

Accuracy of machine tools and methods of test —

Part 30: Specification for machining centres and computer numerically controlled milling machines, horizontal and vertical spindle types

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
- Health and Safety Executive
- Machine Tool Technologies Association
- Ministry of Defence
- 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 Standards Board and comes into effect on 15 December 1992

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The following BSI references relate to the work on this standard:
Committee reference MTE/1
Draft for comment 91/72184 DC

ISBN 0 580 21173 8

Amendments issued since publication

Amd. No.	Date	Comments

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Foreword

This Part of BS 4656 has been prepared under the direction of the Machine, Engineers and Hand Tools Standards Policy Committee. It supersedes BS 4656-20:1985 and BS 4656-27:1985 which are now withdrawn. This Part of BS 4656 takes account of work on machining centres being undertaken within the International Organization for Standardization (ISO) but has been published in advance of the ISO work to meet the needs of the UK manufacturing industry.

The tests described in this Part of BS 4656 are primarily intended for developing and verifying individual machine specifications.

Two basic categories of test are given in this Part of BS 4656: firstly, testing of the machine under no-load or finishing conditions. This category includes testing of the geometric and positioning accuracy of the machine. Secondly, testing of the machine under various loaded conditions. In this category, the influence on the accuracy of the machine of thermally-generated effects is measured and the metal removal rate achievable by the machine is assessed.

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.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 132, 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 4656 specifies with reference to BS 3800-1:1990 both geometrical and practical tests for machining centres and computer numerically controlled (CNC) milling machines of horizontal and vertical spindle types, with a working envelope of up to 3 000 mm.

This Part of BS 4656 applies to machines having a minimum of four numerically controlled axes, three linear (X, Y and Z) and one rotary axis (spindle) and gives the permissible deviations which apply.

2 References

2.1 Normative references

This Part of BS 4656 incorporates, by reference, provisions from specific editions of other publications. These normative references are cited at the appropriate points in the test and the publications are listed on the inside back cover. Subsequent amendments to, or revisions of, any of these publications apply to this Part of BS 4656 only when incorporated in it by updating or revision.

2.2 Informative references

This Part of BS 4656 refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

3 Definitions

For the purposes of this Part of BS 4656 the following definitions apply together with those of BS 3800-1:1990.

NOTE Figure 1 to Figure 4 show types of machines.

3.1

machining centre

a numerically controlled machine tool capable of performing a variety of operations at one set-up of a workpiece (normally two or more of turning, boring, drilling, milling and screwing and threading) and able to select and change tools, position the workpiece and the cutter, and control speeds and feeds and ancillary services (e.g. coolant flow)

NOTE See Figure 1 and Figure 2.

3.2

CNC milling machine

a machine tool equipped with CNC and capable of carrying out only one machining process before manual intervention is required

NOTE See Figure 3 and Figure 4.

4 Application of test methods

4.1 In applying the geometric, dynamic and practical tests detailed in Table 1 to Table 10, reference should be made to BS 3800-1:1990 especially concerning the environment and installation of the machine before testing, warming up of spindles and other moving parts, the description of measuring methods and the recommended accuracy of testing equipment.

4.2 The tests may be applied in any order that is practicable and that makes for ease of mounting of instruments or gauging. The sequence in which the geometrical tests are listed is related to the sub-assemblies of the machine and it is not intended to impose the practical order in which the tests are to be done.

4.3 In respect of safety, the machine, where reasonably practicable, should be fully assembled, including guards, other safeguards and safety devices.

NOTE Attention is drawn to the Health and Safety at Work etc. Act 1974 [1].

4.4 The purchaser shall be at liberty to select, in agreement with the manufacturer, those tests relating to the features that are of interest to him. The appropriate tests are to be clearly stated when the machine is ordered.

4.5 When establishing the tolerance for a measuring range different from that given in this standard (see 2.311 of BS 3800-1:1990) it should be taken into consideration that the minimum value of proportional tolerance is 0.01 mm for geometrical and practical tests.

4.6 Practical tests

NOTE These are described in Table 10 to Table 12.

4.6.1 A cutting test shall be made to demonstrate the use of full continuous rating of spindle motor power.

The manufacturer shall select the actual feeds and speeds for these practical tests in conjunction with the purchaser to suit the particular application/machine combination.

4.6.2 Practical tests should be made with finishing cuts (e.g. depth 0.1 mm, feed 0.1 mm per revolution) and not with roughing cuts, which are liable to generate appreciable cutting forces. The manufacturer shall select the actual feeds and speeds for the practical tests to suit the particular machine.

4.6.3 The results obtained from practical tests and those obtained from geometrical tests where these check the same feature are independent and those from one form of test do not override results from the other form of test.

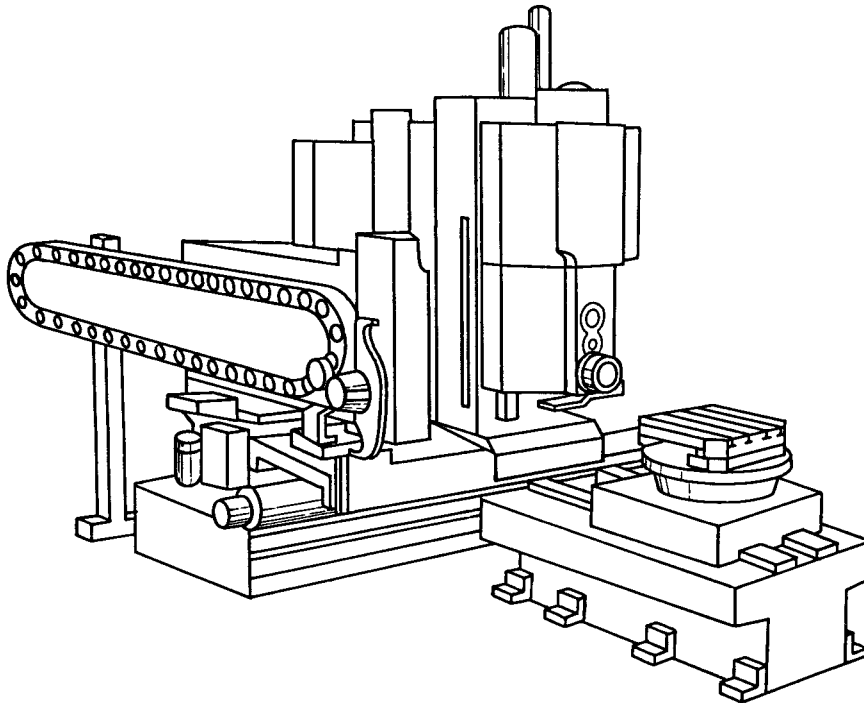


Figure 1 — Horizontal machining centre

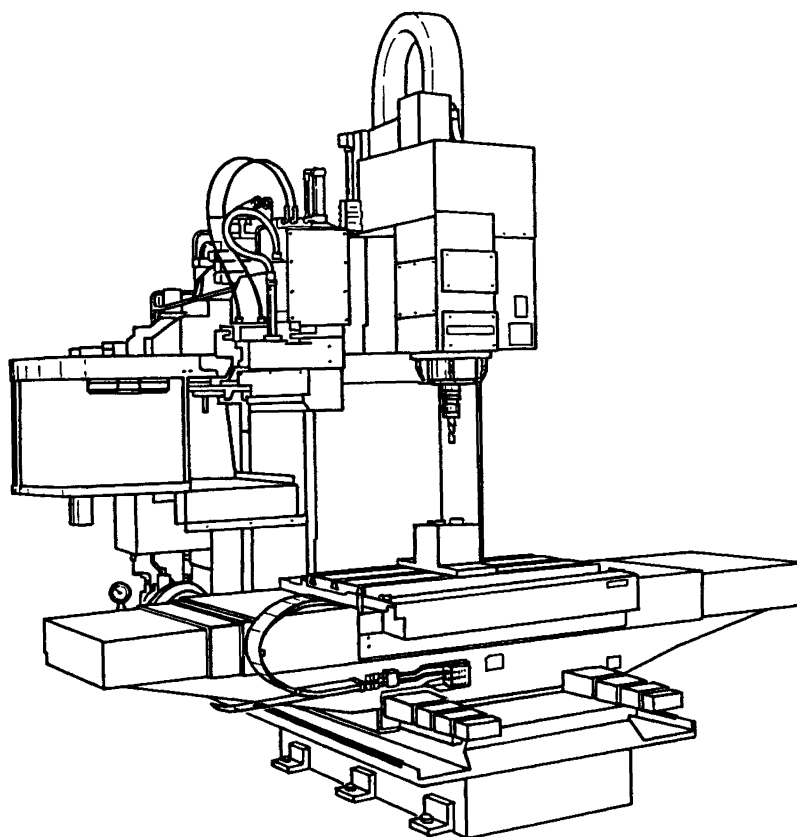


Figure 2 — Vertical machining centre

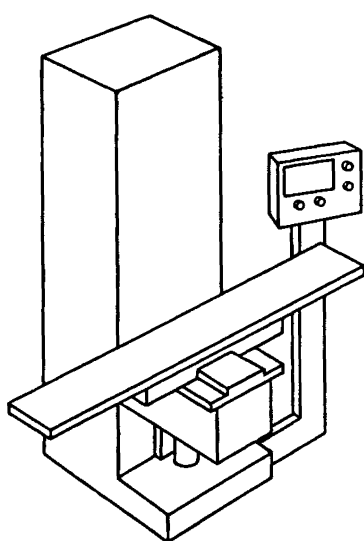


Figure 3 — Horizontal CNC milling machine

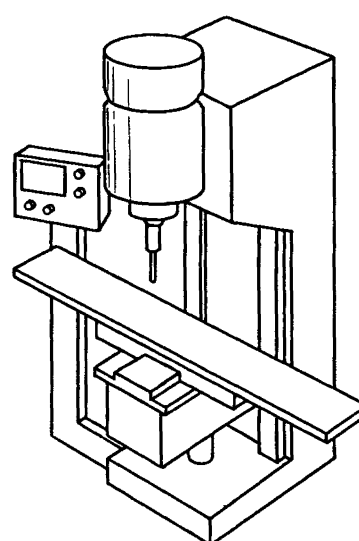


Figure 4 — Vertical CNC milling machine

NOTE This may differ, at present, from the practice pertaining to other types of machine tools.

4.6.4 Where the machine control system employs software compensation, a statement to this effect should be clearly recorded in the test report.

4.6.5 Unless otherwise stated permissible deviations are shown as full indicator movement (FIM); units are in millimetres.

5 Abbreviations

For the purposes of this Part of BS 4656, various methods of expressing permissible deviations are employed, each having a particular type of application. The methods employed are as follows:

- /--- This type of expression applies to deviations of perpendicularity that are ratios.
- for any length of--- This type of expression applies to deviations of straightness and parallelism, and is used in fact for local permissible deviations, the measurement length being obligatory.
- per--- This type of expression applies to deviations of straightness and parallelism and is used to recommend a measurement length, but in this case the proportionality rule comes into operation if the measurement length differs from that indicated.

6 Axes designation

6.1 Basic axes

The basic axes shall be as follows.

- X axis** The longitudinal axis, perpendicular to the axis of rotation of the spindle.
- Y axis** The axis of operation perpendicular to X and Z axes.
- Z axis** The axis of motion parallel to the axis of rotation of the spindle.

NOTE The above definitions apply to the axes of both horizontal and vertical machines, see Figure 5 and Figure 6.

- Rotary spindle axis** The axis for holding and causing the rotation of the cutting tool.

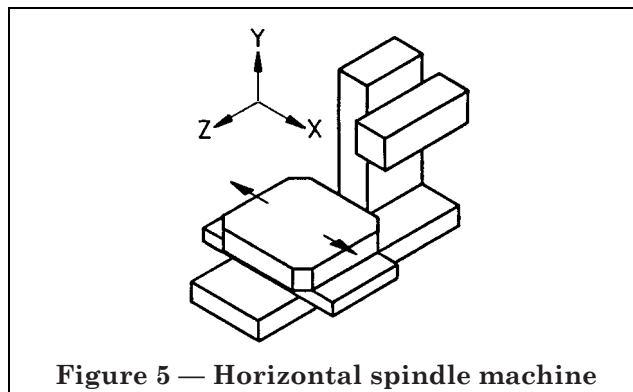


Figure 5 — Horizontal spindle machine

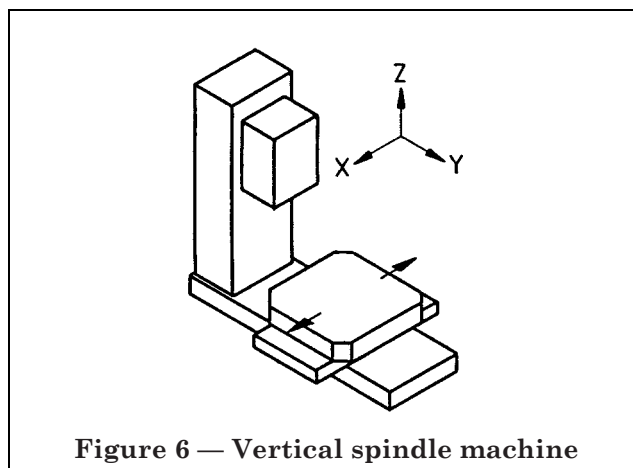


Figure 6 — Vertical spindle machine

6.2 Optional axes

NOTE These are built into the machine if required.

6.2.1 Optional linear axes

If, in addition to the primary slide motions X, Y, Z, there are secondary and tertiary (third) slide motions parallel to these, they shall be designated:

Secondary

- U parallel to X
- V parallel to Y
- W parallel to Z

Tertiary

- P parallel to X
- Q parallel to Y
- R parallel to Z

The primary linear axes shall be those nearest the principal spindle, the secondary shall be the next nearest and the tertiary shall be the farthest away.

NOTE If linear motions exist, which may or may not be parallel to X, Y, Z axes, they may be designated as most convenient.

6.2.2 Optional rotary axes

A, B and C shall define rotary motions about axes parallel to X, Y and Z respectively as follows:

the A axis of rotation is parallel to X motion;

the B axis of rotation is parallel to Y motion;
the C axis of rotation is parallel to Z motion.

NOTE See Figure 7, Figure 8, Figure 9 and Figure 10.

7 Basic features

These comprise a feature on the work locating surface:

- a) tenon slots;
- b) locating registers, etc.

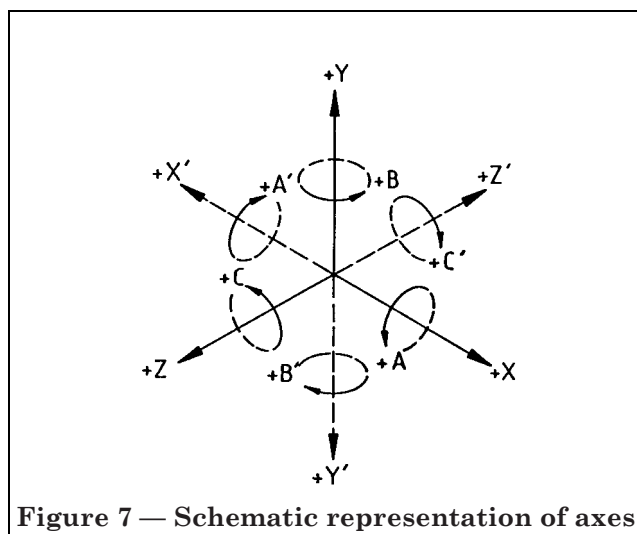


Figure 7 — Schematic representation of axes

8 Optional features

Optional features may include:

- a) single or multi-pallet systems;
- b) swivelling spindle heads.

9 Diagrams

Diagrams are typical only and do not represent a particular make of machine.

10 Classification

The machines considered in this Part of BS 4656 are classified into groups according to the function of their design and of the components moving along the linear axes.

These groups have been classified by category numbers from 1 to 21 (see Figure 11 to Figure 15) and their classification is shown in Figure 11 to Figure 15.

Tests in Table 1 relate to machines having basic axes of categories 1 to 18a) i.e. machines with axes X, Y, Z and spindle rotation.

Tests in Table 2 relate to machines of category 19, i.e. those machines which have additional optional axes. (Tests in Table 1 also apply to category 19.)

Tests in Table 4 and Table 5 are in addition to tests in Table 1, Table 2 and Table 9 and relate to machines with optional features, e.g. multiple pallets of categories 20 and 20a) and swivelling heads of categories 21 and 21a).

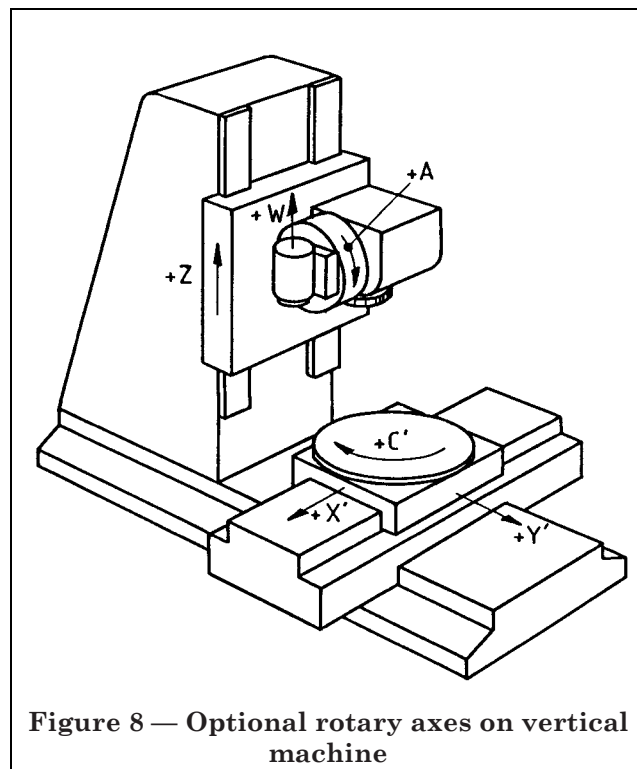


Figure 8 — Optional rotary axes on vertical machine

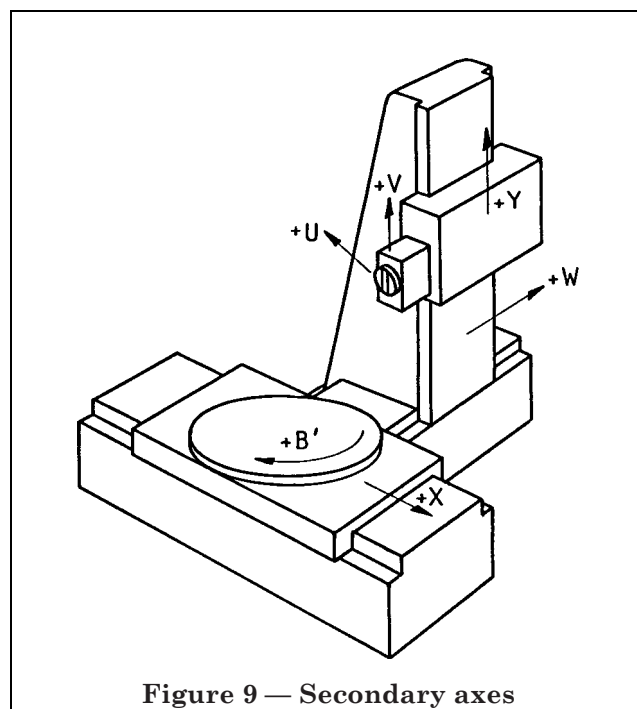


Figure 9 — Secondary axes

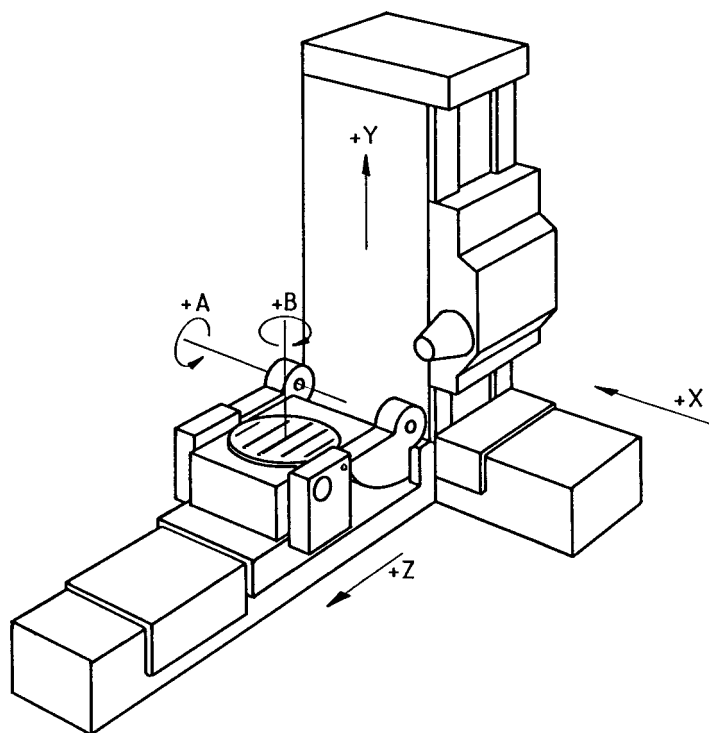


Figure 10 — Optional rotary axes on horizontal machine

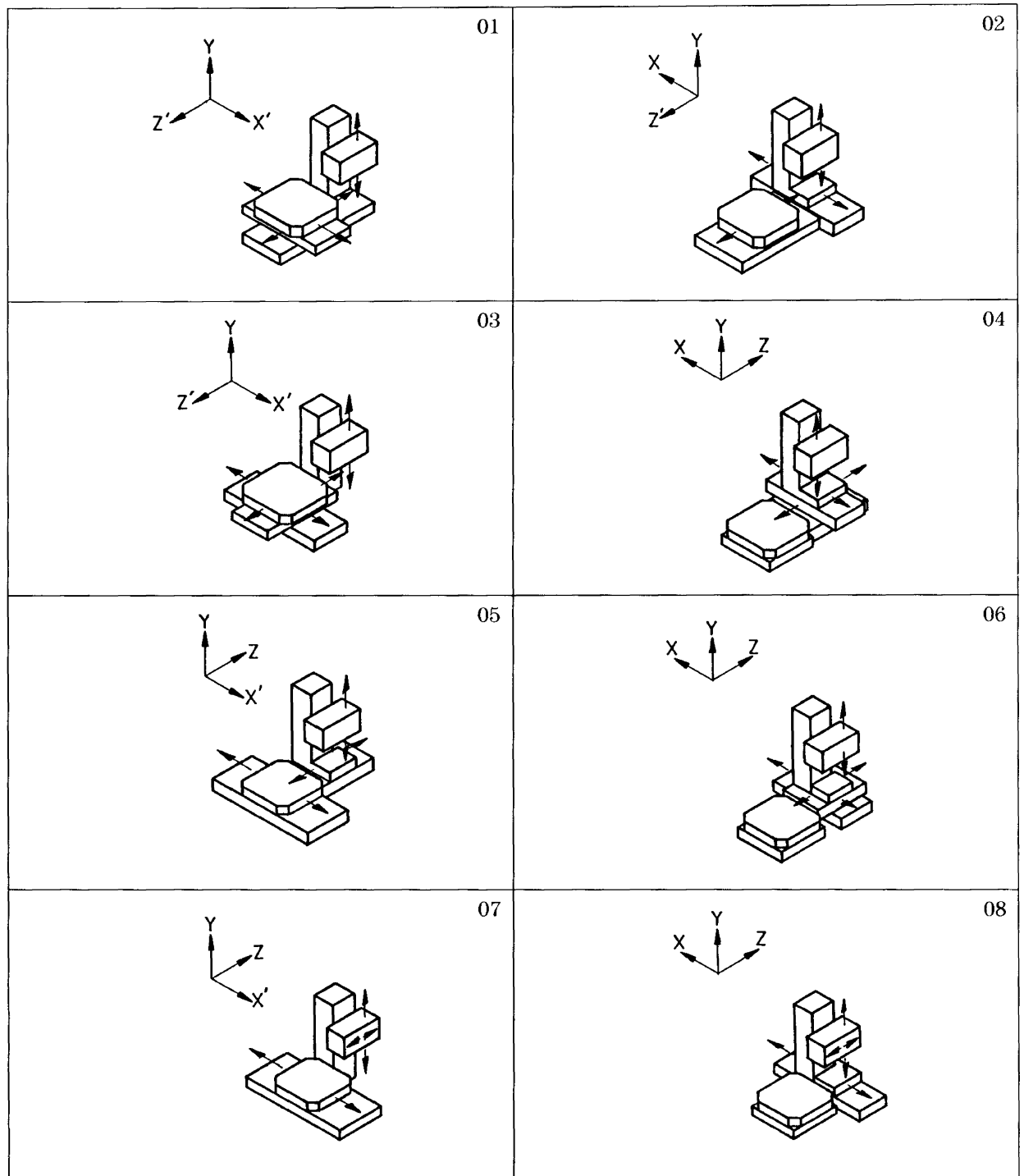


Figure 11 — Typical axes configuration — horizontal spindle type

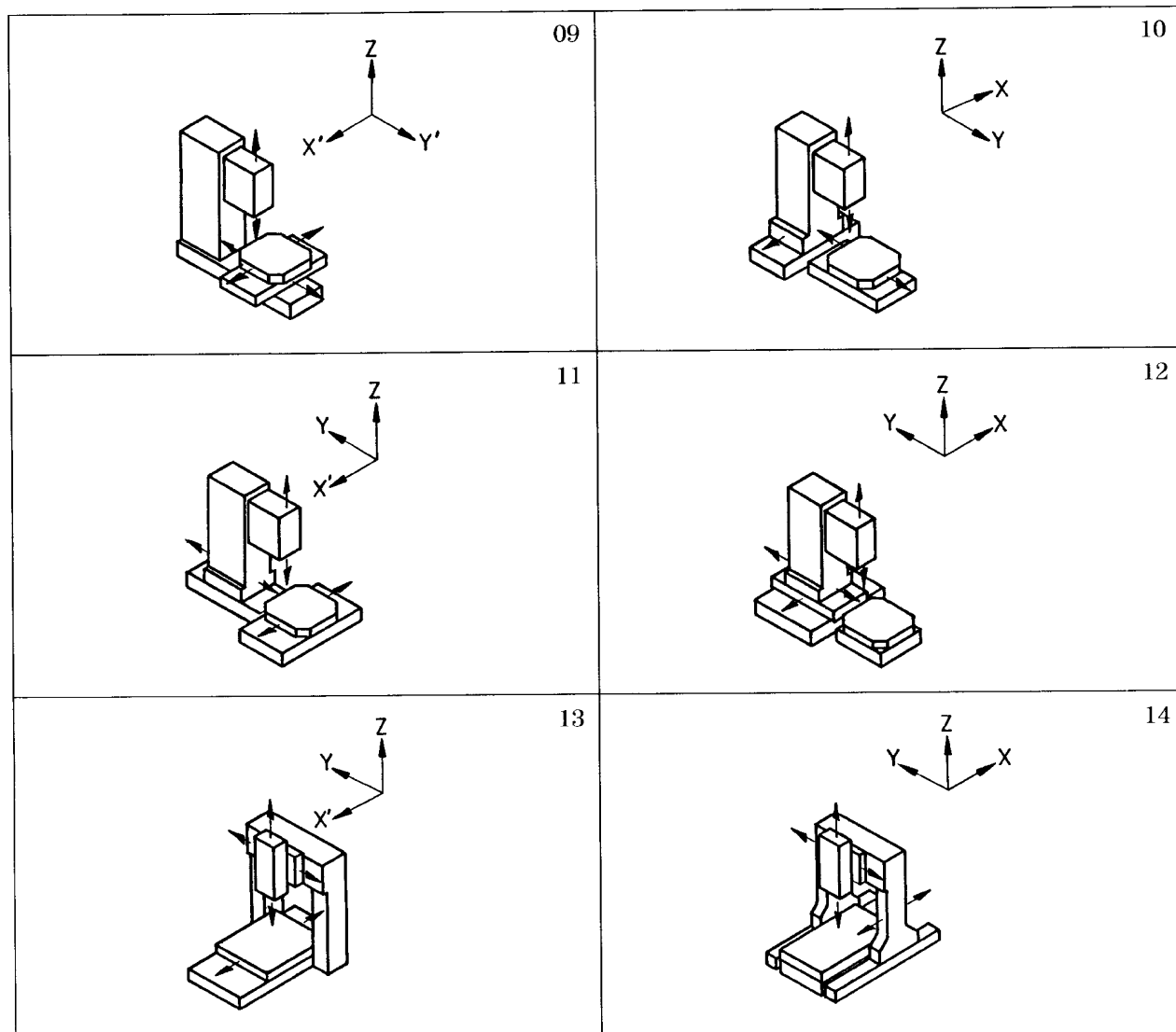
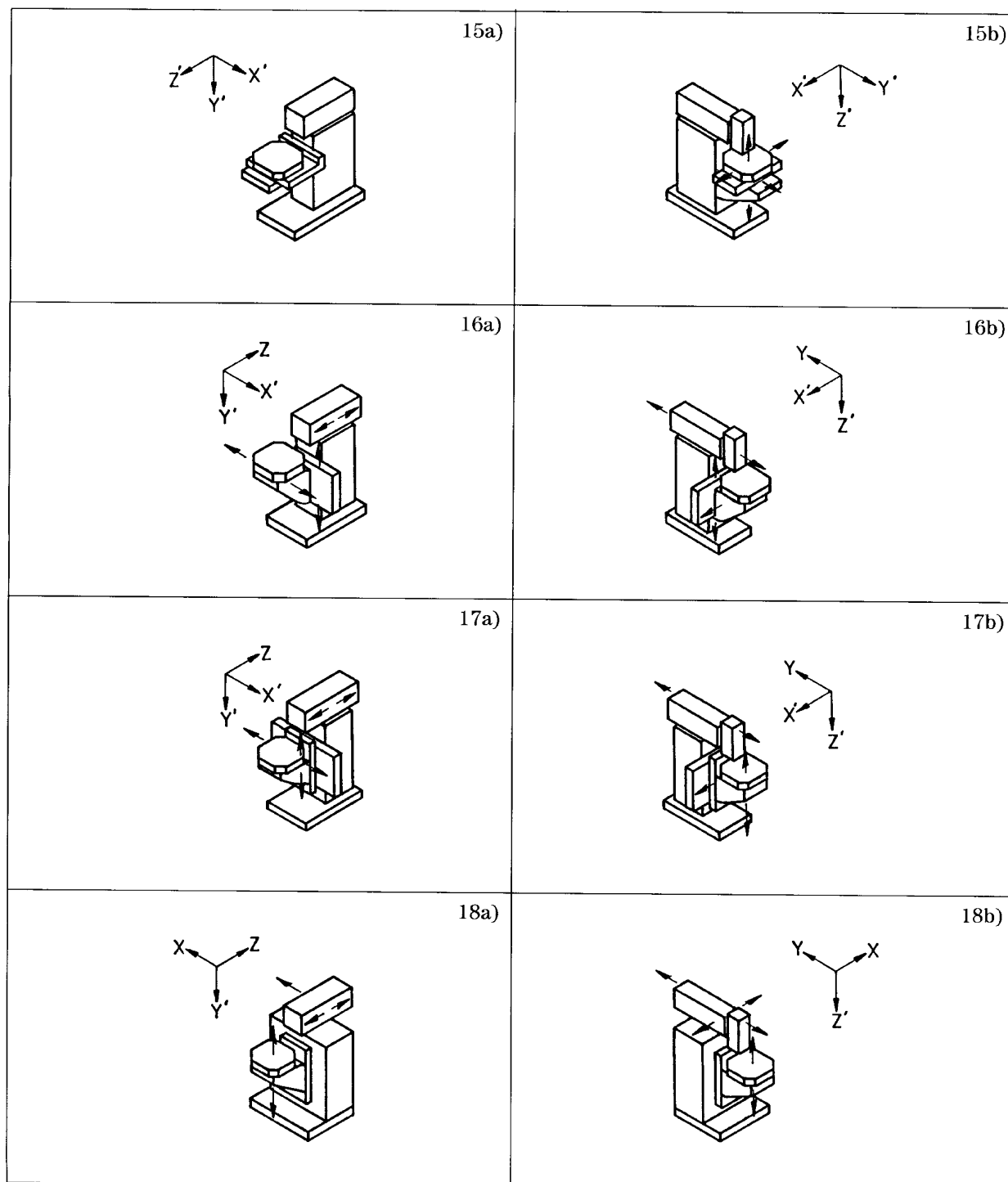


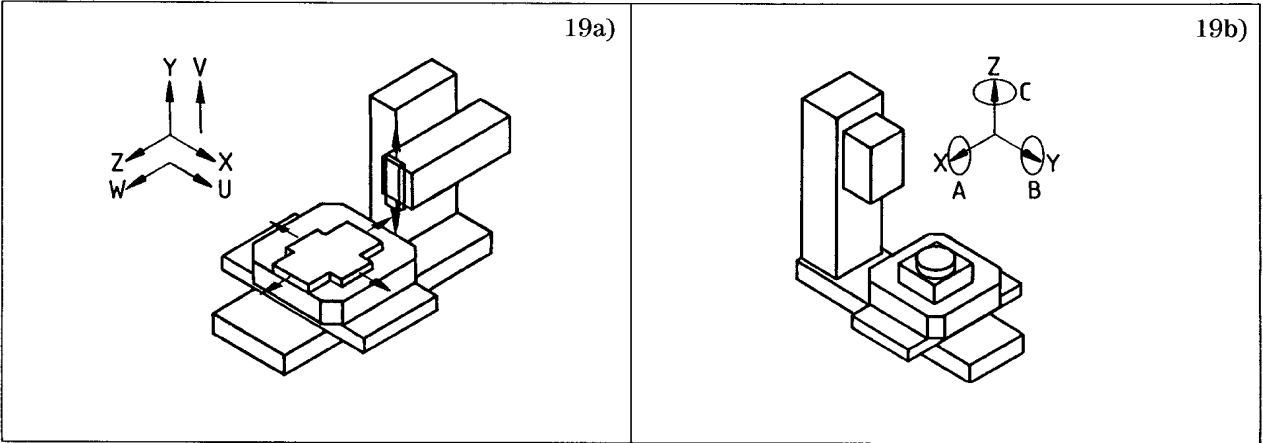
Figure 12 — Typical axes configuration — vertical spindle type



a) Horizontal spindle type

b) Vertical spindle type

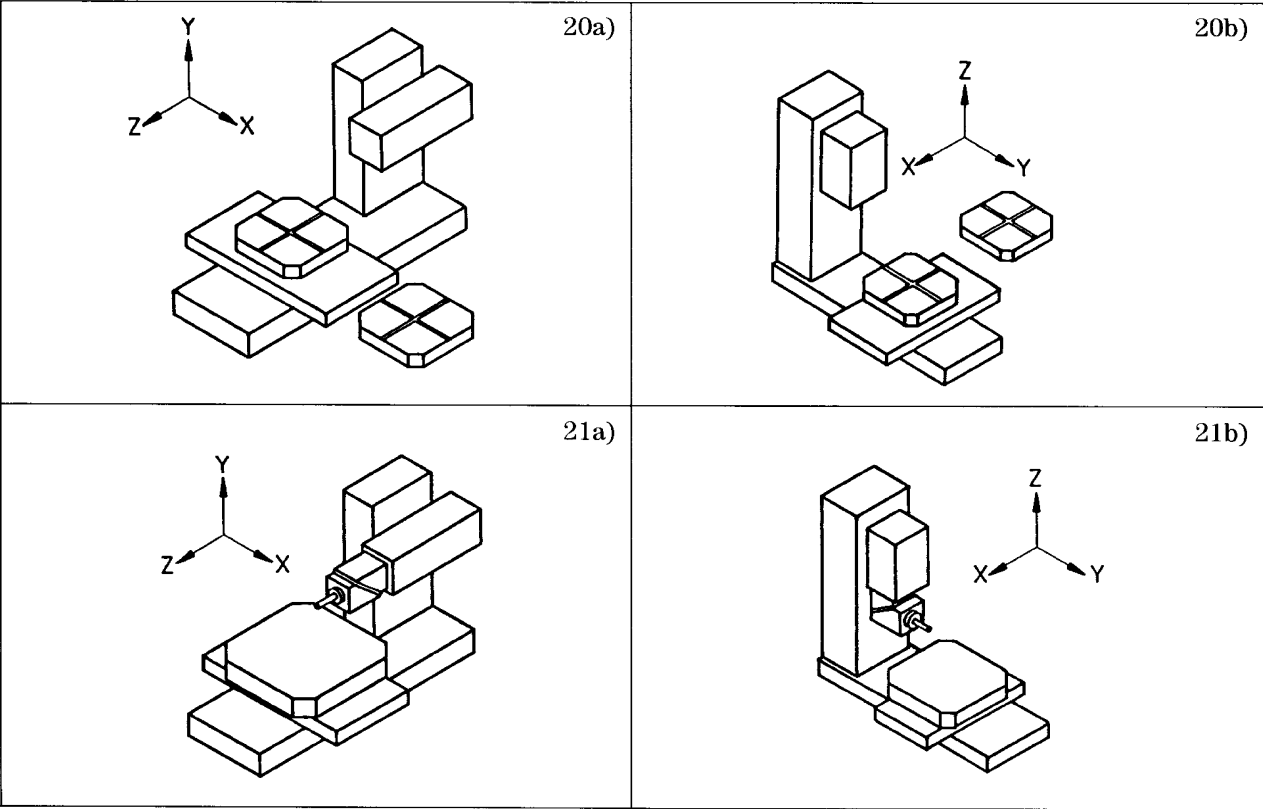
Figure 13 — Typical axes configuration



a) Horizontal

b) Vertical

Figure 14 — Optional axes



a) Horizontal

b) Vertical

Figure 15 — Optional features

11 Summary of tests on fundamental axes

NOTE 1 For convenience the objects of the tests in Table 1 to Table 12 are listed in 11.1 to 11.12

NOTE 2 a) refers to horizontal spindle machine; b) refers to vertical spindle machine.

11.1 Geometrical tests on basic axes (Table 1)

- | | | | |
|------|--|------|--|
| G0 | Levelling of machine | G14b | Angular deviation of the Y axis motion in the YZ plane (Pitch) |
| G1a | Straightness of motion of X axis in the vertical plane XY | G15a | Angular deviation of the Y axis motion in the YZ plane (Yaw) |
| G1b | Straightness of motion of X axis in the vertical plane YZ | G15b | Angular deviation of the Y axis motion in the XY plane (Yaw) |
| G2a | Straightness of motion of X axis in the horizontal plane XZ | G16 | Angular deviation of the Z axis motion in the XY plane (Roll) |
| G2b | Straightness of motion of X axis in the horizontal plane XY | G17 | Angular deviation of the Z axis motion in the YZ plane (Pitch) |
| G3a | Straightness of motion of Y axis in the vertical plane XY | G18 | Angular deviation of the Z axis motion in the XZ plane (Yaw) |
| G3b | Straightness of motion of Y axis in the horizontal plane XY | G19 | Squareness of axis of rotation of the spindle to the X axis |
| G4a | Straightness of motion of Y axis in the vertical plane YZ | G20 | Squareness of axis of rotation of the spindle to the Y axis |
| G4b | Straightness of motion of Y axis in the vertical plane YZ | G21 | Parallelism of spindle axis of rotation to Z axis motion in the XZ plane |
| G5a | Straightness of motion of Z axis in the horizontal plane XZ | G22 | Parallelism of spindle axis of rotation to Z axis motion in the YZ plane |
| G5b | Straightness of motion of Z axis in the vertical plane XZ | G23 | Spindle runout (radial) |
| G6a | Straightness of motion of Z axis in the vertical plane YZ | G24 | Flatness of table |
| G6b | Straightness of motion of Z axis in the vertical plane YZ | G25 | Parallelism of table to X axis motion |
| G7 | Squareness of motion of X axis to motion of Y axis | G26 | Parallelism of table to Y axis motion (vertical machines only) |
| G8 | Squareness of motion of X axis to motion of Z axis | G27 | Parallelism of table to Z axis motion (horizontal machines only) |
| G9 | Squareness of motion of Y axis to motion of Z axis | G28 | Parallelism of reference slot to X axis |
| G10 | Angular deviation of the X axis motion in the YZ plane (Roll) | G29 | Squareness of reference slots |
| G11a | Angular deviation of the X axis motion in the XY plane (Pitch) | | |
| G11b | Angular deviation of the X axis motion in the XZ plane (Pitch) | | |
| G12a | Angular deviation of the X axis motion in the XZ plane (Yaw) | | |
| G12b | Angular deviation of the X axis motion in the XY plane (Yaw) | | |
| G13 | Angular deviation of the Y axis motion in the XZ plane (Roll) | | |
| G14a | Angular deviation of the Y axis motion in the XY plane (Pitch) | | |

11.2 Geometrical tests on linear axes (Table 2)

G30a	Straightness of motion of U axis in the vertical plane XY	G44a	Angular deviation of the W axis motion in the XZ plane (Yaw)
G30b	Straightness of motion of U axis in the vertical plane XZ	G44b	Angular deviation of the W axis motion in the XZ plane (Yaw)
G31a	Straightness of motion of U axis in the horizontal plane XZ	G45	Parallelism of reference slot to optional axis
G31b	Straightness of motion of U axis in the horizontal plane XY	G46	Squareness of reference slots
G32a	Straightness of motion of V axis in the vertical plane XY	G47a	Parallelism of motion of U axis to X axis in the vertical plane XY
G32b	Straightness of motion of V axis in the horizontal plane XY	G47b	Parallelism of motion of U axis to X axis in the horizontal plane XY
G33a	Straightness of motion of V axis in the vertical plane YZ	G48a	Parallelism of motion of U axis to X axis in the horizontal plane XZ
G33b	Straightness of motion of V axis in the vertical plane YZ	G48b	Parallelism of motion of U axis to X axis in the vertical plane XZ
G34a	Straightness of motion of W axis in the horizontal plane XZ	G49a	Parallelism of motion of V axis to Y axis in the vertical plane YX
G34b	Straightness of motion of W axis in the vertical plane XZ	G49b	Parallelism of motion of V axis to Y axis in the horizontal plane YX
G35a	Straightness of motion of W axis in the vertical plane YZ	G50a	Parallelism of motion of V axis to Y axis in the vertical plane YZ
G35b	Straightness of motion of W axis in the vertical plane YZ	G50b	Parallelism of motion of V axis to Y axis in the vertical plane YZ
G36	Angular deviation of the U axis motion in the YZ plane (Roll)	G51a	Parallelism of motion of W axis to Z axis in the horizontal plane ZX
G37a	Angular deviation of the U axis motion in the XY plane (Pitch)	G51b	Parallelism of motion of W axis to Z axis in the vertical plane ZX
G37b	Angular deviation of the U axis motion in the XZ plane (Pitch)	G52a	Parallelism of motion of W axis to Z axis in the vertical plane ZY
G38a	Angular deviation of the U axis motion in the XZ plane (Yaw)	G52b	Parallelism of motion of W axis to Z axis in the vertical plane ZY
G38b	Angular deviation of the U axis motion in the XY plane (Yaw)		
G39	Angular deviation of the V axis motion in the XZ plane (Roll)		
G40a	Angular deviation of the V axis motion in the XY plane (Pitch)		
G40b	Angular deviation of the V axis motion in the YZ plane (Pitch)		
G41a	Angular deviation of the V axis motion in the XY plane (Yaw)		
G41b	Angular deviation of the V axis motion in the XY plane (Yaw)		
G42	Angular deviation of the W axis motion in the XY plane (Roll)		
G43a	Angular deviation of the W axis motion in the YZ plane (Pitch)		
G43b	Angular deviation of the W axis motion in the YZ plane (Pitch)		

11.3 Geometrical tests on rotary axes (Table 3)

G53	Squareness of the rotary axis A to the Y axis
G54	Squareness of the rotary axis A to the Z axis
G55	Squareness of the rotary axis B to the X axis
G56	Squareness of the rotary axis B to the Z axis
G57	Squareness of the rotary axis C to the X axis
G58	Squareness of the rotary axis C to the Y axis
G59	Parallelism of the rotary axis A to the X axis motion in the XY plane
G60	Parallelism of the rotary axis A to the X axis motion in the XZ plane
G61	Parallelism of the rotary axis B to the Y axis motion in the XY plane
G62	Parallelism of the rotary axis B to the Y axis motion in the YZ plane
G63	Parallelism of the rotary axis C to the Z axis motion in the XZ plane
G64	Parallelism of the rotary axis C to the Z axis motion in the YZ plane
G65	Measurement of location feature (e.g. size and radial run out)
G66	Measurement of the axial runout (face)
G67	Measurement of periodic axial slip
G68	Face flatness
G69	Parallelism of location feature to an optional axis
G70	Squareness of location feature

11.4 Geometrical tests on swivel heads used on horizontal spindle type machines (Table 4)

G71	With supplementary spindle vertical, check the squareness of the spindle axis to the X axis motion
G72	With supplementary spindle vertical, check the squareness of the spindle axis to the Z axis motion
G73	With supplementary spindle horizontal, check the squareness of the spindle axis to the X axis motion
G74	With supplementary spindle horizontal, check the squareness of the spindle axis to the Y axis motion
G75	Checking the squareness of the axis of rotation of the head to the XY plane

G76	Checking the parallelism of the supplementary spindle axis to the X axis motion, with the spindle in left and right positions
G77	Checking the parallelism of the supplementary spindle axis to the Y axis motion
G78	Checking the parallelism of the supplementary spindle axis to the Z axis motion

11.5 Geometrical tests on swivel heads used on vertical spindle type machines (Table 5)

G79	With the supplementary spindle horizontal, check the squareness of the spindle axis to the X axis motion
G80	With the supplementary spindle horizontal, check the squareness of the spindle axis to the Y axis motion
G81	With the supplementary spindle horizontal, check the squareness of the spindle axis to the Z axis motion in the YZ plane
G82	With the supplementary spindle horizontal, check the squareness of the spindle axis to the Z axis motion in the XZ plane
G83	Checking the squareness of the axis of rotation of the head to the XY plane
G84	Checking the intersection of the horizontal spindle axis with the vertical axis of rotation of the head
G85	Checking the parallelism of the supplementary spindle axis to the X axis motion
G86	Checking the parallelism of the supplementary spindle axis to the Y axis motion

11.6 Dynamic tests on basic axes (Table 6)

D1	Accuracy and repeatability of X axis
D2	Accuracy and repeatability of Y axis
D3	Accuracy and repeatability of Z axis
D4	Thermal distortion of structure
D5	Thermal distortion of axes
D6	No-load instrumental circular interpolation test in the XY plane
D7	No-load instrumental circular interpolation test in the XZ plane
D8	No-load instrumental circular interpolation test in the YZ plane

11.7 Dynamic tests on linear axes (Table 7)

- D9 Accuracy and repeatability of U axis
- D10 Accuracy and repeatability of V axis
- D11 Accuracy and repeatability of W axis
- D12 Thermal distortion of optical axes

11.8 Dynamic tests on rotary axes (Table 8)

- D13 Accuracy and repeatability of rotation, A axis
- D14 Accuracy and repeatability of rotation, B axis
- D15 Accuracy and repeatability of rotation, C axis
- D16 Checking the thermal drift of the A axis
- D17 Checking the thermal drift of the B axis
- D18 Checking the thermal drift of the C axis
- D19 Cutting test to evaluate indexing accuracy and repeatability

11.9 Dynamic tests on pallets (Table 9)

- D19 To check the repeatability of positioning replacement for an individual master pallet
- D20 To check the repeatability of interchangeable pallets

11.10 Practical tests (Table 10)

- P1 To evaluate the relationship of machine features
- P2 To evaluate indexing accuracy and repeatability
- P3 To determine limitations to rate of metal removal

11.11 Table 11

Dimensions of test pieces for test P1

11.12 Table 12

Dimensions of test pieces for test P2

NOTE In Table 1 to Table 10 column 6 refers to BS 3800-1:1990 unless stated otherwise.

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G0a		Levelling of the machine a) in longitudinal vertical plane (XY) b) in transverse vertical plane (YZ) of a horizontal spindle machine	0.03/300	Precision level and straightedge or electronic instrument	BS 3800-1:1990. 3.11 NOTE These typical diagrams illustrate the minimum levelling requirements prior to test. For specific requirements refer to the manufacturer's instructions.
G0b		Levelling of the machine a) in longitudinal vertical plane (XZ) b) in transverse vertical plane (YZ) of a horizontal spindle machine			

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

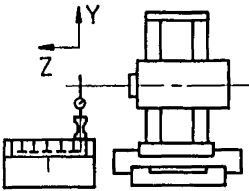
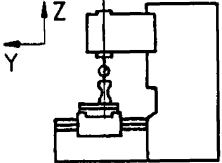
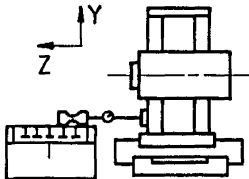
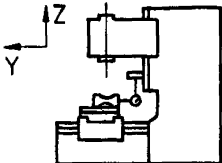
1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G1a		Checking the straightness of motion of the X axis in the vertical plane (XY) of a horizontal spindle machine	Full indicator movement (FIM) method: 0.010 for up to 500 0.015 for 501 to 1 000 0.020 for 1 001 to 1 500 0.025 for 1 501 to 2 000 0.030 for 2 001 to 2 500 0.035 for 2 501 to 3 000 Local tolerance: 0.005 in any 300	Straightedge. Linear measuring probe. Microscope and taut wire. Laser with straightness optics	Y and Z axes to be locked, if possible. If the spindle can be locked the linear measuring probe may be mounted on it. If the spindle cannot be locked, the linear measuring probe shall be placed on the spindle-head slide of the machine
G1b		Checking the straightness of motion of the X axis in the vertical plane (XZ) of a vertical spindle machine			
G2a		Checking the straightness of motion of the X axis in the horizontal plane (XZ) of a horizontal spindle machine			
G2b		Checking the straightness of motion of the X axis in the horizontal plane (XY) of vertical spindle machine			

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

1 No.	2 Diagram	3 Object	4 Permissible deviation	5 Measuring instruments	6 Observations and references to BS 3800
G3a		Checking the straightness of motion of the Y axis in the vertical plane (XY) of a horizontal spindle machine	FIM method: 0.010 for up to 500 0.015 for 501 to 1 000 0.020 for 1 001 to 1 500 0.025 for 1 501 to 2 000 0.030 for 2 001 to 2 500 0.035 for 2 501 to 3 000	Square and linear measuring probe or microscope and taut wire. Laser with straightness optics	X and Z axes to be locked, if possible. If the spindle can be locked the linear measuring probe may be mounted on it. If the spindle cannot be locked, the linear measuring probe shall be placed on the spindle-head slide of the machine. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.
G3b		Checking the straightness of motion of the Y axis in the horizontal plane (XY) of a vertical spindle machine	Local tolerance: 0.005 in any 300		
G4a		Checking the straightness of motion of the Y axis in the vertical plane (YZ) of a horizontal spindle machine			
G4b		Checking the straightness of motion of the Y axis in the vertical plane (YZ) of a vertical spindle machine			

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

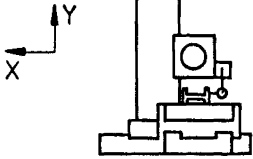
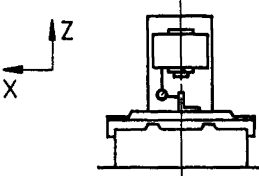
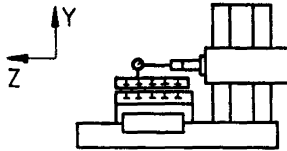
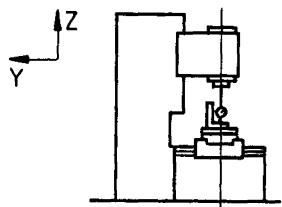
1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G5a		Checking the straightness of motion of the Z axis in the horizontal plane (XZ) of a horizontal spindle machine	FIM method: 0.013 for up to 500 0.015 for 501 to 1000 0.020 for 1 001 to 1500 0.025 for 1 501 to 2000 0.030 for 2 001 to 2500 0.035 for 2 501 to 3000 Local tolerance: 0.010 in any 300	Straightedge and linear measuring probe. Laser with straightness optics	X and Y axes to be locked, if possible. If the spindle can be locked the linear measuring probe may be mounted on it. If the spindle cannot be locked, the linear measuring probe shall be placed on the spindle-head slide of the machine. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.
G5b		Checking the straightness of motion of the Z axis in the vertical plane (XZ) of a vertical spindle machine			
G6a		Checking the straightness of motion of the Z axis in the vertical plane (YZ) of a horizontal spindle machine			
G6b		Checking the straightness of motion of the Z axis in the vertical plane (YZ) of a vertical spindle machine			

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

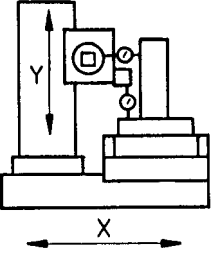
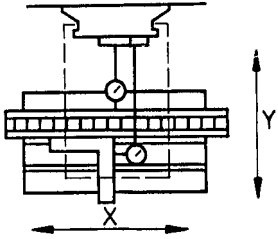
1 No.	2 Diagram	3 Object	4 Permissible deviation	5 Measuring instruments	6 Observations and references to BS 3800
G7a		Checking the squareness of the Y axis motion to the X axis motion of a horizontal spindle machine	0.02/300	Surface plate or straightedge, square and linear measuring probe or cube and linear measuring probe or applicable instruments	The surface plate or straightedge shall be set parallel to the X axis. The Y axis shall then be checked by means of the square standing on the surface plate or aligned by the straightedge. If a cube artefact is used a record of error in parallelism to X axis shall be made and used in the computation of Y axis deviation. If the spindle can be locked the linear measuring probe may be mounted on it. If the spindle cannot be locked, the linear measuring probe shall be mounted to a fixed part of the machine. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.
G7b		Checking the squareness of the Y axis motion to the X axis motion of a vertical spindle machine			

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

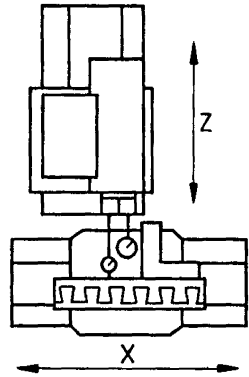
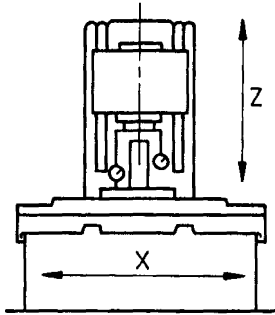
1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G8a		Checking the squareness of the Z axis motion to the X axis motion of a horizontal spindle machine	0.02/300	Straightedge or surface plate, square and linear measuring probe or cube and linear measuring probe or applicable instruments	The straightedge or surface plate shall be set parallel to the X axis. The Z axis shall then be checked by means of the square being aligned by the straightedge or standing on the surface plate. If a cube artefact is used a record of error in parallelism to X axis shall be made and used in the computation of Z axis deviation. If the spindle can be locked the linear measuring probe may be mounted on it. If the spindle cannot be locked, the measuring probe shall be mounted to a fixed part of the machine. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.
G8b		Checking the squareness of the Z axis motion to the X axis motion of a vertical spindle machine			

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

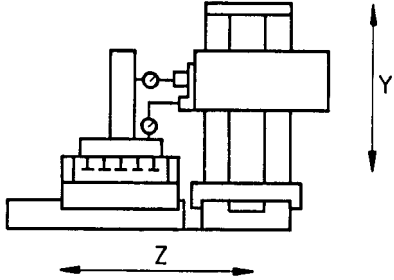
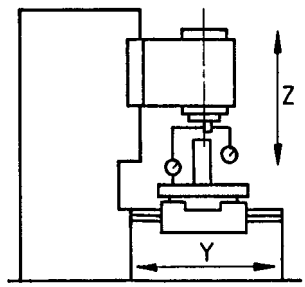
1 No.	2 Diagram	3 Object	4 Permissible deviation	5 Measuring instruments	6 Observations and references to BS 3800
G9a		Checking the squareness of the Y axis motion to the Z axis motion of a horizontal spindle machine	0.02/300	Surface plate, square and linear measuring probe or cube and linear measuring probe or applicable instruments	The surface plate shall be set parallel to the horizontal axis motion. The vertical axis motion shall then be checked by means of the square standing on the surface plate. If a cube artefact is used a record of error in parallelism to the horizontal axis motion shall be made and used in the computation of the vertical axis deviation.
G9b		Checking the squareness of the Z axis motion to the Y axis motion of a vertical spindle machine			If the spindle can be locked the linear measuring probe may be mounted on it. If the spindle cannot be locked, the measuring probe shall be mounted to a fixed part of the machine. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G10a		Checking the angular deviation of the X axis motion in the YZ plane (roll) on a horizontal spindle machine	FIM method: 2 arc seconds (a.s.) for up to 500 3 a.s. for 501 to 1 000 4 a.s. for 1 001 to 1 500 5 a.s. for 1 501 to 2 000 6 a.s. for 2 001 to 2 500 7 a.s. for 2 501 to 3 000 Local tolerance: 1 a.s. in any 300	Precision level of optical angular measuring instrument	For FIM method measurements shall be taken at a minimum of five positions equally spaced along the full X travel and in both directions. The difference of the algebraic maximum and minimum readings shall not exceed the permissible deviation. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.
G10b		Checking the angular deviation of the X axis motion in the YZ plane (roll) on a vertical spindle machine			

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

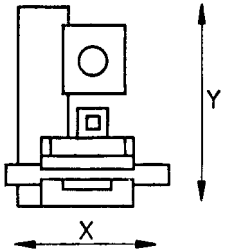
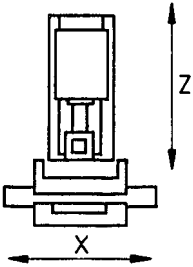
1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G11a		Checking the angular deviation of the X axis motion in the XY plane (pitch) on a horizontal spindle machine	FIM method: 2 a.s. for up to 500 3 a.s. for 501 to 1 000 4 a.s. for 1 001 to 1 500 5 a.s. for 1 501 to 2 000 6 a.s. for 2 001 to 2 500 7 a.s. for 2 501 to 3 000 Local tolerance: 1 a.s. in any 300	Precision level of optical angular measuring instrument	For FIM method measurements shall be taken at a minimum of five positions equally spaced along the full X travel and in both directions. The difference of the algebraic maximum and minimum readings shall not exceed the permissible deviation. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.
G11b		Checking the angular deviation of the X axis motion in the XZ plane (pitch) on a vertical spindle machine			

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

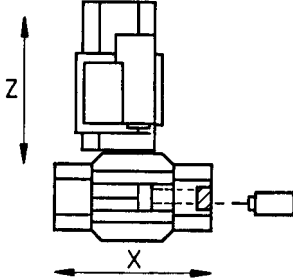
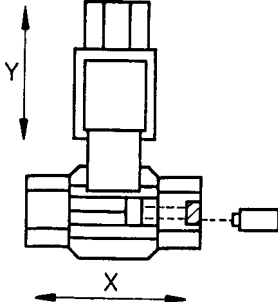
1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G12a		Checking the angular deviation of the X axis motion in the XZ plane (yaw) on a horizontal spindle machine	FIM method: 2 a.s. for up to 500 3 a.s. for 501 to 1 000 4 a.s. for 1 001 to 1 500 5 a.s. for 1 501 to 2 000 6 a.s. for 2 001 to 2 500 7 a.s. for 2 501 to 3 000 Local tolerance: 1 a.s. in any 300	Optical angular measuring instrument	For FIM method measurements shall be taken at a minimum of five positions equally spaced along the full X travel and in both directions. The difference of the algebraic maximum and minimum readings shall not exceed the permissible deviation. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.
G12b		Checking the angular deviation of the X axis motion in the XY plane (yaw) on a vertical spindle machine			

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

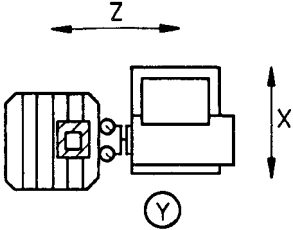
1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G13a		Checking the angular deviation of the Y axis motion in the XZ plane (roll) on a horizontal spindle machine	2 a.s. for up to 500 3 a.s. for 501 to 1 000 4 a.s. for 1 001 to 1 500 5 a.s. for 1 501 to 2 000 6 a.s. for 2 001 to 2 500 7 a.s. for 2 501 to 3 000 Local tolerance: 1 a.s. in any 300	Block, square and linear measuring probes	Measurements shall be taken at a minimum of five positions equally spaced along the full Y axis travel and in both directions. For each measurement position calculate the difference of the two readings. Among these differences the maximum and minimum value shall be selected and the result of $\frac{\text{max. diff.} - \text{min. diff.}}{d}$ shall not exceed the permissible deviation, d being the distance between the linear measuring probes where $d \leq 150$. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

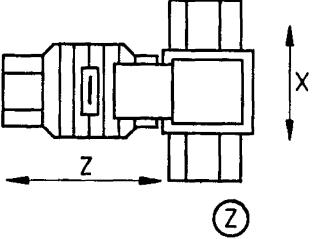
1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G13b		Checking the angular deviation of the Y axis motion in the XZ plane (roll) on a vertical spindle machine	FIM method: 2 a.s. for up to 500 3 a.s. for 501 to 1 000 4 a.s. for 1 001 to 1 500 5 a.s. for 1 501 to 2 000 6 a.s. for 2 001 to 2 500 7 a.s. for 2 501 to 3 000 Local tolerance: 1 a.s. in any 300	Precision level or optical angular measuring instrument	For FIM method measurements shall be taken at a minimum of five positions equally spaced along the full Y axis travel and in both directions. The difference between the algebraic maximum and minimum readings shall not exceed the permissible deviation. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

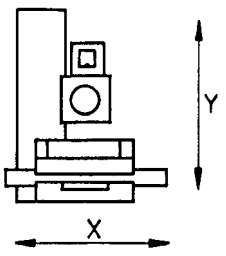
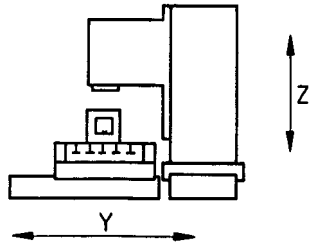
1 No.	2 Diagram	3 Object	4 Permissible deviation	5 Measuring instruments	6 Observations and references to BS 3800
G14a		Checking the angular deviation of the Y axis motion in the XY plane (pitch) on a horizontal spindle machine	FIM method: 2 a.s. for up to 500 3 a.s. for 501 to 1 000 4 a.s. for 1 001 to 1 500 5 a.s. for 1 501 to 2 000 6 a.s. for 2 001 to 2 500 7 a.s. for 2 501 to 3 000 Local tolerance: 1 a.s. in any 300	Precision level or optical angular measuring instrument	For FIM method measurements shall be taken at a minimum of five positions equally spaced along the full Y axis travel and in both directions. The difference between the algebraic maximum and minimum readings shall not exceed the permissible deviation. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.
G14b		Checking the angular deviation of the Y axis motion in the YZ plane (pitch) on a vertical spindle machine			

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

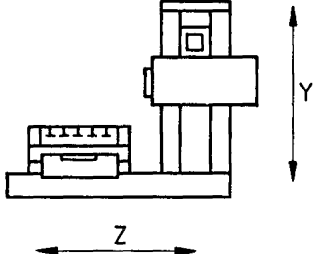
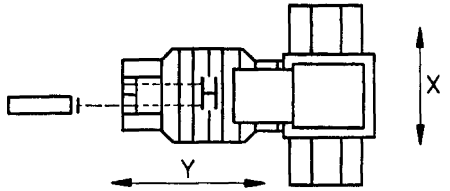
1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G15a		Checking the angular deviation of the Y axis motion in the YZ plane (yaw) on a horizontal spindle machine	FIM method: 2 a.s. for up to 500 3 a.s. for 501 to 1 000 4 a.s. for 1 001 to 1 500 5 a.s. for 1 501 to 2 000 6 a.s. for 2 001 to 2 500 7 a.s. for 2 501 to 3 000 Local tolerance: 1 a.s. in any 300	Precision level or optical angular measuring instrument	For FIM method measurements shall be taken at a minimum of five positions equally spaced along the full Y axis travel and in both directions. The difference between the algebraic maximum and minimum readings shall not exceed the permissible deviation. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.
G15b		Checking the angular deviation of the Y axis motion in the XY plane (yaw) on a vertical spindle machine		Optical angular measuring instrument	

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

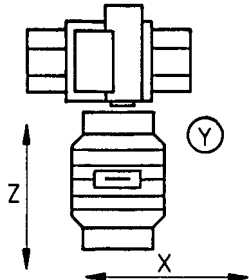
1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G16a		Checking the angular deviation of the Z axis motion in the XY plane (roll) on a horizontal spindle machine	FIM method: 2 a.s. for up to 500 3 a.s. for 501 to 1 000 4 a.s. for 1 001 to 1 500 5 a.s. for 1 501 to 2 000 6 a.s. for 2 001 to 2 500 7 a.s. for 2 501 to 3 000 Local tolerance: 1 a.s. in any 300	Precision level or optical angular measuring instrument	For FIM method measurements shall be taken at a minimum of five positions equally spaced along the full Z axis travel and in both directions. The difference between the algebraic maximum and minimum readings shall not exceed the permissible deviation. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

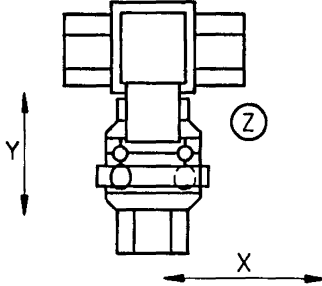
1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G16b		Checking the angular deviation of the Z axis motion in the XY plane (roll) on a vertical spindle machine	2 a.s. for up to 500 3 a.s. for 501 to 1 000 4 a.s. for 1 001 to 1 500 5 a.s. for 1 501 to 2 000 6 a.s. for 2 001 to 2 500 7 a.s. for 2 501 to 3 000 Local tolerance: 1 a.s. in any 300	Straightedge, square and linear measuring probes	Measurements shall be taken at a minimum of five positions equally spaced along the full Z axis travel and in both directions. For each measurement position calculate the difference of the two readings. Among these differences the maximum and minimum value shall be selected and the result of $\frac{\text{max. diff.} - \text{min. diff.}}{d}$ shall not exceed the permissible deviation, d being the distance between the linear measuring probes where $d \geq 150$. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

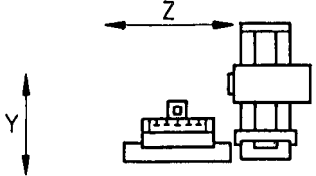
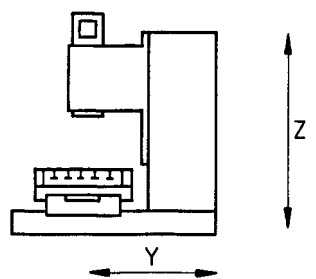
1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G17a		Checking the angular deviation of the Z axis motion in the YZ plane (pitch) on a horizontal spindle machine	FIM method: 2 a.s. for up to 500 3 a.s. for 501 to 1 000 4 a.s. for 1 001 to 1 500 5 a.s. for 1 501 to 2 000 6 a.s. for 2 001 to 2 500 7 a.s. for 2 501 to 3 000 Local tolerance: 1 a.s. in any 300	Precision level or optical angular measuring instrument	For FIM method measurements shall be taken at a minimum of five positions equally spaced along the full Z axis travel and in both directions. The difference between the algebraic maximum and minimum readings shall not exceed the permissible deviation. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.
G17b		Checking the angular deviation of the Z axis motion in the YZ plane (pitch) of a vertical spindle machine			

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

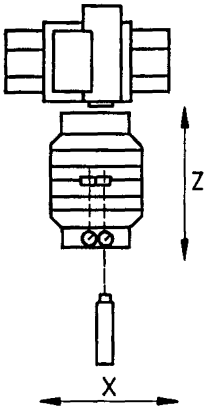
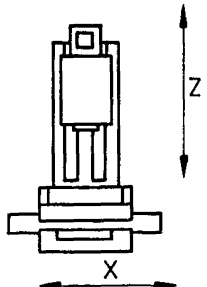
1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G18a		Checking the angular deviation of the Z axis motion in the XZ plane (yaw) on a horizontal spindle machine	FIM method: 2 a.s. for up to 500 3 a.s. for 501 to 1 000 4 a.s. for 1 001 to 1 500 5 a.s. for 1 501 to 2 000 6 a.s. for 2 001 to 2 500 7 a.s. for 2 501 to 3 000 Local tolerance: 1 a.s. in any 300	Optical angular measuring instrument	For FIM method measurements shall be taken at a minimum of five positions equally spaced along the full Z axis travel and in both directions. The difference between the algebraic maximum and minimum readings shall not exceed the permissible deviation. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.
G18b		Checking the angular deviation of the Z axis motion in the XZ plane (yaw) of a vertical spindle machine		Precision level or optical angular measuring instruments	

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

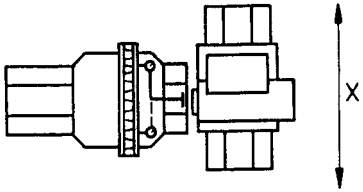
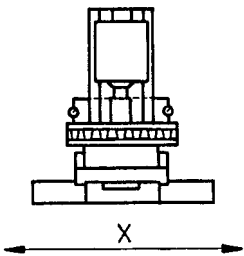
1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G19a		Checking of squareness of axis of rotation of the spindle to the X axis of a horizontal spindle machine	0.02/300 diameter	Straightedge, trammel bar and linear measuring probe	The straightedge shall be set parallel to the X axis. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.
G19b		Checking of squareness of axis of rotation of the spindle to the X axis of a vertical spindle machine	0.02/300 diameter		

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

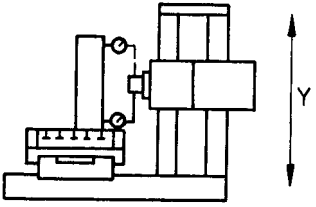
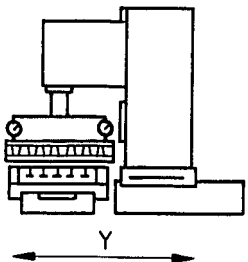
1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G20a		Checking of squareness of axis of rotation of the spindle to the Y axis of a horizontal spindle machine	0.02/300 diameter	Square, trammel bar and linear measuring probe	The square shall be set parallel to the Y axis. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.
G20b		Checking of squareness of axis of rotation of the spindle to the Y axis of a vertical spindle machine	0.02/300 diameter	Straightedge, special arm and linear measuring probe	The straightedge shall be set parallel to the Y axis. NOTE This test measures a basic geometric parameter and is therefore independent of machine configuration.

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

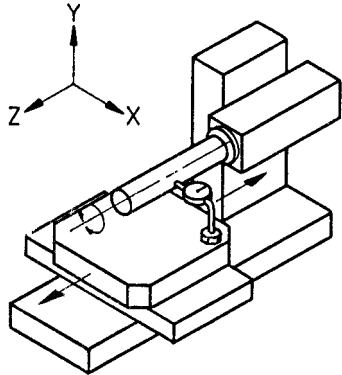
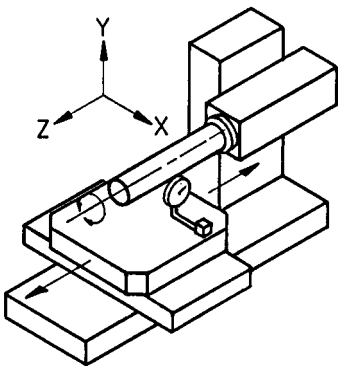
1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G21		Checking of parallelism of the spindle axis of rotation to the Z axis motion in the XZ plane	0.013 for up to 500 0.015 for 501 to 1 000 0.020 for 1 001 to 1 500 0.025 for 1 501 to 2 000 0.030 for 2 001 to 2 500 0.035 for 2 501 to 3 000 Local tolerance: 0.010 in any 300	Test bar and linear measuring probe	Record the measured deviation (D_1) over the axis stroke. Rotate the axis through 180° and record the measured deviation (D_2). The result of $\frac{D_1 + D_2}{2}$ shall not exceed the permissible deviation. NOTE This test measures a combination of basic geometric parameters and as such is dependent upon the configuration of machine as classified by the categories shown in Figure 11, Figure 12, Figure 13, Figure 14 and Figure 15.

Table 1 — Geometrical tests on basic axes for machining centres and CNC milling machines, horizontal and vertical spindle type

All dimensions are in millimetres

1	2	3	4	5	6
No.	Diagram	Object	Permissible deviation	Measuring instruments	Observations and references to BS 3800
G22		Checking of parallelism of the spindle axis of rotation to the Z axis motion in the YZ plane	0.013 for up to 500 0.015 for 501 to 1 000 0.020 for 1 001 to 1 500 0.025 for 1 501 to 2 000 0.030 for 2 001 to 2 500 0.035 for 2 501 to 3 000 Local tolerance: 0.010 in any 300	Test bar and linear measuring probe. Laser interferometer	Record the measured deviation (D_1) over the axis stroke. Rotate the axis through 180° and record the measured deviation (D_2). The result of $\frac{D_1 + D_2}{2}$ shall not exceed the permissible deviation. NOTE This test measures a combination of basic geometric parameters and as such is dependent upon the configuration of machine as classified by the categories shown in Figure 11, Figure 12, Figure 13, Figure 14 and Figure 15.