Hydraulic Installation Guidelines
Appendix E

Friction Type Bolted Connections

Bolted connections that are to transmit torque are best designed as friction connections. In a friction connection the torque is transmitted through the friction between the mating surfaces developed by the clamp load applied by the fasteners. A friction connection is preferred for connections where torque reversals and fluctuations are present, and for connections where slip is not permitted. Friction connections are not difficult to design if the designer has a good understanding of the relationship between normal force, coefficient of friction, and friction force; and the torque / tension relationship of threaded fasteners.

The following procedure can be used to design a friction connection to transmit a specified torque if the designer is familiar with the concepts mentioned above. This is not meant to be a tutorial on the design of connections. If the designer needs more information or background than this appendix provides, a reference such as the book "An Introduction to the Design and Behavior of Bolted Joints" by John F. Bickford should be used.

The design of a friction connection is based on the torque that is to be transmitted, and the Safety Factor that is to be used. Generally, a minimum Safety Factor of 1.5 is used. In this example the maximum torque to be transmitted will be 20,000 lb-in , the bolt circle diameter will be 10 inches, and the coefficient of friction will be .12 (a conservative value for a clean, dry steel to steel connection), and 12 fasteners will be used in the connection.

1. Determine the maximum torque to be transmitted through the connection (20,000 lb-in) and multiply this by the Safety Factor (20,000 x 1.5 = 30,000 lb-in). This is the Design Torque (DT).

2. Select a bolt circle diameter for the fasteners (BCD). This will be 10 inches (BCD = 10 inches).

3. Divide the Design Torque by half of the bolt circle diameter. [DT / (BCD/2)], or 30,000 lb-in /(10 inches /2) = 6,000 lb. This is the Friction Force required (F_f).

4. Divide the Friction Force by the coefficient of friction (μ) to get the required Normal Force, also known as the Total Clamp Load (TCL). [F_f / μ = TCL]. (6000 lb / .12 = 50,000 lb).

5. Decide how many fasteners will be used in the connection. Commonly, eight to twenty four fasteners are used, although more or fewer may be used. Divide the Total Clamp Load by the number of fasteners used to determine the Clamp Load per fastener (CL). [TCL / qty = CL]. (50,000 lb / 12 = 4167 lb).

6. Estimate a nominal diameter (D) to be used for the fasteners. In this example use a nominal diameter of 3/8 inch.

7. Determine the minimum required fastener torque (T_f). The recommended formula for this is: **$T_f = k * D * CL$**, where k is a coefficient based on the fastener material, thread finish and conditions, cleanliness of the threads, and lubrication of the threads. If the threads are clean and free running with no burrs or deformed areas, and if Loctite® #242 or #262 is used a value of 0.2 can be used for k. For this example, $T_f = 0.2 * 3/8$ inch * 4167 lb = 313 lb-in or about 26 lb-ft. For inch fasteners T_f is in lb-in, D is in inches, and CL is in lb. For metric fasteners T_f is Nm, D is in mm, and CL is in kN.

CAUTION ! The value of the coefficient k has a large impact. If the threads are dirty or not free running the value of 0.2 cannot be used. Depending on material, thread condition, and lubrication the value of k can vary from 0.05 to 0.35.

8. If the minimum required fastener torque is greater than the minimum stated in table E1, and less than the torque that it takes to equal the proof load stated in table E2, the size and quantity of fasteners is sufficient. If the minimum required fastener torque is below the value in table E1, the fastener can be tightened to the value in table E1, increasing the Safety Factor. If the minimum required fastener torque is above the value in table E2, the fastener size must be increased, the quantity increased, the bolt circle diameter increased, or a combination of these factors used to obtain an acceptable value. In this example, if a 3/8 inch coarse thread grade 5 bolt is used, the tightening torque would have to be increased to 35 lb-ft to comply with table E1.

The above procedure has been found to be satisfactory based on a number of clutch/brake installations. Special conditions or unusual installations may require special designs or considerations. In any case, it is the responsibility of the designer to determine that the connection is suitable for the application and that the quantity, size, grade, and tightening torque of the fasteners results in a safe and secure connection.

CAUTION!

An improperly designed friction connection may fail during machine operation, resulting in unsafe operation or a hazardous failure of the machine; these conditions can cause serious injury to personnel and damage to equipment. All torque transmitting connections are to be designed by qualified personnel and evaluated for proper safety factor for the intended application.

Conversion terms:
1 kN = 224.809 lb
1 Nm = 0.737 lb-ft = 8.844 lb-in

Table E1

Minimum Fastener Tightening Torque

Nominal Size	Grade 5 lb-ft	Grade 8 lb-ft	Grade 9.8 lb-ft	Grade 9.8 Nm	Grade 10.9 lb-ft	Grade 10.9 Nm	Grade 12.9 lb-ft	Grade 12.9 Nm
1/4 - 20	10	14	- - -	- - -	- - -	- - -	- - -	- - -
5/16 - 18	20	30	- - -	- - -	- - -	- - -	- - -	- - -
3/8 - 16	35	50	- - -	- - -	- - -	- - -	- - -	- - -
1/2 - 13	75	90	- - -	- - -	- - -	- - -	- - -	- - -
5/8 - 11	150	225	- - -	- - -	- - -	- - -	- - -	- - -
3/4 - 10	250	400	- - -	- - -	- - -	- - -	- - -	- - -
1 - 8	600	975	- - -	- - -	- - -	- - -	- - -	- - -
1-1/4 - 7	1120	1920	- - -	- - -	- - -	- - -	- - -	- - -
1-1/2 - 6	1910	3375	- - -	- - -	- - -	- - -	- - -	- - -
M 6 x 1	- - -	- - -	7	9.8	10	13.7	11	15.7
M 8 x 1.25	- - -	- - -	18	25	25	34	29	39
M 10 x 1.5	- - -	- - -	36	49	47	64	58	79
M 12 x 1.75	- - -	- - -	58	79	85	115	100	137
M 14 x 2	- - -	- - -	94	128	130	176	160	216
			Grade 8.8					
M 16 x 2	- - -	- - -	144	196	196	265	240	325
M 20 x 2.5	- - -	- - -	260	354	370	500	440	600
M 24 x 3	- - -	- - -	470	638	670	905	795	1080
M 27 x 3	- - -	- - -	707	960	1000	1355	1205	1640
M 30 x 3.5	- - -	- - -	967	1314	1360	1850	1630	2220

NOTE:

Values for inch fasteners are from the Formula for Wrench Torque for Steel Bolts, Studs, and Cap Screws in the 25th Edition of the Machinery's Handbook.
Values for metric fasteners are from various industry sources.

Metric grade 9.8 is not valid in sizes above 14 mm, 16 mm and larger use grade 8.8.

CAUTION:

Grade classifications for inch and metric fasteners do not use the same systems and the grade numbers cannot be directly compared.

Table E2a

Proof Loads and Resultant Torques for Inch Fasteners

Nominal Size	Grade 5 Proof load lb	Grade 5 Torque lb-ft	Grade 8 Proof load lb	Grade 8 Torque lb-ft
1/4 - 20	2700	11.25	3800	15.8
5/16 - 18	4450	23	6300	32
3/8 - 16	6600	41	9300	58
1/2 - 13	12100	100	17000	141
5/8 - 11	19200	200	27100	282
3/4 - 10	28400	355	40100	500
1 - 8	51500	858	72700	1210
1-1/4 - 7	71700	1493	116300	2420
1-1/2 - 6	104000	2600	168600	4215

Table E2b

Proof Loads and Resultant Torques for Metric Fasteners

Nominal Size	Grade 9.8 Proof Load kN	Grade 9.8 Torque Nm	Grade 10.9 Proof Load kN	Grade 10.9 Torque Nm	Grade 12.9 Proof Load kN	Grade 12.9 Torque Nm
M 6 x 1	14.5	17	18.9	22	22.1	26
M 8 x 1.25	26.4	42	34.4	55	40.3	60
M 10 x 1.5	41.8	80	54.5	105	63.8	125
M 12 x 1.75	60.7	145	79.2	190	92.7	220
M 14 x 2	82.8	230	108	300	127	355
	Grade 8.8					
M 16 x 2	104	330	148	470	173	550
M 20 x 2.5	162	645	230	920	270	1080
M 24 x 3	233	1115	332	1590	388	1860
M 27 x 3	303	1635	431	2325		
M 30 x 3.5	370	2220	527	3160	617	3700

NOTES:

Proof Load values for inch fasteners are from “Fastener Standards”, Sixth Edition, by the Industrial Fasteners Institute.

Proof Load values for metric fasteners are from “Metric Fastener Standards”, Second Edition, by the Industrial Fasteners Institute.

Torque values in tables E2a and E2b are obtained from the formula $T = k*D*L$, where L is the proof load and k = 0.2. Values for torque in tables are not valid if k is not equal to 0.2.