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Determination of coefficient of friction of bolt/nut assemblies under specified conditions

DIN 946

Bestimmung der Reibungszahlen von Schrauben und Muttern unter festgelegten Bedingungen

In keeping with current practice in standards published by the International Organization for Standardization (ISO), a comma has been used throughout as the decimal marker.

1 Scope and field of application

This standard specifies a tightening test for determining the coefficient of friction of bolt/nut assemblies under specified conditions. it is only applicable for comparison purposes, such as a comparison of assemblies with different surface finishes or for cases where different lubricants are used.

Given the variety of boundary conditions in service (e.g. resilience of bolted components, finish of washers), the results of testing in accordance with this standard do not permit conclusions to be drawn as to the behaviour of bolt/nut assemblies in a particular application, e.g. where such assemblies form part of structural configurations.

Note. Besides the method of test described here, the coefficient of friction may also be determined by measuring the change in length of a srew or bolt after application of a given tightening torque.

2 Parameters

d	nominal thread diameter
d_2	bolt thread pitch diameter
d_3	bolt thread minor diameter
$d_{a\,max}$	maximum internal bearing diameter of screw or bolt as in ISO 885 : 1976
d_h	clearance hole diameter
d_w	external diameter of bearing face of bolt head or nut
D_{Km}	mean diameter of bearing face of bolt head or nut relevant for frictional torque
l_K	clamping length
F_V	proofing load
$F_{0,2}$	load at minimum yield stress or 0,2 % proof stress
M_A	tightening torque for generating load F_V
M_G	component of tightening torque acting in thread
M_K	frictional torque acting at bearing face of bolt head or nut
P	pitch
μ_G	coefficient of friction
μ_K	coefficient of friction at bearing face of bolt head or nut
μ_{ges}	reference coefficient for characterizing overall friction behaviour of a bolt/nut assembly

3 Principle

A tightening torque is steadily applied to a bolt/nut assembly at ambient temperature.

In the range of elastic deformation, there is a linear relationship between torque and proofing load. This is expressed by the following formula applicable to bolt/nut assemblies with ISO metric thread (and also to other screw threads with triangular profile and a 60° pitch angle as specified in ISO 68 : 1973).

$$M_A = F_V \left(0{,}159 \cdot P + 0{,}578 \cdot d_2 \cdot \mu_G + \frac{D_{Km}}{2} \cdot \mu_K\right) \quad (1)$$

M_A is composed of a component acting in the thread and serving to apply the proofing load and to overcome friction in the thread, M_G, and a component acting at the bolt head or nut bearing face required to overcome the friction acting here, M_K.

$$M_A = M_G + M_K \quad (2)$$

where

$$M_G = F_V\,(0{,}159 \cdot P + 0{,}578 \cdot d_2 \cdot \mu_G) \quad (3)$$

and

$$M_K = F_V \frac{D_{Km}}{2} \cdot \mu_K \quad (4)$$

The mean diameter required for measuring the coefficient of friction acting at the bearing face of the bolt head or nut is to be calculated from

$$D_{Km} = \frac{d_w + d_h}{2} \quad (5)$$

Equation (5) applies for plane bearing faces located vertically to the bolt axis and makes allowance for the geometrical tolerances as specified in ISO 4759 Part 1. In other cases (e.g. in the case of screws with a 'concave' bearing face), D_{Km} is to be agreed between manufacturer and customer.

Due allowance shall be made for bearing faces which differ in form (e.g. countersunk heads or spherical faces). An accurate determination of the effective radius, $\frac{1}{2} D_{Km\,eff.}$ shall be based on the trace of the head visible after measurement.

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Determination of the coefficient of friction shall be based on the relationships obtained when transforming equations (3) and (4), i.e.

$$\mu_G = \frac{M_G / F_V - 0{,}159 \cdot P}{0{,}578 \cdot d_2} \quad (6)$$

and

$$\mu_K = \frac{2 \cdot M_K}{D_{Km} \cdot F_V} \quad (7)$$

Where the test apparatus (cf. clause 4) does not permit a separate measurement of M_G and M_K, a reference coefficient of friction may be calculated from:

$$\mu_{ges} = \frac{M_A / F_V - 0{,}159 \cdot P}{0{,}578 \cdot d_2 + \frac{D_{Km}}{2}} \quad (8)$$

This coefficient can only be used for assessment of the overall friction behaviour of bolt/nut assemblies but is not suitable for the design of bolted connections in general.

Since the test results are influenced by a variety of parameters, minimum requirements for the test procedure have been specified.

4 Apparatus

For testing, a device shall be used which is capable of receiving a bolt, nut and washer and to which a device for recording the torque-related data is connected. Care shall be taken to ensure that the washer and whichever part (i.e. bolt or nut) is not to be moved during tightening of the assembly are held firmly in place (cf. diagram in figure 1).

For acceptance inspection, the test apparatus and test conditions shall be agreed between the parties concerned since the resilience of the apparatus may have a considerable influence on the test result.

In cases of arbitration, only such coefficients of friction may be compared that have been determined using the same apparatus, the same washer and bolt/nuts with the same thread. The measuring system shall permit determination of M_A, M_G, M_K and F_V with a limit of error of $\pm$ 3 %.

5 Procedure

Each test shall be carried out with a set of new bolts, nuts and washers, with the property classes of bolt and nut being compatible (e.g. 10, 9/10).

When investigating the effect of lubricants on the tightening process, a special test setup may be specified which then may be used for a series of tightening tests. In such cases, bolt, nut and washer shall have the status of reference components.

5.1 Mounting of bolt/nut assembly

The bolt/nut assembly to be tested shall be clamped into the apparatus so that the bolt end projects beyond the surface of the nut (as specified in DIN 78) when this is fitted for a maximum number of eight turns of thread. On the shank side of the nut, there shall be at least two complete turns of thread (i.e. 2 P) not engaged (cf. figure 1).

5.2 Washer

Where no particular agreements have been made as to the condition of the washer under that part of the assembly which is rotated in the tightening process, steel washers shall be used which are to meet the following requirements:

a) polished lengthwise, with $R_a = 0{,}8$ to 1,6 µm;
b) flatness tolerance and parallelism tolerance each of 0,04 mm;
c) bright and degreased;
d) minimum thickness: 0,5 d;
e) hardness: 38 to 42 HRC or 380 to 420 HV 20 (e.g. made of C 45, quenched and tempered);
f) clearance hole diameter, $d_h = d_{a\ max}$ (tolerance H 13), not countersunk.

5.3 Thread tolerance for and surface finish of reference components

Surface finish and thread tolerance for reference components shall comply with the following specifications.

a) Where bolts are to be tested, nuts with a bright finish shall be used as reference components, degreased and capable of being fully loaded (e.g. hexagon nuts), with thread manufactured to tolerance 6 H. If the bolt cannot be easily screwed in by hand, nuts with thread manufactured to a larger tolerance shall be used.

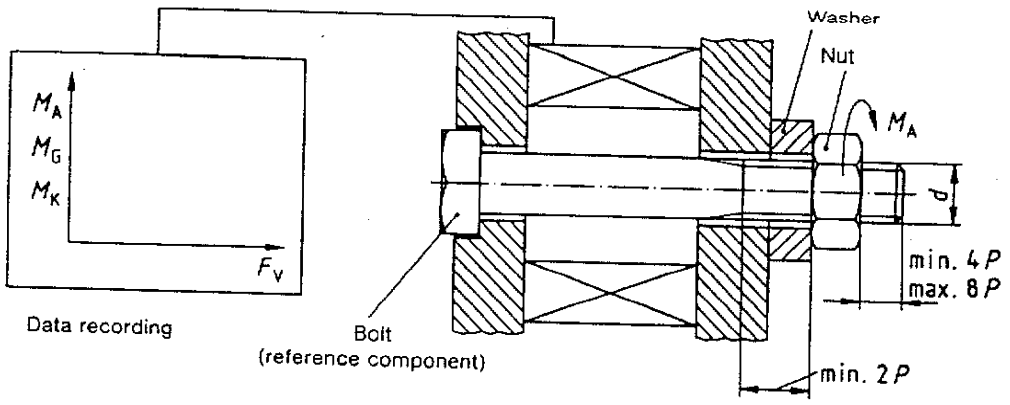

Figure 1. Diagram of test arrangement for measuring proofing load and torques relevant for determining the coefficient of friction

b) Where nuts are to be tested, zinc-phosphated bolts shall be used as reference components, degreased and with thread manufactured to tolerance 6 g (in the uncoated condition). The coated bolt shall permit the nut to be easily mounted by hand.

c) When investigating the effects of lubricants, bolts and nuts shall be used which comply with the requirements specified under items a) and b) above.

Note. A standard dealing with a test method for dry lubricants is currently being prepared.

5.4 Tightening procedure

Tightening of the assembly shall be at a rate of 30 min^{-1}.

6 Evaluation

The coefficients of friction shall be determined from equations (5) to (8), making allowance for the geometry of bolt, nut and washer for the torque applied and the proofing load generated.

The following parameters shall be entered in equations (5) to (8):

a) nominal sizes of d_2 and P (as in DIN 13 Part 1 for coarse pitch threads, as in DIN 13 Parts 2 to 11 for fine pitch threads, and as in ISO 5855 Part 1 or LN 9163 Part 1 for threads used in aerospace applications), and of d_h;

b) size of d_w, in accordance with the relevant product standard.

Evaluation of the test results may best be made by reading the coefficients of friction from the diagrams plotted on the basis of equations (3) and (4). Normally, the minimum value of d_w as specified in the relevant product standard is to be entered in these equations. Where μ_K is to be determined more accurately (e.g. when investigating the effects of lubricants), D_{Km} shall be determined from the trace mark on the bearing face visible after tightening.

The test results shall, where possible, be plotted in a single graph. Where bolt/nut assemblies are to be subjected to repeated tightening and loosening cycles, the results for each assembly shall be plotted separately. Evaluation shall be based on a proofing load obtained for an average value of μ_G or μ_{ges} as determined by testing as specified in VDI 2230 Part 1.

By way of simplification, for normal values of μ, from 0,10 to 0,16, evaluation may be based on a value of F_V equal to $0{,}7 \cdot F_{0.2}$.

Outliers shall be ignored if they can be definitely assigned to abnormal influences (e.g. a chip caught between the threads). As a rule, evaluation shall be based on 12 tests, a different number of tests being subject to agreement.

7 Test report

In the test report, the coefficients of friction (normally, minimum and maximum values) shall be given, together with details of the test conditions as itemized below, and stating any deviations from these conditions.

7.1 Bolt

a) Style or standard designation.

b) Thread tolerance.

c) Property class as in ISO 898 Part 1, if applicable.

d) Details of manufacture (e.g. chip removal, rolling) and subsequent treatment (e.g. quenching and tempering, final rolling).

e) Surface finish (e.g. as in DIN 267 Part 9) and surface condition (e.g. oiled).

7.2 Nut

a) Type or standard designation.

b) Thread tolerance.

c) Property class as in ISO 898 Parts 2 and 6, or DIN 267 Part 4, if applicable.

d) Surface finish (e.g. as in DIN 267 Part 9) and surface condition (e.g. oiled).

7.3 Washer

a) Material.

b) Hardness.

c) Surface roughness.

d) Finish (e.g. polished lengthwise).

e) Thickness.

7.4 Other information

a) Type of test apparatus.

b) Component moved in tightening.

c) Rate of tightening.

d) Temperature and relative humidity.

e) Time between manufacture and testing, where known.

Standards and other documents referred to

DIN 13 Part 1	ISO metric screw threads; 1 mm to 68 mm diameter coarse pitch threads; nominal sizes
DIN 13 Part 2	ISO metric screw threads; 0,2 mm, 0,25 mm and 0,35 mm fine pitch threads with diameters from 1 mm to 50 mm; nominal sizes
DIN 13 Part 3	ISO metric screw threads; 0,5 mm fine pitch threads with diameters from 3,5 mm to 90 mm; nominal sizes
DIN 13 Part 4	ISO metric screw threads; 0,75 mm fine pitch threads with diameters from 5 mm to 110 mm; nominal sizes
DIN 13 Part 5	ISO metric screw threads; 1 mm and 1,25 mm fine pitch threads with diameters from 7,5 mm to 200 mm; nominal sizes
DIN 13 Part 6	ISO metric screw threads; 1,5 mm fine pitch threads with diameters from 12 mm to 300 mm; nominal sizes
DIN 13 Part 7	ISO metric screw threads; 2 mm fine pitch threads with diameters from 17 mm to 300 mm; nominal sizes
DIN 13 Part 8	ISO metric screw threads; 3 mm fine pitch threads with diameters from 28 mm to 300 mm; nominal sizes
DIN 13 Part 9	ISO metric screw threads; 4 mm fine pitch threads with diameters from 40 mm to 300 mm; nominal sizes
DIN 13 Part 10	ISO metric screw threads; 6 mm fine pitch threads with diameters from 70 mm to 500 mm; nominal sizes
DIN 13 Part 11	ISO metric screw threads; 8 mm fine pitch threads with diameters from 130 mm to 1000 mm; nominal sizes
DIN 78	Thread ends and lengths of projection of bolt ends for ISO metric screw threads in accordance with DIN 13 series
DIN 267 Part 4	Fasteners; technical delivery conditions; property classes for nuts (old classes)
DIN 267 Part 9	Fasteners; technical delivery conditions; electroplated fasteners
ISO 68:1973	ISO general purpose screw threads; basic profile
ISO 885:1976	General purpose bolts and screws, metric series; radii under the head
ISO 898-1:1988	Mechanical properties of fasteners; bolts, screws and studs
ISO 898-2:1980	Mechanical properties of fasteners; nuts with specified proof load values
ISO 898-6:1988	Mechanical properties of fasteners; nuts with specified proof load values; fine pitch thread
ISO 4759-1:1978	Tolerances for fasteners; bolts, screws, and nuts with thread diameters from 1,6 to 150 mm and product grades A, B and C
ISO 5855-1:1988	Aerospace; MJ threads; general requirements
LN 9163 Part 1	Aerospace; ISO metric screw threads; fundamental deviations and tolerances
VDI 2230 Part 1	Design for high-strength structural bolting; cylindrical single-screw connections

International Patent Classification

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