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Axial load fatigue testing machines — Dynamic force calibration — Strain gauge technique

Machines d'essai de fatigue par charge axiale — Étalonnage dynamique — Technique des jauges de déformation

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FOREWORD

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO member bodies). The work of developing International Standards is carried out through ISO technical committees. Every member body interested in a subject for which a technical committee has been set up has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 4965 was developed by Technical Committee ISO/TC 17, *Steel*, and was circulated to the member bodies in December 1976. Subsequently, responsibility for this document was transferred to ISO/TC 164, *Mechanical testing of metals*, which was set up in 1975.

It has been approved by the member bodies of the following countries :

Australia	Hungary	Sweden
Austria	India	Switzerland
Belgium	Iran	Turkey
Brazil	Italy	United Kingdom
Canada	Mexico	USA
Chile	New Zealand	USSR
Czechoslovakia	Poland	Yugoslavia
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France	Spain	

The member bodies of the following countries expressed disapproval of the document on technical grounds :

Germany, F.R.
Romania

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0 INTRODUCTION

0.1 It is recognized that whilst calibration services are offered by some laboratories, it is frequently more expedient for fatigue machine users to undertake the regular calibration of their machines themselves. More especially is this so in organizations where technically qualified staff and suitable instrumentation are readily available, albeit for wider engineering applications. In such instances, machine calibration can be conveniently phased to suit the operating needs of a particular fatigue machine.

0.2 This International Standard is particularly concerned with the calibration of axial load machines as the procedures for their calibration are generally more complex. The calibration of rotating bending and torsional fatigue testing machines can usually be carried out simply by direct measurements of the effective test piece length and by direct verification of the applied force or displacement.

0.3 A strain gauge test bar should always be used to check axial load fatigue machines, even though the machine may rely upon a strain gauge load cell for its force measurement, since the force measuring system may have its own mechanical and electrical dynamic characteristics.

1 SCOPE AND FIELD OF APPLICATION

1.1 This International Standard lays down guidelines for dynamic force calibration of fatigue testing machines including special attachments, for example grips, which may affect the calibration of the machine. It deals exclusively with axial load machines in which test pieces, usually symmetrical about a longitudinal axis, are subjected to fluctuating and reversed forces along that axis (see also ISO 1099).

1.2 Whilst it recognized that unsymmetrical specimens (components and structures), are sometimes tested, it is common practice to determine stresses within them from measurements by strain gauges applied to the test specimens as required, and in such cases dynamic force calibration of the machine may not be necessary.

1.3 This International Standard applies both to the calibration of new testing machines by the manufacturer and to the verification of machines in service. In the latter case, it may not be necessary to apply all the procedures required for the overall calibration of a machine.

1.4 The calibration of special-purpose machines and test rigs are not specifically covered in this International Standard, but procedures similar to those described may be applied to suit particular applications.

2 REFERENCES

ISO/R 147, *Load calibration of testing machines for tensile testing of steel.*

ISO/R 373, *General principles for fatigue testing of metals.*

ISO 1099, *Metals — Axial load fatigue testing.*

3 SYMBOLS AND DEFINITIONS

In this International Standard the following symbols are used. Further symbols and definitions relating to fatigue testing are given in ISO/R 373.

3.1 Calibration bars (see also figures 1 and 2)

Symbol	Definition
D	The diameter of the gripped end of the test piece
d	The diameter of the test piece where the stress is a maximum
L_c	The parallel length of the test piece
l	The total length of the electrical resistance strain (ERS) gauges used, i.e. the length of the gauge backing material
r	The transition radius from the parallel length to the gripped ends
a	The thickness of test section of a rectangular cross-section
b	The width of a rectangular cross-section where the stress is a maximum
B	The width of a rectangular cross-section at the gripped end

3.2 Fatigue machine forces (see also tables 1, 2 and 3)

Symbol	Definition
F_{max}	The maximum force of the machine
F_m	The mean force
$F_{m\ max}$	The maximum mean force of the machine
F_R	The dynamic force range
$F_{R\ max}$	The maximum dynamic force range of the machine
$F_{a\ max}$	The maximum force amplitude of the machine $\left(= \frac{1}{2} F_{R\ max}\right)$

4 OBJECT OF CALIBRATION

4.1 Whilst it is relatively simple to carry out a calibration of the forces applied by a fatigue testing machine under static conditions, it is essential to establish that the dynamic forces actually applied to the test piece are those indicated by the machine within acceptable limits of accuracy.

4.2 As some fatigue machines operate over a range of testing frequencies, the inertia effects of moving parts are not constant but vary. For such machines, a dynamic correction factor may therefore have to be applied to the indicated forces to obtain the force actually effective at the test piece. This factor is a function, for example, of the vibrating mass of the machine, of the test piece stiffness and the operating frequency, and the correction data are customarily supplied by the manufacturer of the testing machine. Thus, the object of fatigue testing machine calibration is to compare indicated forces, multiplied by an appropriate correction factor where applicable, with actual test forces over the operating range of the machine.

5 PROCEDURE

5.1 Calibration bars, appropriate to the dimensions of the testing machine and the force ranges to be checked, shall be instrumented by the application of electrical resistance strain (ERS) gauges. Each calibration bar shall be subjected to incremental loading in a static testing machine of known accuracy, and the electrical strain outputs from the gauges recorded. The calibration bar, as calibrated statically, shall then be used for direct measurement of the forces applied by the fatigue testing machine and compared with the indicated forces.

The procedure assumes identical performances of the strain-gauged bar, or load-cell, and instrumentation under static and dynamic conditions : this assumption is essentially valid over the range of frequencies covered by fatigue machines in general use.

5.2 Successful application of the procedure is dependent on a satisfactory design of calibration bar, on the correct use of suitable strain gauges and on the choice of compatible dynamic strain recording instruments (see also clauses 6, 7 and 8).

6 CALIBRATION BARS

6.1 General

6.1.1 Calibration bars of any suitable geometry and material may be used but it is recommended that, where possible, they be of similar form to the test piece normally being tested in the particular fatigue machine. They may be of circular, square or rectangular cross-section, and in the case of circular and square bars a hollow-section is permissible to facilitate the measurement of small forces. ERS load-cells which satisfy the recommendations of this sub-clause and of sub-clauses 6.1.2 and 6.1.3 may also be used.

6.1.2 As a guide to the selection of material and the design of the bar, the maximum stated capacity should be such that 150 % of that capacity does not exceed the 0,01 % proof stress (non-proportional elongation method) of the material.

6.1.3 It is recommended that, at the rated maximum force range at which the bar is to be used, the strain imposed should be approximately 1 200 μm/m either in tension or in compression.

6.2 Proportions

The proportions of calibration bars which have been found satisfactory for use in axial load fatigue testing machines are as follows :

6.2.1 *Bars of circular cross-section* (See note 1)

L_c shall be at least $d + l$. (See also note 2.)

r and D should be equal to or greater than 2 d.

r should be at least equal to D.

Where possible, the length of the enlarged end should be at least equal to D.

6.2.2 *Bars of square and rectangular cross-section*

L_c shall be at least $b + l$. (See also note 2.)

r and B should be equal to or greater than 2 b.

Where possible, the length of the gripped end should be at least equal to B.

NOTES

1 Bars of square cross-section may have circular ends.

2 L_c should not be such that buckling will occur if the strain cycle goes into compression.

6.3 Machining

6.3.1 Bars shall be machined in accordance with ISO 1099, sub-clauses 7.1 to 7.4 inclusive.

6.3.2 The corners of square and rectangular calibration bars shall be dressed to a radius of at least 1,5 mm. The surface of the bar shall not have any stamp marks on critical areas.

7 STRAIN GAUGES

7.1 A sufficient number of active longitudinal strain gauges shall be attached to the calibration bar at mid-length to ensure that an average of the strain can be adequately ascertained. *In no case shall the number of active gauges attached to the bar be less than four.* For bars of square or rectangular section, the gauges shall be positioned on the axis of symmetry of each of the four faces, or symmetrically with respect to the axis. Where it is not possible to position the gauges on the narrow faces of thin flat bars, they shall be placed symmetrically about the axes of the wide faces.

7.2 Suitable techniques should be used to compensate for variations in output signal due to temperature changes. It is recommended that gauges be fixed to the bar in a direction transverse to the applied force within the test section for the purpose of temperature compensation. The transverse gauges shall be positioned on the axes of symmetry or symmetrically with respect to these axes. Recording instruments which allow the use of full Wheatstone bridges, made up exclusively of gauges bonded to the calibration bar, are to be preferred. However, with certain types of recording instruments, it may only be possible to use longitudinal gauges, in which case these should be self-compensating for temperature.

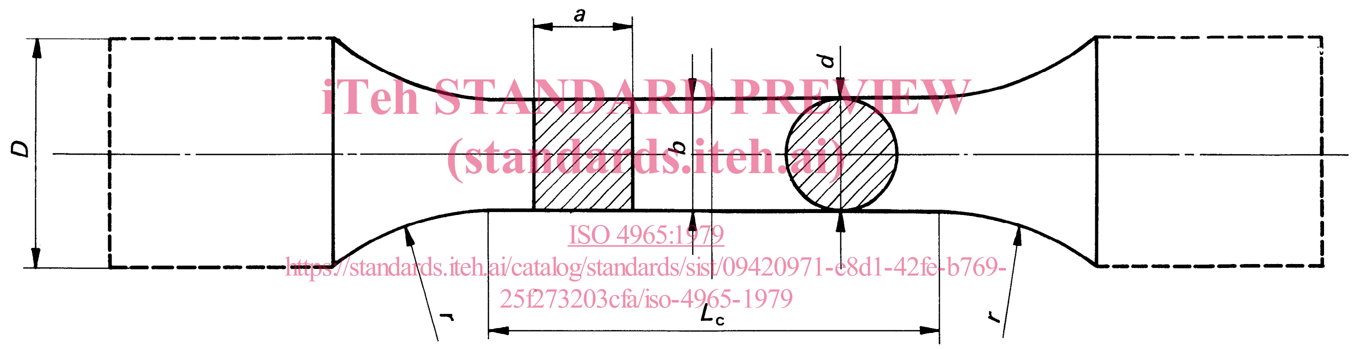

FIGURE 1 — **Calibration bar of circular cross-section or square cross-section with circular ends**

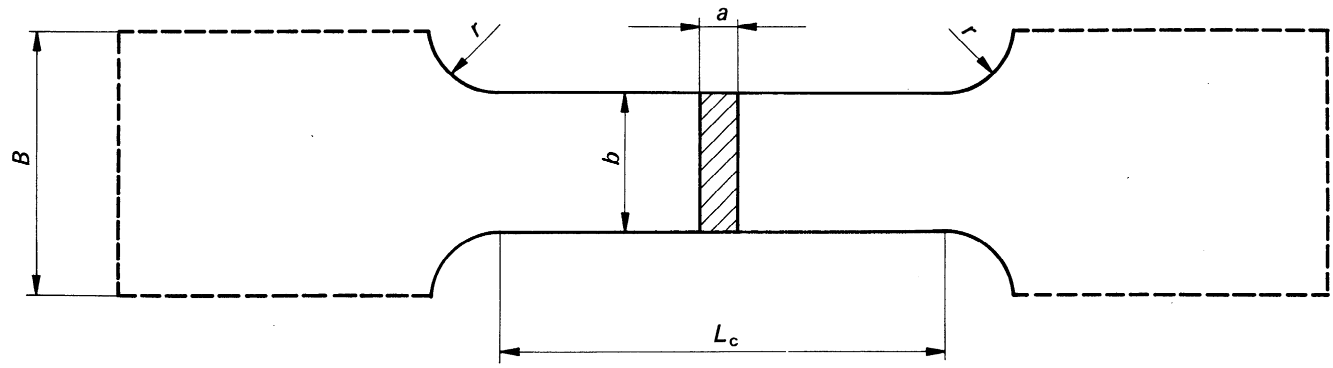

FIGURE 2 — **Calibration bar of rectangular cross-section**

7.3 Gauges should be affixed to the bar in accordance with the manufacturer's instructions for their optimum performance. The surfaces of the calibration bar should be such as to ensure an adequate bond between the strain gauge and the bar. Care should be taken when affixing the strain gauges to ensure that the surfaces of the bar and gauges are free from contamination by oil, grease, etc.

7.4 All gauges should be protected from mechanical damage and environmental influence by the application of suitable materials, which should not, however, significantly affect the stiffness of the bar.

8 RECORDING INSTRUMENTATION

The calibration bar, gauges and associated equipment shall be capable of resolving force changes of one-fifth of the maximum machine errors allowed in the calibration (see 11.1). The design shall be such that the response to fluctuating and reversed forces at the frequencies and waveforms to be used can be predicted, from the response to steady forces, with an uncertainty of not more than one-fifth of the maximum machine errors allowed in the calibration (see clause 11).

9 CALIBRATING THE CALIBRATION BAR

9.1 Preliminary check

Prior to static calibration, it is desirable for the calibration bar to be mounted in a fatigue testing machine and subjected to a sufficient number of cycles to ensure that the strain gauges are functioning satisfactorily under dynamic conditions.

9.2 Testing machine for calibrating the bar

The bar shall be calibrated in a static testing machine complying with grade 1.0 requirements of ISO/R 147. The machine shall not be used below one-fifth of its scale in any of its force ranges.

If the lowest increment or increments give rise to forces less than one-fifth of the machine force range in use, a lower force range may be used to obtain these, provided that this repeats at least one of the force levels employed in the higher machine force range (see 9.4.7).

9.3 Mounting of the calibration bar in the static testing machine

The calibration bar shall be mounted in the machine so that the force centreline of the machine lies through the centreline of the bar and in such a manner that it cannot change its position during the application of the series of calibration forces. In certain types of machine, the loading head is movable and also has to be centralized.

9.4 Calibrating procedure

The sequence for the procedure shall be as follows :

9.4.1 Connect the recording instruments to the calibration bar strain gauges and, after switching on, allow the requisite period for stabilization of all instrumentation. Before commencing calibration, apply and remove several times a force of 1,1 times the maximum force which is to be applied during calibration.

9.4.2 With zero force applied to the bar, set the strain-recording instrument to indicate zero strain. Apply the maximum calibration force and observe the strain produced, then restore the applied force to zero and after a period of not less than 1 min observe any indicated strain. The difference between the two strain readings made at zero force shall not exceed 1 % of the strain observed at maximum force. Note shall be taken of any auxiliary masses, for example gripping arrangements, attached to the bar at the zero force setting (see 10.2.2.2).

9.4.3 Re-set the strain-recording instrument to indicate zero strain at zero force. Apply static forces in not less than five approximately equal increments up to the maximum of the range and down to zero again in the same steps. At each increment and decrement, with the force maintained precisely and steadily, record the electrical strain output from the calibration bar.

If the bar is to be used in tension and compression, it shall be calibrated in both tension and compression.

If the lowest increment or increments employ forces which are less than one-fifth of the machine force range in use, a lower force range may be used for these increments, provided that at least one of the force levels employed in the higher machine force range is repeated. For agreement of the strain readings at the repeated force level, see 9.4.7.

9.4.4 Off-load the machine and record zero-load electrical output from the calibration bar.

9.4.5 Repeat operations 9.4.3 and 9.4.4 twice to obtain three series of incremental and decremental calibration readings. Between the second and third series of readings, the recording instruments shall be disconnected and the calibration bar removed from the testing machine, and then re-mounted in accordance wth 9.3. Re-commence calibration from 9.4.1.

9.4.6 The static calibration of the bar shall be obtained from the average of the difference of the electrical strain outputs from zero force for the corresponding increment and decrement of force in each of the three series of readings. At each calibration force, the incremental and decremental readings shall be averaged and adjustment for the averaged zero force reading shall be applied. The relationship between force and strain should be essentially linear.

9.4.7 For each series, at each calibration force the difference between the strain readings in the two directions should be not greater than 1 % of the strain at maximum force.

Where two machine force ranges have been employed (see 9.4.3), the difference beween strain readings, at those forces common to the two machine ranges, shall be taken as the difference between the highest and lowest readings of the three or four readings recorded.

9.4.8 At each calibration force, the difference between the highest and the lowest of the three average strain outputs shall not exceed 1 % of the average strain at maximum force.

9.5 Recalibration of bar

If it is subsequently necessary to verify the calibration of the bar, the procedure described in 9.4 may be reduced to a single set of readings, i.e. steps 9.4.1 to 9.4.4, provided that the relationship between force and strain does not differ from the original calibration at each of the calibration forces by more than 0,5 % of the original calibration strain at maximum force. Otherwise, the full procedure described in 9.4 shall be carried out.

The time interval between the verifications will depend upon the amount of usage; it is recommended that the verifications be carried out at intervals not exceeding 12 months.

10 PROCEDURE FOR CALIBRATING MACHINE TESTING

10.1 General

The overall calibration consists of procedures covering both static and dynamic operating conditions. Prior to the calibration, it should be ascertained that the machine is in good working order and it should be operated in accordance with the manufacturer's instructions. For the calibration of a fatigue machine over its entire range of force and operating frequency, it is usually necessary to use several calibration bars. No calibration bar shall be used for a force range spanning less than 20 % of its capacity.

10.2 Dynamic calibration of mean forces and force ranges

10.2.1 For the calibration of dynamic forces, the following procedure shall be adopted :

At a number of mean forces, distributed approximately equally throughout the range of mean forces available in the normal operation of the testing machine, several calibrations are performed using different dynamic force ranges. Depending on the type of axial load fatigue testing machine, the mean forces and dynamic force ranges given in table 1, 2 or 3 shall be used for carrying out calibration. The test series given in these tables shall be regarded as the minimum for any given set of conditions. The fixed conditions, which shall be specified, consist of :

a) waveform;

b) specimen compliance and geometry;

c) testing machine configuration, which shall include load cell and grips;

d) frequency;

e) load range in use.

The calibration shall be repeated twice at each mean force to give three series in all. It will be necessary to repeat this procedure if calibration for a different fixed set of conditions is required.

TABLE 1 — **Tension-(or compression)-fatigue testing machines with $F_{a\ max} < F_{max}$ (for example $F_{a\ max} \approx 0{,}5\ F_{max}$)**

$\frac{F_m}{F_{max}}$	0,2	0,4	0,5	0,6	0,8
$\frac{F_R}{F_{max}}$	0,1 0,2 0,3 (0,4)	0,1 0,2 0,3 0,4 0,5 0,6 0,7 (0,8)	0,2 0,4 0,6 0,8 (1,0)	0,1 0,2 0,3 0,4 0,5 0,6 0,7 0,8	0,1 0,2 0,3 0,4

TABLE 2 — **Tension-compression-fatigue testing machines with $F_{a\ max} < F_{max}$ (for example $F_{a\ max} \approx 0{,}5\ F_{max}$)**

$\frac{F_m}{F_{m\ max}}$	− 1,0	− 0,5	0	+ 0,5	+ 1,0
$\frac{F_R}{F_{R\ max}}$	0,2 0,4 0,6 0,8 (1,0)	0,2 0,4 0,6 0,8 1,0	0,2 0,4 0,6 0,8 1,0	0,2 0,4 0,6 0,8 1,0	0,2 0,4 0,6 0,8 (1,0)

TABLE 3 — **Tension-compression-fatigue testing machines with $F_{a\ max} = F_{max}$**

$\frac{F_m}{F_{max}}$	− 0,6	− 0,4	− 0,2	0	+ 0,2	+ 0,4	+ 0,6
$\frac{F_R}{F_{max}}$	0,4 0,8	0,4 0,8 1,2	0,4 0,8 1,2 1,6	0,4 0,8 1,2 1,6 2,0	0,4 0,8 1,2 1,6	0,4 0,8 1,2	0,4 0,8

NOTES

1 For definition of symbols used in the tables, see 3.2.

2 The values given in parentheses cannot be obtained in the majority of machines. In such cases, the last dynamic force range shall equal the full range available at that mean force.

10.2.2 The sequence for the dynamic calibration procedure shall be as follows :

10.2.2.1 Fit the appropriate calibration bar into the machine, observing the requirements of 9.3.

10.2.2.2 Connect the recording instruments to the calibration bar strain gauges and, after switching on, allow sufficient time for stabilization of all instrumentation. The gauge readings at the zero force condition shall be checked and allowance made for any difference arising from gripping attachments of different masses to those used in the static calibration.

10.2.2.3 Adjust the force and speed ranges of the machine as appropriate.

10.2.2.4 Apply the mean force and the various dynamic force ranges, and at each dynamic condition check the operating frequency and record the maximum and minimum values of the fluctuating electrical strain output from the calibration bar.

10.2.2.5 Repeat operation 10.2.2.4 for each mean force level as described above, repeating as required by 10.2.1.

10.2.2.6 Off-load the machine and check zero-load electrical outputs of the calibration bar.

10.2.2.7 Repeat operations 10.2.2.3 to 10.2.2.6 for any additional selected operating frequencies.

10.2.2.8 Where necessary for determining a dynamic correction factor, the testing machine/calibration bar stiffness shall be obtained during the calibration by measuring the ratio of unit length increase between the jaws of the machine to the unit force increase.

11 ASSESSMENT OF MACHINE PERFORMANCE

11.1 Repeatability

For a given indicated force, maximum or minimum, the difference between the highest and the lowest of the three strain outputs shall not exceed 1 % of the average strain at maximum force.

11.2 Accuracy

The results obtained from the procedure described in 10.2 shall be compared with the force readings (corrected as necessary, see 4.2) indicated by the machine. The errors in the maximum and minimum forces under consideration shall not exceed 2 % of the maximum tensile or compressive force of the machine scale in use.

NOTE — This requirement for accuracy is not absolute as the error in the calibration equipment is not taken into account.

12 INITIAL CALIBRATION OF MACHINE

Provided that the requirements for accuracy given in clause 11 are met, the readings indicated by the machine may be used for subsequent tests. If the requirements of clause 11 are not met, calibration curves shall be prepared (see clause 13) and these curves shall be used in subsequent tests.

13 CALIBRATION CURVES

13.1 Preparation

The results obtained from the full procedure described in clause 10 shall be used for establishing basic calibration curves for the testing machine. A curve shall be plotted of the force indicated by the calibration bar against the force indicated by the machine covering each operating frequency selected.

13.2 Presentation of results

Details of the calibration bar and its method of attachment in the machine shall be stated on the calibration curves supplied with the machine. By interpolation, further curves may be derived to cover forces and operating frequencies other than those selected for calibration purposes.

NOTE — The calibration curves described above do not take account of differing mass/frequency relationships of the test piece and attachments. Where required, appropriate dynamic force correction factors (see 10.2.2.8) shall be provided either in the form of a graph or by a formula.

14 RE-CALIBRATION OF MACHINE

For machines in service, it may be necessary to carry out a further calibration, in which case the procedures described in clauses 9 and 10 should be followed. The machine should comply with the requirements for repeatability and accuracy given in clause 11. If the results obtained are not within these accuracy requirements, further calibration curves as described in clause 13 should be prepared.

15 VERIFICATION OF MACHINE

15.1 Procedure

It is permissible, when verifying a machine which has been previously calibrated, to cover only the range of forces and frequencies at which the machine is to be subsequently employed.

15.2 Accuracy of verification

At the conditions selected for verification purposes and applying the calibration curves described in clause 13, as appropriate, the errors found should not exceed the requirements stated in clause 11. If errors greater than those stated in clause 11 are apparent, the testing machine should be completely re-calibrated as described in clause 14 and new calibration curves prepared.

NOTE — Errors greater than those stated in clause 11 may be due to wear in moving parts, misalignment of optical parts, slip of indicator needles, overstraining of springs, etc. It is accordingly recommended that the advice of the testing machine manufacturer be sought if significant errors are found during re-calibration or verification.

15.3 Intervals between verification

The time between verifications will depend on the type of testing machine, the standard of maintenance and the amount of usage. Under normal circumstances, it is recommended that verifications be carried out at intervals not exceeding twelve months. A machine should in any case be verified if it is moved to a new location necessitating dismantling or is subject to major repairs or adjustments.