5088 ± 9	11.5298	10.619 ± 9
M12 x 1.5 -6g	12.0875	10.986 ± 9	11.007	1.73	0.837	11.4467 ± 9	11.4677	10.344 ± 9
M14 -6g	14.1175	12.655 ± 9	12.676	2.7	1.112	13.2727 ± 9	13.2937	11.797 ± 9
M14 x 1.0 -6g	14.055	13.322 ± 7	13.338	2.7	0620	13.5677 ± 7	13.5837	12.871 ± 7
M14 x 1.5 -6g	14.0875	12.986 ± 9	13.007	2.7	0.837	13.4471 ± 9	13.4681	14.344 ± 9
M16 -6g	16.1175	14.655 ± 9	14.676	4.1	1.112	15.2733 ± 9	15.2943	13.797 ± 9
M16 x 1.0 -6g	16.055	15.322 ± 7	15.338	4.1	0.620	15.5678 ± 7	15.5838	14.891 ± 7
M16 x 1.5 -6g	16.0875	14.986 ± 9	15.007	4.1	0.837	15.4471 ± 9	15.4681	12.344 ± 9
M18 -6g	18.1495	16.326 ± 9	16.347	5.8	1.350	17.1384 ± 9	17.1594	15.252 ± 9
M18 x 1.5 -6g	18.0875	16.986 ± 9	17.007	5.8	0.837	17.4475 ± 9	17.4685	16.344 ± 9
M18 x 2.0 -6g	18.1175	16.655 ± 9	16.676	5.8	1.112	17.2737 ± 9	17.2947	15.797 ± 9
M20 -6g	20.1495	18.326 ± 9	18.347	8	1.35	19.139 ± 9	19.160	17.252 ± 9
M20 x 1.5 -6g	20.0875	18.986 ± 9	19.007	8	0.837	19.4476 ± 9	19.4686	18.344 ± 9
M20 x 2.0 -6g	20.1175	18.655 ± 9	18.676	8	1.112	19.274 ± 9	19.295	17.797 ± 9
M22 -6g	22.1495	20.326 ± 9	20.347	10.6	1.35	21.1394 ± 9	21.1604	19.252 ± 9
M22 x 1.5 -6g	22.0875	20.986 ± 9	21.007	10.6	0.837	21.447 ± 9	21.4687	20.344 ± 9
M22 x 2.0 -6g	22.1175	20.655 ± 9	20.676	10.6	1.112	21.2742 ± 9	21.2952	19.797 ± 9
M24 -6g	24.1795	21.995 ± 9	22.016	13.8	1.776	22.8172 ± 9	22.8382	20.704 ± 9
M24 x 1.5 -6g	24.0875	22.986 ± 9	23.007	13.8	0.837	23.4478 ± 9	23.4688	22.344 ± 9
M24 x 2.0 -6g	24.1175	22.655 ± 9	22.676	13.8	1.112	23.2743 ± 9	23.2953	21.797 ± 9

7.4 Tolerance symbols and toleranced properties

Tolerances for form and position (Summary of IN ISO 1101)

	Tolerance symbol and toleranced characteristic		Examples for application: Tolerance zone	Diagram specifications	Explanation
Form	—	**Straightness** of a line			Every generatrix must lie at a distance of t = 0.03mm between two parallel planes.
Form	⏥	**Evenness** of an area			The toleranced area must lie at a distance of 0.05mm between two parallel planes.
Form	○	**Roundness** of the circumference of a cylinder, disc, cone etc.			The toleranced circumferential line of every cross-section perpendicular to the axis must lie at a radial distance of t - 0.02mm bet ween two concentric circles.
Form	⌭	**Cylindrical form**			The toleranced cylinder shell must lie between two coaxial cylinders that have a radial distance of t = 0.05.

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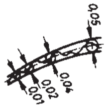
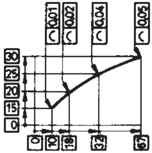
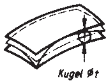
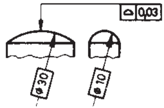
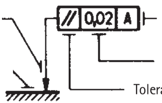
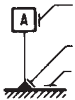
Tolerance symbol and toleranced characteristic			Examples for application: Tolerance zone	Diagram specifications	Explanation
Form	⌒	**Line form** of an arbitrary line (profile)			The toleranced profile must, in every section plane parallel to the drawing plane (in which the profile is toleranced), lie between two cladding lines whose distance through the circle is limited by the diameter t = 0.08 mm. The centers of these circles lie on the geometrically perfect area.
					The toleranced profile must, in every section plane parallel to the drawing plane (in which the profile is toleranced) between two cladding lines whose distance through the circle is limited by the diameter t = 0.01 to 0.05 mm. The centers of these circles lie on the geometrically perfect area.
	⌓	**Area form** of an arbitrary surface area			The toleranced area must lie between two cladding areas, whose distance through the sphere is limited by the diameter t = 0.03 mm. The centers of these spheres lie on the geometrically perfect area.



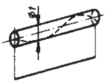
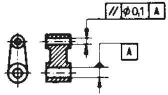
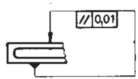
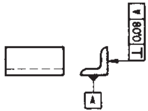
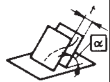
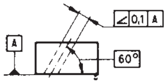


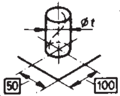
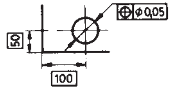
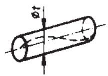
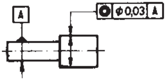
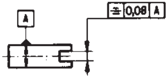
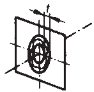
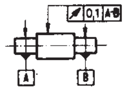
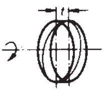
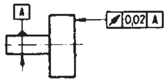
Ⓜ Symbol for max. material condition

50 Theoretically exact mass.

Ref. to axis and center plane

Ref. to line

Tolerance symbol and toleranced characteristic		Examples for application: Tolerance zone	Diagram specifications	Explanation
Position / Direction: //	**Parallelism** of a line (axis) to a reference line (axis)			The toleranced upper bore axis must lie within a cylinder parallel to the reference axis A, of diameter t = 0.1 mm.
	of an area to a reference area			The toleranced area must lie between two planes parallel to the reference area at a distance of t = 0.01 mm.
⊥	**Perpendicularity** of an area to a reference area (of a line ... according to the example for „inclination“)			The toleranced area must lie between two planes which are parallel to each other and perpendicular to the reference area „A“, at a distance of t = 0.08mm.
∠	**Inclination** (Angularity) of a line (axis) to a reference area (of a reference area....according to the example for 'perpendicularity')			The toleranced bore axis must lie at a distance of of t = 0.1mm between two planes parallel to each other and inclined at a geometrically perfect angle of 60° to the reference area A.

	Tolerance symbol and toleranced characteristic		Examples for application: Tolerance zone	Diagram specifications	Explanation
Place	⌖	**Position** of lines (axes) cross-connected with each other or to one or more reference elements			The toleranced axis of the hole must lie within a cylinder of diameter t = 0.05mm, whose axis lies on the geometrically perfect position (with framed dimensions).
Place	◎	**Axial Run-out** (concentricity) of an axis to a reference axis			The toleranced axis of the right cylinder of the shaft must lie within a cylinder of diameter t = 0.03 mm, coaxial to a reference axis
Position	⌯	**Symmetry** of a center plane to a reference center plane			The toleranced center plane of the nut must lie between two parallel planes which have a distance of t = 0.08 mm, and are ordered symmetrically to the reference center plane A of both the outer areas.
Run-out	↗	**Radial Run-out** of a cylinder shell to a (reference) pivot			For rotation around the reference axis A-B, the toleranced circumferential line of every perpendicular cross-section of the shaft's middle cylinder must lie between two concentric circles at a radial distance of t = 0.1 mm.
Run-out		**Axial Run-out**			For rotation around the reference axis A, the lateral run-out may not exceed the value of t = 0.02 mm, measured parallel and at an arbitrary distance from the reference axis A.

7.5 Conversion of German and English Units of Measurements

Lengths	
1 mm = 0.03937014 inches (Zoll)	1 inch = 25.399956 mm
1 m = 3.280851 feet (Fuß)	1 foot = 12 inch = 304.799472 mm
1 m = 1.093616 yards	1 yard = 3 feet = 0.914398 m
1 km = 0.621372 engl. Meile	1 mile = 1760 yards = 1.609341 km
1 km = 0.539614 Seemeile	1 nautc. mile = 1.853178 km
Areas	
1 mm^2 = 0.00155001 sq. in. (Zoll)	1 sq. inch = 6.451578 cm^2
1 m^2 = 19.76398328 sq. feet	1 sq. foot = 144 sq. inch = 929.0272 cm^2
1 m^2 = 1.19599596 sq. yards	1 sq. yard = 9 sq. feet = 8361.2448 cm^2
1 a = 100 m_ = 0.024711 arces	1 arces = 4840 sq. yards = 40.4684 a
1 ha = 100 a = 2.471063 arces	
1 km^2 = 100 ha = 0.3861 sq. miles	1 sq mile = 640 arces = 2.59 km^2
Volumes	
1 cm^3 = 0.061024 cubic inch	1 cubic inch = 16.386979 cm^3
1 dm^3 = 0.035315 cubic feet	1 cubic foot = 28.3167 dm^3
1 m^3 = 1.307957 cubic yard	1 cubic yard = 0.764551 m^3
1 m^3 = 0.353148 Register tons	1 register ton = 100 cubic feet = 2.83167 m^3
1 l = 0.220097 gallons (UK)	1 gallon (US) = 0.83268 gal (UK)
1 l = 0.264323 gallons (US)	1 gallon (US) = 3.78324 l
1 hl = 100 l	
Forces Masses	
1 kg = 2.20462 lbs (pounds)	1 lb = 0.453592 kg
1 kp = 9.80665 N	1 lbf = 4.44822 N
1 N = 0.224809 lbf	1 fi lb = 1.35582 J
1 J = 0.737561 ft lb	1 btu = 1.05506 kJ
Other dimensions	
1 Nm = 1 Joule = 0.737456 ft-lbs	1 ft-lb = 1.35582 Nm
1 Nm = 8.8495 lbs-in	1 lb-in = 0.113 Nm
1 N/mm^2 = 1 MPa = 0.0069 psi	
1 atm = 1.01325 bar	
1 l/100 km = 235.1 miles/gallon (US)	100 miles/gallon (US) = 0.4254 l/100 km

8. Formula Index

A_t	Shearing area at lateral load
A_0	Smallest applicable cross-sectional area of the bolt
d	Diameter of bolt
d_2	Thread diameter of bolt
F_A	Axial force
F_{Kerf}	Clamping force required for fulfillment of the function
F_{KR}	Residual clamping force at working joint
F_M	Assembly preload
F_{Mmin}	Minimum required assembly preload
F_{Mmax}	Maximum assembly preload
F_{MTab}	Tabular value of assembly pre load
F_{Mzul}	Acceptable assembly preload
F_{PA}	Fraction of the axial force which alters the load of the deformed parts
f_{PA}	Elastic deformation of parts through F_{PA}
f_{PM}	Elastic deformation of parts through F_M
F_{PM}	Assembly preload in deformed parts
F_Q	Radial / Shearing force
F_S	Bolt force
F_{SA}	Additional axial bolt force
f_{SA}	Elongation of bolt through F_{SA}
f_{SM}	Elongation of bolt through F_M
F_{SM}	Assembly pre-stressing load in the bolt
F_{Vth}	Change in preload due to temperature
F_Z	Loss in preload due to activation
HB	Brinell hardness
HRc	Rockwell hardness
HV	Vickers hardness
M_A	Initial torque at assembly to achieve F_M
M_G	Part of initial torque operative in thread
M_K	Moment of friction in the head or nut bearing
n	Force transmission factor
P	Pitch
p_B	Surface pressure in working state
p_G	Marginal surface pressure
p_M	Surface pressure in mounting state
R_m	Ultimate tensile strength of the bolt

$R_{P0.2min}$	0.2%-Yield point of bolt
S_F	Safety factor
$s_{red,B}$	Equivalent stress under working load
δ_P	Elastic resilience of joined components
δ_S	Elastic resilience of the bolt
ν	Utilisation factor of yield point
σ_a	Alternating cyclic stress of bolt
σ_A	Tightening factor
σ_{AS}	Stress amplitude of the endurance limit related to A_S
τ	Torsional stress
τ_B	Shearing strength
μ_G	Coefficient of friction of the thread surface
μ_K	Coefficient of friction of the underhead bearing surface
Φ	Ratio of force
Φ_{en}	Ratio of force during centric tension and eccentric force transmission
ϑ	Angle of rotation

9. Literature

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Note

Note

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