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# General tests for machine tools —

**Part 3: Method of testing performance  
of machines operating under loaded  
conditions in respect of thermal  
distortion**

# Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Machine, Engineers and Hand Tools Standards Policy Committee (MTE/-) to Technical Committee MTE/1, upon which the following bodies were represented:

- Advanced Manufacturing Technology Research Institute
- Cranfield Institute of Technology
- Department of Trade and Industry (Mechanical Engineering and Manufacturing Technology Division)
- Health and Safety Executive
- Machine Tool Trades Association
- Ministry of Defence
- Society of British Aerospace Companies Limited

The following were also represented in the drafting of the standard, through subcommittees and panels:

Coopted members

This British Standard, having been prepared under the direction of the Machine, Engineers and Hand Tools Standards Policy Committee, was published under the authority of the Board of BSI and comes into effect on 28 September 1990

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## Foreword

This Part of BS 3800 has been prepared under the direction of the Machine, Engineers and Hand Tools Standards Policy Committee. It is based on a proposal from the Advanced Manufacturing and Technology Research Institute (AMTRI).

This British Standard describes methods of testing machine tools to determine the influence of thermally induced error on workpiece accuracy. The objective of the test is to supplement the information obtained from tests for geometric accuracy in BS 3800-1 and for positioning accuracy and repeatability in BS 4656-16 (which will be revised and published as BS 3800-2). The tests specified are all instrumental tests and do not depend upon measurements of a machined workpiece. Instrumental tests have the ability to quantify the contribution made to the total machining accuracy from a particular source of error.

Other Parts of BS 3800 will deal with statistical methods, vibration and noise.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

**Compliance with a British Standard does not of itself confer immunity from legal obligations.**

### Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 12, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

## 1 Scope

This Part of BS 3800 gives methods for assessing the contribution to workpiece inaccuracy arising from the thermal behaviour of the machine, due to internal heat sources, in respect of:

- a) distortion of the structure; and
- b) drift of the axis drives.

The tests for thermal distortion of the structure are applicable to any machine which incorporates a rotating spindle or spindles supporting the tool or the workpiece. The tests are designed to establish the relative displacements occurring between the tool and workpiece sides of the structure as a result of thermal expansion or contraction of key structural elements.

The tests for thermal drift of the axis drives are applicable to numerically controlled (NC) machines only and are designed to quantify the effects on positioning accuracy and repeatability of thermal expansion and contraction of the axis drives.

## 2 Test conditions

### 2.1 Environment

Where the temperature of the environment can be controlled, it shall be set to 20 °C.

**NOTE** The tests can be carried out at any other ambient temperature.

The ambient temperature shall be continuously recorded during the test, the variation not exceeding 2 °C, although some machines may require closer tolerance. The machine including all of its services, e.g. hydraulics, shall be completely shut down before the start of the test. Both the machine and the measuring instruments shall have been in the test environment long enough, preferably overnight, to be in a thermally stable condition before testing. They shall be protected from draughts and external radiations such as those from overhead heaters, or sunlight, etc.

If the measuring instrument incorporates compensations for environmental factors such as air temperature and pressure, then these shall be used. However, compensations for machine or position feedback temperature shall not be used.

If the measuring instrument incorporates facilities by which the measured data can be normalized to the case of that in which the machine or position feedback system is at 20 °C, then these facilities shall **not** be used.

### 2.2 Machine to be tested

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

All tests shall be carried out with the machine in the unloaded condition.

Where a machine involves rotating both the workpiece and tool on separate spindles, the test shall be carried out for each spindle with respect to a common fixed point.

Where the machine incorporates compensation for thermal errors, the machine compensation system shall be active.

### 2.3 Sequence of testing

The order of carrying out the two types of test is not significant, provided that both tests commence with the machine thermally stable at a steady ambient temperature.

## 3 Thermal distortion of structure

### 3.1 Instrumentation and equipment

**3.1.1 Calibration.** The calibration of all instrumentation used shall be traceable to a national reference standard.

**3.1.2 Instrumentation.** The following instrumentation shall be provided:

- a) non-contacting displacement transducer equipment, five channels minimum, with linear output proportional to measured deflection;
- b) thermocouple, resistance or semiconductor thermometer with an output proportional to temperature.

#### 3.1.3 Test equipment

**3.1.3.1 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 one per minute, and data is stored for subsequent analysis.

**3.1.3.2 Test-mandrel,** preferably about 50 mm in diameter and 150 mm in length and made in a low-expansion alloy material, e.g. invar, shall be attached to the spindle of the machine. The test-mandrel shall be set so as to minimize run-out.

**NOTE** Where significant, the differential expansion of the collet that holds the mandrel may need to be taken into account.

**3.1.3.3 Fixture in which to mount the displacement transducers,** constructed in a low-expansion alloy material, e.g. invar.

### 3.2 Test procedure

Figure 1 and Figure 2 show typical measurement set-ups for a vertical machining centre and a lathe, respectively.

The fixture in which the displacement transducers are mounted shall be securely fixed to the non-rotating workholding or toolholding zone of the machine, so as to be able to monitor:

- a) the relative displacements occurring between the tool and work sides of the machine in the three orthogonal axes parallel to the axes of travel of the machine;
- b) tilt or rotation in the two axes normal to the spindle axis.

The temperature of the machine structure, as close as possible to the front spindle bearing housing, shall be continuously monitored.

The test shall commence by running the spindle at approximately  $0.7 \times$  maximum speed. All transducer outputs shall be monitored until the deflection change, over any 20 min period, in all axes has reduced to less than 15 % of the maximum deflection registered over the first 20 min of the test, or until a period of 4 h has elapsed, whichever occurs first. The machine shall then be allowed to cool down, for a minimum period of 1 h, whilst monitoring of the transducers is continued.

Plot the results in graphs of deflection/temperature versus time, as shown in the example given in Figure 3.

### 3.3 Interpretation of results

The effect of warming up the machine structure on the ability of the machine to maintain the position of the tool relative to the workpiece, can be directly assessed from the deflections versus time graphs.

## 4 Thermal drift of axis drives

NOTE This test is carried out on computerized numerically controlled (CNC) machines only.

### 4.1 Instrumentation

The calibration of all instrumentation used shall be traceable to national reference standards.

A laser interferometer system with linear measurement optics, automatic compensation unit or barometer and thermometer, the latter two of uncertainty not exceeding  $0.5 \text{ mmHg}^{1)}$  and  $0.5^\circ\text{C}$  respectively, shall be provided.

### 4.2 Test equipment

**4.2.1 Computer system**, for data acquisition, storage and analysis linked to the laser interferometer system.

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

### 4.3 Test procedure

The laser reflector and remote interferometer shall be set so as to measure the distance traversed by the moving part of the axis under test. Examples of typical test set-ups are shown in Figure 4 and Figure 5. Test positions shall be selected along the axis under test in accordance with BS 4656-16. These are the command positions. To commence, the axis under test shall be moved to home position in the direction in which the traverse to the test positions is to take place. The measuring system shall then be reset, i.e. set to zero.

An initial test sequence involving a test of the positioning accuracy and repeatability of the axis shall be performed in accordance with the procedures specified in BS 4656-16. This test sequence shall be performed as quickly as possible.

The axis shall then be driven at rapid traverse rate between the two end points, i.e. the positions at each extreme of programmable travel, dwelling at each end point just long enough to record the error, i.e. actual position minus programmed position. The test shall proceed in this manner until the change in the error over any 5 min period at both points has reduced to less than 15 % of the maximum error change over the first 5 min of the test, or until a period of 1 h has elapsed, whichever occurs first.

The initial test sequence described above shall then be repeated.

Finally, the axis shall be positioned at that end of the traverse at which the largest error during warm-up was recorded and shall be left at that position for a minimum of 1 h, during which the error is recorded at 1 min intervals.

The data corresponding to those parts of the test involving the full accuracy and repeatability tests at the five positions along the axis shall be processed and plotted in accordance with BS 4656-16.

Examples of the plots showing the results of the accuracy and repeatability tests before and after warm-up are shown in Figure 6 and Figure 7, and Figure 9 and Figure 10 respectively.

The data corresponding to the error at the end points, collected during the warm-up and cool-down process, shall be plotted in the form of error versus time plots, an example of which is shown in Figure 8.

<sup>1)</sup> 1 mm Hg = 133.322 Pa