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Aerospace series — Dynamic testing of the locking behaviour of bolted connections under transverse loading conditions (vibration test)

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National foreword

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Aéronautique et espace — Essai dynamique des caractéristiques de freinage des éléments de fixation, dans des conditions de charge transversale (essai de vibration)

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Foreword

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information.

The committee responsible for this document is ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 4, *Aerospace fastener systems*.

Aerospace series — Dynamic testing of the locking behaviour of bolted connections under transverse loading conditions (vibration test)

1 Scope

This International Standard applies to the dynamic testing of the locking behaviour of bolted connections in order to investigate the self-loosening behaviour of fasteners for aerospace applications and is mainly intended for development work.

As test apparatuses are different (e.g. stiffness distribution), testing in accordance with this International Standard, therefore, does not allow an absolute statement to be made on the locking behaviour of bolted assemblies under service loads.

Thus, the objective of this test is a comparative evaluation of locking elements under defined test conditions.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16047, *Fasteners — Torque/clamp force testing*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16047 and the following apply.

3.1
clamp force
F
axial tension acting on the bolt shank or compression acting on the clamped member

[SOURCE: ISO 16047:2005, 3.1; modified — without restriction “during tightening”]

3.2
ultimate clamp force
F_u
theoretical maximum clamp force under combined stress condition potentially induced before bolt/nut failure

[SOURCE: ISO 16047:2005, 3.3, modified]

3.3
initial clamp force
F_M
clamp force after tightening of test specimen before test

3.4
relative clamp force loss
Y

$$Y = \left(1 - \frac{F}{F_M}\right) * 100\,\%$$

3.5
number of load cycles
N
number of transverse movements of the glider plate of the apparatus

3.6
pitch diameter
D_2
d_2
diameter of the pitch cylinder or pitch cone

[SOURCE: ISO 5408:2009, 5.9, modified — without reference, without note]

3.7
minor diameter
D_1
d_1
d_3
diameter of an imaginary cylindrical or conical surface tangent to the roots of an external thread and/or to the crests of an internal thread

[SOURCE: ISO 5408:2009, 5.3, modified — without references, without notes]

3.8
tightening torque
T
overall torque applied on nut or bolt head in tightening

[SOURCE: ISO 16047:2005, 3.4, modified — without substitutes]

3.9
self-locking torque
prevailing torque
torque to be applied to the nut or bolt to maintain its movement of rotation in relation to the associated part, the assembly being under no axial load, and the nut-locking system being completely engaged with the bolt (two pitches minimum protrusion, including the end chamfer)

[SOURCE: ISO 5858:1999, 3.15]

3.10
transverse displacement
t_s
transverse movement of the glider plate in both directions from fastener centre line

Note 1 to entry: It is expressed in millimetres.

4 Test principle

The fasteners under test are tightened in a vibration testing machine to achieve a defined clamp force, F_M, and then subjected to dynamic transverse loading. No additional axial operating force is applied to the fasteners.

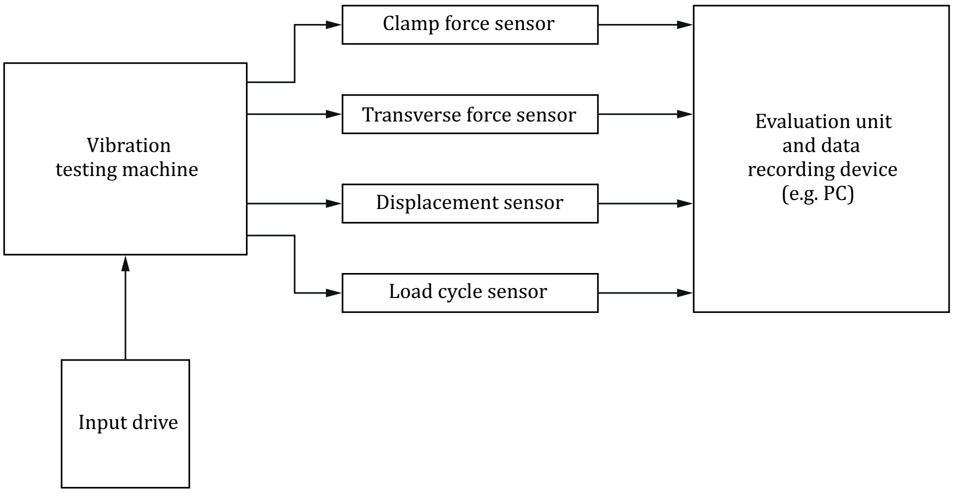
The change in clamp force during the vibration test is measured.

The test terminates after a specified number of load cycles or upon fracture of the bolt, stabilization of residual clamp force, or upon complete loss of clamp force.

5 Apparatus

5.1 Schematic overview of components

See Figure 1.



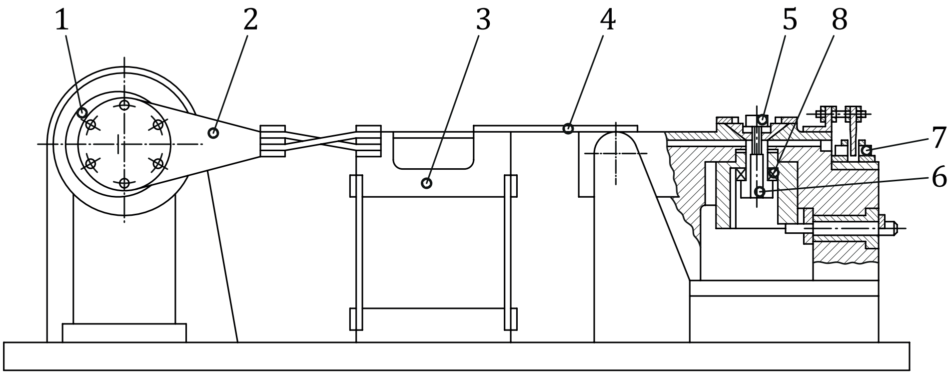
NOTE Transverse force sensor is optional.

Figure 1 — Schematic overview of components

5.2 Test machine description

The machine (see Figure 2 for an example of a vibration testing machine) essentially consists of e.g. a motor drive or a hydraulic drive generating a transverse displacement in the test fixture.

The test fixture consists of a stationary base and a floating glider plate which acts as clamped members in the bolted joint in which the fastener to be tested is installed. The glider plate contains a rotationally immobilized washer (test washer). The stationary base accommodates a clamp force-sensor for measuring the clamp force between the glider plate and the stationary base. In the force-sensor, a test insert is used that it is locked to prevent it from rotating. The relative movement between the stationary base and the glider plate is measured with a displacement sensor.



Key

1 infinitely adjustable eccentric

2 connecting rod

3 transverse force sensor (optional)

4 connecting plate

5/6 fastener test assembly

7 displacement sensor

8 clamp force sensor (axial)

Figure 2 — Example of a vibration testing machine

5.3 Apparatus requirements

The apparatus shall meet the following requirements.

a) The relative movement (transverse displacement) between the stationary base and glider plate shall be infinitely variable, preferably during operation and adjusted through electronic control. In the thread diameter range up to 25,4 mm, the clamped-up testing facility shall permit relative movements of up to ±1,5 mm between the stationary base and the glider plate.

b) Testing frequency between 10 Hz and 15 Hz shall be possible; the frequency during the testing shall be at an accuracy of ±3 %.

c) Measurement uncertainty for the clamp force shall be within ±2 % as measured on the entire measuring chain consisting of sensor, cable, charge amplifier, and data acquisition device. The entire measuring chain shall be calibrated accordingly.

d) Measurement uncertainty for the transverse displacement shall be within ±3 % as measured on the entire measuring chain consisting of sensor, cable, charge amplifier, and data acquisition device. The entire measuring chain shall be calibrated accordingly.

e) The stationary base and the glider plate shall be concentric within ±0,1 mm at the mid-position of transverse displacement.

f) The following variables are to be measured and recorded: initial clamp force, clamp force in relation to number of load cycles, test frequency, transverse displacement plus the applied installation torque values.

g) The glider plate shall be precisely guided in the transverse direction within a tolerance of ±0,10 mm of lateral movement.

h) The stationary base and the glider plate shall be designed such that the clamp force cannot bend them. The gap between the stationary base and glider plate at fastener position shall be 1 mm ± 0,05 mm under load.

6 Test procedure

The test procedure consists of two elements; the reference test and the verification test.

The reference tests are to be carried out on an unsecured bolted joint, assembled in the same way, and with the same parameters as specified for the verification tests that will determine the securing effect of the securing element under test.

During the reference tests, the effective transverse displacement is varied through corresponding adjustments to the drive for the test equipment (the stroke). For reasons of reproducibility, the transverse displacement at which the pre-stressing force is fully lost after 300 ± 100 load cycles shall be ascertained three times, using new parts each time. This transverse displacement provides the basis for the verification tests.

For reasons of reproducibility, a valid reference test shall be carried out three times, using new parts each time. The verification test has to be done in the same condition and settings as the reference test.

The glider plate is positioned to zero transverse displacement. The fasteners to be tested (bolt or nut) is inserted and tightened to the defined clamp force. The effective transverse displacement is verified continuously during the vibration test. The clamp force is recorded versus the number of load cycles (see Figure 3). The test is carried out at room temperature.

If locking element is not damaged after test, it can be tested multiple times to validate self-locking behaviour at multiple installation cycles, if required by test requester.

7 Test settings

Self-locking elements (e.g. nut, washer, split pin, lock wire, etc.) shall be tested typically with a transverse displacement t_S = ±0,5 mm for fastener dimensions up to and including M12/0.500" and t_S = ± 0,8 mm for fastener dimensions above M12/0,500" and at a frequency of 12,5 Hz and with the clamp force specified in Table 1 and Table 2 (representing 75 % of calculated F_u). Clamp force has to be adjusted to the weakest element of the assembly either bolt or nut strength class.

The length to diameter ratio shall be as short as possible and preferably around 2,0 to 2,5.

Different test settings could be defined by test requester.

To achieve reproducible results, the following factors need to be defined unambiguously:

a) initial clamp force (see examples Table 1 and Table 2);

b) testing frequency;

c) effective transverse displacement;

d) adjustment of the test fixture to the fastener length.

Table 1 — Example of clamp force settings (metric series)

Values in Newton

Thread	Clamp force[a] F_M setting [N] for strength class								
	450 MPa	600 MPa	900 MPa	1 000 MPa	1 100 MPa	1 210 MPa	1 275 MPa	1 500 MPa	1 800 MPa
MJ 4 × 0,7	3 146	4 194	6 292	6 991	7 690	8 459	8 913	10 486	12 583
MJ 5 × 0,8	5 073	6 764	10 146	11 274	12 401	13 641	14 374	16 910	20 292
MJ 6 × 1,0	7 212	9 617	14 425	16 028	17 631	19 394	20 435	24 042	28 850
MJ 7 × 1,0	10 290	13 721	20 581	22 868	25 154	27 670	29 156	34 301	41 162
MJ 8 × 1,0	13 900	18 533	27 799	30 888	33 977	37 375	39 382	46 332	55 599
MJ 8 × 1,25	13 122	17 496	26 244	29 160	32 076	35 283	37 179	43 739	52 487
MJ 10 × 1,25	21 754	29 006	43 509	48 343	53 177	58 495	61 638	72 515	87 018
MJ 10 × 1,5	20 767	27 690	41 535	46 150	50 765	55 841	58 841	69 225	83 070
MJ 12 × 1,25	32 481	43 308	64 963	72 181	79 399	87 339	92 030	108 271	129 925
MJ 14 × 1,5	44 023	58 698	88 047	97 830	107 613	118 374	124 733	146 745	176 094
MJ 16 × 1,5	58 842	78 456	117 684	130 760	143 836	158 219	166 719	196 140	235 367
MJ 18 × 1,5	75 782	101 043	151 564	168 405	185 245	203 770	214 716	252 607	303 128
MJ 20 × 1,5	94 844	126 458	189 688	210 764	231 840	255 024	268 724	316 146	379 375
MJ 22 × 1,5	116 027	154 702	232 053	257 837	283 621	311 983	328 742	386 756	464 107
MJ 24 × 2,0	134 806	179 741	269 611	299 568	329 525	362 477	381 949	449 352	539 222

NOTE 1 Clamp force setting = 75 % calculated F_u.

NOTE 2 Applying these values on regular metric series (see DIN 13 and ISO 965) will result in slightly higher test loads.

[a] Calculated with mean values from ISO 5855-2.

Table 2 — Example of clamp force settings (inch series)

Values in Newton

Thread	Clamp force[a] setting [N] for strength class								
	75 ksi	**90 ksi**	**125 ksi**	**145 ksi**	**160 ksi**	**180 ksi**	**200 ksi**	**220 ksi**	**240 ksi**
.1640-36	3 972	4 763	6 623	7 683	8 474	9 534	10 595	11 655	12 715
.1900-24	4 794	5 749	7 993	9 272	10 228	11 507	12 787	14 066	15 346
.2500-20	8 679	10 408	14 470	16 787	18 516	20 832	23 149	25 465	27 782
.3125-18	14 225	17 059	23 718	27 515	30 349	34 146	37 943	41 741	45 538
.3750-16	20 959	25 134	34 945	40 539	44 715	50 309	55 904	61 498	67 093
.4375-14	28 745	34 472	47 927	55 599	61 326	68 999	76 671	84 344	92 017
.5000-13	38 246	45 865	63 767	73 976	81 596	91 804	102 013	112 222	122 431
.5625-12	48 966	58 721	81 641	94 711	104 467	117 537	130 607	143 677	156 747
.6250-11	60 784	72 894	101 346	117 571	129 680	145 905	162 130	178 355	194 579
.7500-10	89 539	107 378	149 290	173 190	191 028	214 929	238 829	262 729	286 629
.8750-9	123 307	147 873	205 591	238 504	263 070	295 984	328 897	361 811	394 725
1.0000-8	161 674	193 884	269 561	312 716	344 926	388 081	431 236	474 390	517 545
1.1250-7	203 975	244 612	340 090	394 536	435 173	489 619	544 065	598 511	652 957
1.2500-7	257 555	308 866	429 424	498 171	549 483	618 230	686 978	755 726	824 473
1.3750-6	307 934	369 282	513 422	595 617	656 965	739 160	821 355	903 550	985 746
1.500-6	373 010	447 323	621 923	721 489	795 802	895 367	994 933	1 094 498	1 194 064
1.7500-5	505 137	605 774	842 221	977 054	1 077 691	1 212 524	1 347 358	1 482 191	1 617 025
2.0000-4.5	663 577	795 779	1 106 389	1 283 514	1 415 716	1 592 841	1 769 966	1 947 091	2 124 216

NOTE Clamp force setting = 75 % calculated F_u.

[a] Calculated with mean values from ISO 3161 for external threads.

For other diameter and/or strength classes, use Formula 2 for tensile stress area:

$$F_u = \frac{\pi}{4} d_3^{\,2} \left\{ 2 - \left(\frac{d_3}{d_2} \right)^2 \right\} \times \text{Strength level} \tag{2}$$

where

d_2 is the mean pitch diameter, in mm;

d_3 is the mean root (minor) diameter, in mm;

F_u is the ultimate clamp force, in N.

NOTE 1 Resulting values to be rounded off.

NOTE 2 Strength level (in MPa) = strength class.

NOTE 3 Values in Table 1 and Table 2 were calculated with mean values for d_2 and d_3.

8 Evaluation

The locking behaviour during the vibration test is characterized by the clamp force versus number of load cycles profile.

The way the test is evaluated shall be specified on a case-by-case basis. For evaluation example, see Table 3.

In practice, any of the following three options are used:

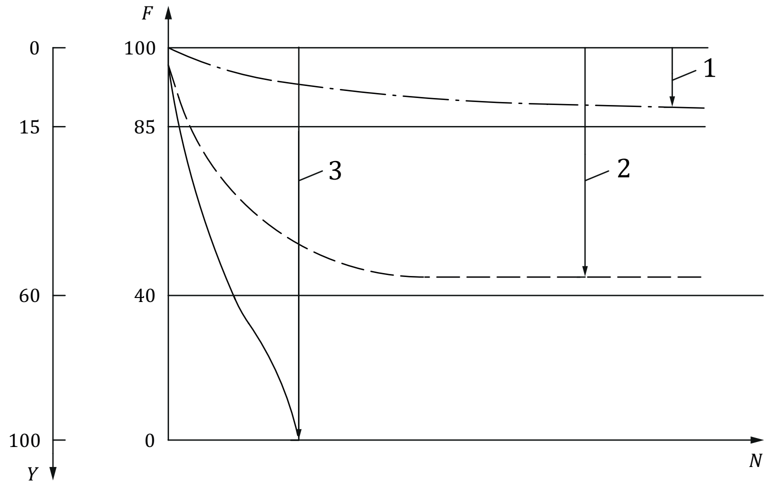
a) determination of the number of load cycles at time of complete loss of clamp force;

NOTE The loss of clamp force is often generated during only a few load cycles. So it is statistically difficult to determine the exact reproducible residual clamp force for a certain number of load cycles.

b) determination of the residual clamp force following a defined number of load cycles;

c) determination of the number of load cycles completed until fatigue fracture of the bolt.

Figure 3 shows the visualization of different test results.



Key

1-3 see Table 3

N number of load cycles (-)

F clamp force (%)

Y relative clamp force loss (%), see 3.4

NOTE *F* in % of initial clamp force F_M.

Figure 3 — Different self-locking characteristics

Table 3 — Table for evaluation

Rating	**Explanation**	**Relative residual clamp force after test** F/F$_M$ (%)	**Relative clamp force loss** Y (%)
1	Good self-locking behaviour	100...85	0...15
2	Acceptable loss of clamp force (dependent on particular application)	85..40	15...60
3	Poor self-locking behaviour	40...0	60...100

NOTE 1 If particular variations are found in self-locking behaviour in one test series, the necessary torque value to apply the clamp load has to be checked to analyse if seizing/galling of the fasteners occurred during installation.

NOTE 2 Seizing phenomena occurring during the vibration test can be detected by inspecting the fasteners and measuring the loosening torque following the end of the test.

9 Documentation

All parameters listed below have to be documented in a test report. Additionally, testing temperature, manufacturer, and type of the testing machine, as well as of bolt, nut, and additional washer in testing arrangement have to be documented. For lubricated components, the date of manufacturing should also be listed. The protocol also has to include the name of testing laboratory, date of testing, and name of inspector and, if available, the lot number of tested fasteners.

The following characteristics shall be documented as a minimum:

a) detailed information about the tested fastening system (e.g. nut, washer, bolt) and its material, dimensions, surface treatment, lubricant, locking device, etc.;

b) maximum self-locking torque (if applicable) during assembly (0,5 turns to 1,0 turns before applying clamp force);

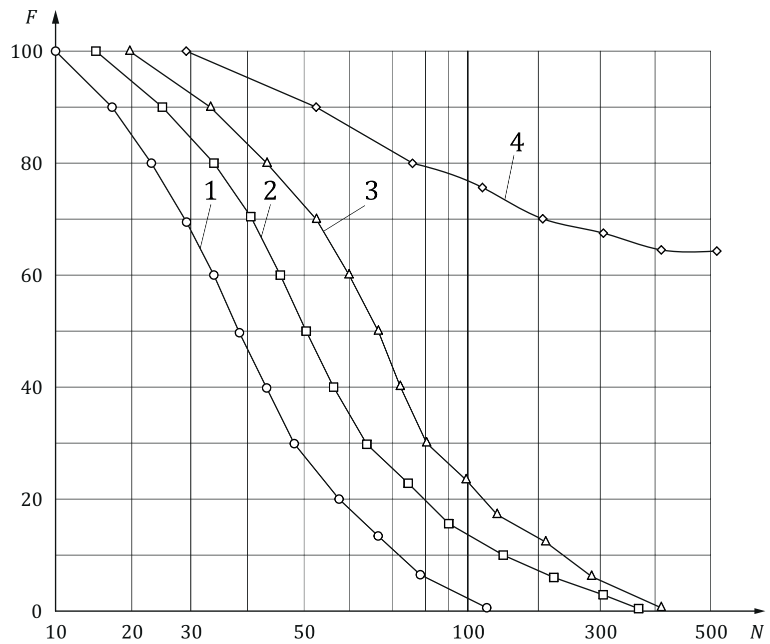
c) initial clamp force F_M;

d) necessary tightening torque value to achieve F_M;

e) clamp force during test and number of load cycles (see Figure 4);

f) maximum self-locking torque (if applicable) after the vibration test without clamp force after one turn;

g) number of tested fasteners.



Key

1-4 different test specimen

N number of load cycles (-)

F clamp force (%)

NOTE *F* in % of initial clamp force F_M.

Figure 4 — Example of a typical F-N diagram

Bibliography

[1] ISO 965 (all parts), *ISO general purpose metric screw threads — Tolerances*

[2] ISO 3161, *Aerospace — UNJ threads — General requirements and limit dimensions*

[3] ISO 5855-2, *Aerospace — MJ threads — Part 2: Limit dimensions for bolts and nuts*

[4] DIN 13 (all parts), *ISO general purpose metric screw threads*

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