2

Bolt Tightening

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Torque and Tension

Why do we tighten screws?

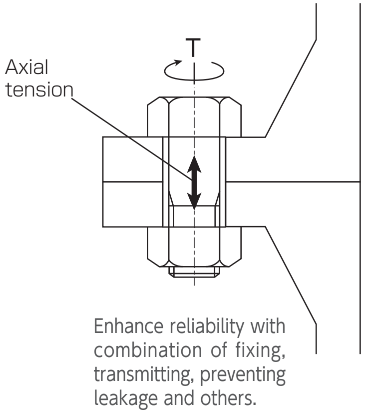
Screw tightening is carried out in order to stop objects from moving (to fix them). Followings are major objectives of the screw tightening.

1. For fixing and jointing objects
2. For transmitting driving force and braking force
3. For sealing drain bolts, gas and liquid

The fixing force at this time is called the axial tension (tightening force), and the target of screw tightening is to "apply an appropriate axial tension."

Although axial tension control should normally be carried out, because axial tension is difficult to measure, torque control is used for its substitute characteristics that allow tightening administration and operations to be carried out easily.

Figure 2-1.



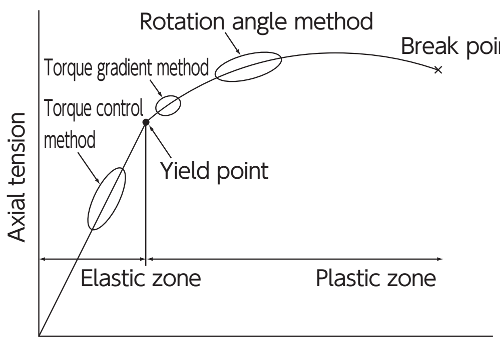
2-1

Various tightening methods

Table 2-1. Various tightening methods

Tightening method	Description	Advantages and disadvantages
Torque control method	Bolt tightening is controlled by the torque value. This is the most widely used method.	Tightening control and operation is easy. Since the torque value does not change because of the bolt length, standardization is easy. The dispersion band of the axial tension is wide and bolt efficiency is low.
Rotation angle method	Bolt tightening is controlled by the angle. The bolt is tightened to a defined angle from the snug torque.	When bolts are tightened within the plastic zone, dispersion of axial tension is small and operation is easy. Since tightening will go beyond the yield point, there is a limitation on the threaded joint with additive load or retightening. It is difficult to define the tightening angle.
Torque gradient method	The bolt is tightened from the proportional point until the yield point is reached. An electronic circuit carries out arithmetic processing of the angle, torque, etc.	Since the dispersion width of the axial tension is small, the efficiency of the bolted joint is large. Inspection of the bolt itself is possible. Tightening will go beyond the yield point. The tightening device is expensive. In the service field, the tightening method is not available.
Elongation measurement method	Bolt tightening is controlled by the elongation of the bolt, generated by bolt tightening. Elongation is measured by micrometer, ultrasonically, or with a mandrel.	The dispersion of the bolt is very small. Tightening within the elastic zone is available. The efficiency of the bolted joint is large. Additive loading and second-time tightening are possible. End face finishing of the bolt is required. The tightening cost is high.
Loading method	While the defined tensile load is applied to the bolt, tightening is controlled by the load given to the bolt.	Axial tension can be directly controlled. Torsion stress of the bolt is not generated. The tightening device and bolts are specially made. High cost.
Heating method	The bolt is heated to generate elongation. Tightening is controlled by the temperature.	Space and force are not required for tightening. There is no clear relation between the heat and axial tension. Temperature setting control is difficult.

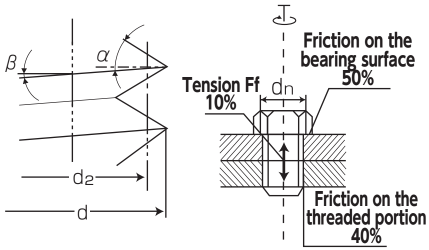
Figure 2-2. Tightening control methods



2-2 Screw and Torque

Relation formula between screw and torque

Figure 2-3.
Detail drawing **Relational drawing**



T : Torque ········ [N・m]
Ff : Axial tension··· [N]
d_2 : Pitch diameter [mm] (See P.122 Table 8-1)
d_n : Pitch diameter of bearing surface
·················· [mm] (See P.122 Table 8-1)
μ : Friction coefficient of threaded portion
·················· (See P.32 Table 2-2)
μ_n : Friction coefficient of bearing potion
·················· (See P.32 Table 2-2)
α : Half angle of screw thread···ISO Screw 30°
β : Lead angle [tan β] · (See P.122 Table 8-1)

Formula of screw (1)

$$T = Ff\left\{\frac{d_2}{2}\left(\frac{\mu}{\cos\alpha} + \tan\beta\right) + \mu_n\frac{d_n}{2}\right\} \div 1000$$

Friction on the threaded portion　Tension Ff　Friction on the bearing surface

Example: For a M8 bolt at Ft = 8000 [N], the tightening torque is

From P.122 Table 8-1. $d_2 = 7.188$ [mm]
$d_{n1} = 11.27$ [mm] (Hexagon nut style)
$\tan\beta = 0.0554$

From P.32 Table 2-2.

$\mu = \mu_n = 0.15$　$\alpha = 30°$

$$T = 8000\left\{\frac{7.188}{2}\left(\frac{0.15}{\cos 30°} + 0.0554\right) + 0.15\left(\frac{11.27}{2}\right)\right\} \div 1000$$

$= 13.4$ [N・m]

Formula of pitch diameter of bearing surface (d_{n1}, d_n)

a. Hexagon bearing surface (first type nut, bolt)

$$d_{n1} = \frac{0.608B^3 - 0.524d_H^3}{0.866B^2 - 0.785d_H^2}$$

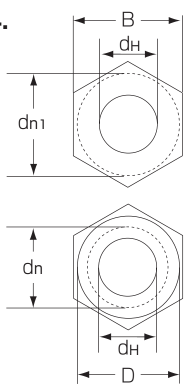
B: Hexagon width across flats [mm]　d_H: Bearing surface inside diameter [mm]

b. Round shape bearing surface (second, third type nut)

$$d_n = \frac{2}{3} \cdot \frac{D^3 - d_H^3}{D^2 - d_H^2}$$

D: Bearing surface outside diameter [mm]　d_H: Bearing surface inside diameter [mm]

Figure 2-4.



Formula of screw (2)

$$T = K \cdot d \cdot Ff \text{ or } Ff = \frac{T}{K \cdot d}$$

K: Torque coefficient (See P.32 Table 2-2)
d: Nominal size of screw [mm]

Example: Axial tension to tighten a M20 screw to T = 400 [N•m]

d=20 [mm] K = 0.2 (See P.32 Table 2-2)

$$Ff = \frac{400}{0.2 \times 20 \div 1000} = 100000 \text{ [N]}$$

2-3 Torque Coefficient

(1) Formula of torque coefficient

$$K = \frac{1}{2d}\left[d_2\left(\frac{\mu}{\cos\alpha} + \tan\beta\right) + \mu_n \cdot d_n\right]$$

d is the nominal screw diameter [mm]

(2) The torque coefficient is not stable

Table 2-2. Torque coefficient and friction coefficient

Lubrication	Torque coefficient Min. - Avg. - Max.	Friction coefficient Min. - Avg. - Max.
General machine oil Spindle oil Machine oil Turbine oil Cylinder oil	0.14 ~ 0.20 ~ 0.26	0.10 ~ 0.15 ~ 0.20
Low friction oil Double sulfurous molybdenum Wax based oil	0.10 ~ 0.15 ~ 0.20	0.067 ~ 0.10 ~ 0.14
Fcon Bolt tension stabilization (See P.438)	0.16 ~ 0.18 ~ 0.20	0.12 ~ 0.135 ~ 0.15

Note: The values in this table are for standard screw joints. They are not applicable for special conditions.

$K \approx 1.3\mu + 0.025$

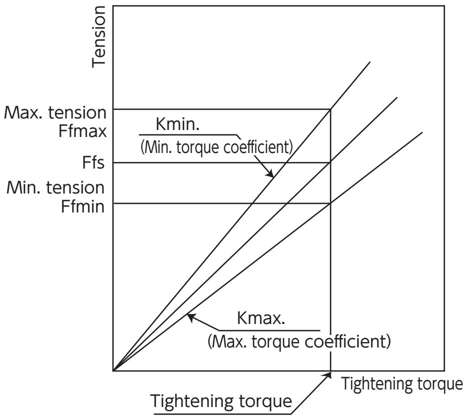
Min. and max. indicate the width of dispersion ($\pm 3\sigma$). The variation width will be smaller if the conditions are limited. (by lubrication oil, shape, etc.)

(3) Even when the torque is stable, axial tension may vary

Factors of defective torque coefficients

- Lubrication
- Machine factors of the bolted Joint
- Environment
- Tightening speed
- Reutilization screw

Figure 2-5. Relation between tightening torque and tightening axial tension



Example: When the tightening torque is stable, how will the axial tension change if the torque coefficient is changed?

Ft = T / (K·d)

Nominal diameter: d = 10 [mm] = 0.01 [m]
Tightening torque: T = 24 [N·m]
Torque coefficient: Kmin. = 0.14, K = 0.2, Kmax. = 0.26

Kmin. = 0.14

Ffmax = 24 / (0.14 × 0.01) = 17140 [N]

Kmax. = 0.26

Ffmin = 24 / (0.26 × 0.01) = 9230 [N]

K = 0.2

Ffs = 24 / (0.2 × 0.01) = 12000 [N]

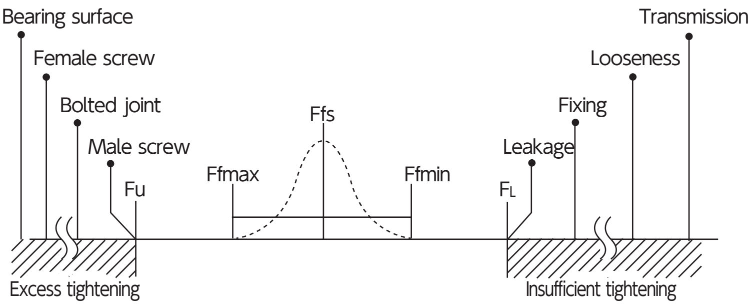
The axial tension will change to around double at Kmin. and Kmax.

2-4 Method for Determining Tightening Torque

(1) Applying appropriate tightening torque

Male screw strength Female screw strength Strength of bolted joint Bearing surface strength	Fu > Ffmax ~ Ffs ~ Ffmin > F_L	Fixing Sealing Transmission Looseness

Figure 2-6. Applying appropriate tightening torque

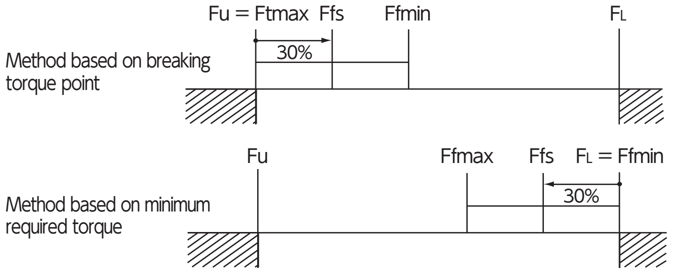


(2) Methods for determining the tightening torque

Table 2-3. Methods for determining the tightening torque

1. Standardization	To establish company standardization of tightening torque. (See P.35 Figure 2-8)
2. Confirmation of the present tightening torque	To establish the present tightening torque and confirm it.
3. Method based on breaking torque (Determination of upper limit)	To adopt 70% of the breaking torque as the tightening torque for screw joints. (Ffmax = Fu)
4. Method based on axial tension (Determination of lower limit)	To adopt 130% of the minimum required tightening torque, the level that prevents loosening, as the tightening torque. (Ffmin = F_L)
5. Method based on axial tension measurement	To specify the tightening torque as the optimal axial tension by measuring with an axial tension meter.

Figure 2-7. Various defective joints



(3) Standardize the tightening torque

Figure showing relation between screw and torque

Calculation formula

$$T = K \cdot d \cdot Ff$$

$$As = \frac{\pi}{4}\left(\frac{d_2+d_3}{2}\right)^2$$

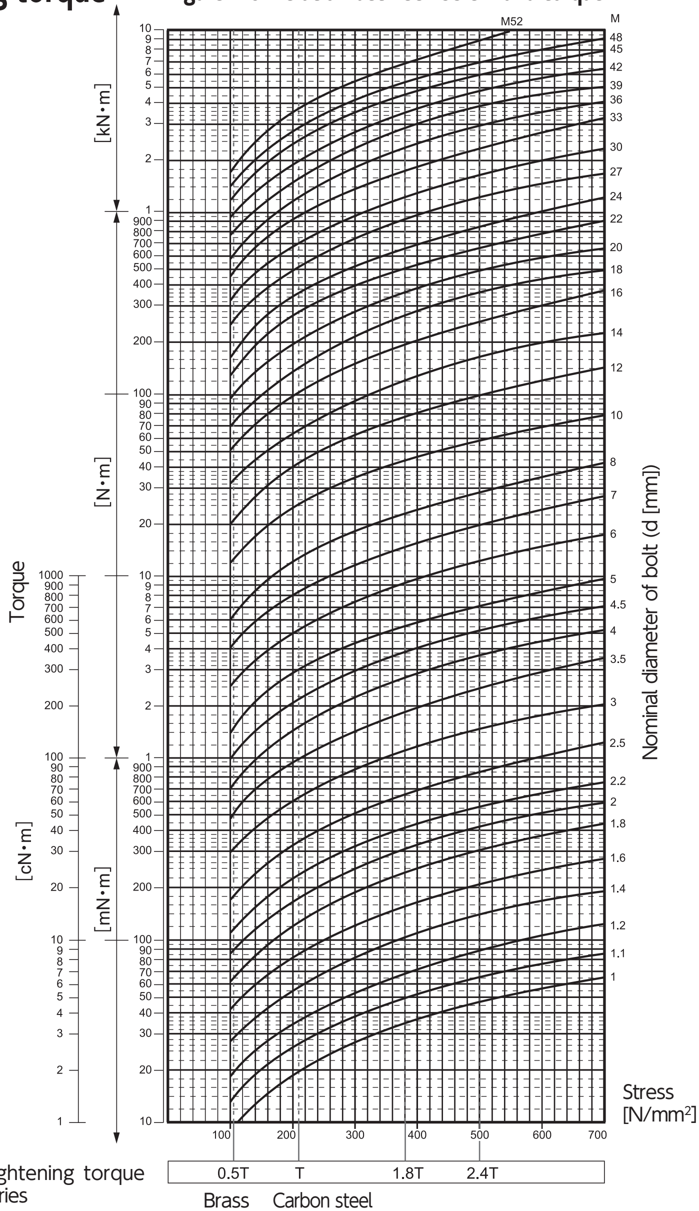
$$d_3 = d_1 - \frac{H}{6}$$

$$H = 0.866025P$$

$$\sigma = \frac{Ff}{As}$$

- T : Tightening torque [N·m]
- K : Torque coefficient 0.2 ($\mu \approx 0.15$)
- d : Nominal diameter of bolt [mm]
- Ff : Axial tension [N]
- As: Stress area of bolt [mm²] (JIS B 1082)
- d_2 : Effective diameter of bolt [mm] (JIS B 0205)
- d_3 : Value of 1/6 of fundamental triangle height subtracted from root diameter of bolt (d_1) [mm]
- d_1 : Root diameter of bolt [mm] (JIS B 0205)
- H : Fundamental triangle height [mm]
- P : Pitch [mm]
- σ: Tensile stress of bolt [N/mm²]

Figure 2-8. Relation between screw and torque



2-4 Method for Determining Tightening Torque

Standard tightening torque

Table 2-4. Standard tightening torque [N·m] (Reference value)

Nominal diameter	T [N·m]	0.5T series [N·m]	1.8T series [N·m]	2.4T series [N·m]
M1	0.0195	0.0098	0.035	0.047
(M1.1)	0.027	0.0135	0.049	0.065
M1.2	0.037	0.0185	0.066	0.088
(M1.4)	0.058	0.029	0.104	0.140
M1.6	0.086	0.043	0.156	0.206
(M1.8)	0.128	0.064	0.23	0.305
M2	0.176	0.088	0.315	0.42
(M2.2)	0.23	0.116	0.41	0.55
M2.5	0.36	0.18	0.65	0.86
M3	0.63	0.315	1.14	1.50
(M3.5)	1	0.5	1.8	2.40
M4	1.5	0.75	2.7	3.6
(M4.5)	2.15	1.08	3.9	5.2
M5	3	1.5	5.4	7.2
M6	5.2	2.6	9.2	12.2
(M7)	8.4	4.2	15	20.0
M8	12.5	6.2	22	29.5
M10	24.5	12.5	44	59
M12	42	21	76	100
(M14)	68	34	122	166
M16	106	53	190	255
M18	146	73	270	350
M20	204	102	370	490
(M22)	282	140	500	670
M24	360	180	650	860
(M27)	520	260	940	1240
M30	700	350	1260	1700
(M33)	960	480	1750	2300
M36	1240	620	2250	3000
(M39)	1600	800	2900	3800
M42	2000	1000	3600	4800
(M45)	2500	1260	4500	6000
M48	2950	1500	5300	7000
(M52)	3800	1900	6800	9200
M56	4800	2400	8600	11600
(M60)	5900	2950	10600	14000
M64	7200	3600	13000	17500
(M68)	8800	4400	16000	21000

Standard bolt stress: 210 [N/mm^2] Stress area of bolt

Table 2-5. Standard tightening torque [kgf·cm] (Reference value)

Nominal diameter	T [kgf·cm]	0.5T series [kgf·cm]	1.8T series [kgf·cm]	2.4T series [kgf·cm]
M1	0.199	0.100	0.357	0.479
(M1.1)	0.275	0.138	0.500	0.663
M1.2	0.377	0.189	0.673	0.897
(M1.4)	0.591	0.296	1.06	1.43
M1.6	0.877	0.438	1.59	2.10
(M1.8)	1.31	0.653	2.35	3.11
M2	1.79	0.897	3.21	4.28
(M2.2)	2.35	1.17	4.18	5.61
M2.5	3.67	1.84	6.63	8.77
M3	6.42	3.21	11.6	15.3
(M3.5)	10.2	5.1	18.4	24.5
M4	15.3	7.6	27.5	36.7
(M4.5)	21.9	11.0	39.8	53.0
M5	29.4	14.7	53.0	70.6
M6	53.0	26.5	93.8	124
(M7)	85.7	42.8	153	204
M8	127	63.2	224	301
M10	250	127	449	602
M12	428	214	775	1020
(M14)	693	347	1240	1690
M16	1080	540	1940	2600
M18	1490	744	2750	3570
M20	2080	1040	3770	5000
(M22)	2880	1430	5100	6830
M24	3670	1840	6630	8770
(M27)	5300	2650	9590	12600
M30	7140	3570	12800	17300
(M33)	9790	4890	17800	23500
M36	12600	6320	22900	30600
(M39)	16300	8160	29600	38700
M42	20400	10200	36700	48900
(M45)	25500	12800	45900	61200
M48	30100	15300	54000	71400
(M52)	38700	19400	69300	93800
M56	48900	24500	87700	118000
(M60)	60200	30100	108000	143000
M64	73400	36700	133000	178000
(M68)	89700	44900	163000	214000

Note: Conversion values rolled up to effective 3-digits.

Screws and applicable "T" series

Table 2-6. Screws and applicable "T" series

	Standard T series	0.5T series	1.8T series	2.4T series
Applicable screws (Strengths) (Material)	4.6 ~ 6.8 SS, SC, SUS	- Brass, Copper, Aluminum	8.8 ~ 12.9 SCr, SNC, SCM	10.9 ~ 12.9 SCr, SNC, SCM, SNCM
Axial tension standard value [N/mm^2] Min - Max	210 160 ~ 300	105 80 ~ 150	380 290 ~ 540	500 380 ~ 710
Application	To be applied to ordinary screws, unless otherwise specified	Male and female screws with copper, aluminum or plastic, for die-cast plastic products	Durable screw joints made of special steel including those affected by additional dynamic loads (Friction clamping)	
Applicable products	Ordinary products	Electronic products	Vehicles, Engines	Construction products

* The maximum to the minimum of the axial stress is considered as the dispersion of the torque coefficient.
Example: σ max = 210 × (0.2 ÷ 0.14) = 300 [N/mm^2]
Torque coefficient: 0.14 (minimum)~0.2 (average) ~ 0.26 (maximum)

(4) Standard tightening torque

Table 2-7. Standard tightening torque and bolt axial tension

Nominal diameter	Stress area of bolt [mm²]	T series				0.5T series				1.8T series				2.4T series			
		Std. tightening torque [N·m]	Std. axial tension Ffs [N]	Max. axial tension Ffmax [N]	Min. axial tension Ffmin [N]	Std. tightening torque [N·m]	Std. axial tension Ffs [N]	Max. axial tension Ffmax [N]	Min. axial tension Ffmin [N]	Std. tightening torque [N·m]	Std. axial tension Ffs [N]	Max. axial tension Ffmax [N]	Min. axial tension Ffmin [N]	Std. tightening torque [N·m]	Std. axial tension Ffs [N]	Max. axial tension Ffmax [N]	Min. axial tension Ffmin [N]
M1	0.46	0.0195	97.5	139.5	75.1	0.0098	48.8	69.8	37.6	0.035	175.5	251	135.2	0.047	234	334.7	180.2
(M1.1)	0.588	0.027	122.8	175.5	94.5	0.0135	61.4	87.8	47.3	0.049	221	315.9	170.1	0.065	294.6	421.2	226.8
(M1.2)	0.732	0.037	154.2	220.5	118.8	0.0185	77.1	110.3	59.4	0.066	277.5	396.9	213.7	0.088	370	529.1	284.9
(M1.4)	0.983	0.058	207.2	296.3	159.5	0.029	103.6	148.2	79.8	0.104	372.9	533.2	287.1	0.14	497.2	711	382.8
M1.6	1.27	0.086	268.8	384.4	207	0.043	134.4	192.2	103.5	0.156	483.8	691.8	372.5	0.206	645	922.4	496.7
(M1.8)	1.7	0.128	356	509	273.8	0.064	178	255	136.9	0.23	640	916	492.8	0.305	854	1221	657.1
M2	2.07	0.176	440	630	339	0.088	220	315	170	0.315	792	1133	610	0.42	1056	1511	814
(M2.2)	2.48	0.23	523	748	403	0.115	262	374	202	0.41	941	1346	725	0.55	1255	1794	966
M2.5	3.39	0.36	720	1030	555	0.18	360	515	278	0.65	1296	1854	998	0.86	1728	2472	1331
M3	5.03	0.63	1050	1502	809	0.315	525	751	405	1.14	1890	2703	1456	1.5	2520	3604	1941
(M3.5)	6.78	1	1429	2043	1100	0.5	715	1022	550	1.8	2572	3678	1980	2.4	3429	4903	2640
M4	8.78	1.5	1880	2680	1440	0.75	940	1340	720	2.7	3380	4830	2600	3.6	4500	6440	3470
(M4.5)	11.3	2.15	2390	3420	1840	1.08	1190	1710	920	3.9	4300	6150	3310	5.2	5730	8200	4410
M5	14.2	3	3000	4290	2310	1.5	1500	2150	1160	5.4	5400	7720	4160	7.2	7200	10300	5540
M6	20.1	5.2	4330	6200	3340	2.6	2170	3100	1670	9.2	7800	11150	6010	12.2	10400	14870	8010
(M7)	28.9	8.4	6000	8580	4620	4.2	3000	4290	2310	15	10800	15440	8320	20	14400	20590	11090
M8	36.6	12.5	7810	11170	6020	6.2	3910	5590	3010	22	14060	20110	10830	29.5	18750	26810	14440
M10	58	24.5	12250	17520	9430	12.5	6130	8760	4720	44	22050	31530	16980	59	29400	42040	22640
M12	84.3	42	17500	25000	13480	21	8750	12500	6740	76	31500	45000	24260	100	42000	60100	32340
(M14)	115	68	24300	34700	18700	34	12100	17400	9350	122	43700	62500	33660	166	58300	83300	44880
M16	157	106	33100	47400	25500	53	16600	23700	12800	190	59600	85300	45900	255	79500	113700	61200
(M18)	192	146	40600	58000	31200	73	20300	29000	15600	270	73000	104400	56200	350	97300	139200	74900
M20	245	204	51000	72900	39300	102	25500	36500	19600	370	91800	131300	70700	490	122400	175000	94200
(M22)	303	282	64100	91700	49400	140	32000	45800	24700	500	115400	165000	88800	670	153800	220000	118400
M24	353	360	75000	107300	57800	180	37500	53600	28900	650	135000	193100	104000	860	180000	257400	138600
(M27)	459	520	96300	137700	74100	260	48100	68900	37100	940	173300	247900	133500	1240	231000	330000	178000
M30	561	700	116700	166800	89800	350	58300	83400	44900	1260	210000	300300	161700	1700	280000	400000	216000
(M33)	694	960	145500	208000	112000	480	72700	104000	56000	1750	261800	374400	201600	2300	349000	499000	269000
M36	817	1240	172000	246000	133000	620	86000	123000	66300	2250	310000	443300	238700	3000	413000	591000	318000
(M39)	976	1600	205000	293000	158000	800	103000	147000	79000	2900	369200	528000	284300	3800	492000	704000	379000
M42	1120	2000	238000	340000	183000	1000	119000	170000	91700	3600	429000	613000	330000	4800	571000	817000	440000
(M45)	1310	2500	278000	397000	214000	1250	139000	199000	107000	4500	500000	715000	385000	6000	667000	953000	513000
M48	1470	2950	307000	439000	237000	1500	154000	220000	118000	5300	553000	791000	426000	7000	738000	1055000	568000
(M52)	1760	3800	365000	523000	281000	1900	183000	261000	141000	6800	658000	941000	506000	9200	877000	1254000	675000
M56	2030	4800	429000	613000	330000	2400	214000	306000	165000	8600	771000	1103000	594000	11600	1029000	1471000	792000
(M60)	2360	5900	492000	703000	379000	2950	246000	352000	189000	10600	885000	1266000	681000	14000	1180000	1687000	909000
M64	2680	7200	563000	804000	433000	3600	281000	402000	217000	13000	1013000	1448000	780000	17500	1350000	1931000	1040000
(M68)	3060	8800	647000	925000	498000	4400	324000	463000	249000	16000	1165000	1666000	897000	21000	1553000	2221000	1196000

2-5 Tolerance of Tightening Torque

Tolerance of Tightening Torque

For threaded joints, sometimes more definite tightening control is necessary, while at other times relatively rough control is adequate just so that joints will not loosen. The axial tension will be influenced by the dispersion of the torque coefficient and the tolerance of the tightening torque. In order to limit the axial tension dispersion, it will be meaningless simply to limit the tightening torque tolerance without also limiting the torque coefficient dispersion.

Tolerance of tightening torque Table 2-8.

Class	Tightening torque		Torque coefficient		Axial tension	
	Torque value	Tolerance	Coefficient	Tolerance	Dispersion	Upper/lower limit (Ratio)
Special	Measured value	± 5%	Measured value	± 15%	± 15% 115 ～ 85%	0.75
1st class	Measured value	± 10%	Measured value	± 20%	± 20% 120 ～ 80%	0.65
2nd class	Standard torque (measured value)	± 20%	0.14 ～ 0.26 (0.10 ～ 0.20)	± 30%	± 35% 135 ～ 65%	0.50
3rd class	Standard torque	± 30%	0.12 ～ 0.28 (0.09 ～ 0.20)	± 40%	± 50% 150 ～ 50%	0.35

( ) Values in brackets are when using disulfide molybdenum or wax as lubrication.

Relation formula of standard deviation

When you require strict bolt management, the following formulas express the relationships using the standard deviation (%) of the dispersion of the tightening torque and the torque coefficient.

Dispersion in axial tension (σ_n), torque coefficient (σ_k), and tightening torque (σ_t) relation

$$\sigma_n = \sqrt{\sigma k^2 + \sigma t^2}$$

In order to make σ_n smaller, it is necessary to make σ_k and σ_t smaller, respectively. Since it is easy to manage the tightening torque, $\sigma_k \approx \sigma_t$ will be set if $\sigma_k = 1/3\ \sigma_t$ is approximately controlled.

Example:

$K = 0.2 \pm 0.06\ (3\sigma)$

$\sigma_k\ \frac{0.06}{3X0.2} = \times 100\ (\%) = 10\ (\%)$

$\sigma_t = 3\%$

$\sigma_n\ \sqrt{10^2 + 3^2} = 10.4\%$

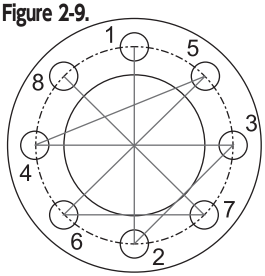
$(3\sigma_n = 31.2\%)$

2-6 Tightening of Tension Stability (Tightening Procedures)

Various tightening methods for stabilizing the initial axial tension have been devised.

(1) Zigzag tightening

Figure 2-9.



It is recommended to tighten nuts in a diagonal sequence as shown in the drawing.

First time············ Tighten to around 50% of the specified torque in turns.
Second time······· Tighten to around 75% of the specified torque in turns.
Third time························ Tighten to 100% of the specified torque in turns.

It is recommended to tighten all the bolts equally, and to avoid applying torque to one or several bolts on one side.

(2) Two steps tightening

The tightening sequence will not follow this drawing if tightening will be done using multiple automatic nutrunners. In the first step the nuts should be tightened provisionally. (50% of the tightening torque)
Next the final tightening should be done with 100% torque. The method consists of tightening in two steps.

(3) Two times tightening

In the case where there will be a delay for axial tension transmission and adequate initial axial tension will not be obtained, such as due to an existing soft part such as packing or rubber in the flap tightened, this is a method of securing initial axial tension by first tightening the nuts with 100% torque and then tightening them once more with 100% torque.

(4) Stabilized tightening

When the bearing will be deformed (including burr and surface roughness) by the tightening, this is a method of preventing initial axial tension drop by tightening the nuts with 100% torque, then loosening them and tightening them once more with 100% torque.