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Temperature verification method applied to dynamic fatigue testing

Méthode de vérification de la température appliquée aux essais de fatigue dynamique

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 164, *Mechanical Testing of Metals*, Subcommittee SC 05, *Fatigue, fracture and toughness testing*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

It is the aim of this document to provide methodologies to verify the error in indicated measurement relative to the actual temperature of the specimen test piece. Therefore, it is essential to account for all factors, inclusive of environmental effects; not limiting the assessment to, for example, the performance of a recording system and the thermoelectric coefficient of a batch of thermocouple wire.

Certain types of test and advanced simulation rely on accurately controlled and rapidly changing temperature during the test, usually synchronised with control of mechanical loading. Within the scope of this document, that would usually be a thermo-mechanical fatigue test.

Where temperature varies deliberately and rapidly during the test, it is appropriate to verify the degree of time lag in system temperature reading. Without this evaluation (and implicitly a correction) then either the apparent temperature accuracy or the phase accuracy may need to be unnecessarily reduced.

This document has been written with the intention of using congruent language and approach to that used for calibration of extensometers[1] and verification of force measurement[2][3].

Temperature verification method applied to dynamic fatigue testing

1 Scope

This document establishes verification procedures to determine the accuracy, speed of response, and stability of temperature measurement for materials testing equipment. These procedures are specified for the expected use in fatigue tests on metals where these characteristics are important to the fidelity of tests at high or varying temperature.

The principles set out include sufficient provision for both contacting and non-contacting methods of temperature measurement.

This document is for the end-to-end verification of registered value compared with "true" specimen temperature at the point of measurement. It cannot be used to specify the correct method or location of measurement.

NOTE The methodologies could be found applicable to test types beyond mechanical fatigue of metals, but that is outside the remit of this document.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
test system
equipment used to perform the (fatigue) test during which this temperature measurement is to be utilised.

Note 1 to entry: This includes the gripping or fixtures, a representative specimen, the heating system (all parts which influence the measurement), measurement conditioning device (e.g. thermocouple conditioning system), data recording device and software.

Note 2 to entry: This verification is expected to take place on a complete test system, but it does not strictly require the presence of the load frame provided that all parts influencing the specimen environment are held in a representative configuration.

Note 3 to entry: The operating environment of the test system should be considered as part of the verification, because changes in temperature of conditioning electronics can affect the measurement, especially if the cold junction of a thermocouple or the detector array of a thermo-optical device is not at constant temperature.

Note 4 to entry: to entry:: Good laboratory conditions would typically be maintained by some form of climate control, but that is not always possible and it does not guarantee to prevent local problems for specific instruments.

3.2
representative specimen
test piece to be used in the verification process

Note 1 to entry: It should be of the same dimensions and material as the specimen(s) to be tested. In certain cases this may be unfeasible so a very similar geometry to that expected in the final test schedule, with comparable conductivity and emissivity should be used. Ideally, this would be an actual test specimen, but some deviation is acceptable, provided it does not significantly affect the heat transfer characteristics of the system.

3.3
reference system
independent measurement system to be used to verify the *test system* (3.1)

Note 1 to entry: This should have a resolution at least 3 times smaller than that which will be published for the verification (preferably more than 5 times) and should be traceable to a certified constant reference.

3.4
resolution
resolution of the temperature measurement system
fluctuation amplitude (half of the difference between maximum and minimum indicated values) of the noise on the indicated temperature, over a period of 30 s or 30 consecutive readings at the intended rate of data acquisition (whichever is larger)

Note 1 to entry: expressed in K or °C.

Note 2 to entry: Stated for specific temperature test point(s),or may be described as a function of indicated temperature.

3.5
bias error
bias error of the temperature measurement system
difference between indicated temperature and reference measurement, for the mean average of values measured over 30 s or 30 consecutive readings at the intended rate of data acquisition (whichever is larger) at constant temperature

Note 1 to entry: expressed in K or °C.

Note 2 to entry: Alternatively, the average of values during one complete loading cycle may be used for slower isothermal cycles, whose duration exceeds 30 s.

Note 3 to entry: Stated for specific temperature test point(s), or may be described as a function of indicated temperature.

3.6
measurement drift
maximum variation between indicated temperature and reference measurement, during a representative test period

Note 1 to entry: expressed in K or °C.

Note 2 to entry: Stated for specific temperature test point(s), or may be described as a function of indicated temperature.

3.7
time lag
delay, between a known change in specimen temperature and the resultant change in indicated temperature

Note 1 to entry: expressed in seconds.

Note 2 to entry: This determination is made on the basis of delay in rate of temperature change, thus requires a method of heating capable of significant changes in specimen heating rate within a few seconds.

3.8
stabilisation time
amount of time after a change in temperature ramp rate, during which the combination of heating system and measurement device leads to an additional level of error in reading

Note 1 to entry: This is pertinent to variable temperature tests (typically thermo-mechanical fatigue) where certain combinations of temperature control system and measurement device can lead to a temporarily unstable or significantly inaccurate measurement, at points when there is a significant change in heat flow into or out of the specimen. It will generally not be relevant to isothermal test scenarios.

3.9
in situ verification
verification performed with the complete *test system* (3.1) in a fully assembled state, with all system components which will be present in the test

Note 1 to entry: including (but not limited to):

— Mechanical grips or other fixtures used to introduce loads to the specimen

— Furnace or temperature chamber or other environmental enclosure

— Transparent or open ports used to allow access to for other monitoring or measurement devices

— Baffles or wadding used to prevent unintended convective heat loss

— Shields or sheathing or other materials used to protect transducers

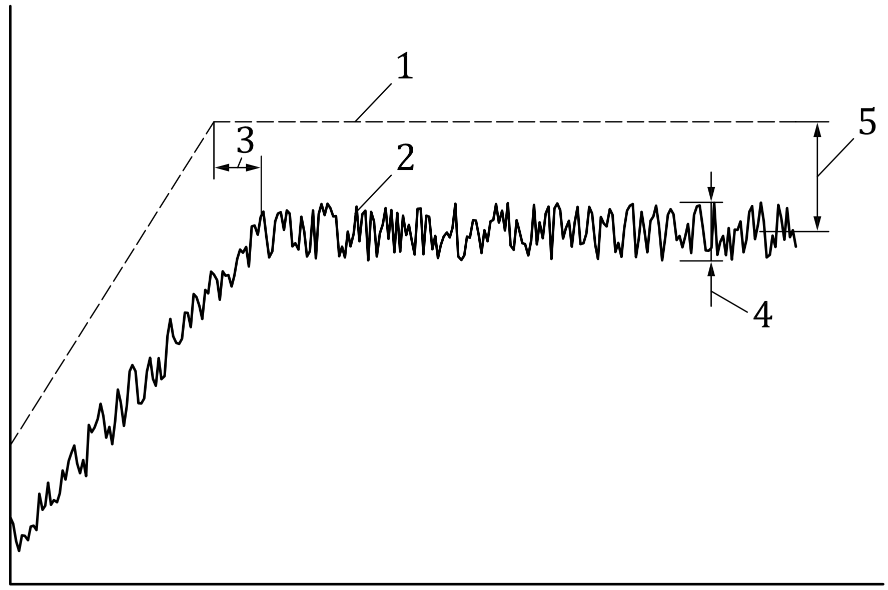
— Cooling systems such as fans or water circulators

— Transducer extension cables

Note 2 to entry: The purpose of using a fully representative verification is to capture errors which may be introduced by “parasitic” heating or cooling effects on the measurement device.

4 Measurement behaviour

Figure 1 provides a schematic representation summarising the characteristic behaviours of interest in this document, as described by the terms defined in 3.4 to 3.9, in the context of how they would be observed during a ramp-dwell test.



Key

Vertical axis: temperature
Horizontal axis: time
1 model specimen temperature
2 indicated specimen temperature corresponding to model
3 time lag
4 resolution (of the temperature measurement system)
5 isothermal bias error

Figure 1 — illustration of temperature measurement characteristics

Note 1 to entry a separate time lag will also be present between the command signal of the temperature control system and the specimen temperature. This is not the same as the time lag to be measured by the methods in this document, although a similar quantification method is possible.

Annex A provides general information on common temperature measurement techniques for specimens in fatigue test systems. These are intended to assist in consideration of techniques for both the test system and the reference system,

5 Representative verification equipment

5.1 Reference measurements

The reference system should be capable of providing a measurement whose centre can be localised within < 2 mm from the central measurement point to be verified and should be < 1 mm where possible. Where possible, any aspect of area-averaging should be comparable between the reference and the test system.

The verified accuracy and resolution of the test system cannot exceed that of the reference system. (That is to say, an isothermal accuracy of 0,1 °C could not be verified using a reference system whose resolution is only 0,5 °C).

The reference system should be stable (or have a proven, repeatable, drift correction) to better than 1 % of reading in °C, over the duration of the verification process at the selected temperature(s). For thermocouple-based references, the cold junction temperature should be appropriately controlled, for example using a “triple point” bath or similar device.

NOTE Detailed discussion of laboratory equipment, resolution and uncertainties in the context of thermocouple verification can be found in ASTM E2846[7].

5.2 Direct physically connected thermocouples (welded to specimen)

At the time of writing, an unsheathed thermocouple, with thin wires (<0,25 mm), welded to the surface of a specimen is generally considered the most reliable, practical method of measuring the skin temperature of a metallic specimen[6] and there is a published European code of practice for use in fatigue testing[7].

For that reason, it should be acceptable to verify this type of measurement on the basis of a summation of errors, which should include (but not be limited to) errors generated by:

— thermocouple conductor composition

— use of thermocouple compensating cables

— conditioning electronics calibration

— cold junction temperature stability

ASTM E2846[7] provides some guidance on use of this approach and developing an expanded uncertainty. ASTM E220[10] provides a normative calibration method for an individual thermocouple before integration into the test system.

This method of determination is not infallible and great care should be taken in ensuring correct placement of wires and good, clean, conductive weld points. It is necessary to eliminate sources of stray EMF, by ensuring close interlinking of earth between specimen and test system (note that a mechanical test frame does not always have an earth link to the temperature measurement electronics in use), and avoiding unbalanced induced current effects from passing thermocouple conductors near to strong electromagnetic fields.

If at all possible, the system should be subject to a full in situ verification, even if frequent partial verifications are performed on system components off-line.

5.3 Contacting thermocouples and other contacting devices not welded to specimen

A full in situ verification should be performed if a contacting device is used (as opposed to a welded thermocouple).

Many fatigue tests are performed using temperature “probes” contacting the specimen, but not welded to the surface (see Annex A). This can take the form of:

— a sheathed thermocouple, whose tip is gently spring-loaded against the surface

— an unsheathed thermocouple, bead welded and tied onto the specimen

— an unsheathed thermocouple, with its junction point held against the specimen by tensioning the wires

— other devices and placement methods

This can be a more practical solution than welding, due to the fact that it allows the measurement location to be placed within the parallel length or gauge length, without, in theory, interfering with the surface condition of the specimen (which the normative references mentioned in this document require to be tightly controlled). Furthermore, performing a good, clean thermocouple weld demands considerable skill on the part of the operator. However, in this case, environmental effects could add