INTERNATIONAL STANDARD

ISO 4965-1

First edition
2012-07-15

Metallic materials — Dynamic force calibration for uniaxial fatigue testing —

Part 1:
Testing systems

Matériaux métalliques — Étalonnage de la force dynamique uniaxiale pour les essais de fatigue —

Partie 1: Systèmes d'essai

Reference number
ISO 4965-1:2012(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established 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. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 4965-1 was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 5, *Fatigue testing*.

This first edition of ISO 4965-1, together with ISO 4965-2, cancels and replaces ISO 4965:1979, which has been technically revised.

ISO 4965 consists of the following parts, under the general title *Metallic materials — Dynamic force calibration for uniaxial fatigue testing*:

— *Part 1: Testing systems*

— *Part 2: Dynamic calibration device (DCD) instrumentation*

Introduction

In a dynamic test, the force experienced by the test-piece (F_t) might differ significantly from the force indicated by the testing system (F_i). The dynamic errors result from inertial forces acting on the force transducer and any dynamic errors in the electronics of the force indicating system. Inertial forces equate to the grip mass (interposed between the force transducer and the test-piece) multiplied by its local acceleration, and therefore depend on

a) the amplitude of motion

b) the frequency of motion, and

c) the grip mass.

The amplitude of motion will, in turn, depend on the applied force and the mechanical configuration of the testing system, including the compliances of the load train, the test-piece, the reaction frame, and the base mounting. For a given frequency and over a given force range, different combinations of compliance values will result in different amplitudes of motion [the motion of a grip holding a very compliant test-piece may even be in the opposite direction (anti-phase) to that of the same grip holding a much stiffer test-piece].

For the purpose of this part of ISO 4965, there must be a linear relationship between the applied force and the displacement of the actuator. Using Method A and the calculated correction factor, the force measurement system will be dynamically calibrated to within 1 % of the applied force range. Using Method B and two dynamic calibration devices (DCDs) of different compliance, the force measurement system will be dynamically calibrated to within 1 % of the applied force range, if the actual test-piece has a compliance between those of the two DCDs.

Method A (Replica test-piece method) – This method is used for calibrating a dynamic testing system with a DCD, allowing errors of up to 10 % in the indicated force range to be corrected for, using a generated correction factor. The DCD must have the same compliance and mass as the specimens to be tested and the entire load train must be the same as that to be used for the actual testing. Before commencing a new series of dynamic tests, the correction factor relating the indicated force range (ΔF_i) to the test-piece force range (ΔF_t) can be determined using a strain gauged replica test-piece. This factor can be applied either as a correction to the results or to modify the force applied by the testing system, reducing the dynamic force error to less than 1 %. This correction factor is dependent on test frequency, and therefore will have to be determined over the entire range of anticipated test frequencies.

Method B (Compliance envelope method) – This method is used to calibrate a dynamic testing system for use with varying test-piece configuration, using two DCDs of different compliance. The low compliance DCD should have a compliance lower than that of any test-piece to be tested, and the high compliance DCD should have a compliance above that of any test-piece. An operating envelope of test-piece compliance versus frequency can be established for the testing system, within which dynamic errors are maintained to within 1 % of the applied force range. It is assumed that the compliance of the load train is insignificant when compared with the compliance of either DCD. If this is not the case, and the machine is to be used with varying load train compliance values, additional calibration runs will need to be performed.

Metallic materials — Dynamic force calibration for uniaxial fatigue testing —

Part 1: Testing systems

1 Scope

This part of ISO 4965 describes two methods (see Introduction) for determining the relationship between the dynamic force range (ΔF_t) applied to a test-piece in a uniaxial, sinusoidal, constant amplitude test and the force range indicated (ΔF_i) by the testing system.

These methods are applicable to dynamic testing systems operating away from system resonant frequencies and are relevant to testing systems where the dynamic force measurement errors are either unknown or where they are expected to exceed 1 % of the applied force range.

The dynamic force measurement errors are determined by comparison of the peak forces indicated by the dynamic testing system with those measured by the strain gauged dynamic calibration device (DCD). This DCD has previously undergone static calibration (see 5.2.1) against the testing system indicator.

For Method A *(Replica test-piece method)*, the dynamic calibration is applicable over the validated range of frequencies for that type of test-piece only. A frequency-dependent correction factor is applicable for the correction of dynamic force measurement errors of up to 10 % of dynamic force range. By using such a correction factor, the actual test-specimen dynamic force measurement error will be reduced to less than 1 % of the dynamic force range.

For Method B *(Compliance envelope method)*, the dynamic calibration is applicable over the range of test frequencies validated for test-pieces whose compliance lies between those of the two DCDs. No correction factor is applicable, as Method B does not permit dynamic force measurement errors above 1 % of the dynamic force range.

NOTE Annex A provides guidance on when the system should be re-calibrated by the methods described in this part of ISO 4965.

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 7500-1, *Metallic materials — Verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Verification and calibration of the force-measuring system*

ISO 4965-2, *Metallic materials — Dynamic force calibration for uniaxial fatigue testing — Part 2: Dynamic calibration device (DCD) instrumentation*

3 Terms, definitions, and symbols

For the purposes of this part of ISO 4965, the terms, definitions, and symbols in ISO 4965-2 and the following apply. Figure 1 gives a schematic diagram of the calibration set-up.

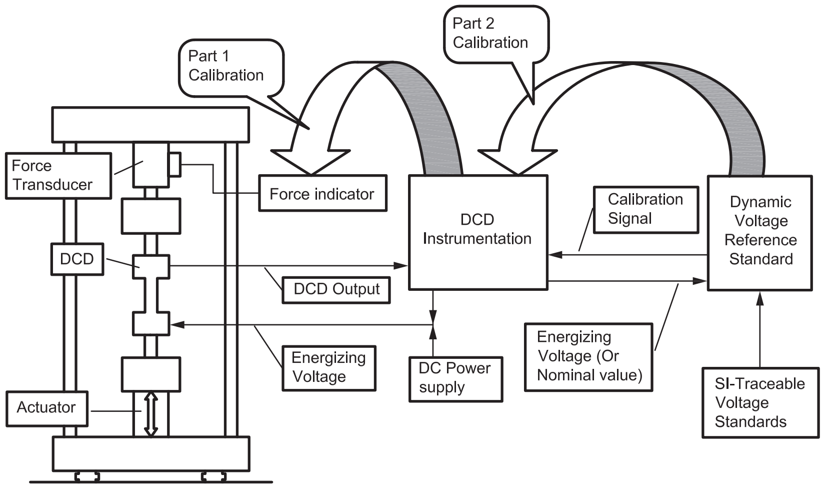


Figure 1 — Schematic diagram of ISO 4965 calibration methodology

3.1
correction factor
C
ratio between the dynamic force range determined by a DCD (ΔF_{DCD}) and the dynamic force range indicated by the testing system (ΔF_i), at the same testing frequency

3.2
DCD
dynamic calibration device
strain-gauged replica test-piece (or, for Method B, proving device) that, for Method A, has the same mass and compliance as the specimens to be tested or, for Method B, is of known compliance

3.3
DCD force
F_{DCD}
force measured by the DCD, calculated from i_{DCD} after static calibration against the testing system

NOTE See Formulae (2) and (3).

3.4
DCD indication
i_{DCD}
output of the DCD instrumentation

NOTE As the DCD instrumentation needs to have previously been calibrated against electrical standards, the DCD indication will be in electrical units, such as mV or mV/V.

3.5
DCD instrumentation
instrumentation used in conjunction with the DCD, including strain gauge bridge output conditioning electronics and display

NOTE The DCD instrumentation may also supply the DCD energising voltage – it could then display the DCD output as an mV/V ratio.

3.6
dynamic force range
ΔF
difference between the maximum (peak) and minimum (valley) values of force under cyclic conditions

3.7
dynamic testing system
combination of actuator, reaction frame, load train, and instrumentation used to perform cyclic force testing, indicating the applied peak and valley force values

3.8
indicated force
F_i
force measured by the dynamic testing system's statically-calibrated force transducer and indicated by its instrumentation, under both static and dynamic conditions

3.9
indication error
e_i
difference in the force ranges indicated by the testing system instrumentation and the DCD instrumentation, expressed as a percentage of the DCD force range

3.10
load train
all components, excluding the specimen/DCD, that transmit the force between the actuator and the reaction frame of the dynamic testing system, including the force transducer, adaptors, grips, and other fixtures

4 General requirements

4.1 Temperature

The ambient temperature at which the dynamic calibration of the uniaxial dynamic testing system is performed shall be recorded. It is recommended that the calibration be performed at a constant ambient temperature, and care should be taken to shield the DCD from draughts and direct sunlight.

4.2 Dynamic testing system

4.2.1 Static calibration

The dynamic testing system shall have a current certificate of static calibration to ISO 7500-1, Class 1 or better, for the relevant loading conditions.

4.2.2 Calibration frequencies

The dynamic testing system shall be dynamically calibrated over the range of frequencies where dynamic testing is to be performed, with the exception of any test frequencies at which a system resonance affects the force measurement accuracy, as specified in 5.1.1. It is also recommended that, to keep amplitude errors to less than 0,2 %, the maximum test frequency should not exceed 25 % of the testing system instrumentation's bandwidth (see Annex B) for two pole filter systems, or 6 % of this bandwidth for single pole filter systems.

Filtering of the measured forces directly affects the dynamic accuracy of these measured forces. Therefore, any filters shall be added before conducting the dynamic calibration. The calibration is only valid with the filters used at the time of calibration.

If Method B is used, the same frequency range shall be used for each of the two DCDs. System resonant frequencies lead to localized areas of increased errors. Care must be taken to identify such areas, with both DCDs, so that actual testing is not performed at frequencies where excessive errors occur.

4.2.3 Dynamic force range

The indicated force end levels used for the dynamic calibration procedure shall lie within the statically calibrated force range of the dynamic testing system, and at the peak values anticipated for the test-piece. The dynamic calibration force range shall also be in between 10 % and 100 % of each DCD's dynamic rating. The dynamic force range shall be either through-zero, or tension-only, or compression-only. Tension-only dynamic calibrations are not valid in compression and vice versa. Through-zero calibrations verify both tension and compression. This part of ISO 4965 requires that, if a single force range is to be used for dynamic calibration, there is at each test frequency a linear (though potentially different) relationship between applied force and actuator displacement – one way to demonstrate this would be to record and then plot the actuator position as a function of applied force during, or subsequent to, the machine's static force calibration.

NOTE Inertial errors are proportional to acceleration and therefore also to displacement – a linear relationship between force and displacement ensures that inertial errors are proportional to force and thus constant as a proportion of force range, enabling the calibration to be performed over a single force range.

If there is not a linear relationship between applied force and actuator displacement, multiple dynamic force range calibrations are needed before the system is determined to be dynamically calibrated.

The peak and valley values used should be within the working range of the calibration device.

In Method B, the dynamic force ranges used for the two DCDs can be different, but the same frequency range shall be used.

4.2.4 Load train

For Method A, the load train fixtures and fittings employed for the actual dynamic testing shall be used, and the DCD must have the same mass, compliance, and damping as the specimens to be tested (i.e. it should be a standard specimen with strain gauges attached).

For Method B, the calibration shall be performed using a load train with the greatest mass to be used in subsequent testing, as this should maximize the inertial errors generated. A significant change in the compliance of the load train will also affect the dynamic errors generated.

If the machine is to be used to test specimens using load trains of different compliance values (for example, by the insertion of rods for use in a furnace), the followings steps shall be taken.

— Determine the compliance (C_1) of the less compliant DCD (this value should be available from the manufacturer).

— Determine the range of compliances ($\Delta C = C_{\text{maximum}} - C_{\text{minimum}}$) of the load trains to be used (this can be done by actuator displacement measurement at the same force, with the same specimen).

— If $\Delta C > C_1/10$, both DCDs shall be used to calibrate the machine using both the load train of maximum compliance and the load train of minimum compliance.

4.2.5 Mounting of dynamic calibration device (DCD)

The DCD shall be mounted in the load train and attached in the same location as the test-piece would during actual testing.

4.2.6 Dynamic testing system

The dynamic testing system shall be capable of controlling and applying a repeated cyclic force onto the specimen, and providing a read-out of this cyclic force. Typically, a waveform generator either integral to the test system or externally connected to it is used to provide the cyclic waveform of the test. The achieved test force range or end levels are measured and recorded. The dynamic testing system shall be capable of consistently applying repetitive end levels during the entire test. The peak and valley forces as indicated by the dynamic testing system shall repeat within 1 % of the applied force range for every cycle during the entire test. Subclause 5.1.2 specifies the procedure employed to test whether this requirement is met.

4.2.7 DCD instrumentation

The DCD instrumentation shall have been calibrated in accordance with ISO 4965-2. For instrumentation calibrated using a nominal excitation voltage and displaying in voltage units, this value of excitation voltage shall be used during calibration of the testing system. For instrumentation that generates its own excitation voltage and gives an indication in mV/V, the same settings shall be used during the calibration of the dynamic testing system's force measurement system as were used during the ISO 4965-2 calibration of the DCD instrumentation.

5 Procedure

5.1 Initial checks

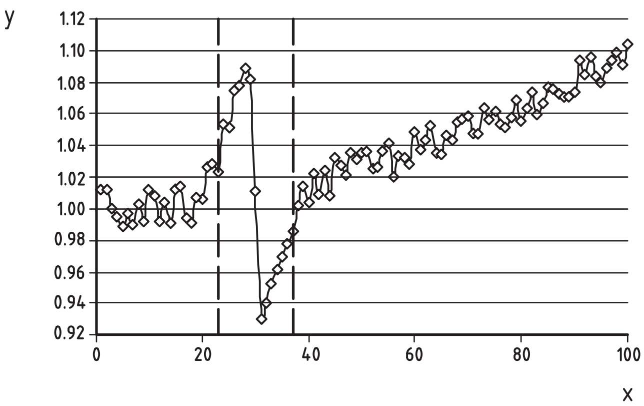
5.1.1 System bandwidth

The purpose of this check is to determine the range of frequencies over which the testing system can be verified. One technique that can be used to check the dynamics of the entire measurement system (mechanical and electrical effects) is to fracture a brittle test-piece (under displacement control) and record the sudden change in force signal. The bandwidth can then be calculated as in Annex B, which also gives guidance on estimation of the testing system instrumentation's bandwidth.

Another technique that can be used to determine valid frequency ranges is to perform a frequency sweep – this helps identify localized areas of error that don't follow the general trend, due to the presence of significant resonant frequencies. Increase the testing frequency slowly, with the cyclic force range fixed at a moderate amplitude, in a continuous manner or in small steps from the minimum to the maximum of the test frequency calibration range, with each DCD mounted in the load train. Read and record the peak and/or valley outputs of the DCD, or the output of an accelerometer fixed within the load train, at each test frequency. Plot the amplitude of the measured values against frequency, fit a curve to the data points, and identify individual values which deviate from the underlying trend by more than 5 % of its value – such transient variations may indicate system resonance. If any transient variations are detected, reduce the range of test frequencies to be verified to avoid the system resonant frequencies. The resulting frequency range shall not span any system resonant frequency. When Method B is being used, any system resonant frequencies indicated during the use of either DCD shall be avoided during the actual testing.

It is recommended that the test frequency sweep be performed in force control to ensure sufficient control resolution.

To avoid system resonance, testing systems can be verified over more than one test frequency range, thus avoiding the critical system resonant frequencies. Subsequent actual testing shall also avoid these critical system resonant frequencies. For example, the test system could be verified between frequencies of 0 Hz and 23 Hz and between 37 Hz and 100 Hz to avoid a critical system resonant frequency of 30 Hz. Then, no actual testing would be allowed in the range from 23 Hz to 37 Hz, the frequency range within which the output deviates significantly from the underlying trend, as illustrated in Figure 2.



Key

x frequency, in Hz

y normalized output

Figure 2 — Example plot illustrating frequency range to be avoided due to resonant behaviour

NOTE 1 Monitoring the waveform distortion at each test frequency in the sweep can be a helpful tool in identifying system resonant frequencies, although the tools to do this comprehensively are quite advanced. If distortion is apparent on a simple oscilloscope trace, the testing system is definitely not operating correctly.

NOTE 2 Alternative methods for determining the key frequency ranges of interest are being developed – these include determination of the Fast Fourier Transform (FFT) of the machine's force indication when a step input is applied to the actuator, with no specimen present, and determination of the FFT of the force rate when a step force input is applied to a specimen – and may also be used to determine the valid calibration frequency ranges. These methods can also be used to determine the influence of crosshead position. Further details can be found in Reference [1].

NOTE 3 Another method which can give information about the presence of resonant frequencies is the plotting of force against displacement while sweeping the frequency range. The area of the hysteresis loop is likely to increase significantly close to a resonance, and may even exhibit a figure of 8 shape due to higher harmonics.

5.1.2 Applied force repeatability

Establish the applied force repeatability for the dynamic testing system as measured by its own force measurement system. At each verification frequency, cycle the dynamic testing system at least 50 times, and record the corresponding peak and valley end levels of each cycle, as measured by the force measurement system. These end levels shall not vary by more than 1 % of the total force range being applied at all verification frequencies.

5.2 Calibration procedure

5.2.1 Static calibration of DCD

5.2.1.1 Statically calibrate the DCD against the dynamic testing system indicator, using the force range determined in 4.2.3, by slowly cycling the force between the selected upper and lower force levels at least three times and then holding the force constant on the testing system and reading the DCD indication. Take readings at the four following static force values:

a) peak force + 5 % of the force range (= $[p + 5]$);

b) peak force − 5 % of the force range (= $[p - 5]$);

c) valley force + 5 % of the force range (= $[v + 5]$);

d) valley force − 5 % of the force range (= $[v - 5]$).

When the dynamic force range is through-zero [i.e. tension (positive) and compression (negative)], use the end levels listed above.

When the dynamic force range is tension-only and the [valley force − 5 % of the force range] value is below zero, the zero force value should be used.

When the dynamic force range is compression-only and the [peak force + 5 % of the force range] value is above zero, the zero force value should be used.

Indicated force		DCD indication
$F_i\ [p + 5]$	(Peak Force + 5 % of the force range)	$i_{DCD}\ [p + 5]$
$F_i\ [p - 5]$	(Peak Force − 5 % of the force range)	$i_{DCD}\ [p - 5]$
$F_i\ [v + 5]$	(Valley Force + 5 % of the force range)	$i_{DCD}\ [v + 5]$
$F_i\ [v - 5]$	(Valley Force − 5 % of the force range)	$i_{DCD}\ [v - 5]$

5.2.1.2 Repeat 5.2.1.1 twice to generate three sets of readings, and then determine the average of the three sets of readings.

5.2.1.3 If Method B is being used, repeat 5.2.1.1 and 5.2.1.2 for the second DCD.

5.2.1.4 For both peak and valley force levels, calculate the coefficients of the straight line, which joins the two adjacent values to give the static force relationship between the DCD indication and the dynamic testing system force indication using the averaged values determined in 5.2.1.2.

For peak force levels,

$$F_{\mathrm{DCD}}(p) = m_p \cdot i_{\mathrm{DCD}} + c_p \tag{1}$$

where

$$m_p = \frac{F_{\mathrm{i}}[p+5] - F_{\mathrm{i}}[p-5]}{i_{\mathrm{DCD}}[p+5] - i_{\mathrm{DCD}}[p-5]}$$, and

$$c_p = F_{\mathrm{i}}[p+5] - m_p \cdot i_{\mathrm{DCD}}[p+5]$$

For valley force levels,

$$F_{\mathrm{DCD}}(v) = m_v \cdot i_{\mathrm{DCD}} + c_v \tag{2}$$

where

$$m_v = \frac{F_{\mathrm{i}}[v+5] - F_{\mathrm{i}}[v-5]}{i_{\mathrm{DCD}}[v+5] - i_{\mathrm{DCD}}[v-5]}$$, and

$$c_v = F_{\mathrm{i}}[v+5] - m_v \cdot i_{\mathrm{DCD}}[v+5]$$

5.2.2 Dynamic calibration of testing system force indication

5.2.2.1 Take peak and valley readings from the force indicator of the dynamic testing system (F_{i}) and from the DCD (i_{DCD}) at each of five increasing test frequencies approximately equally distributed (either linearly or logarithmically) over the range determined in 4.2.2 and at four decreasing test frequencies approximately midway between these test frequencies. Where the system is being calibrated over more than one range, due to the presence of system resonant frequencies, three increasing and two decreasing test frequencies shall be applied in each range. The force amplitude of the test should be that determined in 4.2.3.

Allow the testing system to settle at each new frequency before taking the peak and valley reading.

5.2.2.2 If Method B is being used, repeat 5.2.2.1 using the second DCD.

6 Calculation of results

6.1 Calculate DCD forces and measured force ranges

Calculate the DCD force values (F_{DCD}) at each dynamic peak and valley from the DCD indications (i_{DCD}) and the coefficients determined in 5.2.1.4, and then calculate the DCD force range (ΔF_{DCD}) using Formula (3) and the indicated force range (ΔF_{i}) using Formula (4).

$$\Delta F_{\mathrm{DCD}} = F_{\mathrm{DCD}}(p) - F_{\mathrm{DCD}}(v) \tag{3}$$

$$\Delta F_{\mathrm{i}} = F_{\mathrm{i}}(p) - F_{\mathrm{i}}(v) \tag{4}$$

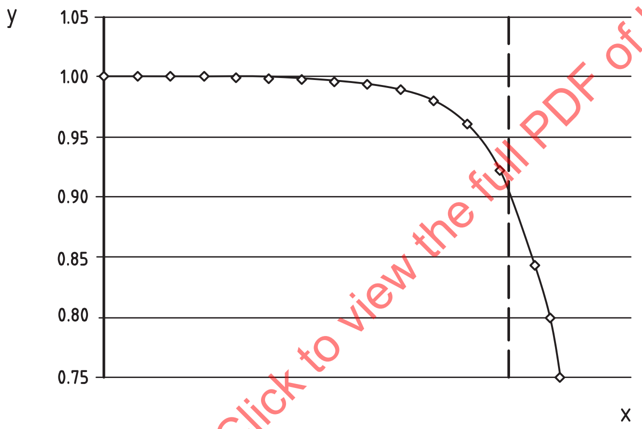
6.2 Replica test-piece — Method A

Calculate the correction factor (C) at each frequency using Formula (5).

$$C = \frac{\Delta F_{\mathrm{DCD}}}{\Delta F_{\mathrm{i}}} \qquad (5)$$

For operating conditions where the dynamic force error is less than 1 % of the applied force range (i.e. the dynamic correction factors are between 0,99 and 1,01), no dynamic force range correction is required for testing. For operating conditions where the dynamic force error is greater than 1 % but less than 10 % of the applied force range (i.e. the correction factor is either between 0,90 and 0,99 or between 1,01 and 1,10), a correction factor shall be applied. For operating conditions where the dynamic force error exceeds 10 % (i.e. the correction factor is either below 0,90 or above 1,10), the dynamic testing system shall be deemed to have failed calibration and should not be used for testing. Once the correction factor is applied, the actual test-specimen dynamic force error will be reduced to less than 1 % of the dynamic force range.

The correction factor can be expressed either as a curve by plotting it against frequency (an idealised example is given in Figure 3) or as a best fit function over the calibrated frequency range, avoiding any critical system resonant frequencies identified in 5.1.2.



Key

x frequency

y correction factor

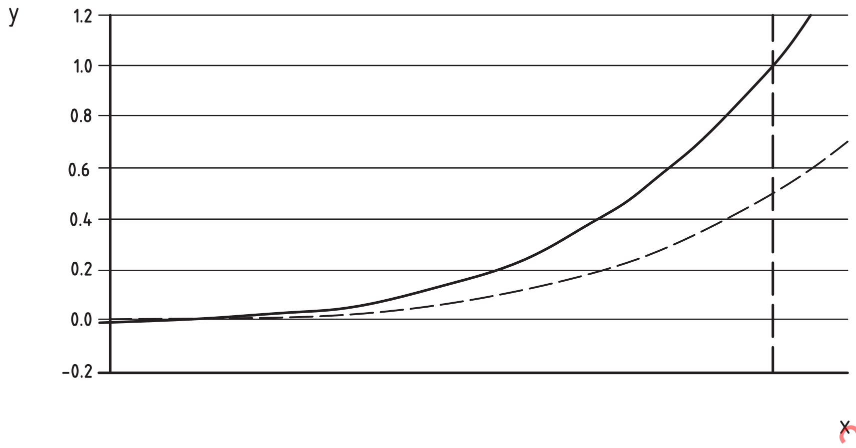
Figure 3 — Example of a Method A calibration result

6.3 Compliance envelope — Method B

Calculate the indication error, e_{i}, at each frequency using Formula (6).

$$e_{\mathrm{i}} = \frac{\Delta F_{\mathrm{i}} - \Delta F_{\mathrm{DCD}}}{\Delta F_{\mathrm{DCD}}} \times 100 \qquad (6)$$

The indication errors determined using the two DCDs are plotted against frequency in order to define the calibrated range over which the dynamic testing system can be used for actual testing (see Figures 4 and 5). The calibrated range of the testing system is that in which none of the dynamic force errors exceeds 1 % of the applied force range. If the difference in compliance between the two DCDs is small, it is likely that they will have similar shape curves as shown (in an idealised form) in Figure 4, where both errors can be either increasing or decreasing with increasing frequency. If there is a large difference between their compliances, then one DCD may have an error that increases with increasing frequency and the other may have an error that decreases with increasing frequency, as shown (again, in an idealised form) in Figure 5. The actual test frequency limits are determined such that the error does not exceed 1 % of the dynamic force range. No actual testing is allowed at any frequency where the error for either DCD exceeds 1 % of the dynamic force range.



Key

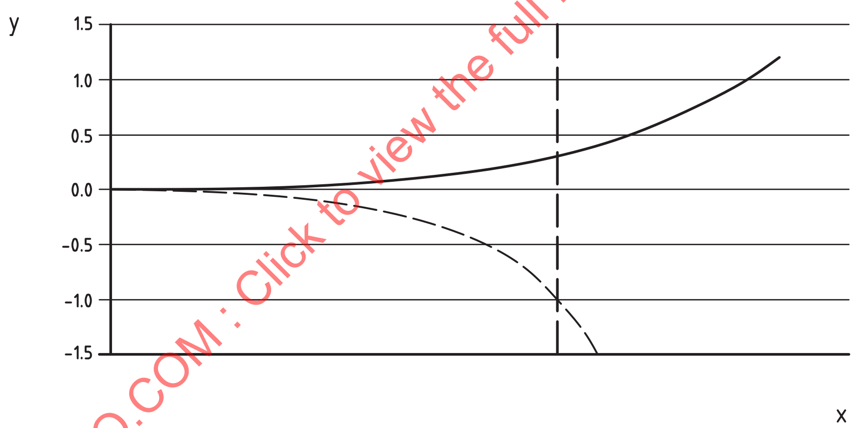
x frequency

y indication error, %

___ Less compliant DCD

- - - More compliant DCD

Figure 4 — Typical calibration envelope for a small change in compliance between two low compliance DCDs



Key

x frequency

y indication error, %

___ Less compliant DCD

- - - More compliant DCD

Figure 5 — Typical calibration envelope for a large change in compliance between the two DCDs

7 Report

7.1 General information

The report shall include the following information:

a) the force indicators and the verified indication range;

b) the range of frequency over which the verification was attempted;

c) the testing system, including the manufacturer, model number, serial number and the identifiers for all components which make up the load train;

d) the mass of load train components between the load cell and test-piece;

e) the geometry, material, compliance, and unique identifier for each dynamic calibration device used, including the manufacturer and serial number;

f) the Standard to which static calibration of the testing system has been performed (i.e. ISO 7500-1:2004), the class achieved, and the date of the static calibration;

g) the ambient temperature at the time of the calibration;

h) the name of the organization that carried out the calibration;

i) the date of the calibration;

j) a reference to this part of ISO 4965, i.e. to ISO 4965-1.

7.2 Results of dynamic calibration

The report shall include the following calibration results:

a) for Method A, the valid frequency range in which no correction factor is needed and, if applicable, the correction factor derived and its valid frequency range;

b) for Method B, the range of frequencies within which all dynamic indication errors are less than 1 % of the force range;

c) any observations, notes, or recommendations concerning the dynamic verification.

7.3 Re-calibration

The report shall include guidance concerning re-calibration, as given in Annex A.