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Petroleum and related products — Determination of the extreme-pressure and anti-wear properties of fluids — Four ball method (European conditions)

Pétrole et produits connexes — Détermination des propriétés extrême pression et anti-usure des fluides — Essai quatre billes (conditions européennes)

Reference number
ISO 20623:2003(E)

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 20623 was prepared by Technical Committee ISO/TC 28, *Petroleum products and lubricants*.

Petroleum and related products — Determination of the extreme-pressure and anti-wear properties of fluids — Four ball method (European conditions)

WARNING — The use of this International Standard may involve hazardous materials, operations and equipment. This International Standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this International Standard to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.

1 Scope

This International Standard specifies procedures for the measurement of the extreme-pressure (EP) and anti-wear properties of lubricating oils and fluids by means of the four ball machine. The conditions of test are those that apply in Europe and other areas that have similar electrical supply characteristics (200 V to 250 V, 50 Hz). In North America, the conditions of test are slightly different, but provide a similar ranking of the lubricating properties of fluids. The test conditions are not intended to simulate particular service conditions, but to provide information over a range of standard conditions for the purpose of research, development, quality control and fluid ranking. The output is used in lubricant specifications.

2 Normative references

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

ISO 683-17:1999, *Heat-treated steels, alloy steels and free-cutting steels — Part 17: Ball and roller bearing steels*

ISO 3170:—[1)], *Petroleum liquids — Manual sampling*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
wear
removal of metal from the test pieces

NOTE Under conditions of low load and low friction, wear causes only small circular scars on the three stationary balls and a ring on the rotating ball. The diameters of these scars are slightly larger than the diameter of the indentation due to the static load (Hertz diameter).

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1) To be published. (Revision of ISO 3170:1988)

3.2
seizure
localized fusion of metal between the rubbing surfaces of the test pieces

NOTE Seizure is indicated by an increase in friction and wear, and results in roughened scars and a ring on the balls.

3.3
weld
fusion of metal between the rubbing surfaces sufficient for metal to merge and the balls to weld together in the form of a pyramid

3.4
mean Hertz load
MHL
single number representation, of the overall wear-load diagram that covers loads from well below seizure to welding

NOTE The MHL is expressed in newtons.

3.5
wear-load curve
logarithmic plot of the load against the mean wear-scar diameter

3.6
flash temperature parameter
FTP
single number representation of the critical flash temperature above which a given fluid will fail under given conditions

NOTE Under the conditions of this International Standard, the FTP is given by:

$$\mathrm{FTP} = \frac{10m}{d^{1,4}}$$

where

m is the applied load, expressed in newtons;

d is the wear-scar diameter at load $10m$, expressed in millimetres.

3.7
initial seizure delay load
lowest load at which seizure occurs

3.8
2,5 second seizure delay load
load corresponding to a 2,5 s delay between the start of the run and the onset of seizure

4 Principle

A single ball is rotated in contact with three fixed balls, the fluid under test being used to lubricate the balls. A lever enables loads to be applied and resulting measurements of wear, friction and weld are obtained.

5 Reagents and materials

5.1 Cleaning solvents

Solvents appropriate to the material last tested. For mineral oils, light hydrocarbons and acetone are suitable. For some hydraulic fluids, an alcohol of low molecular mass will assist in the first cleaning stage.

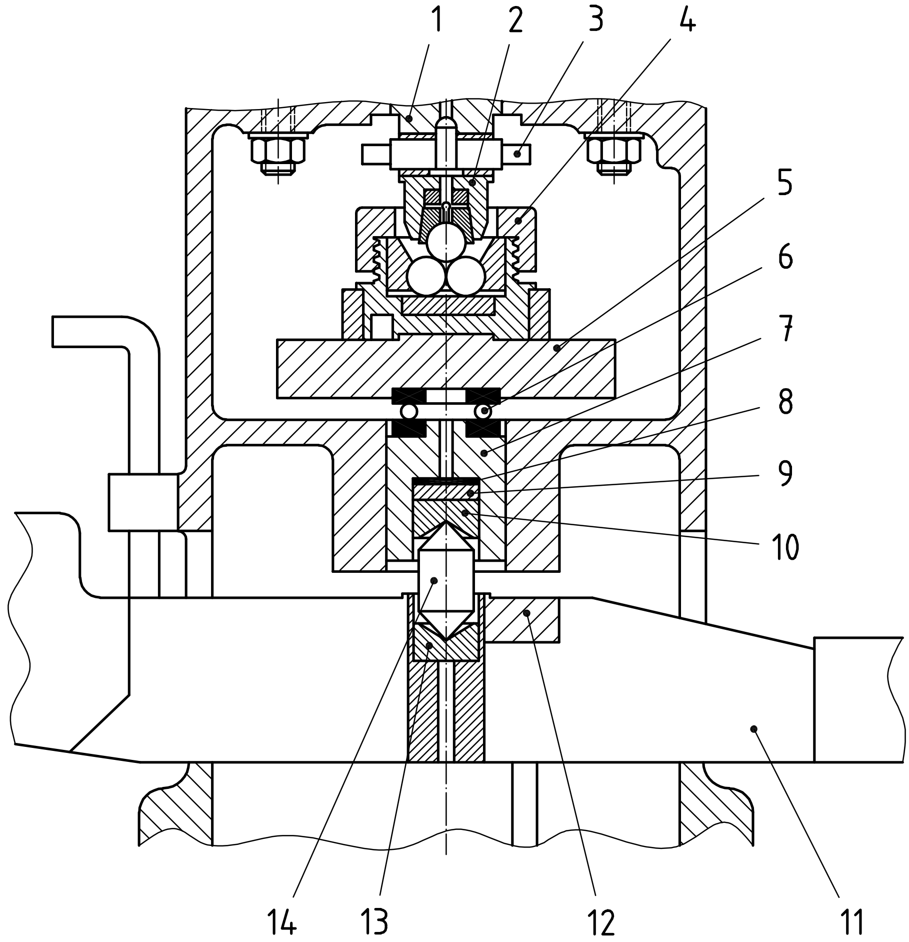
6 Apparatus

WARNING — The apparatus requires the use of heavy mass discs and due care shall be exercised when applying them or removing them from the load lever. The apparatus also contains unguarded rotating components, and due care shall be taken to avoid contact with the shaft, or entrainment of clothing or hair.

6.1 Four-ball extreme-pressure lubricant testing machine

Essentially a device by means of which a bearing ball may be rotated in contact with three fixed bearing balls immersed in the fluid under test, with no provision for temperature control. A sectional view is illustrated in Figure 1. Loads are applied to the balls by means of discs on a load lever. The upper rotating ball is held in a special chuck (see Figure 2) at the lower end of the vertical spindle of a constant-speed electric motor, operating at 147 rad/s to 157 rad/s (1 450 r/min to 1 500 r/min). The lower fixed balls are held against each other in a steel cup by means of a clamping ring and locking nut. The cup assembly is supported, above the load lever, by a disc which rests on a thrust bearing, thus allowing horizontal displacement and automatic alignment of the three lower balls against the upper ball. The frictional torque exerted on the three lower balls is measured by means of a calibrated arm, attached to the cup assembly, which is connected to the spring of a friction recording device (6.2).

NOTE It is important to distinguish between the four-ball extreme-pressure lubricant testing machine specified in this International Standard, and the four ball wear tester, which is limited to loads of up to 500 N.

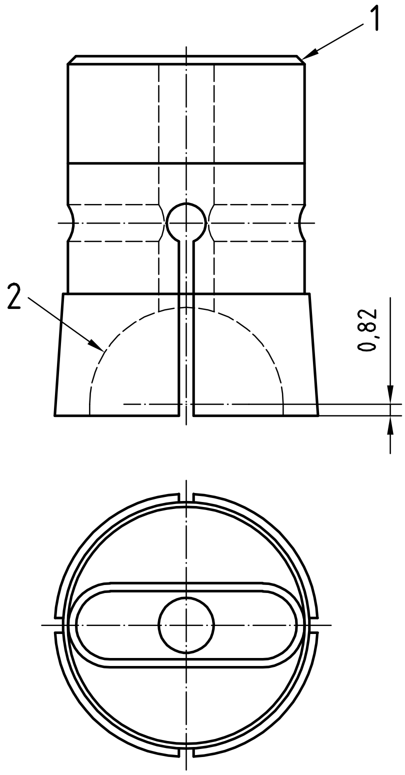


Key

1 ball chuck holder
2 ball chuck
3 cam for removing ball chuck
4 ball pot assembly
5 ball pot mounting disc
6 thrust bearing
7 cross head
8 brass shims
9 rubber disc
10 step bearing
11 counter-weighted lever arm
12 fulcrum
13 step bearing
14 pressure pin

Figure 1 — Illustrative sectional view of four-ball EP testing machine

Dimensions in millimetres



Material: collet steel

Key

1 external dimensions to suit the machine

2 6,33/6,35 spherical radius, ground and lapped to provide a tight fit for SKF steel ball No. RB 12.7/3-10995A

Figure 2 — Upper ball chuck

6.2 Friction recording device (optional)

A device mounted on a calibrated guide bar and consisting of a spring with one end anchored with the other end attached, by a wire, to the calibrated arm on the cup assembly. The extension of the spring in resisting the frictional torque is transmitted through a link mechanism to a pen which records its travel at a drum rotating at approximately 0,1 rad/s (0,8 r/min to 1,0 r/min). The spring stiffness required and the distance of the recorder from the vertical axis of the upper ball is variable, and dependent upon the coefficient of friction and the loads applied. The spring shall be calibrated by the procedure described in Annex B.

NOTE Three standard spring stiffnesses are available, namely weak, medium and strong, and each spring needs to be recalibrated when attached to a different recorder.

6.3 Loading discs

A series of masses designed for the application of loads from 60 N to 8 kN.

6.4 Microscope

Equipped with a calibrated measuring scale capable of measuring with an accuracy of ± 0,01 mm.

6.5 Timer

Manual or electronic, capable of reading to the nearest 0,2 s.

6.6 Test balls

Lime polished, chrome alloy steel balls of 12,700 0 mm ± 0,000 5 mm diameter, conforming to the requirements of ISO 683-17:1999, type 1. The balls shall be specially supplied for four ball testing.

NOTE Balls are available from a single supplier or their distributors under the SKF designation RB 12.7/3-10995A. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of these products.

6.7 Assembly device

A plate with three pins bolted firmly to a bench, to facilitate the assembly and removal of the lower balls in the ball cup. The pins locate with holes in the underside of the cup to enable the locking nut to be tightened or loosened without the cup turning.

7 Samples and sampling

Unless otherwise specified, samples shall be taken by the procedure described in ISO 3170.

8 Preparation of apparatus

8.1 Before starting a series of tests, run the machine (6.1) unloaded for a minimum of 15 min. Clean all appropriate parts of the machine with the cleaning solvent (5.1) and dry in a stream of dry air, or with a clean, dry, lint-free cloth.

8.2 Clean four new test balls (6.6) for each run with the cleaning solvent and dry with a clean, dry, lint-free cloth.

9 General procedure

9.1 Place the ball cup on the assembly device (6.7). Put three clean balls into the cup, hold them in position with the clamping ring, and secure the assembly by tightening the locknut to a torque of 68 N·m ± 7 N·m. Pour in sufficient sample (8 ml to 10 ml) to cover the balls to a depth of at least 3 mm.

9.2 Fit a clean ball into the upper ball chuck and check that it cannot be rotated by hand within the chuck. Reject chucks in which the ball is loose. Fit the chuck into the taper at the end of the motor spindle.

9.3 Mount the ball-cup assembly centrally under the spindle in contact with the fourth ball. Place the mounting disc between the thrust bearing and the cup so that, when the cup is lowered into position, it sits squarely on the disc and is free to rotate with it.

9.4 Suspend the disc hanger, which has a mass of 1 kg, from the appropriate notch on the load lever, and place the required masses (6.3) on it to give the desired load.

9.5 If an indication of friction is required, set the friction recording device (6.2) at a scale reading on its guide bar equivalent to the load. Similarly, set the clip on the calibrated arm to the same scale reading and link to the friction recorder. At loads of 1 kN and less, set the friction recorder and clip at position 100, in which case the apparent value of coefficient of friction shall be multiplied by 100/applied load. Wrap a new chart paper around the recorder drum, oscillate the spring to obtain its position of zero deflection, and rotate the drum through one revolution to obtain a zero-friction reference line on the chart.

9.6 Release the load lever and apply the load slowly to the balls, taking care to avoid shock loading as this may deform the balls permanently. Check that the three lower balls centre themselves against the upper ball.

9.7 Start the main motor, the timer (6.5), and the friction recorder drum if required.

9.8 Allow the machine to run for the appropriate length of time, stop the motor, switch off the recorder if running, and remove the load from the balls by raising the lever arm and locking it in position.

9.9 Disconnect the friction recorder if connected. Remove the cup from the machine. Pour out the test portion from the cup and rinse the assembly with cleaning solvent. Remove the balls (see the following note), wash again with cleaning solvent, dry and place in a suitable marked container for safe keeping and subsequent measurement of scar diameters.

NOTE When the test requires measurement of scar diameters, this may be done either before or after removing the balls from the cup, according to the type and optical axis of the microscope being used. It is helpful to mark the surface of the balls with an electric etcher to indicate the position of the wear scars, particularly when these are very small, otherwise there may be difficulty in finding the scars again.

9.10 If values for the coefficient of friction are required, read and record the pen deflections, expressed in millimetres, from the friction chart.

9.11 Clean the locknut, lock ring, etc., in preparation for the next test. Remove the upper ball chuck from the machine and knock the ball out of the chuck by means of the hardened-steel pin and a hammer. Clean the chuck thoroughly.

9.12 Repeat the above procedure, using four new balls and a fresh test portion for each run, for all the determinations and different loads required to complete a specified test procedure.

10 Test procedures

10.1 Mean Hertz load (MHL)

10.1.1 A specimen data sheet for the recording of results is given in Annex A. The applied loads are given in newtons (N), although the actual loading disc masses are likely to be in kilograms. 1 kgf ≈ 9,806 N.

Users should use a series of masses that most closely correspond to the examples given in Annex A and work out the load correction factors using the equation given in Clause 11. For example, for the base load, an added 40 kg to the 1 kg disc hanger mass gives an applied load of 402,05 N.

10.1.2 Carry out a series of runs applying a starting load of 400 N ± 5 N (marked “base”) and allowing the machine to run under load for the specified time period of 10,0 s ± 0,2 s or 60,0 s ± 0,5 s. Carry out subsequent runs at successively higher loads until welding of the balls occurs.

NOTE The choice of run time will depend upon the fluid type and the specification requirement.

10.1.3 Switch off immediately when welding occurs to prevent excessive wear on the chuck.

NOTE At the point of weld, the chuck will spin round on the top ball.

10.1.4 Carry out two check runs at the weld load. If welding does not occur in the second run, carry out a run at the next higher load and check that welding occurs.

10.1.5 If the verified welding occurs at or below 3,55 kN, carry out additional runs at successively lower loads below 400 N to provide a total of 20 runs exclusive of the welding load. If welding occurs above 3,55 kN, do not carry out any additional runs below 400 N.

10.1.6 After each run, measure the two wear-scar diameters using the microscope (6.4) to the nearest 0,01 mm in the direction of rubbing and at right angles to it, on each of the three lower balls, and record them in columns 1 to 6 on the data sheet, an example of which is given in Annex A (see the note to 9.9).

NOTE Several different types of wear scar may be found. At low loads before seizure has occurred, the wear scar is normally circular with well-defined edges and measurement presents no difficulty. At light loads after seizure, the wear scar is still approximately circular, but the edges are frequently ragged, and sometimes may be obscured by metal worn off during the run, adhering to the scar on the trailing edge. This obstruction may be easily removed with a penknife to reveal the true edge.

10.2 Wear-load curve, welding load, flash temperature parameter and initial seizure load

10.2.1 Carry out a series of runs of 10 s ± 0,2 s or 60 s ± 0,5 s with loads in 100 N steps up to 1 kN, then in 250 N steps up to 3 kN, and finally in 500 N steps up to 8 kN. The lowest load shall be such that at least three runs are carried out below the initial seizure load, and the highest load shall be the welding load, which is confirmed by additional runs 100 N below the welding load.

NOTE The results from the mean Hertz load runs may be used as part of the plot of the wear-load curve, but additional runs will be required to define more closely the shape of the curve.

10.2.2 Measure the wear-scar diameters as described in 10.1.6.

10.2.3 Plot a wear-load curve of the type illustrated in Figure 3 or 4.

NOTE The initial seizure load may be confirmed by the output of the friction recording device, if used. If the 2,5 s seizure delay is required, the use of the friction recording device becomes mandatory.

10.3 Wear test

10.3.1 Select the duration of the run, the applied load and the temperature in accordance with the specified requirements, and carry out the run in the manner described in 10.1.

NOTE For hydraulic fluids, a test for 1 h under an applied load of 150 N has been found to correlate with wear in pump tests.

10.3.2 Measure the wear-scar diameters as described in 10.1.6.

11 Calculations

11.1 General

Where spherical balls are in contact under load, the theoretical diameter of the circular area of contact produced by elastic deformation of the material is the Hertz diameter. A plot of Hertz diameter against load on a log/log basis is a straight line (illustrated in Figure 3), and is known as the Hertz line. Two suitable reference points for this line as applied to the four ball machine are the Hertz diameters at 392 N and 3,10 kN, which are 0,300 mm and 0,597 mm respectively.

11.2 Mean Hertz load

11.2.1 Calculate corrected load factors, Ld_H, from the rationale given below.

The corrected load, L_c, is obtained by reducing the actual load, L_a, in the proportion of the ratio of the Hertz diameter, H, at that load to the measured wear-scar diameter, D_m, as given in the following equation:

$$L_\mathrm{c} = L_\mathrm{a}\left(\frac{H}{D_\mathrm{m}}\right)$$

Since the actual loads and the corresponding Hertz diameters are known, their product can be used as a factor, Ld_H, in calculating the corrected loads from the measured scar diameters.

Calculate the mean Hertz load (MHL) from the sum of the corrected loads divided by 20. An alternative exists, but is not general, for the calculation when some of the applied loads exceed 3,10 kN. In that case, the mean Hertz load becomes the sum of the corrected loads at 3,10 kN and below, plus the average of the corrected loads above 3,10 kN, divided by 20. The product type and specification will determine which calculation is used.

11.3 Wear-load curve, flash temperature parameter and initial seizure load

11.3.1 From the curve plotted in 10.2.3, a form as shown in Figure 3 or 4 will be derived.

11.3.2 Read the initial seizure load from the curve as the point at which there is a sharp increase in wear. If there is doubt, as is illustrated in Figure 4, the friction recorder chart, if used, will indicate a significant temporary increase in friction during seizure conditions.

11.3.3 Calculate the flash temperature parameter (FTP) for each of the test runs using the following equation:

$$\text{FTP} = \frac{L_\text{a}}{d^{1,4}}$$

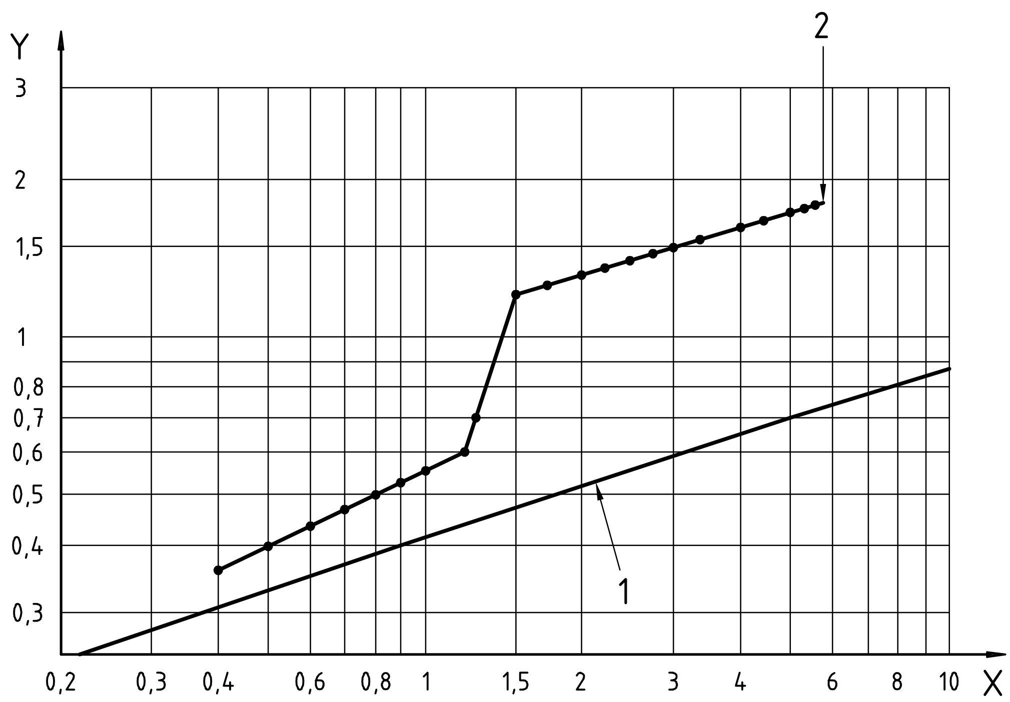
where

L_a is the actual applied load, expressed in newtons;

d is the mean wear-scar diameter at the corresponding load.

The FTP may be read directly from the wear-load curve by use of a special set square with an angle of 35°32′ ($\cot^{-1} = 1,4$). With the base horizontal, the FTP is calculated from the point at which the lowest point on the curve that the hypotenuse touches with the rest of the curve lying above it. Since all points on the hypotenuse have equal values of $L_\text{a}/d^{1,4}$, the magnitude can be read off from the point at which the hypotenuse intersects d = 1 mm.

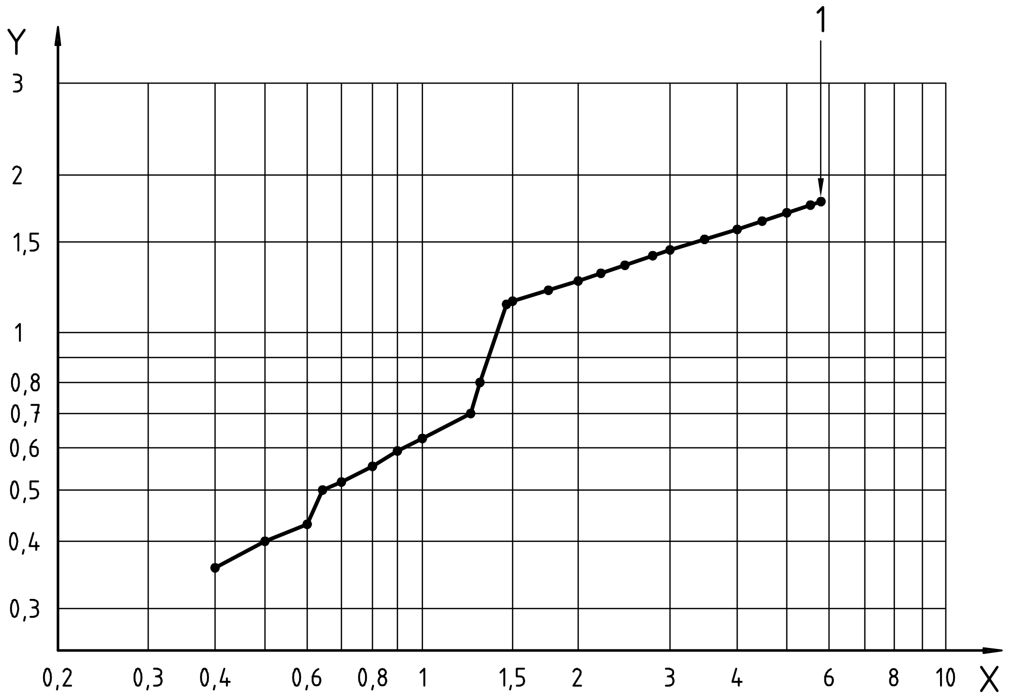
The FTP is the maximum value calculated.



Key

X load, kN
Y wear-scar diameter, mm
1 Hertz line
2 welding load

Figure 3 — Wear-load curve



Key

X load, kN

Y wear-scar diameter, mm

1 welding load

Figure 4 — Wear-load curve

12 Expression of results

12.1 Report the weld load to the nearest 100 N as WL (10 s) or WL (60 s), as appropriate.

12.2 Report the mean Hertz load to the nearest 10 N as MHL (10 s) or MHL (60 s), as appropriate. If the alternative calculation has been used, report as MHLA (10 s) or MHLA (60 s).

12.3 Report the initial seizure load to the nearest 50 N as ISL (10 s) or ISL (60 s), as appropriate.

12.4 Report the flash temperature parameter as the FTP (10 s) or FTP (60 s), as appropriate.

12.5 Report the mean wear-scar diameter to the nearest 0,01 mm from the wear test (10.3) as MSWD with the duration, load and temperature following in parentheses, e.g. MSWD (1 h, 150 N, 20 °C).

12.6 If required, supply the wear-load curve.

13 Precision

13.1 General

The precision, as determined by statistical examination according to ISO 4259[1] of interlaboratory test results on a matrix of lubricating oils and greases using the test balls specified in the note to 6.6, is given in 13.2 and 13.3. These precision estimates were first published in 1997.

13.2 Repeatability

The difference between two test results obtained by the same operator with the same apparatus under constant operating conditions on identical test material would in the long run, in the normal and correct operation of the test method, exceed the values given in Table 1 in only one case in twenty.

13.3 Reproducibility

The difference between two single and independent test results obtained by different operators working in different laboratories on identical test material would in the long run, in the normal and correct operation of the test method, exceed the values given in Table 1 in only one case in twenty.

Table 1 — Precision values

Characteristic	Repeatability [a]	Reproducibility [a]
Weld load, N	0,004 77$X^{1,5}$	0,008 97$X^{1,5}$
ISL, N	0,150X	0,381X
MHL, N	0,013 4$X^{1,5}$	0,028 4$X^{1,5}$
MWSD, mm	0,176X	0,296X

[a] where X is the average of the results being compared.

14 Test report

The test report shall contain at least the following information:

a) a reference to this International Standard;

b) the type and complete identification of the product tested;

c) the result of the test (see Clause 12);

d) any deviation, by agreement or otherwise, from the procedure specified;

e) the date of the test.

Annex A
(normative)

Mean Hertz load data sheet

A.1 Table A.1 gives an illustration of a typical data sheet for the recording of mean Hertz load data. The corrected load factors, Ld_H, are for the applied loads given, but users will need to calculate these factors for the actual loads used in the series of tests.

Table A.1 — Mean Hertz load data

Applied load, L	**Wear-scar diameter** mm						**Average diameter,** D_m	**Load factor**	**Corrected load**
N	**1**	**2**	**3**	**4**	**5**	**6**	mm	Ld_H	Ld_H/D_m
60								0,954	
70								1,120	
80								1,400	
90								1,638	
100								1,880	
110								2,134	
130								2,685	
140								2,940	
160								3,520	
180								4,122	
200								4,740	
220								5,390	
250								6,375	
280								7,420	
320								8,864	
360								10,37	
400 (base)								11,98	
450								14,00	
500								16,10	
560								18,70	
630								21,86	
710								25,70	
790								29,62	
890								34,71	
1 000								40,50	
1 120								47,15	
1 260								55,19	
1 410								64,01	
1 580								74,58	
1 780								87,40	
2 000								102,2	
2 240								118,8	
2 510								138,3	
2 820								161,6	
3 160								188,0	
								Total, A	

Table A.1 — (*continued*)

Applied load, L	**Wear-scar diameter** mm						**Average diameter,** D_m	**Load factor**	**Corrected load**
N	**1**	**2**	**3**	**4**	**5**	**6**	mm	Ld_H	Ld_H/D_m
3 550								219,4	
3 980								255,5	
4 470								298,1	
5 010								347,2	
5 620								404,6	
6 310								472,6	
7 080								550,8	
7 940								641,6	
								Total, B **OR** Average, C	

Mean Hertz load, MHL = $\frac{A+B}{20}$

Mean Hertz load (alternative), MHLA = $\frac{A+C}{20}$

Annex B
(normative)

Calibration of friction recorder springs

B.1 Objective

The differing frictional characteristics of lubricants evaluated by this International Standard necessitate the use of different helical springs, which depend upon the applied loads. For each spring, whether weak, medium or strong, an individual spring constant is required for the calculation of coefficient of friction. A spring shall be recalibrated whenever it is used with a different recorder.

B.2 Method

B.2.1 Insert the spring between holders and place paper on the recorder drum. Engage the recorder and rotate the drum in order to draw a base line on the paper.

B.2.2 Lay the friction recording device on its near side between two parallel bars, such that the height and the space in between will allow for free movement of a mass carrier, as illustrated in Figure B.1.

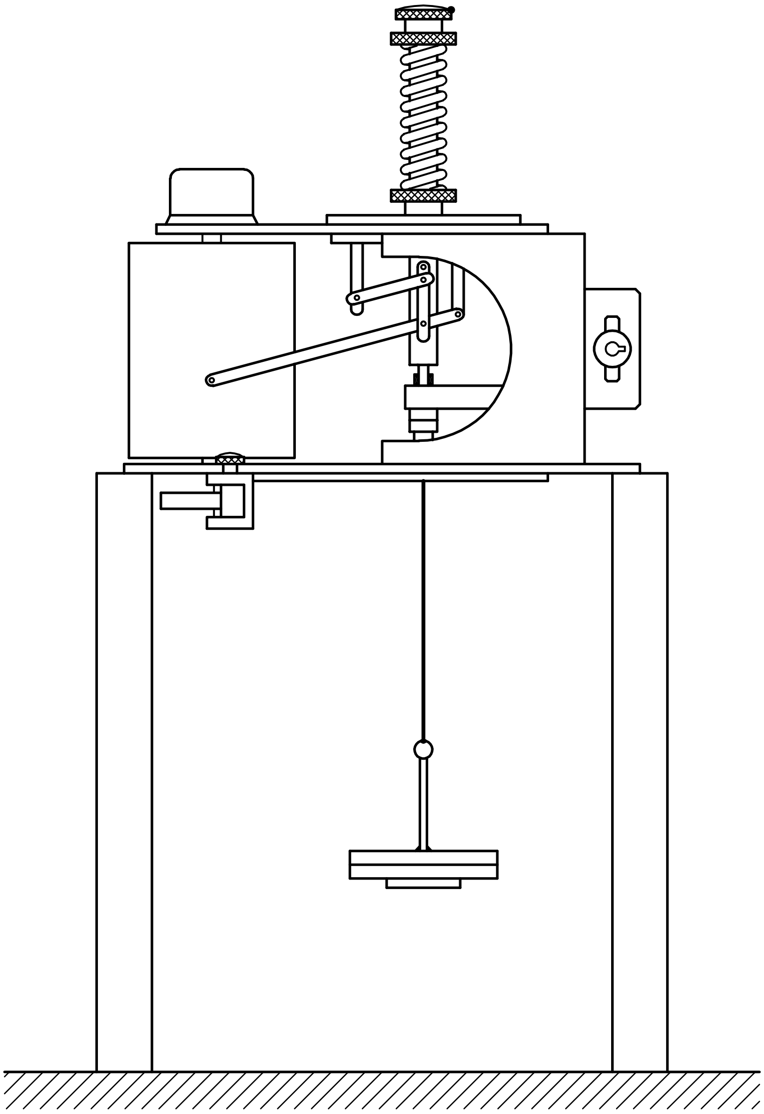


Figure B.1 — Friction recorder spring calibration apparatus

B.2.3 Attach one end of a fine steel wire to the link of the recording arm and hang a mass carrier (of known mass) to the other end.

B.2.4 Place a suitable known mass on the carrier and measure the distance from the base line travelled by the indicator pen. Divide the total mass by the distance to give a figure relative to the spring rate.

B.2.5 Repeat this procedure at two further masses.

B.2.6 Take the average of the three spring rates.

B.3 Calculation

The friction torque, T, on the lower balls is expressed by either of the following two equations:

$$T = \frac{\mu \times 3L \times r}{\sqrt{6}} \quad (1)$$

$$T = F \times M \quad (2)$$

where

μ is the coefficient of friction;

L is the applied load, expressed in newtons;

r is the distance from the centre of the contact surfaces on the lower balls to the axis of rotation (3,67 mm);

F is the force exerted on the recorder spring, expressed in newtons;

M is the length of the torque lever arm, expressed in millimetres.

Combining Equations (1) and (2) gives:

$$\mu = \frac{\sqrt{6} \times F \times M}{3 \times r \times L} \quad (3)$$

but

$$F = f \times d \quad (4)$$

where

f is the spring rate, expressed in newtons per millimetre;

d is the deflection of the indicator, expressed in millimetres.

thus

$$\mu = \frac{\sqrt{6} \times f \times d \times M}{3 \times r \times L} \quad (5)$$

Since M is selected for each load, L, according to the graduation on the torque arm and the friction recorder mounting, M/L is a constant, which may vary between machines, and hence the requirement for checking. Since also f and r are constants, Equation (5) can be reduced to:

$$\mu = K \times d \quad (6)$$

where K is the spring constant, expressed by:

$$K = 0{,}222 \times f \times M/L \text{ mm}^{-1} \quad (7)$$

Bibliography

[1] ISO 4259:1992, *Petroleum products — Determination and application of precision data in relation to methods of test*

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