INTERNATIONAL STANDARD

ISO 10791-7

Third edition
2020-01

Test conditions for machining centres —

Part 7: Accuracy of finished test pieces

Conditions d'essai pour centres d'usinage —

Partie 7: Exactitude des pièces d'essai usinées

Reference number
ISO 10791-7:2020(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

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.

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).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 39, *Machine Tools*, Subcommittee SC 2, *Test conditions for metal cutting machine tools.*

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.

This third edition cancels and replaces the second edition (ISO 10791-7:2014), which has been technically revised.

The main changes compared to the previous edition are as follows:

— new Clause 3 has been added;

— new Annex A has been added.

A list of all parts of this ISO series can be found on the ISO website.

Introduction

A machining centre is a numerically controlled machine tool capable of performing multiple machining operations, including milling, boring, drilling, and tapping, as well as automatic tool changing from a magazine or similar storage unit in accordance with a machining programme. Most machining centres have facilities for automatically changing the direction in which the workpieces are presented to the tool.

The purpose of the ISO 10791 series is to supply information as widely and comprehensively as possible on tests and checks which can be carried out for comparison, acceptance, maintenance, or any other purpose.

The International Organization for Standardization (ISO) draw[s] attention to the fact that it is claimed that compliance with this document may involve the use of a patent.

ISO takes no position concerning the evidence, validity and scope of this patent right.

The holder of this patent right has assured ISO that he/she is willing to negotiate licences under reasonable and non-discriminatory terms and conditions with applicants throughout the world. In this respect, the statement of the holder of this patent right is registered with ISO. Information may be obtained from the patent database available at www.iso.org/patents.

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

Test conditions for machining centres —

Part 7: Accuracy of finished test pieces

1 Scope

This document specifies, by reference to the relevant parts of ISO 230, several families of tests for machining centres with horizontal or vertical spindle or with universal heads of different types, standing alone, or integrated in flexible manufacturing systems. This document also establishes the tolerances or maximum acceptable values for the test results corresponding to general purpose and normal accuracy machining centres.

This document is also applicable, totally or partially, to numerically controlled milling and boring machines, when their configuration, components, and movements are compatible with the tests described herein.

This document specifies standard test pieces with reference to ISO 230-1, cutting tests under finishing conditions. It also specifies the characteristics and dimensions of the test pieces themselves. This document is intended to supply minimum requirements for assessing the cutting accuracy of the machining centres with 3 to 5 simultaneous machining axes. Annex A introduces a freeform test piece for five-axis machining centres. This machining test is applied to machining centres using five-axis flank milling of freeform surfaces.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 230-1, *Test code for machine tools — Part 1: Geometric accuracy of machines operating under no-load or quasi-static conditions*

3 Terms and definitions

For the purposes of this document, the terms given in ISO 230-1 and the following apply.

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

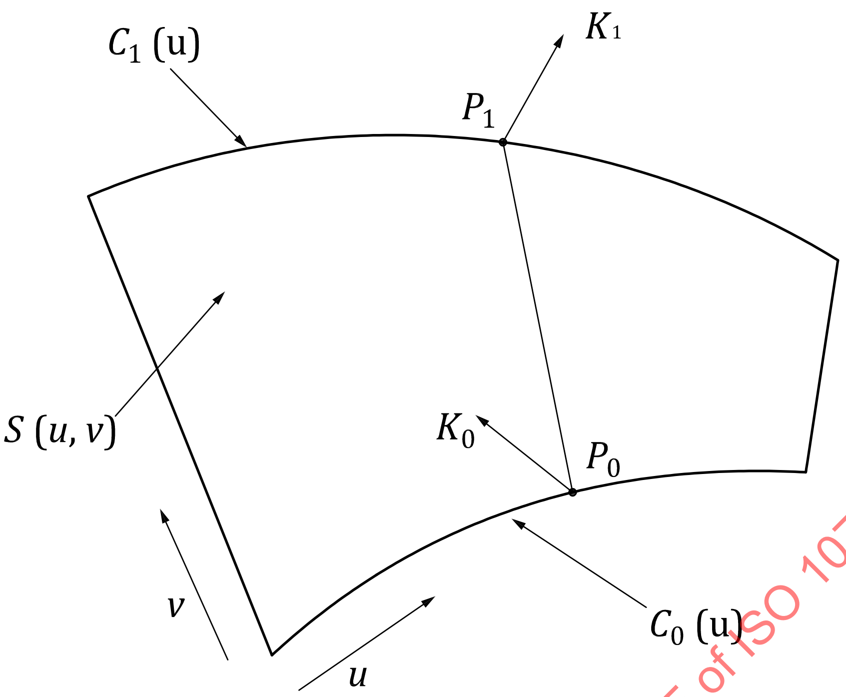
— ISO Online browsing platform: available at https://www.iso.org/obp

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

3.1
ruled surface
surface containing a family of straight lines

Note 1 to entry: A ruled surface is shown in Figure 1, where each isoparametric line (parameter u constant) is a straight line, called a rule. The parametric equation for the ruled surface in Figure 1 is given in Formula (1):

$$S(u,v)=(1-v)\times C_0(u)+v\times C_1(u)\left[u\in(0,1),v\in(0,1)\right] \quad (1)$$



Key

u, v	parameters in u-direction and v-direction
$C_0(u)$, $C_1(u)$	curves in space both defined on the same parametric interval $u(0, 1)$
$S(u, v)$	surface generated by the movement of a rule moving over two curves $C_0(u)$ and $C_1(u)$ that provide its direction
P_0, P_1	two end points of a rule
K_0, K_1	vector normal to $S(u, v)$ at P_0 and P_1

Figure 1 — Ruled surface

3.2
non-uniform rational B-spline
NURBS
mathematical model commonly used in computer graphics for generating and representing curves and surfaces.

Note 1 to entry: A NURBS curve is defined by its order, a set of weighted control points, and a knot vector. The order defines the number of nearby control points that influence any given point on the curve. The control points determine the shape of the curve, and the weight of each point varies according to the governing parameter. The knot vector is a sequence of parameter values that determines where and how the control points affect the NURBS curve.

Note 2 to entry: NURBS is commonly used in computer aided design, manufacturing, and engineering and is a part of numerous industry wide standards, such as STEP (Standard for the Exchange of Product Model Data, see ISO 10303-21).

3.3
quasi-uniform rational B-spline
special type of non-uniform rational B-spline

Note 1 to entry: For an n^{th} order quasi-uniform rational B-spline, the weights of all the control points are the same, and the knot vector is uniformly distributed with multiplicity n at the start and the end. For example, the number of control points is m, then the knot vector is as per Formula (2):

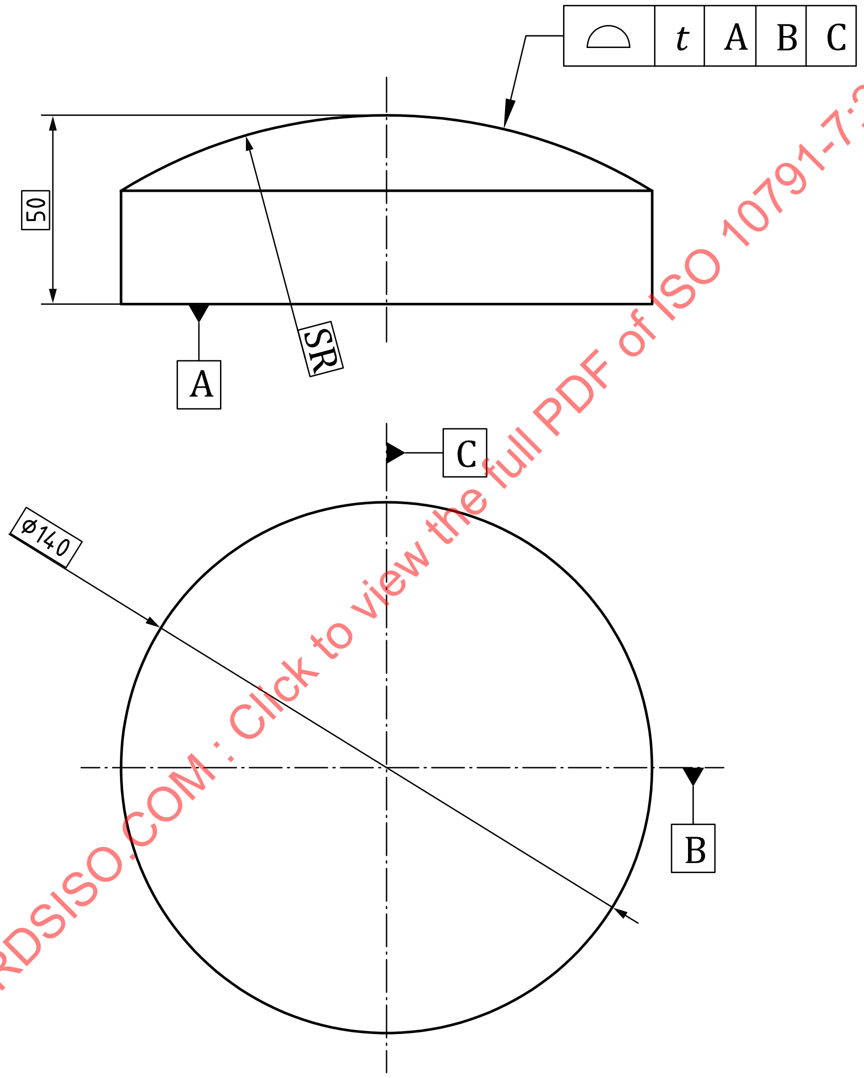
$$\left(\underbrace{0,0,\ldots,0}_{n},\frac{1}{m-n-1},\frac{2}{m-n-1},\ldots,\frac{m-n-2}{m-n-1},\underbrace{1,1,\ldots,1}_{n}\right) \tag{2}$$

3.4

surface profile tolerance related to datums

tolerance zone defined by two surfaces enveloping spheres with diameter ***t***, the centres of which are situated on a surface having the theoretically exact geometrical form with respect to datums

Note 1 to entry: See Figure 2, Figure 3 and ISO 1101:2017, 17.9.



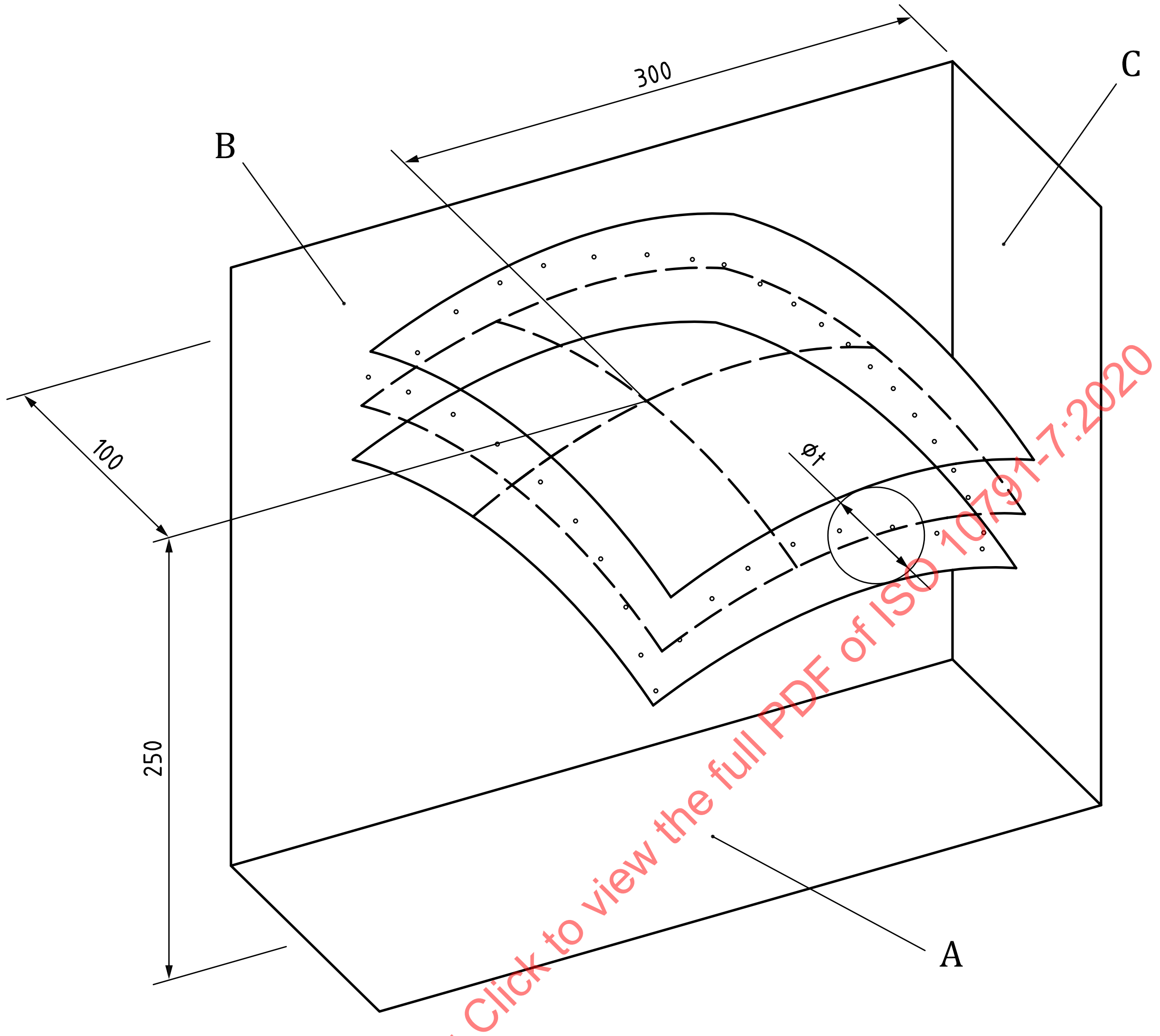
Key

A, B, C datum planes

SR nominal radius of sphere

t tolerance

Figure 2 — Indication and explanation of surface profile tolerance related to datums A, B, C



Key

A, B, C datum planes

⌀*t* tolerance zone (diameter of the enveloped spheres)

Figure 3 — Surface profile tolerance zone related to datums A, B, C

4 Preliminary remarks

4.1 Measuring units

In this document, all linear dimensions and deviations are expressed in millimetres. All angular dimensions are expressed in degrees. Angular deviations are, in principle, expressed in ratios (e.g. 0,00x /1 000), but in some cases, microradians or arcseconds can be used for clarification purposes. Formula (3) should be used for conversion of angular deviations or tolerances:

$$0{,}010/1\ 000 = 10\ \mu\text{rad} \approx 2'' \quad (3)$$

4.2 Reference to ISO 230-1

To apply this document, reference shall be made to ISO 230-1, especially for the installation of the machine before testing, warming up of the machine, description of measuring methods, and evaluation and presentation of the results.

4.3 Testing sequence

The sequence in which the tests are presented in this document does not define the practical order of testing. In order to make the mounting of fixtures and machining easier, tests can be performed in any order.

4.4 Tests to be performed

When testing a machine tool, it is not always necessary or possible to carry out all the tests described in this document. When the tests are required for acceptance purposes, it is up to the user to choose, in mutual agreement with the manufacturer/supplier, those tests relating to the components and/or the properties of the machine tool which are of interest. These tests are to be clearly stated when ordering a machine tool. A mere reference to this document for the acceptance tests cannot be considered as binding for any contracting party without specifying the tests to be carried out and without mutual agreement on the relevant expenses.

In principle, no more than one piece of each type should be machined for acceptance purposes. In case of special requirements, such as statistical assessment of the machine tool performance (e.g. according to ISO 26303, short-term capability), the machining of more test pieces is to be agreed between the manufacturer/supplier and the user.

4.5 Measuring instruments

The measuring instruments indicated in the tests described in Clause 4 are examples only. Other instruments measuring the same quantities and having the same or smaller measurement uncertainty can be used.

4.6 Location of test pieces

The test piece should be placed approximately in the middle of the X-axis, and in positions along the Y- and Z-axes suitable for the location of the test piece and/or fixture, and for the tool lengths if not specified otherwise in the test procedure.

4.7 Fixing of test pieces

The test piece shall be conveniently mounted on a proper fixture, such that maximum stability of tools and fixture is achieved. The mounting surfaces of the fixture and of the test piece shall be flat. It is recommended that a suitable means of fixturing be used to allow for tool breakthrough and full length machining of a centre hole, for example. It is also recommended to mount the test piece on the fixture with countersink/counterbored screws such that subsequent machining does not interfere with the screws. Other methods are possible and can be selected. Overall height of the test piece depends on the selected method of fixing.

4.8 Material of test pieces, tooling, and cutting parameters

The test piece material, tooling, and the subsequent cutting parameters are subject to mutual agreement between the manufacturer/supplier and the user and shall be recorded. The parameters provided in the cutting tests are for suggestions only. The test piece material shall be specified.

4.9 Sizes of test pieces

If the test pieces come from previous cutting tests and are re-useable, their characteristic dimensions should remain within ±10 % of those indicated this document. When the test pieces are re-used, a shallow cut shall be made to clean up all surfaces before new finishing test cuts are taken.

It is also recommended that type and serial number of the machine tool, date of test, and names and orientation of the axes are marked on the test pieces.

Preliminary cuts should be taken in order to make the depth of cut as constant as possible.

The nominal size of test pieces can be modified by mutual agreement between the manufacturer/supplier and the user. The tool size and other machining conditions can also be modified.

4.10 Types of test pieces

In this document, five types of test piece are considered, some of them in two or three sizes. Types, sizes, and corresponding designation of the particular test piece are shown in Table 1. Among these types, M1 and M2 are applicable to 3-, 4-, and 5-axis machining centres. M3 and M5 are applicable only to 5-axis machining centres. M4 is applicable to 4- and 5-axis machining centres.

Table 1 — Types, sizes, and designation of the test pieces

Dimensions in millimetres

Type	Nominal size	Designation
M1 Positioning and contouring test piece	80	Test piece ISO 10791-7, M1_80
	160	Test piece ISO 10791-7, M1_160
	320	Test piece ISO 10791-7, M1_320
M2 Face milling test piece	80	Test piece ISO 10791-7, M2_80
	160	Test piece ISO 10791-7, M2_160
M3 Cone frustum test piece	15[a]	Test piece ISO 10791-7, M3_15
	45[a]	Test piece ISO 10791-7, M3_45
M4 Three-step square test piece	80	Test piece ISO 10791-7, M4_80
	160	Test piece ISO 10791-7, M4_160
	320	Test piece ISO 10791-7, M4_320
M5 Freeform test piece	—	Test piece ISO 10791-7, M5

[a] Half-apex angle of test piece, in degrees.

4.11 Information to be recorded

For tests made according to the requirements of this document, the following information shall be compiled as completely as possible and included in the test report:

a) material and designation of the test piece;

b) material, dimensions, coating, and the number of teeth of the tools used;

c) cutting speed;

d) feed speed;

e) depth of cut;

f) other cutting conditions, e.g. cutting fluid;

g) position and orientation of the workpiece in the work space;

h) direction of cuts (where applicable).

4.12 Software compensation

When software facilities are available for compensating some geometric errors, based on a mutual agreement between the manufacturer/supplier and the user, the relevant test can be carried out with these compensations. When the software compensation is used, this shall be stated in the test report.

5 Machining tests

Object	**M1**

Checking the performance of the machine tool under different kinematic conditions, i.e. only one axis feed, linear interpolation of two axes and circular interpolation by machining five bored holes and a series of finishing passes on different profiles.

NOTE 1 This test is usually performed in the XY plane of the machine tool, but can be performed in the other coordinate planes when a universal spindle head is available.

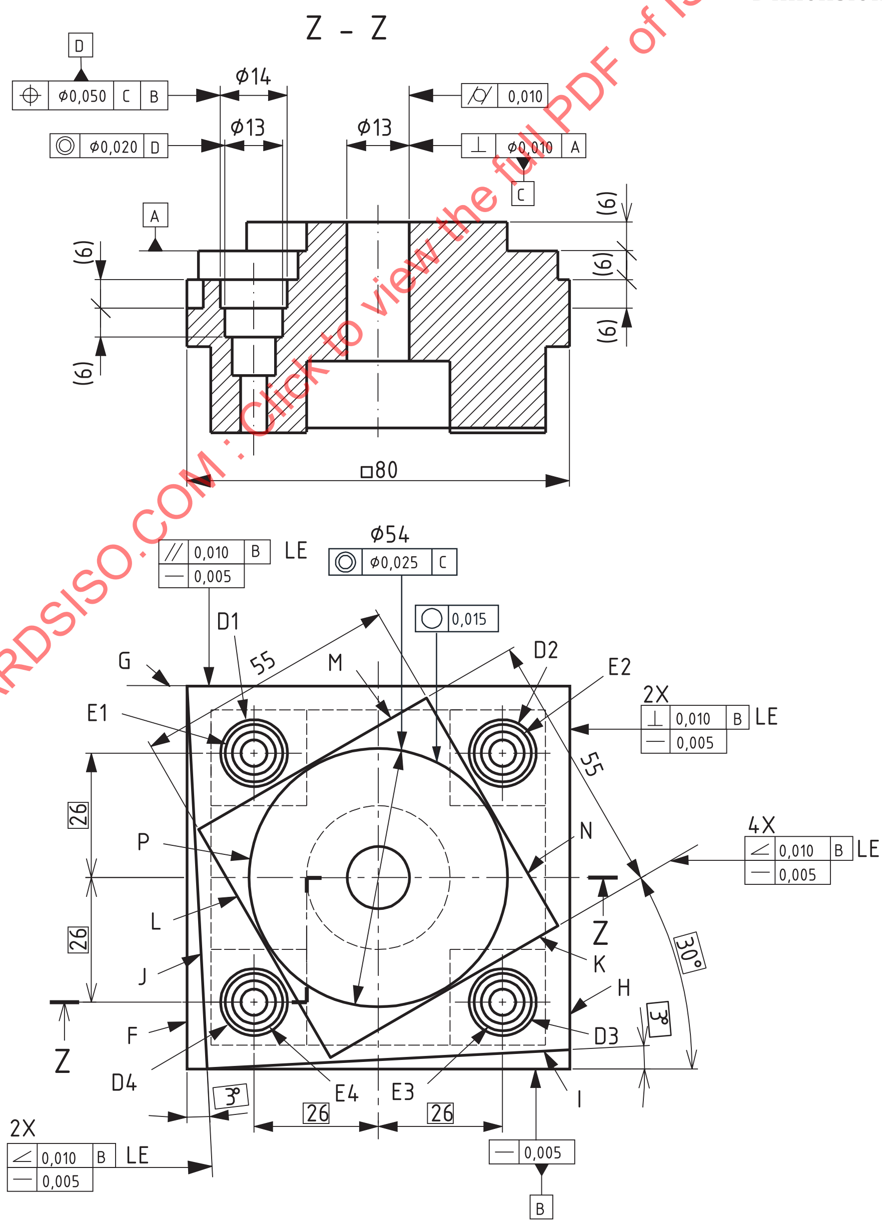
NOTE 2 Test M4 defines additions to test M1 for testing accuracy and positioning of rotary and swivelling axes.

Diagram

Three sizes of contouring test piece are considered and their dimensions are shown below.

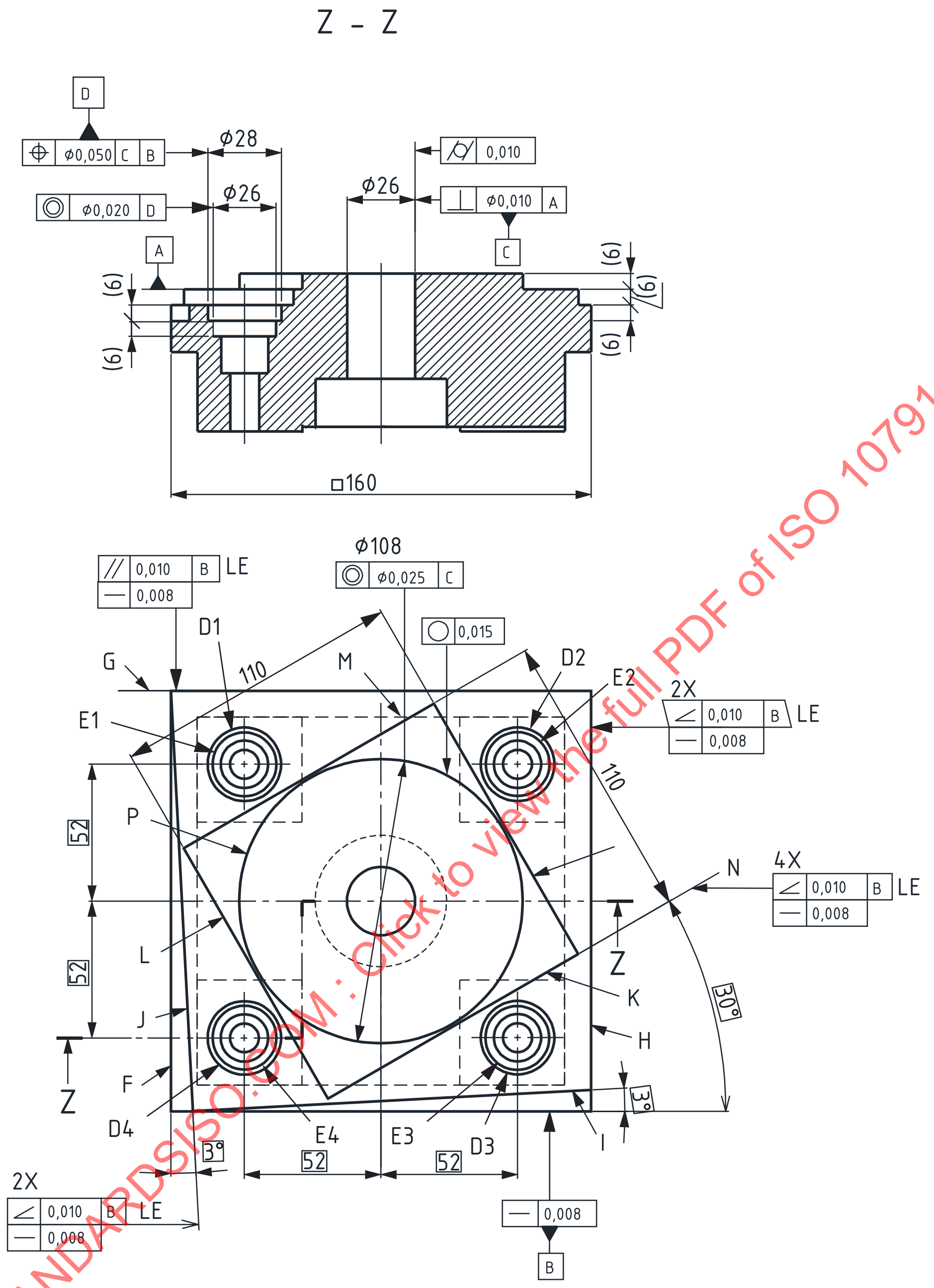
Test piece ISO 10791-7, M1_80

Dimensions in millimetres



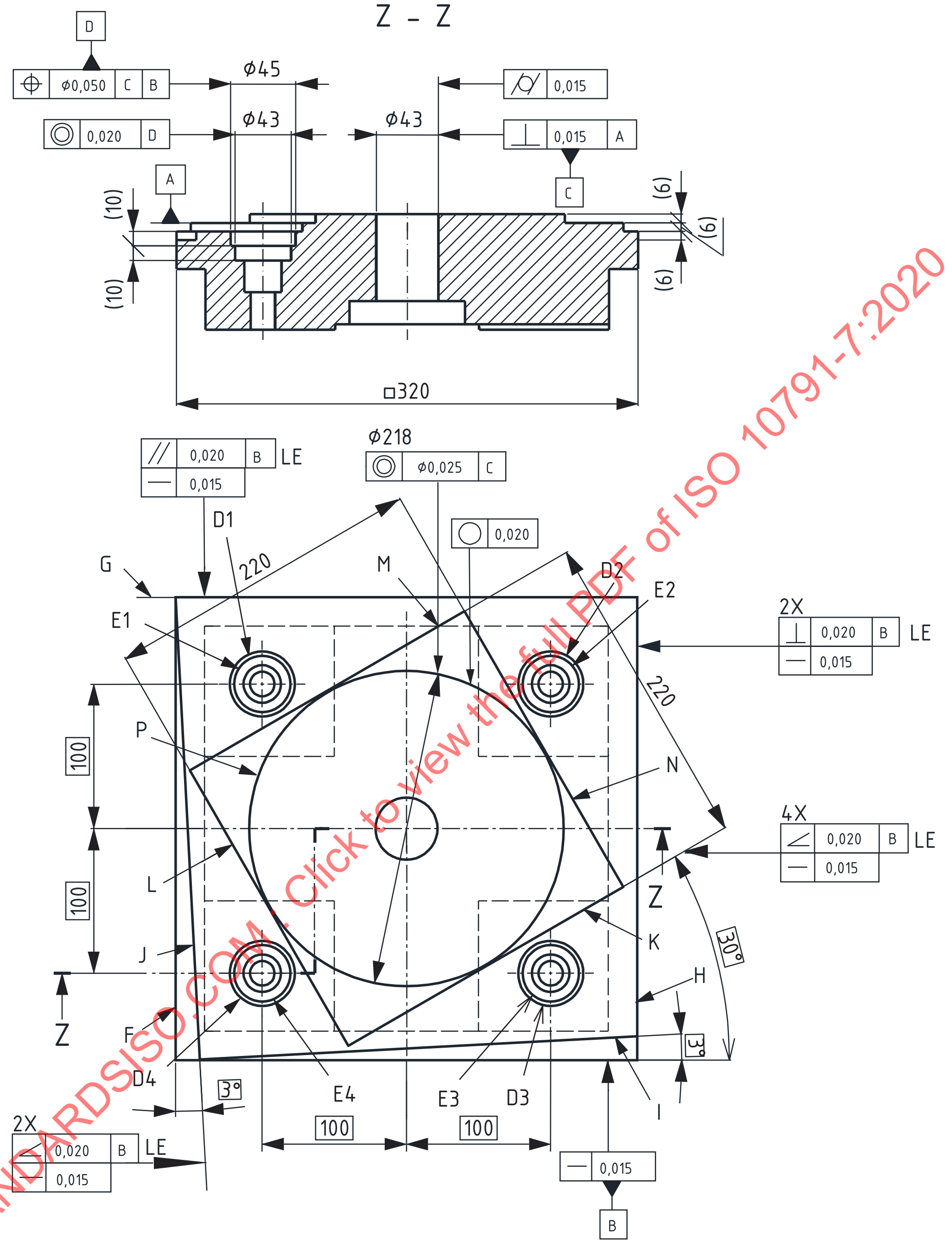
Test piece ISO 10791-7, M1_160

Dimensions in millimetres



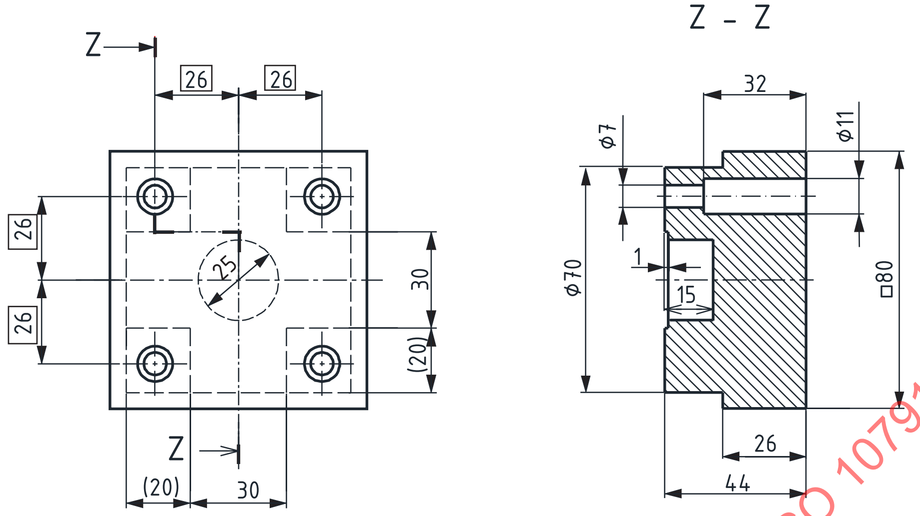
Test piece ISO 10791-7, M1_320

Dimensions in millimetres



Part blank for ISO 10791-7, M1_80

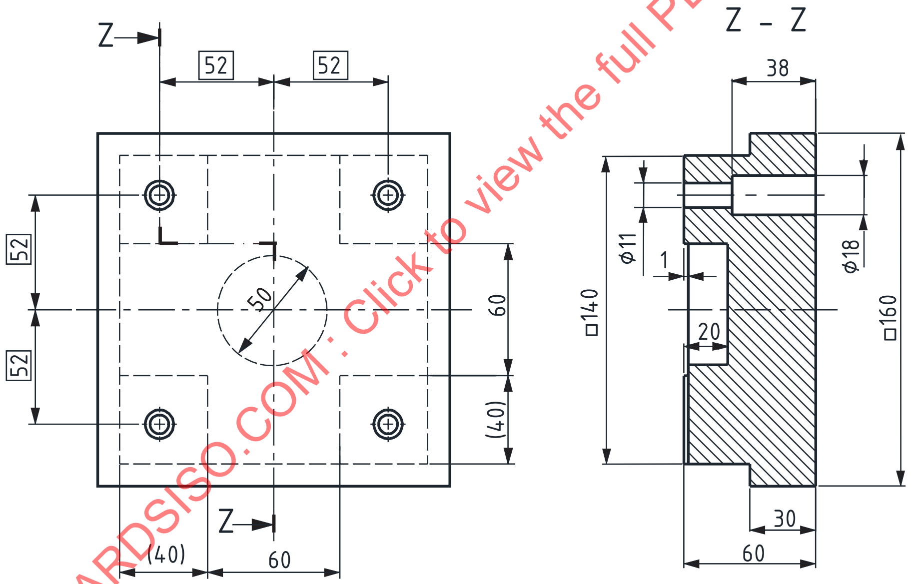
Dimensions in millimetres



NOTE Fixing dimensions are related to M6 cap screws.

Part blank for ISO 10791-7, M1_160

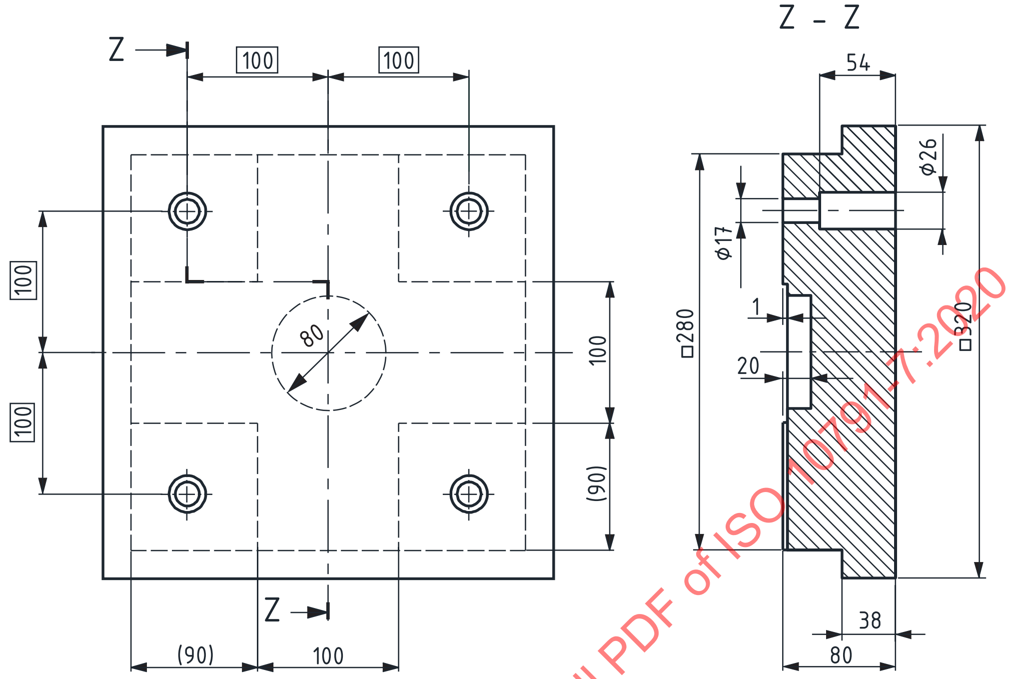
Dimensions in millimetres



NOTE Fixing dimensions are related to M10 cap screws.

Part blank ISO 10791-7, M1_320

Dimensions in millimetres



NOTE Fixing dimensions are related to M16 cap screws.

Datum surface B shall be parallel to one of the linear axes.

The bored holes (E) shall be approached in the positive direction of the positioning axes, the counter-bored holes (D) shall be approached in the negative direction.

The diamond (K-L-M-N) on the upper face of the square shall only be machined when two linear axes are used (e.g. X and Y).

Sloping faces (I and J), with an angle of 3° and a depth of 6 mm on the top of the external square sides, should only be machined when two linear axes are used (e.g. X and Y).

Since the different contouring surfaces are machined at different axial heights, face contact should be avoided by keeping the tool a fraction of a millimetre apart from the lower plane surface. The overall height of the test piece depends on the selected method of fixing.

Cutting speed should be about 50 m/min for cast iron and 300 m/min for aluminium. Feed speed should be about 0,05 mm/tooth to 0,1 mm/tooth. Depth of cut should be 0,2 mm in the radial direction for all the milling operations and about 6 mm in the axial direction for the slab milling operations.

The same tool can be used to machine all the contouring test surfaces; an end mill with a cutting edge 35 mm long and 30 mm in diameter is recommended. A boring tool may be used for holes.

Tolerances	**Measured deviations**
See Table 2.	See Table 2.

Measuring instruments

See Table 2.

Observations and references to ISO 230-1

Preliminary cuts shall be taken in order to make the depth of cut as constant as possible.

Table 2 — Contouring test piece geometric tests

Dimensions in millimetres

Object and references to the drawing		Tolerances Nominal size 80	Tolerances Nominal size 160	Tolerances Nominal size 320	Measuring instruments	Measured deviations
Central hole	Cylindricity of the bored hole C	0,010	0,010	0,015	Coordinate measuring machine (CMM)	
	Perpendicularity between the bored hole C axis and datum plane A	0,010	0,010	0,015	CMM	
Square	Straightness of the side B	0,005	0,008	0,015	CMM or straightness reference artefact and linear displacement sensor	
	Straightness of the side F					
	Straightness of the side G					
	Straightness of the side H					
	Perpendicularity of the side H to datum plane B	0,010	0,010	0,020	CMM or squareness reference artefact and linear displacement sensor	
	Perpendicularity of the side F to datum plane B					
	Parallelism of the side G to datum plane B	0,010	0,010	0,020	CMM or height gauge and linear displacement sensor	
Diamond	Straightness of the side K	0,005	0,008	0,015	CMM or straightness reference artefact and linear displacement sensor	
	Straightness of the side L					
	Straightness of the side M					
	Straightness of the side N					
	Angularity of 30° angle of side K to datum plane B	0,010	0,010	0,020	CMM or sine bar and linear displacement sensor	
	Angularity of 60° angle of side L to datum plane B					
	Angularity of 30° angle of the side M to datum plane B					
	Angularity of 60° angle of the side N to datum plane B					
Circle	Roundness of the contouring circle P	0,015	0,015	0,020	CMM or linear displacement sensor with reference rotary axis or roundness-measuring instruments	
	Concentricity of the external circle P and datum hole C	0,025	0,025	0,025		
Sloping faces	Straightness of the face I	0,005	0,008	0,015	CMM or straightness reference artefact and linear displacement senor	
	Straightness of the face J					

NOTE 1 If possible, take the test piece to a coordinate measuring machine (CMM) and take the required measurements.

To minimize the influence of the test piece distortion due to its clamping, it is recommended to measure the parts while still clamped to the fixture plate.

NOTE 2 For the straight sides (or the square, diamond, and sloping faces), touch the measured surface by the probe at least at 10 points in order to obtain the straightness, perpendicularity, and parallelism deviations.

NOTE 3 For the roundness (or cylindricity) test, if the measurement is not continuous, check at least 15 points (for cylindricity in each measured plane).

Table 2 *(continued)*

Object and references to the drawing		Tolerances Nominal size 80	160	320	Measuring instruments	Measured deviations
	Angularity of 3° of the side I to datum plane B	0,010	0,010	0,020	CMM or sine bar and linear displacement sensor	
	Angularity of 93° of the side J to datum plane B					
Bored holes	Position of the hole D1 with respect to datum hole C	0,050	0,050	0,050	CMM	
	Position of the hole D2 with respect to datum hole C					
	Position of the hole D3 with respect to datum hole C					
	Position of the hole D4 with respect to datum hole C					
	Concentricity of inner hole E1 with respect to outer hole D1	0,020	0,020	0,020	CMM or linear displacement sensor with reference rotary axis, or roundness-measuring instruments	
	Concentricity of inner hole E2 with respect to outer hole D2					
	Concentricity of inner hole E3 with respect to outer hole D3					
	Concentricity of inner hole E4 with respect to outer hole D4					

NOTE 1 If possible, take the test piece to a coordinate measuring machine (CMM) and take the required measurements.

To minimize the influence of the test piece distortion due to its clamping, it is recommended to measure the parts while still clamped to the fixture plate.

NOTE 2 For the straight sides (or the square, diamond, and sloping faces), touch the measured surface by the probe at least at 10 points in order to obtain the straightness, perpendicularity, and parallelism deviations.

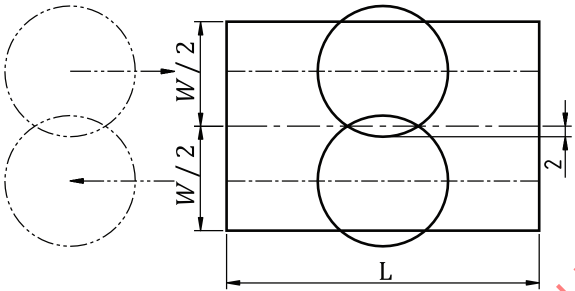
NOTE 3 For the roundness (or cylindricity) test, if the measurement is not continuous, check at least 15 points (for cylindricity in each measured plane).

Object	**M2**
Checking the flatness of a surface machined by a finish face milling operation performed by bidirectional two cuts. If the machine tool has a universal spindle head, the tests can be performed in other planes as well. NOTE Usually the test is performed by a longitudinal movement along the X-axis and a transverse movement along the Y-axis, but can be performed otherwise, subject to mutual agreement between manufacturer/supplier and user.	

Diagram

ISO 10791-7, M2_80 and ISO 10791-7, M2_160

Dimensions in millimetres



A choice of two sets of dimensions for test piece and relevant tooling is left to mutual agreement between the manufacturer/supplier and the user.

Face width *W* mm	Face length *L* mm	Cut width mm	Cutter diameter mm
80	100 to 130	40	50
160	200 to 250	80	100

Face milling cutter with indexable inserts (see ISO 6462 and ISO 1832) is recommended. Neither the maximum corner radius nor chamfer of cutter inserts should exceed 2 mm.

Material of the test piece shall be agreed upon between manufacturer/supplier and user of the machine tool. If cast iron is used, with a feed speed of 300 mm/min, the feed per tooth is almost constant and close to 0,12 mm. The depth of cut should not exceed 0,5 mm. The axis square to the machined surface (usually Z) shall not be programmed to move during the test.

Tolerance | **Measured deviations**

Object	Tolerances
Flatness of machined surface	ISO 10791-7, M2_80: 0,020 ISO 10791-7, M2_160: 0,030

NOTE The straightness check parallel to the milling direction would show the influence of the ingoing or outgoing of the cutter.

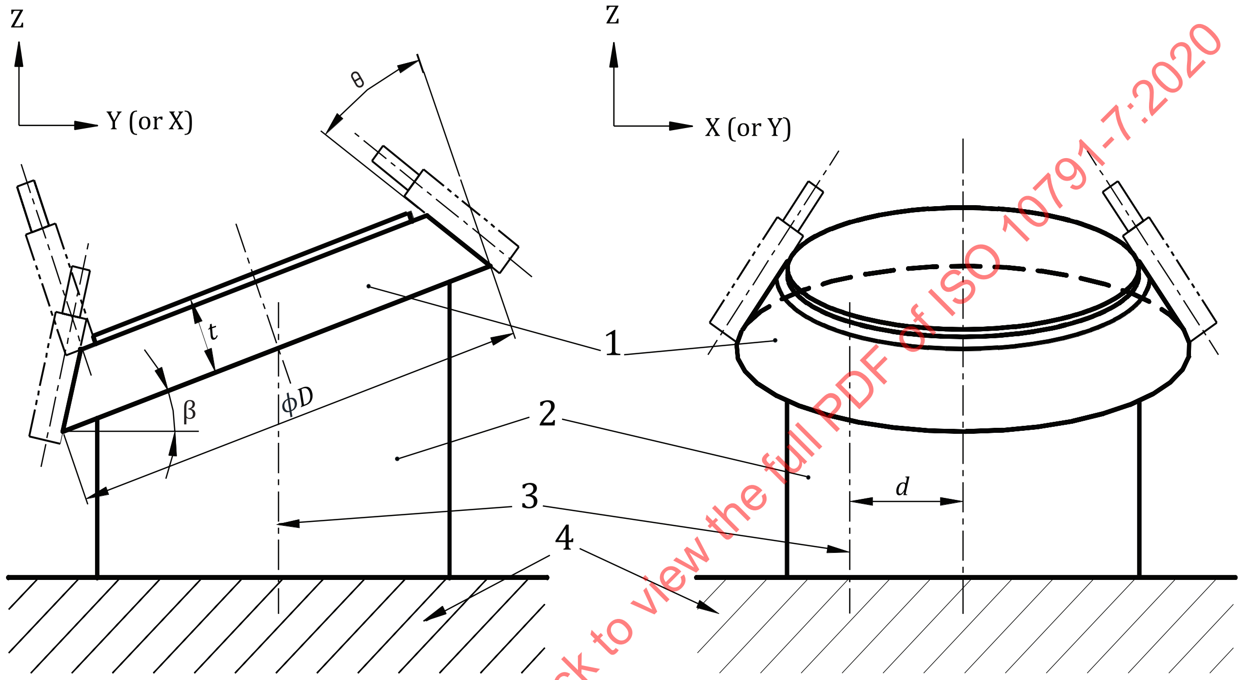
Measuring instruments
Straightness reference artefact, gauge blocks, linear displacement sensor and CMM
Observations and references to ISO 230-1
The blank shall be provided with a base suitable for being fastened to the work holding table/pallet or to a fixture, providing a sufficient stiffness both for horizontal and vertical machines. Preliminary cuts should be taken in order to make the depth of cut as constant as possible. When mounted, the cutter shall conform to the following tolerances: a) run-out < 0,020 mm; b) run-out of the face at tool diameter < 0,030 mm.

Object	**M3**

Checking the cutting performance of five-axis machining centres under the five-axis simultaneous feed motion by machining the cone-shaped test piece with flank milling (cone frustum test piece).

NOTE This test is applicable to all five-axis machining centres with three linear axes and two rotary axes. When the test is performed on the machine with two rotary axes on the workpiece side, the positioning error of Z-axis, E_{ZZ}, does not influence the test result.

Diagram



Key

1 test piece

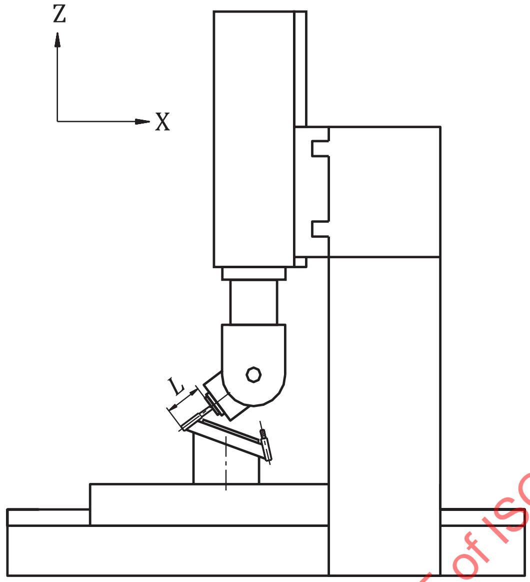
2 fixture

3 axis average line of rotary table

4 rotary table

NOTE The diagram above shows the test piece setup in the workpiece coordinate system. Keys 3 and 4 are only for five-axis machining centres with a rotary table. For machines with two rotary axes on the spindle head, the offset d is not needed.

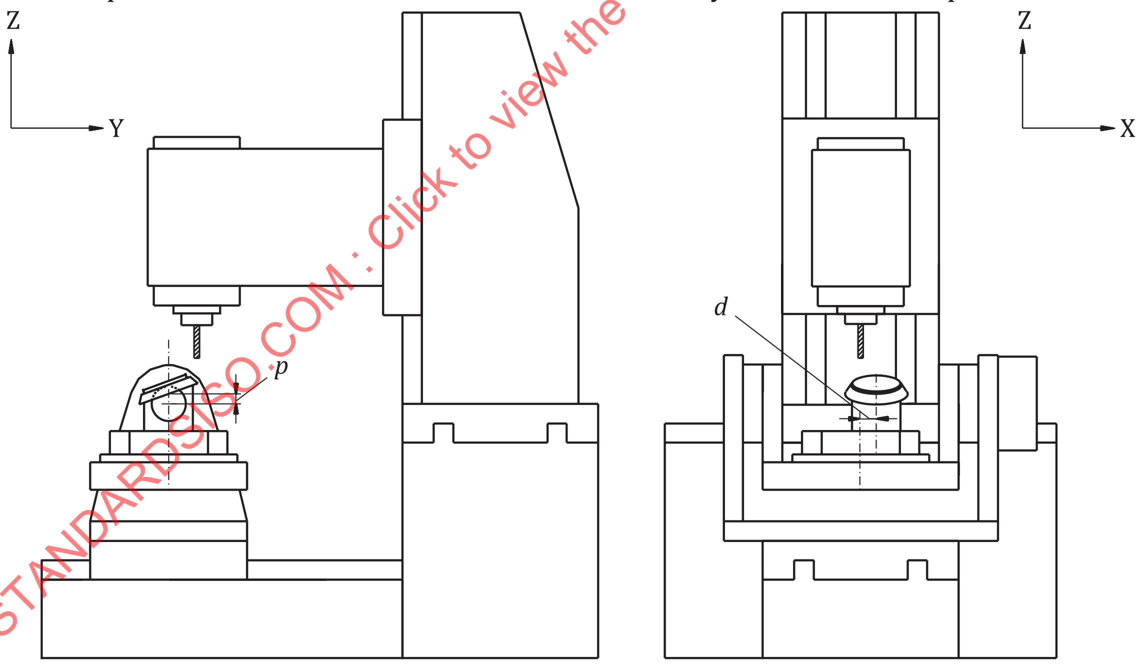
Layout of test piece on a five-axis machine tool with two rotary axes on the spindle head:



Key

L tool length

Layout of test piece on a five-axis machine tool with two rotary axes on the workpiece side:

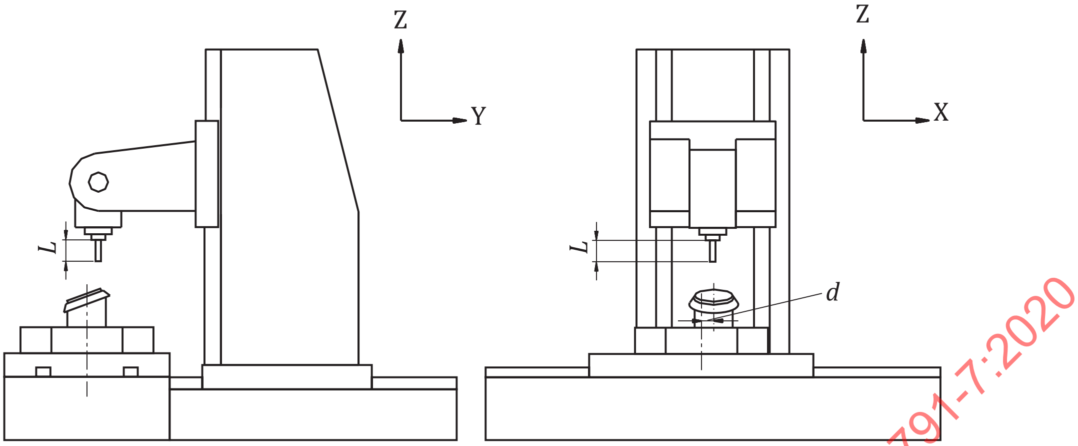


Key

d offset from rotary axis

p offset from swivelling axis

Layout of test piece on a five-axis vertical spindle machining centre with a tilting head and a rotary table:



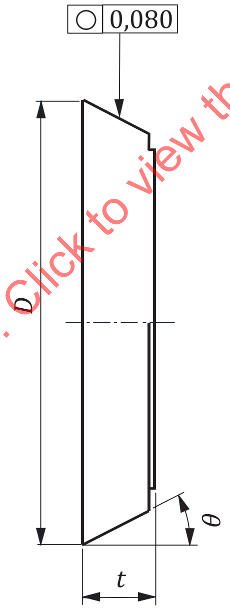
Key

L tool length

d offset from rotary axis

Test piece ISO 10791-7, M3_15 (θ = 15°) and Test piece ISO 10791-7, M3_45 (θ = 45°):

Dimensions in millimetres



Either of the two alternative conditions (sizes of contouring test piece and setting positions) are considered and their dimensions are given in the table below.

Diameter of bottom surface *D*	**Thickness** *t*	**Inclination angle** β	**Half apex angle** θ	**Centre offset** (in case of rotary table) *d*
Test piece ISO 10791-7, M3_15				
80 mm	20 mm	10°	15°	25 % of the diameter of rotary table size (or the maximum possible)
Test piece ISO 10791-7, M3_45				
80 mm	15 mm	30°	45°	25 % of the diameter of rotary table size (or the maximum possible)

The final shape of the test piece, as shown in the diagram above, shall result from the following machining:

a) The test piece should be fixed on the table with inclination angle β to the table surface as shown in the table above.

b) The bottom centre of the test piece should have the centre offset distance, *d*, as shown in the diagrams above, from the rotary table axis average line (only in case of rotary table). When the test cannot be performed due to limited strokes of linear axes, the offset may be reduced based on a mutual agreement between the manufacturer/supplier and user.

c) The bottom centre of the test piece shall have an offset p from the swivelling axis (only in case of swivelling rotary table), which shall be stated with the test report. The offset p is recommended to be larger than 10 % of the table diameter, but may be reduced based on a mutual agreement between the manufacturer/supplier and user.

d) The outer surface of the frustum shall be machined by flank milling (rough and finish cut allowed). The cutter path shall be circle at constant speed in the workpiece coordinate system.

e) A ring-shaped flat surface shall be machined on the top surface of the workpiece as the reference for the measurement. It shall be machined by the same cutting tool used for the finishing. It shall be machined by driving linear axes only, with rotary axes fixed.

The test setup can be modified based on a mutual agreement between the manufacturer/supplier and user. For example, on a five-axis machine tool with a tilting head and a rotary table, the setup shown above may not be possible due to the limitation in the stroke of A-axis or Y-axis. In such a case, by installing the test piece with the inclination angle β = 90° using a square fixture on the machine table, the test may be possible. Note that such a modification may significantly reduce the moving range of each axis compared to the original setup, which often reduces geometric errors of the machined test piece. For example, on a machine tool with a tilting head and a rotary table, the rotary table makes full (360°) rotation in the original setup, while it does not in the modified setup with β = 90°. Similarly, when the centre offset, *d*, is reduced, the moving range of each axis often becomes smaller. When the setup is modified, it shall be stated in the report. The tolerances given in Table 3 are for the original setups. A flat end mill with a cutting edge 40 mm long and 20 mm in diameter is recommended. When a ϕ20 tool cannot be used, a smaller tool (e.g. ϕ10) may be used based on a mutual agreement between the manufacturer/supplier and user. Attention must be paid on the influence of tool deflection. Cutting speed, feed speed, and depth of cut shall be agreed upon between manufacturer/supplier and user. As default values, the following may be chosen: cutting speed of 50 m/min for cast iron and 300 m/min for aluminium, feed rate of 0,05 mm/tooth, depth of cut of 0,1 mm in radial direction. NOTE The dimension of the ring-shaped surface is arbitrary, as long as it can be used as the reference for the measurement.
Tolerance See Table 3. — **Measured deviations** See Table 3.
Measuring instruments See Table 3.
Observations and references to ISO 230-1 Preliminary cuts shall be taken in order to make the depth of cut as constant as possible. The information on the inclination angle and centre offset distances, as well as the tool length, *L*, shall be included in the test report. If easily available, the range of movement of each axis (three linear axes and two rotary axes) shall be reported. For interpretation of test results see [14].

Table 3 — Cone frustum test piece geometric tests for test pieces ISO 10791-7, M3_15 and ISO 10791-7, M3_45

Dimensions in millimetres

Object	Tolerances	Measuring instruments	Measured deviations
Cone upper surface (2 mm apart from top) **a) Roundness**	0,080	Roundness-measuring instruments or coordinate measuring machine (CMM) or linear displacement sensor and rotary table	a)
Cone lower surface (2 mm apart from bottom) **b) Roundness**	0,080	Roundness-measuring instruments or CMM or linear displacement sensor and rotary table	b)

Object	**M4** **Additions to Type M1 test piece**

Checking the accuracy of angular positioning and of the position of rotary axis average lines.

NOTE 1 This test is applicable to all five-axis machining centres with three linear and two rotary axes.

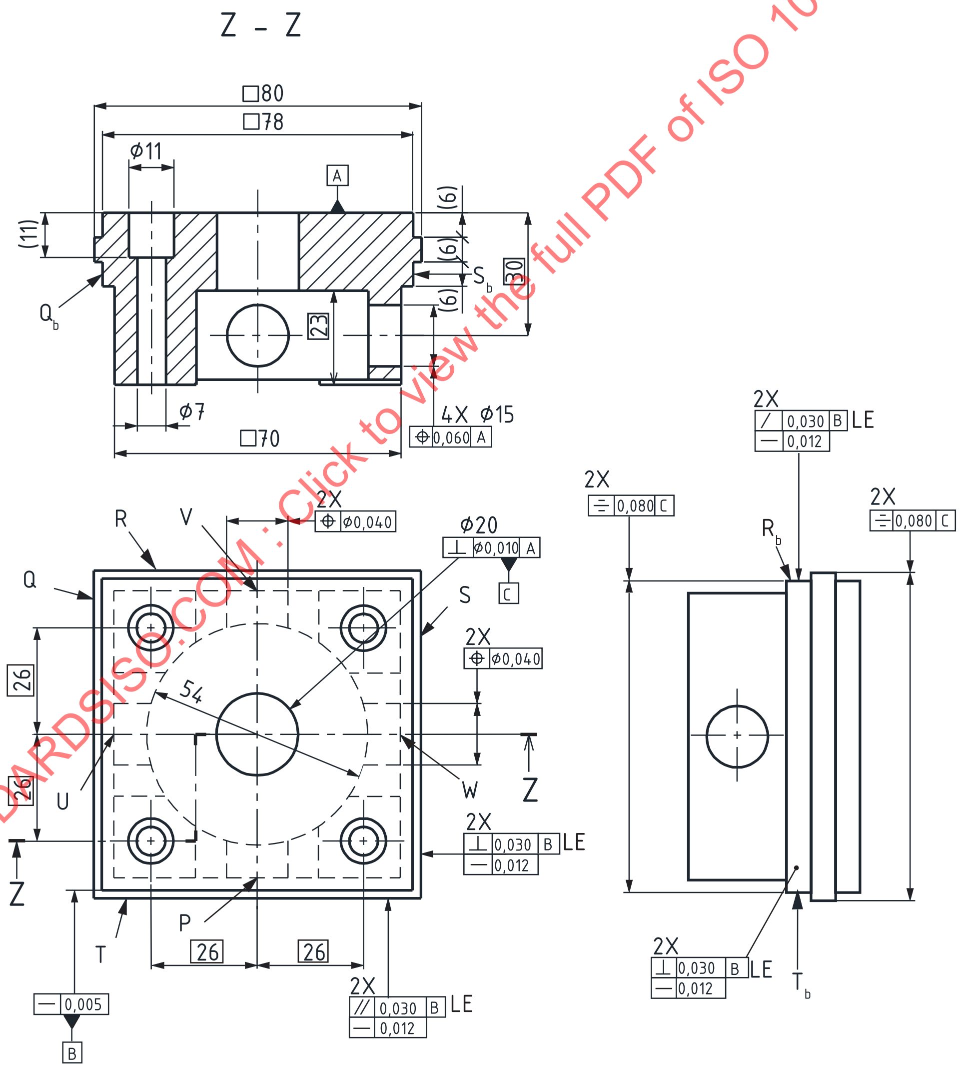
NOTE 2 The test piece described below can be designed as part of Type M1 test piece in accordance with this document.

NOTE 3 Feature 2 (see diagram) can be also machined on a 4-axis machining centre with rotary table. But it does not apply to machines with two rotary axes on the spindle head.

Diagram

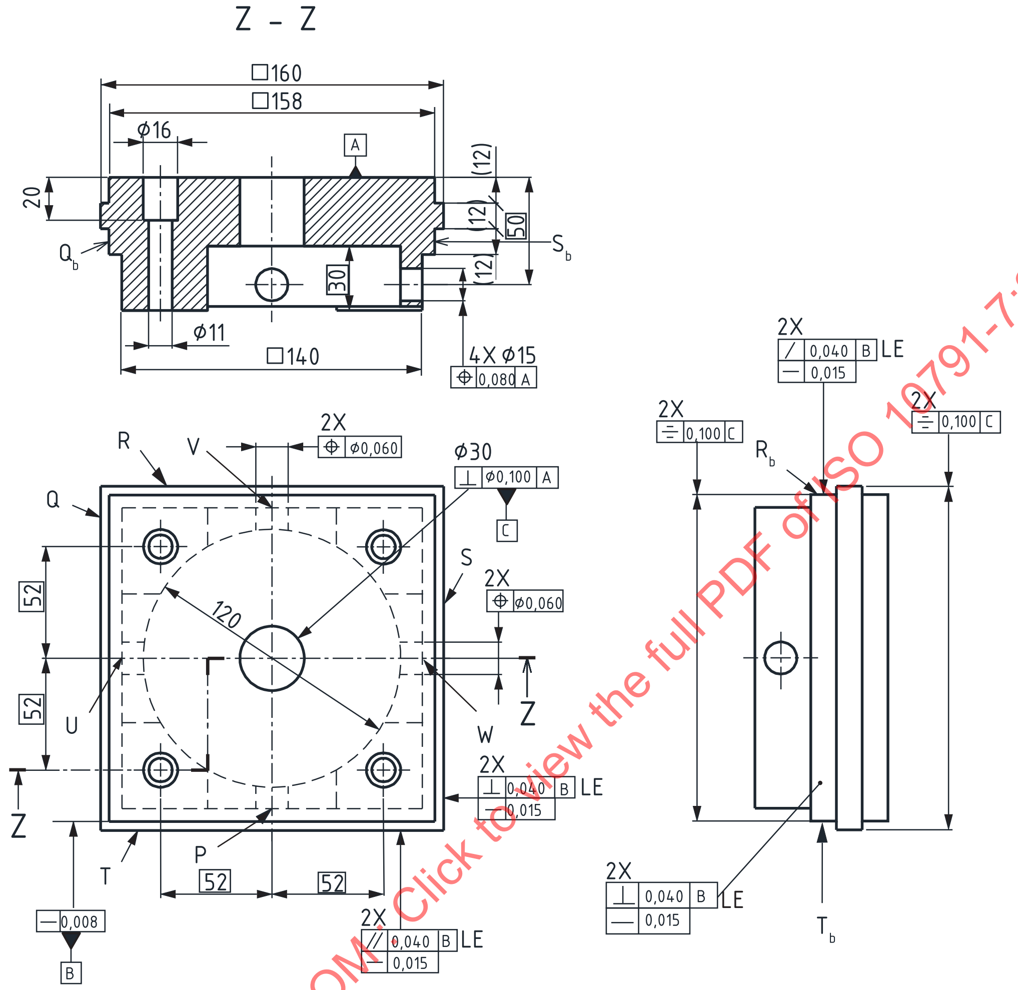
Test piece ISO 10791-7, M4_80

Dimensions in millimetres



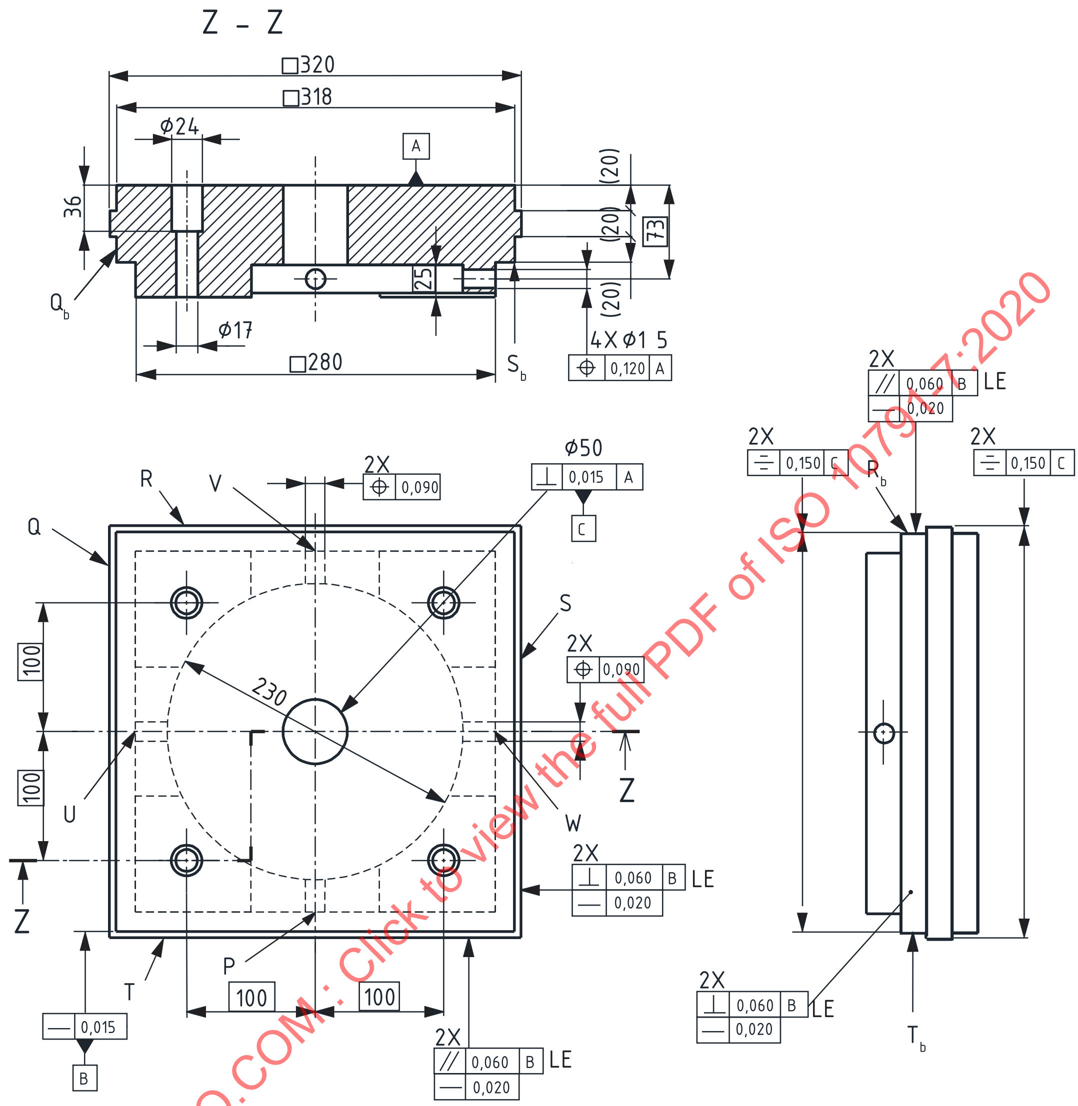
Test piece ISO 10791-7, M4_160

Dimensions in millimetres



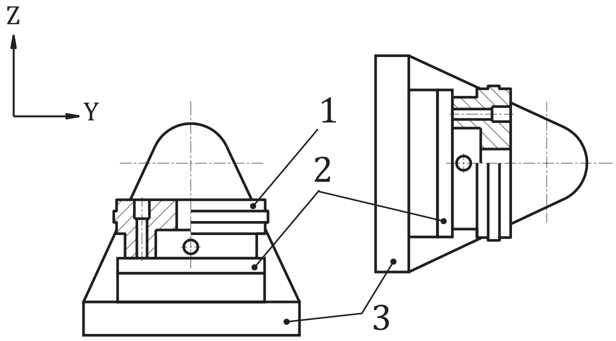
Test piece ISO 10791-7, M4_320

Dimensions in millimetres



The part blanks used for M1 test shall be used as the part blanks for M4 test.

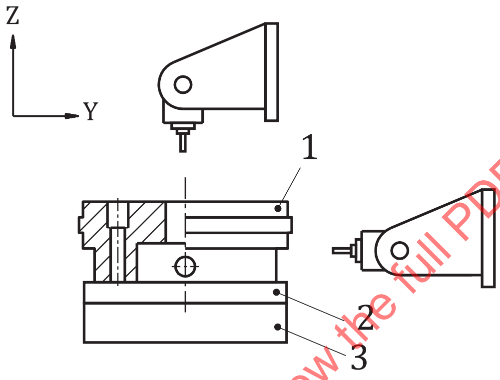
The layout of the test piece on a machine tool with two rotary axes on the workpiece side:



Key

1 test piece
2 rotary table
3 cradle

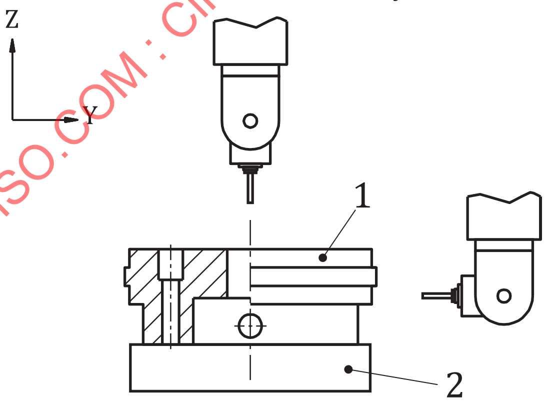
The layout of the test piece on a machine tool with a tilting head and a rotary table:



Key

1 test piece
2 rotary table
3 machine table

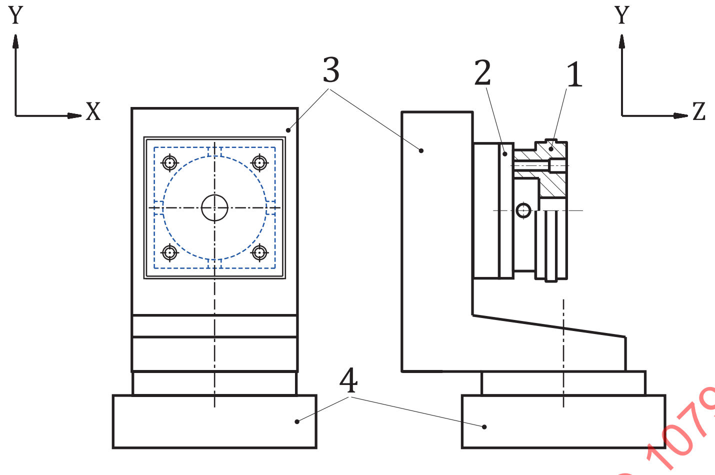
The layout of the test piece on a machine tool with two rotary axes on the spindle side:



Key

1 test piece
2 machine table

The layout of the test piece on a machine with table-on-table configuration:



Key

1 test piece

2 rotary table

3 swivelling table

4 table saddle

The final shape of the test piece, as shown in the diagram above, shall result from the following machining sequences:

a) Feature 1: Top square shall be machined by end milling using two linear motions (X- and Y-axes).

b) Feature 2 (S, Q, R, T): Middle square shall be machined by end milling using one linear and one rotary axis with the following machining sequence (not applicable for machines with two rotary axes on the spindle head):

   1) end milling of first plane (face) of the square parallel to x-axis;

   2) rotating test piece with rotary axis C by 90°;

   3) end milling of next plane parallel to X-axis;

   4) repetition of 2) and 3) until all 4 planes are end milled.

c) Feature 3: Bottom square shall be machined by face milling using one or two linear and one or two rotary axes with the following machining sequence:

   1) swiveling axis (or tilting head) is rotated by 90°;

   2) first plane is face milled by moving along a linear axis;

   3) rotary axis C (table or spindle head) is rotated by 90°;

   4) next plane is face milled by moving along either same linear axis or the one orthogonal to the first linear axis (for machines with two rotary axes on the spindle head);

   5) repetition of 3) and 4) until all 4 planes are face milled.

If the swiveling axis (or tilting head) can be rotated by ±90°, the following procedure shall be applied:

6) swiveling axis (or tilting head) is rotated by 90°;

7) first plane is face milled by moving along a linear axis;

8) rotary axis C (table or spindle head) is rotated by 180°;

9) second plane is face milled by moving along the same linear axis (this may require preparatory move along the orthogonal axis);

10) swiveling axis (or tilting head) is rotated by −180°, rotary axis C (table or spindle head) is rotated by −90°;

11) third plane is face milled by moving along either the same linear axis or the one orthogonal to the first linear axis (for machines with two rotary axes on the spindle head);

12) rotary axis C (table or spindle head) is rotated by 180°;

13) forth plane is face milled by moving along the previous linear axis (this may require preparatory move along the orthogonal axis).

d) Feature 4: Radial holes.

1) swiveling axis (or tilting head) is rotated by 90°;

2) first hole, dia. 15 mm is machined by circular milling, dia. of tool is 10 mm;

3) rotary axis C (table or spindle head) is rotated by 90°;

4) next hole is machined by circular milling;

5) repetition of 2) and 3) until all 4 holes are machined by circular milling.

If the swiveling axis (or tilting head) can be rotated by ±90°, the following procedure shall be applied:

6) swiveling axis (or tilting head) is rotated by 90°;

7) first hole, dia. 15 mm is machined by circular milling, dia. of tool is 10 mm;

8) rotary axis C (table or spindle head) is rotated by 180°;

9) second hole is machined by circular milling;

10) swiveling axis (or tilting head) is rotated by −180°, rotary axis C (table or spindle head) is rotated by −90°;

11) third hole is machined by circular milling;

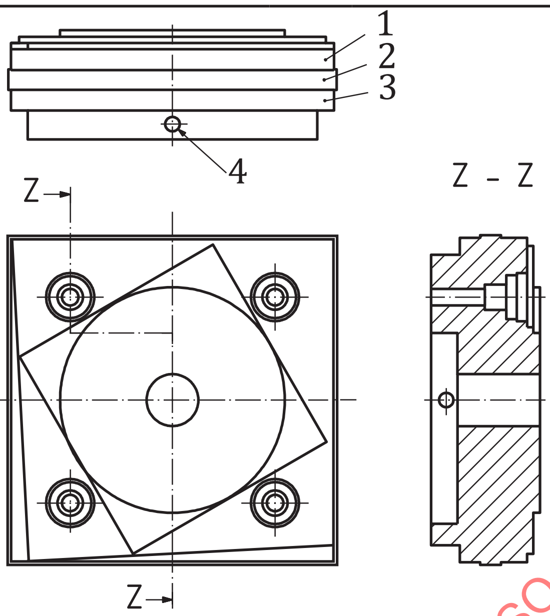
12) rotary axis C (table or spindle head) is rotated by 180°;

13) fourth hole is machined by circular milling.

Cutting parameters are subject to mutual agreement between manufacturer/supplier and user of the machine tool.

NOTE 1 M1 and M4 test pieces can be made to one test piece. The following figures represent such embodiments. Alternatively, M1 and M4 test pieces can be combined using proper fixturing that may provide more flexibility in testing.

NOTE 2 Holes can be machined by using a boring tool.



Key

1 feature 1: top square feature machined using linear motions along X- and Y-axes

2 feature 2 (S, Q, R, T): middle square feature machined using one linear and rotary axis (C)

3 feature 3 (bottom square): face milled square feature machined using one linear and two rotary axes

4 feature 4: radial holes

Tolerance	**Measured deviations**
The end-milled square (feature 1) shall satisfy the tolerances given in M1 test piece. Other tolerances are given in Table 4.	See Table 4.

Measuring instruments

See Table 4.

Observations and references to ISO 230-1

Preliminary cuts shall be taken in order to make the depth of cut as constant as possible.

The distance between the centre positions of the reference bore C and the axis average line of rotary table, as well as the distance between the reference surface C and the axis average line of swivelling axis, shall be reported.

Table 4 — Three-step square test piece geometric tests for test pieces ISO 10791-7, M4_80, _160, and _320

Dimensions in millimetres

Object and references to the drawing		**Tolerances Nominal size**			**Measuring instruments**	**Measured deviations**
		80	**160**	**320**		
Middle square	Straightness of the side Q	0,012	0,015	0,020	Coordinate measuring machine (CMM) or straightness reference artefact and linear displacement sensor	
	Straightness of the side R					
	Straightness of the side S					
	Straightness of the side T					
	Symmetry to datum hole C	0,080	0,100	0,150	CMM	

Table 4 *(continued)*

Object and references to the drawing		Tolerances Nominal size			Measuring instruments	Measured deviations
		80	160	320		
	Squareness of the side Q to datum plane B	0,030	0,040	0,060	CMM or squareness reference artefact and linear displacement sensor	
	Squareness of the side S to datum plane B					
	Parallelism of the side R to datum plane B				CMM or height gauge and linear displacement sensor	
	Parallelism of the side T to datum plane B					
	Difference of L1 and L2, where L1 is the distance between planes Q and S, L2 is the distance between planes R and T	0,100	0,120	0,180	CMM	
Bottom square	Straightness of the side Q_b	0,012	0,015	0,020	CMM or straightness reference artefact and linear displacement sensor	
	Straightness of the side R_b					
	Straightness of the side S_b					
	Straightness of the side T_b					
	Symmetry to datum hole C	0,080	0,100	0,150	CMM	
	Squareness of the side Q_b to datum plane B	0,030	0,040	0,060	CMM or squareness reference artefact and linear displacement sensor	
	Squareness of the side S_b to datum plane B					
	Parallelism of the side R_b to datum plane B				CMM or height gauge and linear displacement sensor	
	Parallelism of the side T_b to plane B					
	Difference of L3 and L24, where L3 is the distance between planes Q_b and S_b, L4 is the distance between planes R_b and T_b	0,100	0,120	0,180	CMM	
Radial holes	Difference of hole U position in distance to datum plane A[a,b]	0,060	0,080	0,120	CMM	
	Difference of hole V position in distance to datum plane A[a,b]					
	Difference of hole W position in distance to datum plane A[a,b]					
	Difference of hole P position in distance to datum plane A[a,b]					
	Difference of hole U position to hole W[a]	0,040	0,060	0,090	CMM	
	Difference of hole V position to hole P[a]					

[a] The difference is affected by the uncertainty in the determination of tool length and by tool wear.

[b] When re-using the test piece, the nominal value of the distance to datum plane A should be decreased.

Annex A
(informative)

Accuracy of a finished freeform test piece (M5)

A.1 General

This test is only intended to assess the performance of a five-axis machining centre with three linear and two rotary axes. Though the test results are intended to show mainly the effects of geometric errors of a machining centre, and the performance of the NC controller and servo controllers, other factors can influence the test results, for example, the accuracy of the CAD model, the tool path generation by CAM software, the measurement uncertainty with the freeform measurement by a coordinate measuring machine (CMM). The complex nature of this test dictates that it cannot be used for error identification.

The freeform test piece specified in this annex is primarily for the use of aerospace industry (although other complex part manufacturers can also use it). It is an optional test, which can be used according to the mutual agreement between supplier/manufacturer and user.

STEP file and measuring points file can be downloaded from http://standards.iso.org/iso/10791/-7/ed-3/en.

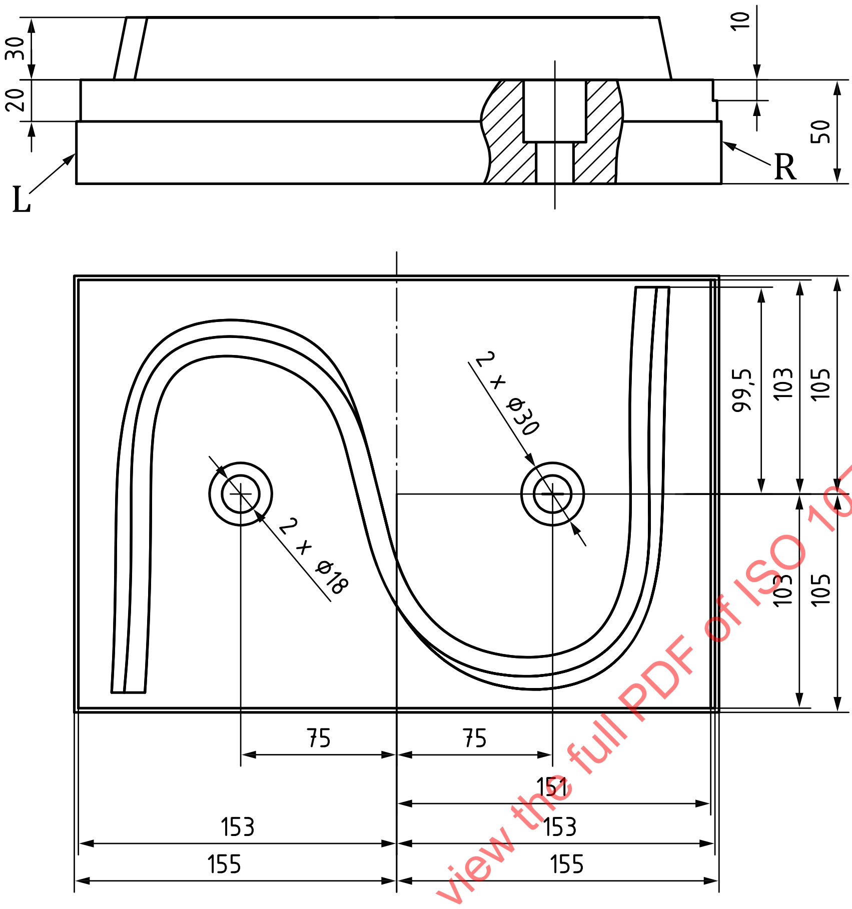
A.2 Geometric definition of the test piece

The test piece is formed of an S-shaped fillet and a rectangular base, the final shape is shown in Figure A.1. The S-shape fillet is defined by two ruled surfaces. As shown in Figure A.2 a), ruled surface A is generated according to Formula (1) by two fourth-order (cubic) quasi-uniform rational B-splines which are defined by two sets of control points P_i and Q_i (see Table A.1). Similarly, as shown in Figure A.2 b), ruled surface B is generated by two fourth-order (cubic) quasi-uniform rational B-splines which are defined by two sets of control points M_i and N_i (see Table A.2).

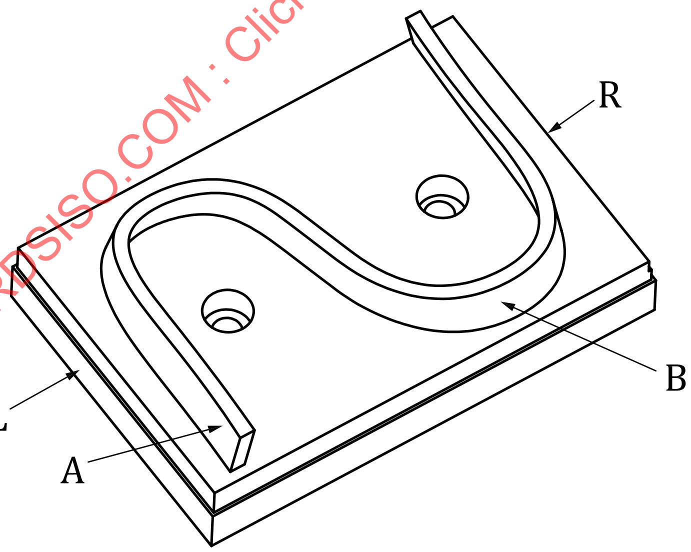
NOTE 1 During flank milling of a non-developable ruled surface, the existence of twist angle implies that it is impossible to machine the workpiece perfectly using a non-zero diameter tool, with the cutter positioning on the surface leading to inevitable interference. Overcut and undercut on the ruled surfaces due to tool diameter and the twist angle can be as large as 20 µm. As shown in Figure 1, P_0, P_1 are the end points of a rule, and K_0, K_1 are vectors normal to $S(u, v)$ at P_0 and P_1, the twist angle is the angle between K_0 and K_1.

NOTE 2 The CAM system used impacts the errors generated when machining a set surface. It is possible to use the NC interpolation capabilities in NURBS if available to minimize errors (lessen the effects of dynamic errors of the machine). If used, this function should be reported.

Dimensions in millimetres



a) 2D



b) 3D

Key

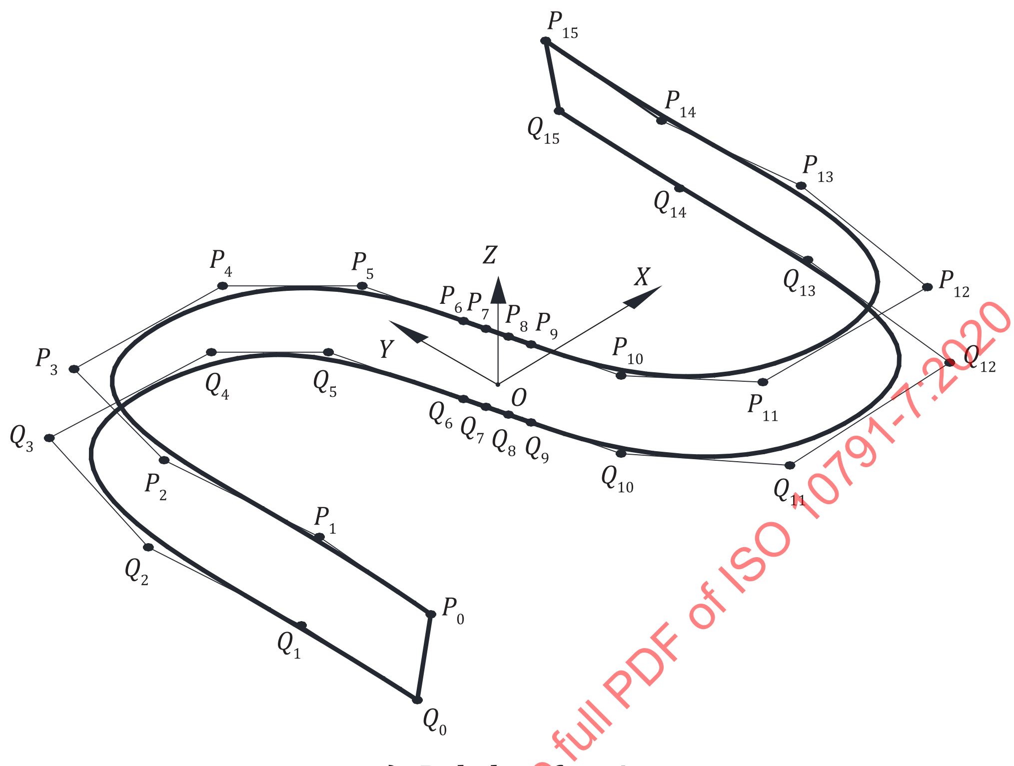
A ruled surface A

B ruled surface B

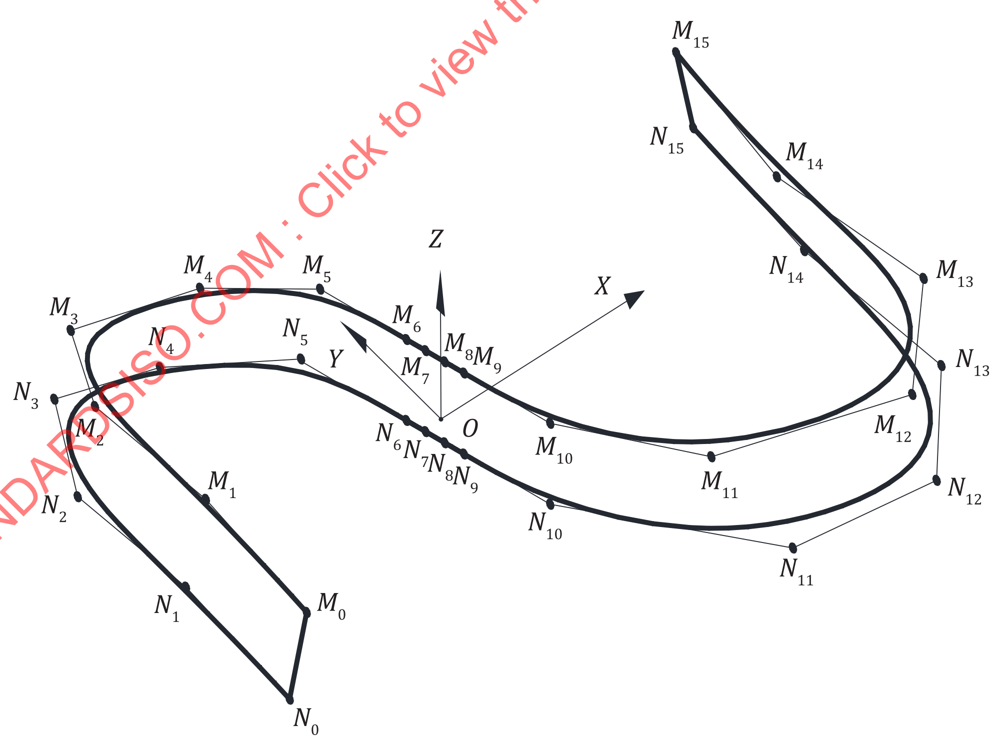
L left side of the test piece

R right side of the test piece

Figure A.1 — Geometry of the test piece



a) **Ruled surface A**



b) **Ruled surface B**

Figure A.2 — Definition of the ruled surfaces

Table A.1 — Control points of ruled surface A

P_i	POS_X	POS_Y	POS_Z
P_0	−131	−95,5	30
P_1	−126	−41	30
P_2	−131	23	30
P_3	−116	78	30
P_4	−51	77	30
P_5	−20	46	30
P_6	−11	10	30
P_7	−9	2	30
P_8	−7	−6	30
P_9	−5	−14	30
P_{10}	3	−46	30
P_{11}	32	−80	30
P_{12}	103	−81	30
P_{13}	116	−13	30
P_{14}	110	43	30
P_{15}	115	99,5	30

Q_i	POS_X	POS_Y	POS_Z
Q_0	−137	−95,5	0
Q_1	−134	−41	0
Q_2	−138	23	0
Q_3	−118	87	0
Q_4	−49	84	0
Q_5	−23	58	0
Q_6	−11	10	0
Q_7	−9	2	0
Q_8	−7	−6	0
Q_9	−5	−14	0
Q_{10}	3	−46	0
Q_{11}	36	−88	0
Q_{12}	111	−84	0
Q_{13}	119	−13	0
Q_{14}	118	43	0
Q_{15}	121	99,5	0

Table A.2 — Control points of ruled surface B

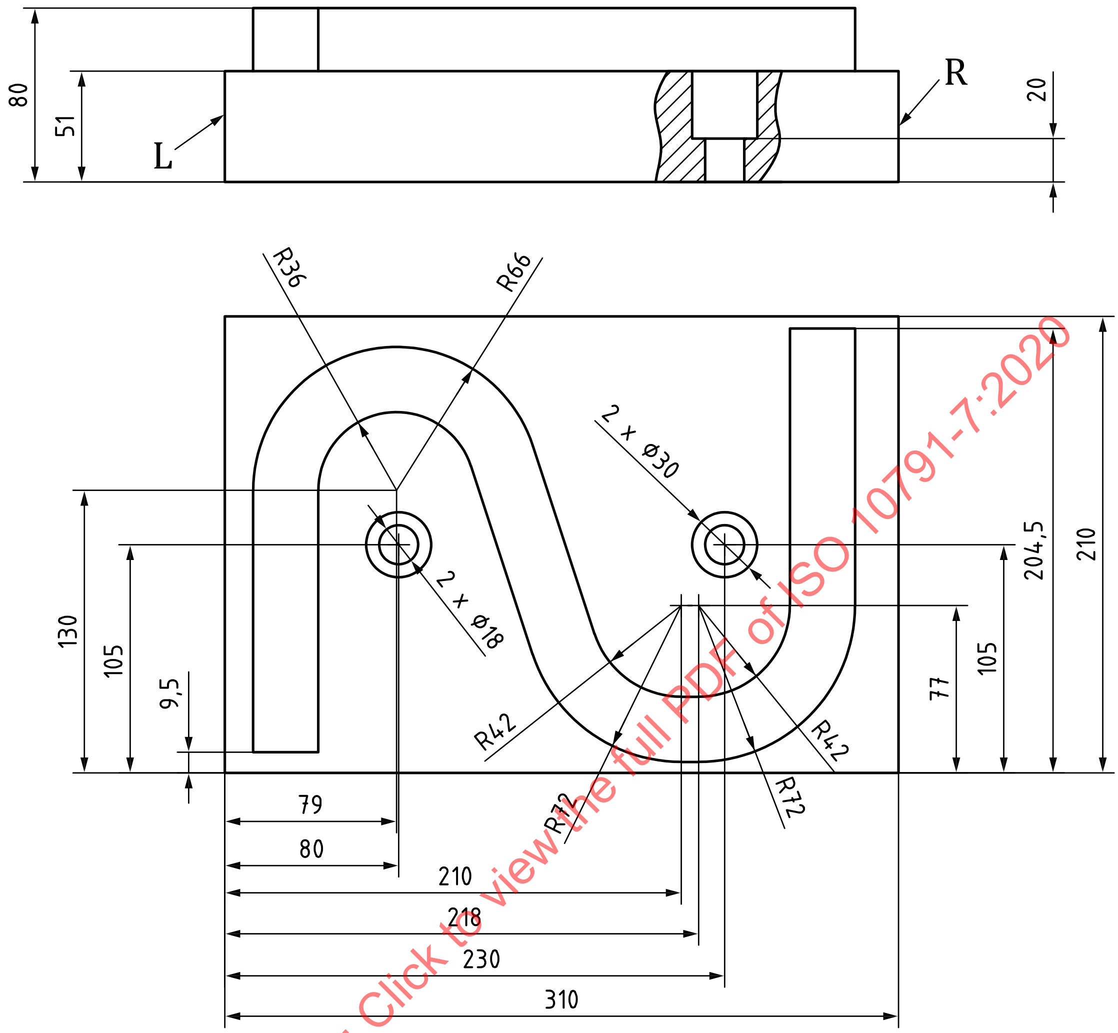
M_i	POS_X	POS_Y	POS_Z
M_0	−121	−95,5	30
M_1	−117	−29	30
M_2	−121	30	30
M_3	−107	68	30
M_4	−62	67	30
M_5	−31	48	30
M_6	−22	12	30
M_7	−20	4	30
M_8	−18	−4	30
M_9	−16	−12	30
M_{10}	−7	−48	30
M_{11}	26	−88	30
M_{12}	95	−91	30
M_{13}	129	−42	30
M_{14}	118	28	30
M_{15}	125	99,5	30

N_i	POS_X	POS_Y	POS_Z
N_0	−127	−95,5	0
N_1	−124	−29	0
N_2	−128	30	0
N_3	−108	76	0
N_4	−62	74	0
N_5	−33	56	0
N_6	−22	12	0
N_7	−20	4	0
N_8	−18	−4	0
N_9	−16	−12	0
N_{10}	−7	−48	0
N_{11}	30	−95	0
N_{12}	100	−97	0
N_{13}	132	−46	0
N_{14}	127	27	0
N_{15}	131	99,5	0

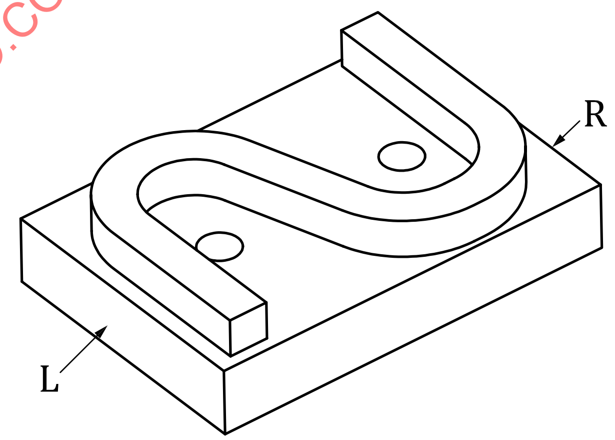
A.3 Raw material definition

The geometric definition of the part blank is shown in Figure A.3.

Dimensions in millimetres



a) 2D



b) 3D

Key

L left side of the test piece

R right side of the test piece

Figure A.3 — Geometry of the part blank

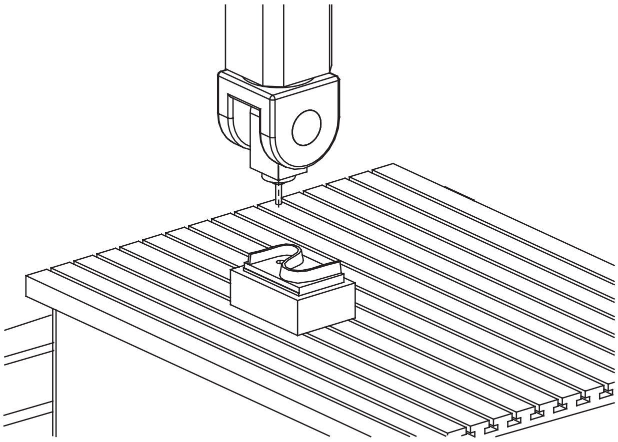
The part blank should be machined from all sides to provide stress relief. The flatness error of the bottom plane should be smaller than 0,05 mm, and other dimensional tolerances should be ±0,1 mm. The recommended material for this test is aluminium alloy, though other materials may also be used, according to the mutual agreement between the supplier/manufacturer and the user.

A.4 Machining

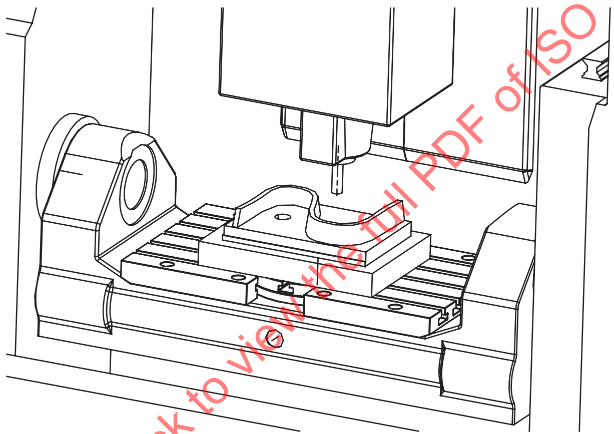
A.4.1 Fixing of the part blank

At least two bolts or other clamping methods can be used to achieve enough stability and to minimize distortion. Care should be taken to ensure that the combination of clamping and the non-flatness of the bottom surface does not distort the test piece.

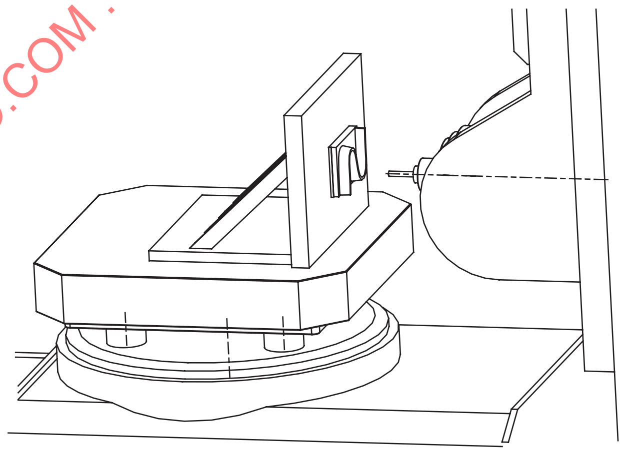
Figure A.4 shows examples of positioning and clamping of the test piece, on three different types of five-axis machining centres.



a) Machining centre with two rotary axes on the spindle head



b) Machining centre with two rotary axes on the workpiece side



c) Machining centre with a tilting head and a rotary table

Figure A.4 — Examples of positioning the test piece on three different types of five-axis machining centre