INTERNATIONAL STANDARD

ISO 230-3

Second edition
2007-08-15

Test code for machine tools —

Part 3: Determination of thermal effects

Code d'essai des machines-outils —

Partie 3: Évaluation des effets thermiques

Reference number
ISO 230-3:2007(E)

Contents

Page

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 230-3 was prepared by Technical Committee ISO/TC 39, *Machine tools*, Subcommittee SC 2, *Test conditions for metal cutting machine tools*.

This second edition cancels and replaces the first edition (ISO 230-3:2001), which has been technically revised.

ISO 230 consists of the following parts, under the general title *Test code for machine tools*:

— *Part 1: Geometric accuracy of machines operating under no-load or finishing conditions*

— *Part 2: Determination of accuracy and repeatability of positioning numerically controlled axes*

— *Part 3: Determination of thermal effects*

— *Part 4: Circular tests for numerically controlled machine tools*

— *Part 5: Determination of the noise emission*

— *Part 6: Determination of positioning accuracy on body and face diagonals* (*Diagonal displacement tests*)

— *Part 7: Geometric accuracy of axes of rotation*

— *Part 9: Estimation of measurement uncertainty for machine tool tests according to series 230, basic equations* [Technical Report]

The following part is under preparation:

— *Part 8: Determination of vibration levels* [Technical Report]

Determination of the measuring performance of a machine tool is to form the subject of a future part 10.

Introduction

The purpose of ISO 230 is to standardize methods for testing the accuracy of machine tools, excluding portable power tools.

This part of ISO 230 specifies test procedures for determining thermal effects caused by a variety of heat inputs resulting in the distortions of a machine tool structure or the positioning system. It is a recognized fact that the ultimate thermo-elastic deformation of a machine tool is closely linked to the operating conditions. The test conditions described in this part of ISO 230 are not intended to simulate the normal operating conditions, but to facilitate performance estimation and the determination of the effects of environment on machine performance. For example, use of coolants may significantly affect the actual thermal behaviour of the machine. Therefore, these tests should be considered only as the preliminary tests towards the determination of actual thermo-elastic behaviour of the machine tool if such determination becomes necessary for machine characterization purposes. The tests are designed to measure the relative displacements between the component that holds the tool and the component that holds the workpiece as a result of thermal expansion or contraction of relevant structural elements.

The tests specified in this part of ISO 230 can be used either for testing different types of machine tool (type testing) or individual machine tools for acceptance purposes. When the tests are required for acceptance purposes, it is up to the user to choose, in agreement with the supplier/manufacturer, those tests relating to the properties of the components of the machine which are of interest. The mere reference to this part of the test code for the acceptance tests, without agreement on the parts to be applied and the relevant charges, cannot be considered as binding for one or other of the contracting parties. One significant feature of this part of ISO 230 is its emphasis on environmental thermal effects on all the performance tests described in other parts of ISO 230 related to linear displacement measurements (such as linear displacement accuracy, repeatability and the circular tests). The supplier/manufacturer will need to provide thermal specifications for the environment in which the machine can be expected to perform with the specified accuracy. The machine user will be responsible for providing a suitable test environment by meeting the supplier's/manufacturer's thermal guidelines or otherwise accepting reduced performance. An example of environmental thermal guidelines is given in Annex C.

A relaxation of accuracy expectations is required if the thermal environment causes excessive uncertainty or variation in the machine tool performance and does not meet the supplier's/manufacturer's thermal guidelines. If the machine does not meet the performance specifications, the analysis of the combined standard thermal uncertainty provides help in identifying sources of problems. Combined standard thermal uncertainty is defined in 3.6, as well as in ISO/TR 16015.

Test code for machine tools —

Part 3:
Determination of thermal effects

1 Scope

This part of ISO 230 defines three tests for the determination of thermal effects on machine tools:

— an environmental temperature variation error (ETVE) test;

— a test for thermal distortion caused by rotating spindles;

— a test for thermal distortion caused by moving linear axes.

The test for thermal distortion caused by moving linear axes (see Clause 7) is applicable to numerically controlled (NC) machines only and is designed to quantify the effects of thermal expansion and contraction as well as the rotational deformation of structure. For practical reasons, it is applicable to machines with linear axes up to 2 000 mm in length. If used for machines with axes longer than 2 000 mm, it will be necessary to choose a representative length of 2 000 mm in the normal range of each axis for the tests.

The tests correspond to drift tests according to ISO/TR 16015 and define the evaluation and the detailed procedure for machine tools.

NOTE It is not foreseen that numerical tolerances will be determined for the tests specified in this part of ISO 230.

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 1:2002, *Geometrical Product Specifications (GPS) — Standard reference temperature for geometrical product specification and verification*

ISO 230-1:1996, *Test code for machine tools — Part 1: Geometric accuracy of machines operating under no-load or finishing conditions*

ISO/TR 16015:2003, *Geometrical product specifications (GPS) — Systematic errors and contributions to measurement uncertainty of length measurement due to thermal influences*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TR 16015 and the following apply.

3.1
machine scale
measurement system integrated into a machine providing the linear or rotary position of the machine's axis

3.2
coefficient of thermal expansion
α
ratio of the fractional change of the length of a measured object or of the scale of length test equipment to the change in temperature

NOTE For the purposes of this part of ISO 230, a range of temperature from 20°C to T is considered; the following expression is used:

$$\alpha(20,T) = \frac{L_T - L_{20}}{L_{20} \cdot (T - 20)}$$

where L is the length of a measured object or of a portion of the scale of a length test equipment.

3.3
nominal coefficient of thermal expansion
α_{n}
approximate value for the coefficient of thermal expansion over a range of temperature from 20°C to T

3.4
uncertainty of coefficient of thermal expansion
u_α
parameter that characterizes the dispersion of the values that could reasonably be attributed to the coefficient of thermal expansion

3.5
thermal expansion
Δ_{E}
change in the length of a measured object or a portion of the scale of length test equipment in response to a temperature change

3.6
nominal thermal expansion
Δ_{NE}
estimate of the thermal expansion of a measured object or a portion of the scale of length test equipment from 20°C to their average temperatures at the time of measurement

NOTE This estimate is based on nominal coefficients of thermal expansion:

$$\Delta_{\text{NE}} = \alpha_n \cdot L \cdot (T - 20)$$

3.7
uncertainty in nominal thermal expansion due to uncertainty in α
$u_{\Delta_{\text{NE}}}$
uncertainty in the nominal thermal expansion arising from uncertainty in the coefficient of thermal expansion

NOTE This uncertainty can be calculated by

$$u_{\Delta_{\text{NE}}} = L \cdot (T - 20) \cdot u_\alpha$$

3.8
uncertainty of length due to temperature measurement
u_{TM}
uncertainty in a measured length due to the uncertainty of the temperature at which the length measurement was made

3.9
nominal differential thermal expansion
NDE
difference between the estimated expansion of a measured object and that of the test equipment owing to their temperatures deviating from 20 °C

3.10
uncertainty of nominal differential thermal expansion
u_{NDE}
combined uncertainty caused by the uncertainties of thermal expansion of the measured object and that of the test equipment

NOTE 1 It is obtained as the square root of the sum of the squares of the uncertainties of nominal expansions of the measured object and the test equipment:

$$u_{NDE} = \sqrt{u_{EM}^2 + u_{ET}^2}$$

where

u_{EM} is the uncertainty of nominal expansion of the measured object;

u_{ET} is the uncertainty of nominal expansion of the test equipment.

NOTE 2 For evaluation of uncertainly, see ISO/TR 16015:2003, 5.3.4.

3.11
environmental temperature variation error
ETVE
estimate of the maximum possible measurement variation induced solely by the variation of the environment temperature during any time period while performance measurements are carried out on a machine tool

EXAMPLE The notation ETVE(Z, 8 °C) indicates that the ETVE value is obtained along the Z direction and the value corresponds to an environmental temperature variation of 8 °C.

NOTE It is recognized that ISO terminology normally requires the term *deviation* instead of *error* in this term. However, due to the long history of ETVE usage, it was decided to treat it as an exception.

3.12
uncertainty due to environmental temperature variation error
u_{ETVE}
standard measurement uncertainty contribution in performance measurements carried out on a machine tool, caused by the effects of environmental temperature changes

NOTE 1 It is calculated as the square root of the square of ETVE divided by 12 (see ISO TR 230-9):

$$u_{ETVE} = \sqrt{\frac{\text{ETVE}^2}{12}}$$

NOTE 2 The basis for the estimation of this uncertainty for a machine tool is the environment test according to Clause 5.

3.13
combined standard thermal uncertainty

u_{CT}

combined uncertainty in length measurements caused by an environment with a temperature other than a constant and uniform 20 °C

NOTE 1 This term is equivalent to *combined standard dimensional uncertainty due to thermal effects* as defined in ISO/TR 16015.

NOTE 2 It is a combination by square root of sum of squares of uncertainty of environmental temperature variation error (u_{ETVE}), length uncertainty due to temperature measurements (u_{TM}) and the uncertainty of nominal differential thermal expansion (u_{NDE}):

$$u_{CT} = \sqrt{u_{ETVE}^2 + u_{TM}^2 + u_{NDE}^2}$$

NOTE 3 A detailed description of the estimation of the combined standard thermal uncertainty is given in ISO/TR 16015.

3.14
drift $d(\alpha O\beta)_{xx,60}$

range of linear or angular displacement of axis average line of spindle β in the direction of α within the first 60 min of the tests for thermal distortion caused by rotating spindle (at position xx)

EXAMPLE The notation $d(XOC)_{P1,60}$ indicates that the drift of axis average line of spindle C in direction X at position P1 (away from the spindle nose) is referenced.

NOTE 1 Possible notations for α are X, Y, Z, A, B. Possible notations for β are C, C1, A, B or any spindle axis. Possible notations for xx are: P1 (position P1, away from the spindle nose) and P2 (position P2, close to spindle nose); position reference xx is omitted for values of linear displacement in the Z direction and angular displacements (A and B).

NOTE 2 For notation $\alpha O\beta$, see ISO 230-7.

3.15
drift $d(\alpha O\beta)_{xx,t}$

range of linear or angular displacement of axis average line of spindle β in direction of α within the total spindle running period, t, of the tests for thermal distortion caused by rotating spindle (at position xx)

EXAMPLE The notation $d(XOC)_{P1,t}$ indicates that the drift of axis average line of spindle C in direction X at position P1 (away from the spindle nose) is referenced.

NOTE 1 Possible notations for α are X, Y, Z, A, B. Possible notations for β are: C, C1, A, B or any spindle axis. Possible notations for xx are P1 (position P1, away from the spindle nose) and P2 (position P2, close to spindle nose); position reference xx is omitted for values of linear displacement in the Z direction and angular displacements (A and B).

NOTE 2 For notation $\alpha O\beta$, see ISO 230-7.

3.16
drift $d(\alpha O\gamma)_{xx,60}$

range of linear or angular displacement, in the direction of α, of moved machine component along linear axis γ within the first 60 min of the tests for thermal distortion caused by moving linear axis (at position xx)

EXAMPLE The notation $d(BOX)_{1,60}$ indicates that the drift of linear axis X in direction B (rotation around Y) at target position 1 (right position in Figure 8) is referenced.

NOTE Possible notations for α are X, Y, Z, A, B, C. Possible notations for γ are X, X1, Y, Z, W or any linear axis. Possible notations for xx are: 1 and 2, xx might be also expressed in words, e.g. left and right.

3.17
drift $d(\alpha O \gamma)_{xx,t}$
range of linear or angular displacement of moved machine component along linear axis γ in direction α within the total moving period, t, of the tests for thermal distortion caused by moving linear axis

EXAMPLE The notation $d(BOX)_{1,t}$ indicates that the drift of linear axis X in direction B (rotation around Y) at target position 1 (right position in Figure 8) is referenced.

NOTE Possible notations for α are: X, Y, Z, A, B, C. Possible notations for γ are: X, X1, Y, Z, W or any linear axis. Possible notations for xx are 1 and 2; xx might be also expressed in words, e.g. left and right.

4 Preliminary remarks

4.1 Measuring units

In this part of ISO 230, all linear dimensions and deviations are expressed in millimetres. All angular dimensions are expressed in degrees. Angular deviations are, in principle, expressed in ratios, but in some cases micro-radians or arc-seconds may be used for clarification purposes. The equivalent of the following expressions should always be kept in mind:

0,010/1 000 = 10 μrad ≈ 2″

The temperatures are expressed in degrees Celsius (°C).

4.2 Reference to ISO 230-1

For the application of this part of ISO 230, refer to ISO 230-1, especially for the installation of the machine before testing and for accuracy of test equipment.

4.3 Recommended instrumentation and test equipment

The measuring instruments recommended here are only examples. Other instruments capable of measuring the same quantities and having the same or smaller measurement uncertainty may be used. The following instrumentation and test equipment are recommended for application of Clauses 5 to 7:

a) displacement measuring system with adequate range, resolution, thermal stability and measurement uncertainty (e.g. laser interferometer for thermal distortion caused by moving linear axes, capacitive, inductive or retractable contacting displacement sensors for environment testing and thermal distortion caused by rotating spindles);

b) temperature sensors (e.g. thermocouple, resistance or semiconductor thermometer) with adequate resolution and measurement uncertainty;

c) data acquisition equipment, such as a multi-channel chart recorder which continuously monitors and plots all channels, or a computer-based system in which all channels are sampled at least once every 5 min [1)], and data is stored for subsequent analysis;

   NOTE Manual data processing is permissible if a computer system is not available.

d) test mandrel, preferably made of steel, with the design to be specified in machine-specific standards or agreed between supplier/manufacturer and user, see ISO 230-1:1996, A.3;

---

1) Some temperature compensation systems exhibit cycle times shorter than 5 min. In such cases, the frequency for monitoring should be increased to five readings per cycle, if possible.

e) fixture in which to mount the displacement sensors, preferably made of steel, with the design to be specified in machine-specific standards or agreed between the supplier/manufacturer and the user, and with a design that should minimize local distortions caused by temperature gradients in the fixture;

f) when evaluating angular deviations, the distance between displacement sensors has to be selected in order to achieve adequate range, resolution and measurement uncertainty.

When necessary and practicable, the axial displacement sensor (see Figures 1, 2 and 3) may be placed directly against the spindle nose to eliminate the effect of the thermal expansion of the test mandrel.

Long-term accuracy of the measuring equipment shall be verified — for example, by transducer drift tests (see A.5).

The measuring instruments shall be thermally stabilized before starting the tests.

4.4 Machine conditions prior to testing

The machine shall be completely assembled and fully operational in accordance with the supplier's/manufacturer's instructions which must be recorded. All necessary levelling operations, geometric alignment and functional checks shall be completed satisfactorily before starting the tests.

The machine shall be powered up with auxiliary services operating and axes in the "Hold" position, with no spindle rotation, for a period sufficient to stabilize the effects of internal heat sources as specified by the supplier/manufacturer or as indicated by the test instrumentation. The machine and the measuring instruments shall be protected from draughts and external radiation such as those from overhead heaters or sunlight.

All tests shall be carried out with the machine in the unloaded condition. Where testing a machine involves rotating both the workpiece and the tool on separate spindles, the tests in accordance with Clauses 5 and 6 shall be carried out for each spindle with respect to a common fixed location on the machine structure. If any hardware- or software-based compensation capability or facilities for minimizing thermal effects, such as air or oil showers, are available on the machine tool, they shall be used during the tests and their usage recorded.

4.5 Test sequence

The tests given in Clauses 5 to 7 may be used either singly or in any combination.

4.6 Test environment temperature

In accordance with ISO 1, all dimensional measurements shall be made when the measuring instruments and the measured objects (for example, a machine tool) are in equilibrium with the environment, with the temperature maintained at 20 °C. If the environment is at a temperature other than 20 °C, nominal differential thermal expansion (NDE) correction between the measurement system and the measured object (machine tool) shall be made to correct the results in order to correspond with those for 20 °C. For example, in a typical linear displacement measurement using laser interferometer, ambient temperature around the laser beam and the temperature of machine scale should be recorded during the measurements. The expected length change of the laser interferometer (due to change in laser wavelength as a function of the ambient temperature and pressure) and that of the machine scale (as a response to its temperature) shall be calculated. The difference between these two length expansions is calculated as NDE and used to correct the raw measurement data from the laser interferometer to determine the linear displacement deviations at 20 °C. However, since the aim in this part of ISO 230 is to identify the machine's behaviour under possibly varying environmental temperature conditions, the requirement for NDE corrections is relaxed. NDE correction is allowed only between the test equipment and the part of the machine where the workpiece is usually located. Built-in NDE correction used for the normal operation of the machine tool shall be used; additional NDE correction only for the measurements shall not be used to correct the thermal distortions of machine scales.

5 ETVE test

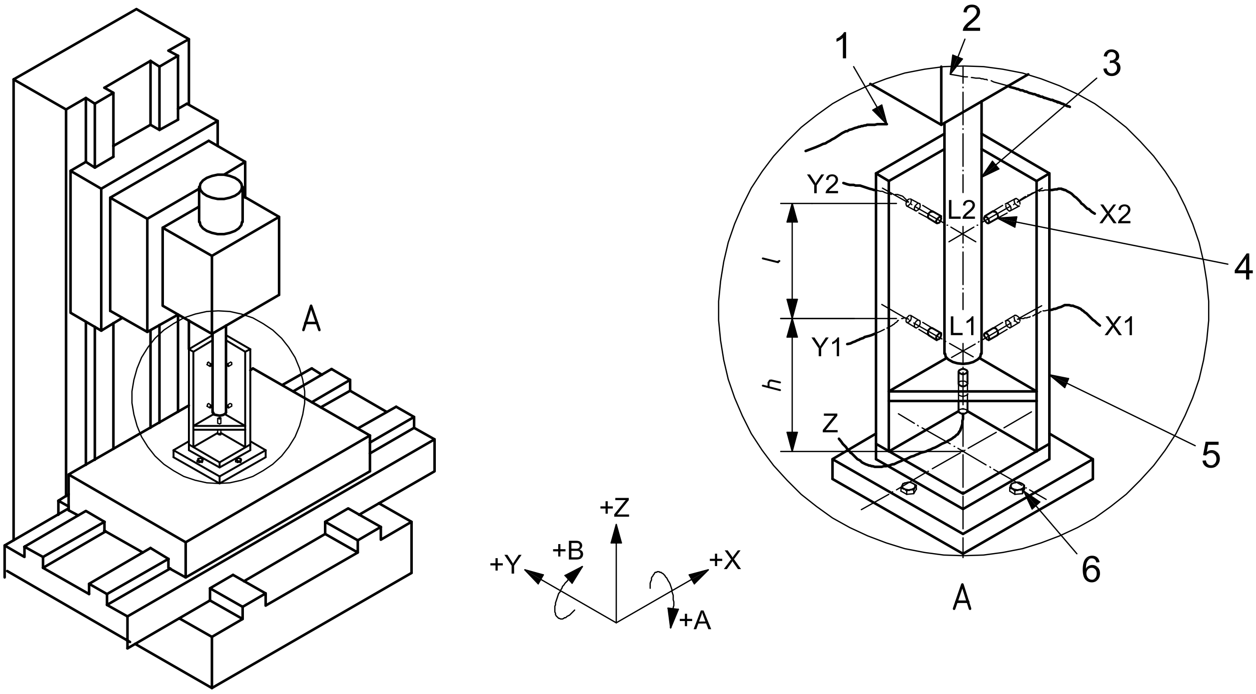
5.1 General

An ETVE test is designed to reveal the effects of environmental temperature changes on the machine and to estimate the thermally induced error during other performance measurements. Such tests shall not be used for machine comparison. The ETVE shall be determined by the drift test using the procedure given in 5.2. If the correct operation of the measuring instrument requires compensation for environment factors such as air temperature and pressure, then these shall be used. If the measuring instrument incorporates facilities for NDE correction, then these facilities should be used, provided that the material temperature sensor is placed on the part of the machine where the workpiece is normally located. The use of such facilities shall be recorded.

It is recommended that the supplier/manufacturer offer guidelines on the thermal environment which can be considered as acceptable for the machine to perform in with the specified accuracy. Such general guidelines could contain, for example, a specification on the mean room temperature, maximum amplitude and frequency range of deviations from this mean temperature and environmental thermal gradients (see Annex C). It is the user's responsibility to provide an acceptable thermal environment for the operation and the performance testing of the machine tool at the installation site. However, if the user follows the guidelines provided by the machine supplier/manufacturer, the responsibility for machine performance according to the specifications reverts to the machine supplier/manufacturer.

The total uncertainty in the performance measurements of the machine tool caused by the thermal effects is defined as the combined standard thermal uncertainty. The combined standard thermal uncertainty, u_{CT}, can be estimated with the help of the described test, when the environmental conditions during the performance measurement and the ETVE test are comparable. It shall not exceed an amount that is mutually agreed upon between the user and the supplier/manufacturer.

It is a requirement that the machine axes be powered up and in the "Hold" position (see 4.4.). On some machine designs, especially on a vertical or slant axis, the axis may warm up in "Hold" position. If this is the case, the ETVE test may be carried out with the machine completely shut off. This condition shall be stated in the test report.



Key

1 ambient air temperature sensor

2 spindle bearing temperature sensor

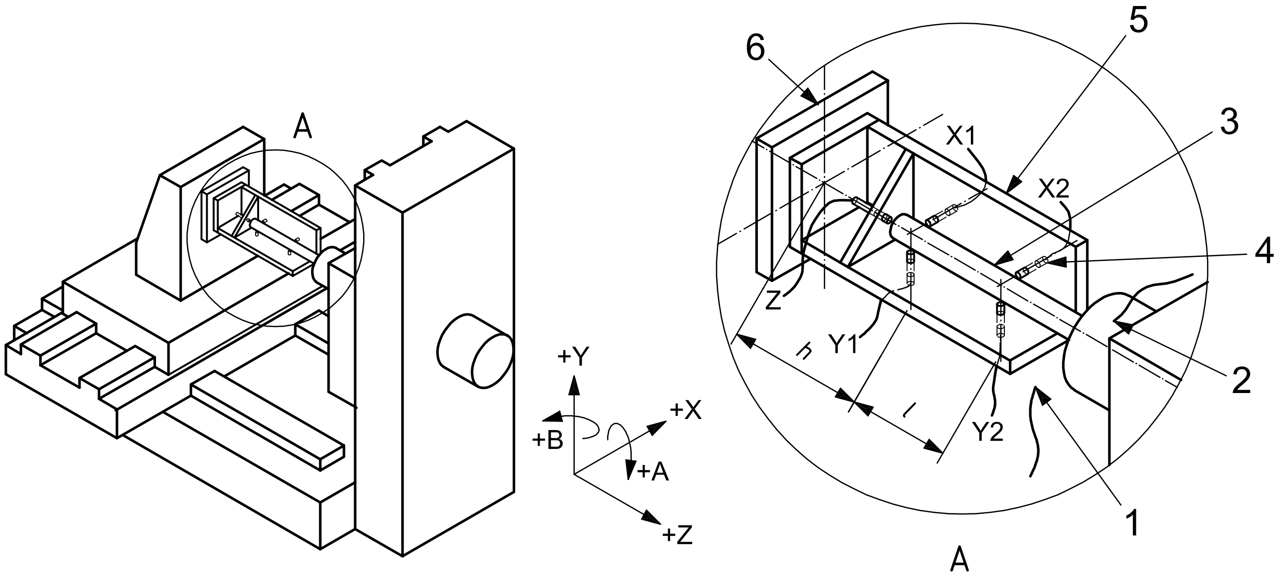
3 test mandrel

4 linear displacement sensors

5 fixture

6 fixture bolted to table

Figure 1 — Typical set-up for testing ETVE and thermal distortion of structure caused by rotating spindle and by moving linear axis on vertical spindle machining centre



Key

1 ambient air temperature sensor

2 spindle bearing temperature sensor

3 test mandrel

4 linear displacement sensors

5 fixture

6 fixture bolted to table

Figure 2 — Typical set-up for testing of ETVE and thermal distortion of structure caused by rotating spindle and by moving linear axis on horizontal spindle machining centre