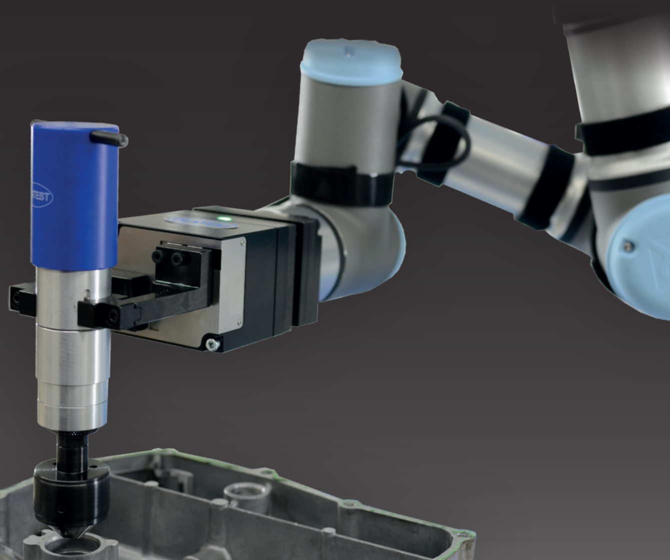
DIATEST Mitutoyo

ENGLISH EDITION

METROLOGIST REFERENCE BOOK

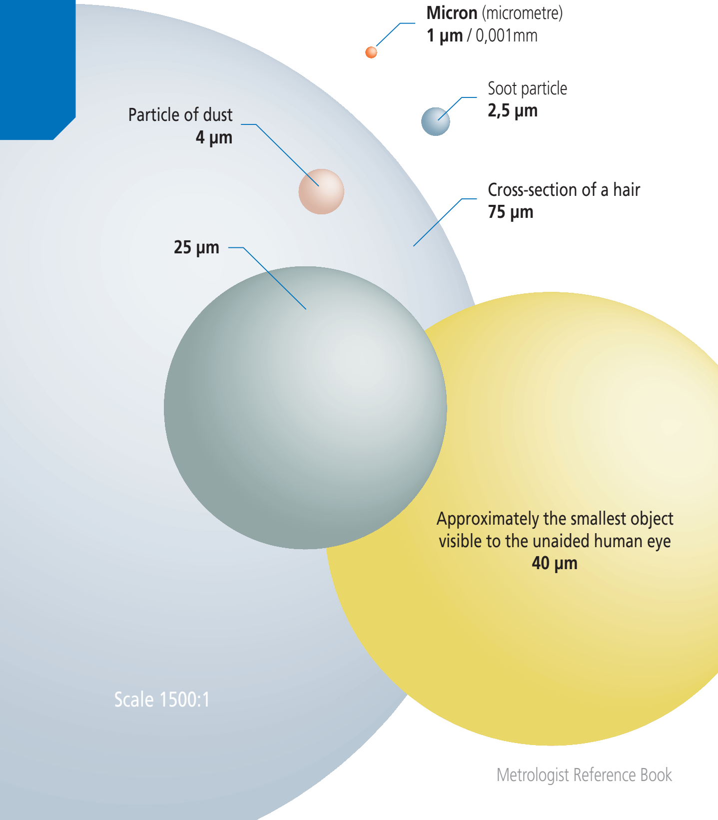
Equivalents, conversions, geometric tolerancing symbols, hardness comparisons, triangle solutions, mensuration, roughness measurement, thermal expansion



Contents

Making Sense of Microns

Did you know?
A 100 mm steel gauge block increases in length by 11 µm as its temperature changes from 20 °C to 30 °C.



The Greek Alphabet and Basic Mathematical Symbols

Uppercase	Α	Β	Γ	Δ	Ε	Ζ	Η	Θ
Lowercase	α	β	γ	δ	ε	ζ	η	θ
Name	Alpha	Beta	Gamma	Delta	Epsilon	Zeta	Eta	Theta

Uppercase	Ι	Κ	Λ	Μ	Ν	Ξ	Ο	Π
Lowercase	ι	κ	λ	μ	ν	ξ	ο	π
Name	Iota	Kappa	Lambda	Mu	Nu	Xi	Omicron	Pi

Uppercase	Ρ	Σ	Τ	Υ	Φ	Χ	Ψ	Ω
Lowercase	ρ	σ	τ	υ	ϕ	χ	ψ	ω
Name	Rho	Sigma	Tau	Upsilon	Phi	Chi	Psi	Omega

+	plus/add
–	minus/subtract
±	plus or minus
x	multiply/times
÷	divide
/	divide
=	is numerically equal to
≡	is identical or equivalent to
≠	does not equal
≈	is approximately equal to
∝	is proportional to
~	is of the order of
>	is greater than
<	is less than
≥	is greater than or equal to
≤	is less than or equal to

>>	is much greater than
<<	is much less than
Σ	the sum of the terms indicated
Π	the product of the terms indicated
Δ	finite difference or increment
∴	therefore
∠	angle
//	parallel to
⊥	perpendicular to
:	is to
√x	square root of x
√x	n^{th} root of x
→	approaches the limit
∞	infinity

Conversions

Metric length units

	nm	µm	mm	cm	dm	m	km
1 nm	1	0,001	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-12}
1 µm	1000	1	0,001	10^{-4}	10^{-5}	10^{-6}	10^{-9}
1 mm	10^{6}	1000	1	0,1	0,01	0,001	10^{-6}
1 cm	10^{7}	10000	10	1	0,1	0,01	10^{-5}
1 dm	10^{8}	100000	100	10	1	0,1	10^{-4}
1 m	10^{9}	10^{6}	1000	100	10	1	0,001
1 km	10^{12}	10^{9}	10^{6}	100000	10000	1000	1

Metric units and Anglo-American units

	in	ft	yd	µm	mm	m
1 in	1	0,08333	0,02778	25400	25,4	0,0254
1 ft	12	1	0,3333	304800	304,8	0,3048
1 yd	36	3	1	914400	914,4	0,9144
1 µm	$3{,}937\times10^{-5}$	$3{,}281\times10^{-6}$	$1{,}094\times10^{-6}$	1	0,001	10^{-6}
1 mm	0,03937	$3{,}281\times10^{-3}$	$1{,}094\times10^{-3}$	1000	1	0,001
1 m	39,37	3,281	1,094	10^{6}	1000	1

Fractional / decimal equivalents

Frac inch	mm	Dec inch
1/64	0,397	0,0156
1/32	0,794	0,0312
1/16	1,588	0,0625
1/8	3,175	0,125
1/4	6,35	0,25

Frac inch	mm	Dec inch
3/8	9,525	0,375
1/2	12,7	0,5
3/4	19,05	0,75
1	25,4	1,0

Solution of the Triangle

S.
05

Solution of the oblique-angled triangle

Law of sines

$$\sin\alpha : \sin\beta : \sin\gamma = a : b : c$$

$$a = \frac{b}{\sin\beta}\sin\alpha = \frac{c}{\sin\gamma}\sin\alpha$$

$$b = \frac{a}{\sin\alpha}\sin\beta = \frac{c}{\sin\gamma}\sin\beta$$

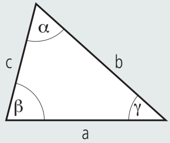
$$c = \frac{a}{\sin\alpha}\sin\gamma = \frac{b}{\sin\beta}\sin\gamma$$

Law of cosines

$$a^2 = b^2 + c^2 - 2\,b\,c \cdot \cos\alpha$$

$$b^2 = c^2 + a^2 - 2\,a\,c \cdot \cos\beta$$

$$c^2 = a^2 + b^2 - 2\,a\,b \cdot \cos\gamma$$



Area

$$A = \frac{1}{2}\,b\,c\sin\alpha = \frac{1}{2}\,a\,c\sin\beta = \frac{1}{2}\,a\,b\sin\gamma$$

Solution of the right-angled triangle

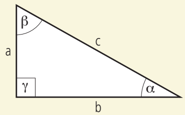
The right-angled triangle

$$\sin\alpha = \frac{\text{Opposite leg}}{\text{Hypotenuse}} = \frac{a}{c}$$

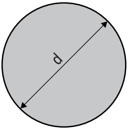
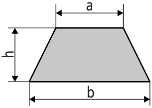
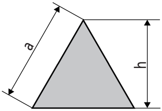
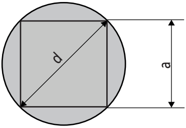
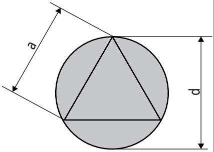
$$\cos\alpha = \frac{\text{Adjacent leg}}{\text{Hypotenuse}} = \frac{b}{c}$$

$$\tan\alpha = \frac{\text{Opposite leg}}{\text{Adjacent leg}} = \frac{a}{b}$$

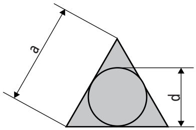
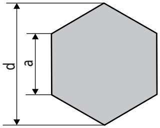
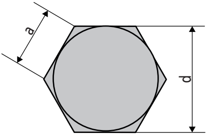
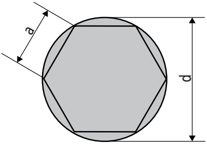
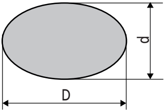
$$\cot\alpha = \frac{\text{Adjacent leg}}{\text{Opposite leg}} = \frac{b}{a}$$



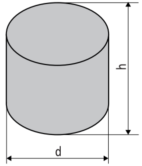
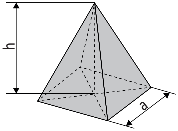
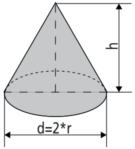
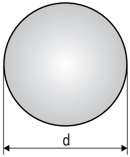
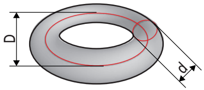
Mensuration

	Area of a Circle: $A = \frac{\pi d^2}{4}$	Circumference of a circle: $U = \pi \cdot d$
	Area of a trapezium: $A = \frac{a + b}{2} \cdot h$	
	Area of a triangle: $A = \frac{a \cdot h}{2}$	
	Side of a square insribed in a circle: $a = \frac{d}{\sqrt{2}}$	
	Side of an equilateral triangle inscribed in a circle: $a = \frac{d \cdot \sqrt{3}}{2}$	

Mensuration

	Diameter of a circle inscribed in an equivalent triangle: $d = \frac{a \cdot \sqrt{3}}{3}$	
	Area of a regular hexagon: $A = \frac{3 \cdot a^2 \cdot \sqrt{3}}{2}$	Width across corners of a regular hexagon: $d = 2 \cdot a$
	Diameter of a circle inscribed in a regular hexagon: $d = a \cdot \sqrt{3}$	
	Side of a regular hexagon inscribed in a Circle: $a = \frac{d}{2}$	
	Area of an ellipse: $A = \frac{\pi \cdot D \cdot d}{4}$	

Mensuration

	Area of a cylinder: $A = \pi \cdot d \cdot \left(\frac{d}{2} + h\right)$	Volume of a cylinder: $V = \frac{\pi \cdot d^2 \cdot h}{4}$
	Area of a regular four-sided pyramid: $A = a^2 + a \cdot \sqrt{4 \cdot h^2 + a^2}$	Volume of a regular four-sided pyramid: $V = \frac{a^2 \cdot h}{3}$
	Area of a cone: $A = \pi \cdot r \cdot (r + m)$ $m = \sqrt{h^2 + r^2}$	Volume of a cone: $V = \frac{\pi \cdot r^2 \cdot h}{3}$
	Area of a sphere: $A = \pi \cdot d^2$	Volume of a sphere: $V = \frac{\pi \cdot d^3}{6}$
	Area of a torus: $A = \pi^2 \cdot d \cdot D$	Volume of a torus: $V = \frac{\pi^2 \cdot D \cdot d^2}{4}$

International Product Standards

Small Tools	Geometrical Product Specifications (GPS) – Dimensional measuring equipment – part 1: Calipers – design and metrological characteristics	EN ISO 13385-1
	Geometrical Product Specifications (GPS) – Dimensional measuring equipment – part 2: Caliper depth gauges – design and metrological characteristics	EN ISO 13385-2
	Geometrical Product Specifications (GPS) – Dimensional measuring equipment: Height gauges – design and metrological characteristics	EN ISO 13225
	Geometrical Product Specifications (GPS) – Dimensional measuring equipment: Micrometers for external measurements – design and metrological characteristics	EN ISO 3611
	Geometrical Product Specifications (GPS) – Dimensional measuring equipment: Mechanical dial gauges – design and metrological characteristics	EN ISO 463
	Geometrical Product Specifications (GPS) – Dimensional measuring equipment: Dial test indicators (lever type) – design and metrological characteristics	EN ISO 9493
	Geometrical Product Specifications (GPS) – Length standards – Gauge Blocks	EN ISO 3650
	Geometrical Product Specifications (GPS) – Dimensional measuring equipment: Electronic digital indicator gauge – design and metrological characteristics	EN ISO 13102

International Product Standards

Surface Texture	Geometrical Product Specifications (GPS) – Surface texture: Profile method-Nominal characteristics of contact (stylus) instruments	EN ISO 3274
	Geometrical Product Specifications (GPS) – Surface texture: Profile method – terms, definitions and surface texture parameters	EN ISO 4287
	Geometrical Product Specifications (GPS) – Surface texture: Profile method – rules and procedures for the assessment of surface texture	EN ISO 4288
	Geometrical Product Specifications (GPS) – Surface texture: Profile method – measurement standards – part 1: Material measures	EN ISO 5436
	Geometrical Product Specifications (GPS) – Surface texture: Profile method – metrological characteristics of phase correct filters	EN ISO 11562
	Geometrical Product Specifications (GPS) – Surface texture: Profile method – Surface having stratified functional properties – part 1: Filtering and general measurement conditions	EN ISO 13565-1
	Geometrical Product Specifications (GPS) – Surface texture: Profile method – Surface having stratified functional properties – part 2: Height characterisation using the linear material ratio curve	EN ISO 13565-2
	Geometrical Product Specifications (GPS) – Surface texture: Profile method – surfaces having stratified functional properties – part 3: Height characterization using the material probability curve	EN ISO 13565-3
	Geometrical Product Specifications (GPS) – Surface texture: Profile method – Motif parameters	EN ISO 12085

International Product Standards

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Coordinate Measuring Machines		
	Geometrical Product Specifications (GPS) – Acceptance and reverification tests for coordinate measuring machines (CMM) – part 1: Vocabulary	EN ISO 10360-1
	Geometrical Product Specifications (GPS) – Acceptance and reverification tests for coordinate measuring machines (CMM) – part 2: CMMs used for measuring linear dimensions	EN ISO 10360-2
	Geometrical Product Specifications (GPS) – Acceptance test and reverification test for coordinate measuring machines (CMM) – part 3: CMMs with the axis of a rotary table as a fourth axis	EN ISO 10360-3
	Geometrical Product Specifications (GPS) – Acceptance test and reverification tests for coordinate measuring machines (CMM) – part 4: CMMs used in scanning mode	EN ISO 10360-4
	Geometrical Product Specifications (GPS) – Acceptance and reverification tests for coordinate measuring machines (CMM) – part 5: CMMs using single and multiple stylus contacting probing systems	EN ISO 10360-5
	Geometrical Product Specifications (GPS) – Acceptance and reverification tests for coordinate measuring machines (CMM) – part 6: Estimation of errors in computing Gaussian associated features	EN ISO 10360-6
	Geometrical Product Specifications (GPS) – Acceptance and reverification tests for coordinate measuring machines (CMM) – part 7: CMMs equipped with imaging probing systems	EN ISO 10360-7

International Product Standards

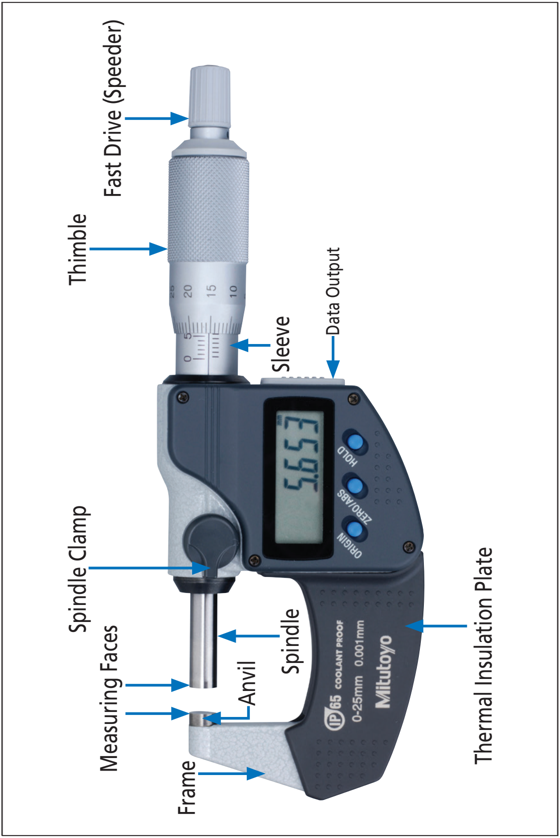
Coordinate Measuring Machines	Geometrical Product Specifications (GPS) – Acceptance and reverification tests for coordinate measuring systems (CMS) – part 8: CMMs with optical distance sensors	EN ISO 10360-8
	Geometrical Product Specifications (GPS) – Acceptance and reverification tests for coordinate measuring systems (CMS) – part 9: CMMs with multiple probing systems	EN ISO 10360-9
	Geometrical Product Specifications (GPS) – Guidelines for the evaluation of coordinate measuring machine (CMM) test uncertainty	ISO/TS 23165

Hardness Testing Machines	Metallic materials – Vickers hardness test – part 1: Test method	EN ISO 6507-1
	Metallic materials – Vickers hardness test – part 2: Verification and calibration of testing machines	EN ISO 6507-2
	Metallic materials – Vickers hardness test – part 3: Calibration of reference blocks	EN ISO 6507-3
	Metallic materials – Vickers hardness test – part 4: Tables of hardness values	EN ISO 6507-4
	Metallic materials - Rockwell hardness test - part 1: Test method	EN ISO 6508-1
	Metallic materials - Rockwell hardness test - part 2: Verification and calibration of testing machines and indenters	EN ISO 6508-2

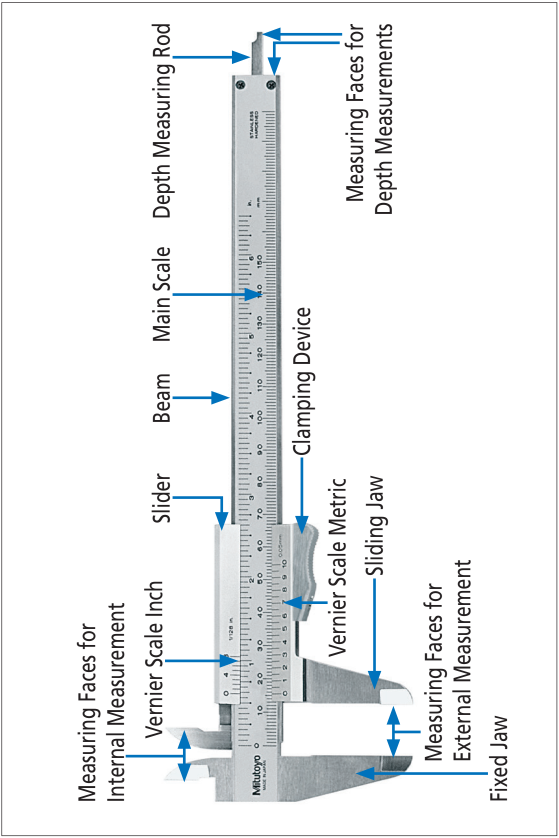
International Product Standards

Hardness Testing Machines	Metallic materials – Rockwell hardness test – part 3: Calibration of reference blocks	EN ISO 6508-3
	Plastics – Determination of hardness – part 2: Rockwell hardness	EN ISO 2039-2
	Metallic materials – Brinell hardness test – part 1: Test method	EN ISO 6506-1
	Metallic materials – Brinell hardness test – part 2: Verification and calibration of testing machines	EN ISO 6506-2
	Metallic materials – Brinell hardness test – part 3: Calibration of reference blocks	EN ISO 6506-3
	Metallic materials – Brinell hardness test – part 4: Table of hardness values	EN ISO 6506-4
	Metallic materials – Knoop hardness test – part 1: Test method	EN ISO 4545-1
	Metallic materials – Knoop hardness test – part 2: Verification and calibration of testing machines	EN ISO 4545-2
	Metallic materials – Knoop hardness test – part 3: Calibration of reference blocks	EN ISO 4545-3
	Metallic materials – Knoop hardness test – part 4: Table of hardness values	EN ISO 4545-4
	Metallic and other inorganic coatings – Vickers and Knoop microhardness tests	EN ISO 4516
	Metallic materials – Conversion of hardness values	EN ISO 18265

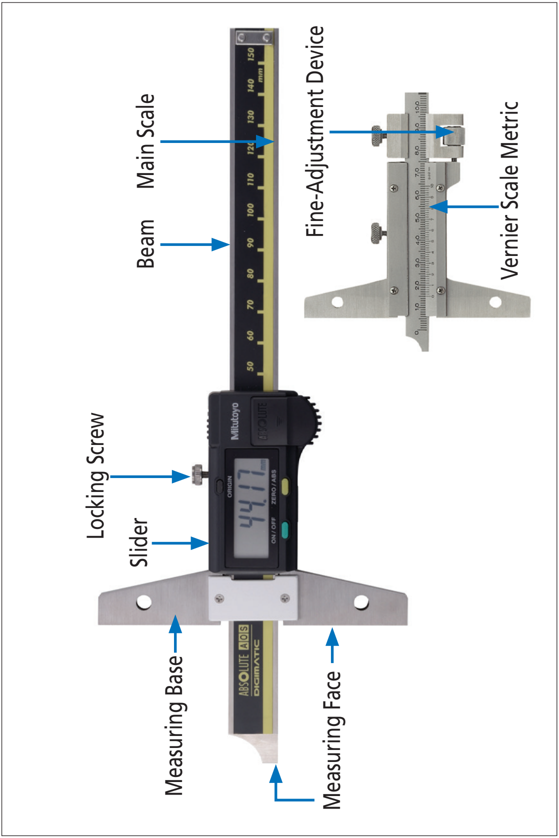
Nomenclature Micrometer



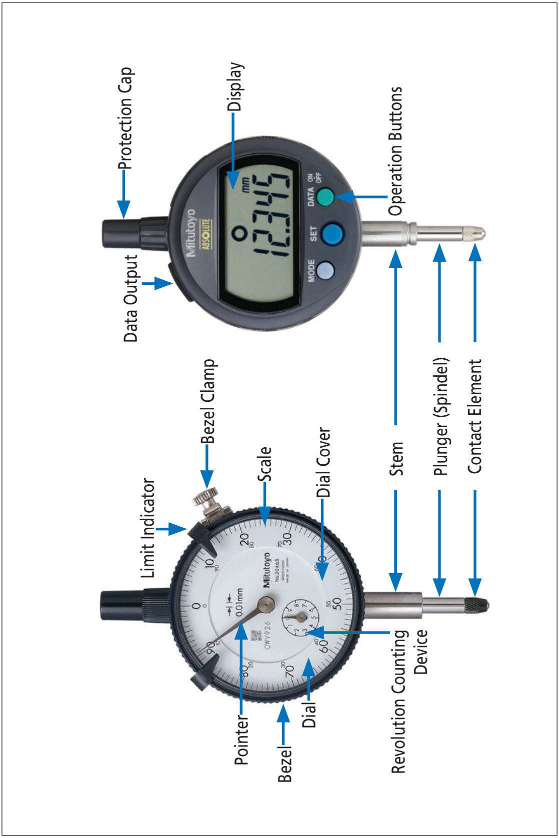
Nomenclature Caliper



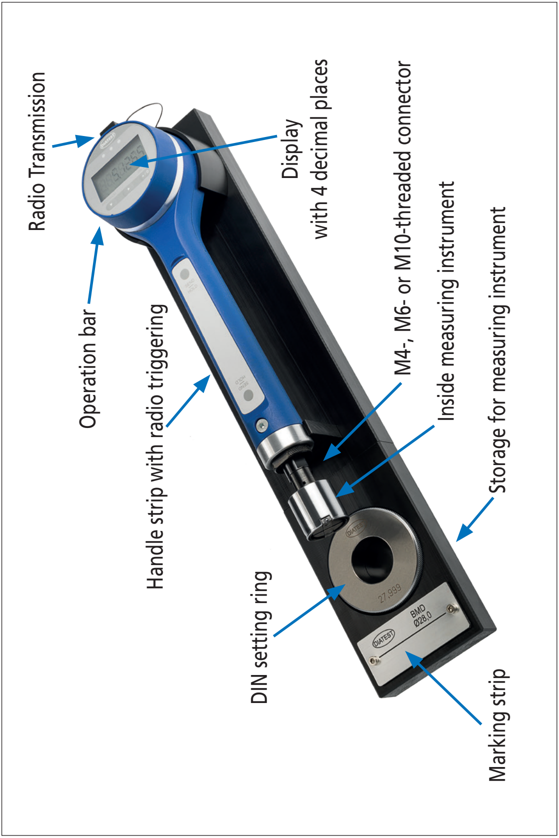
Nomenclature Depth Caliper



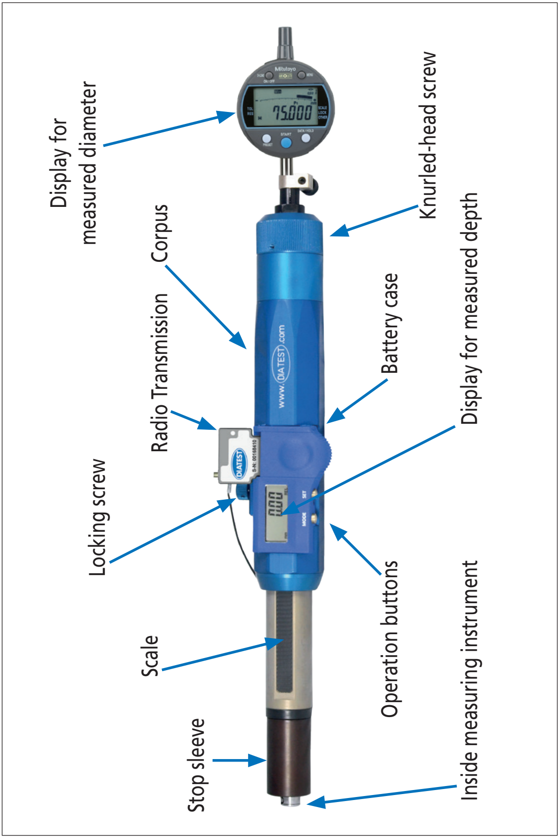
Nomenclature Indicator



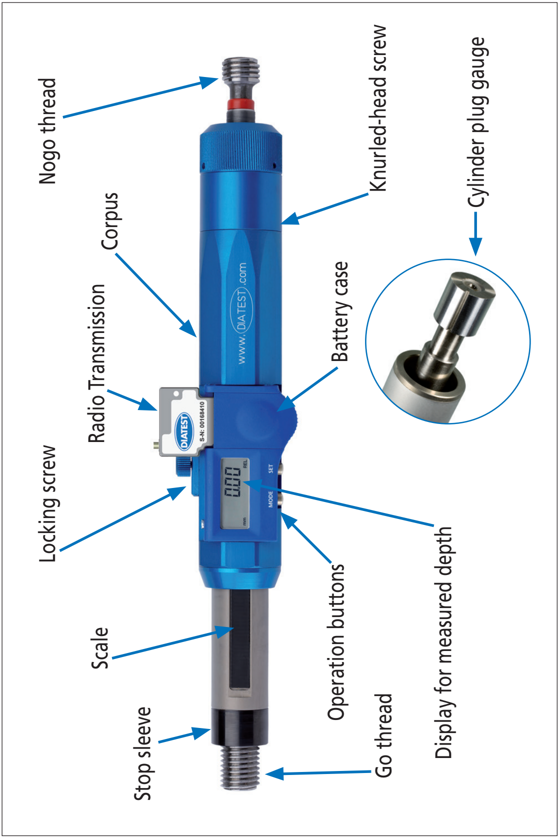
Nomenclature Complete system for bore gauging



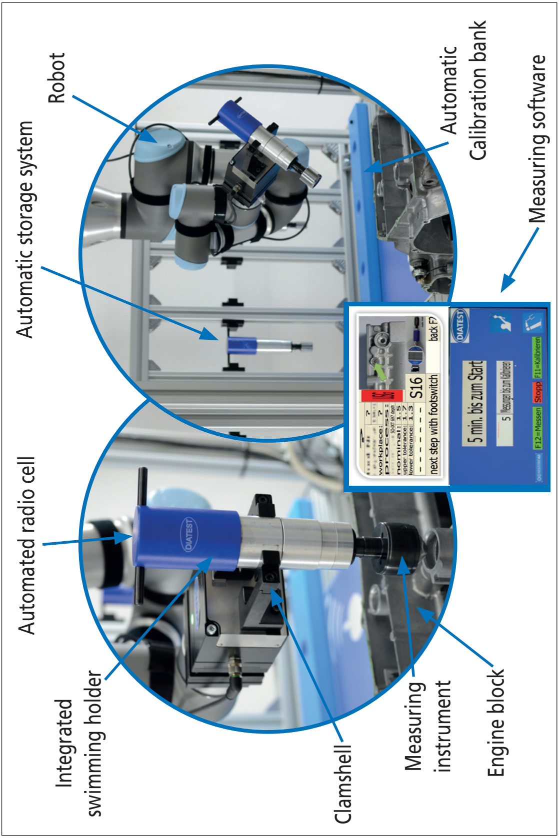
Nomenclature Measurement of diameter and depth at the same time



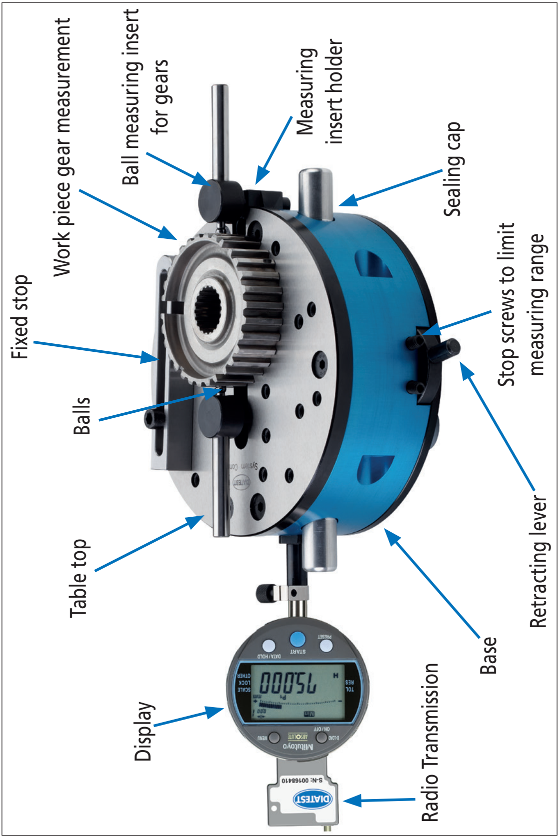
Nomenclature Detecting of Nogo gauges and gauging of threads/depths



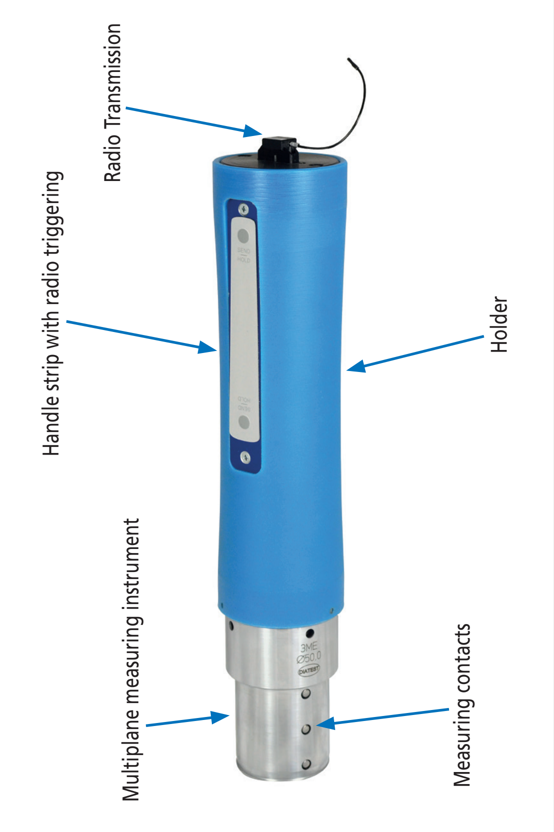
Nomenclature Automated measuring cell for bores and depths of threads



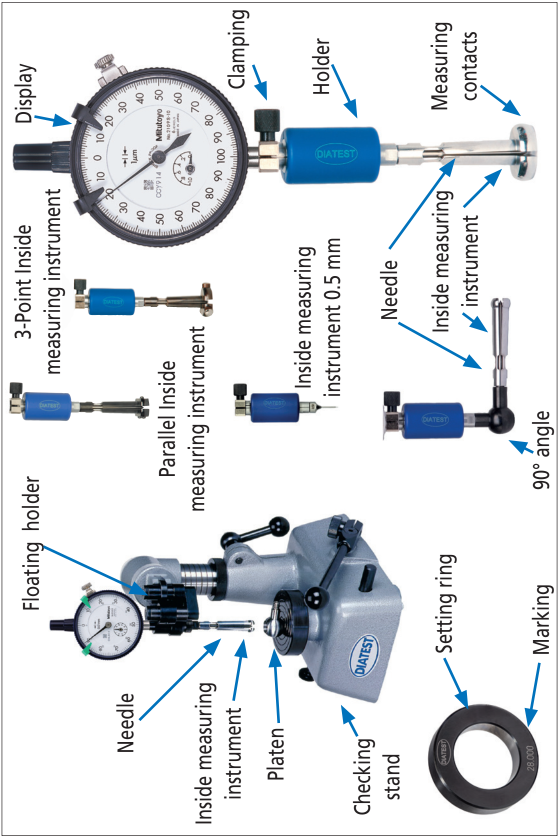
Nomenclature Measuring tables



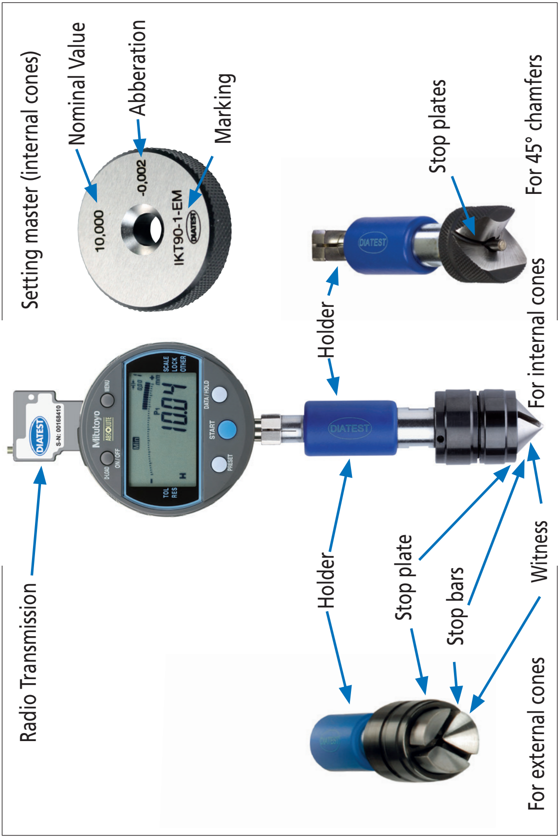
Nomenclature Nomenclature Bore measurement on several planes with wireless system



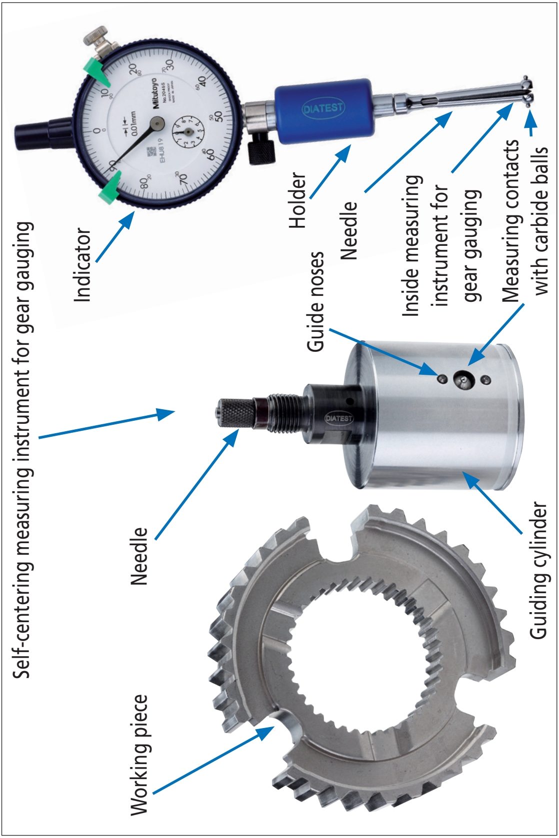
Nomenclature 2-Point Inside Measuring Instrument



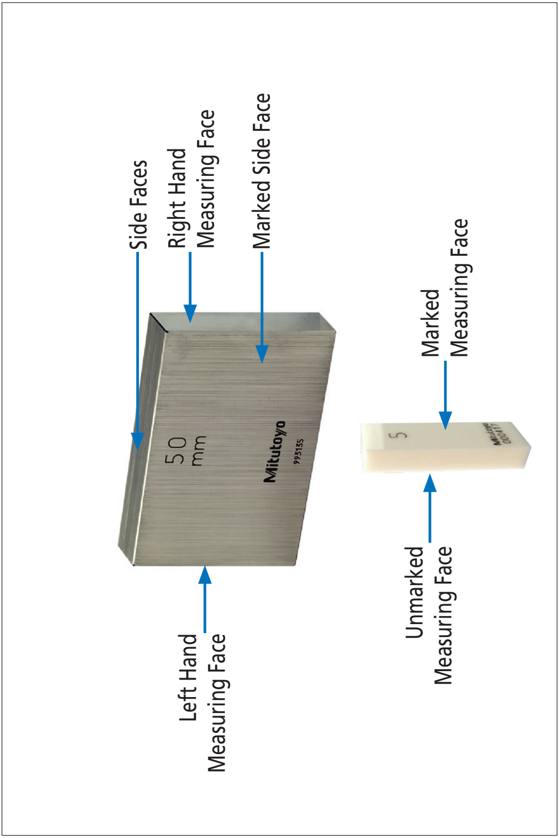
Nomenclature Measurement of conical bores, external cones or 45° chamfers



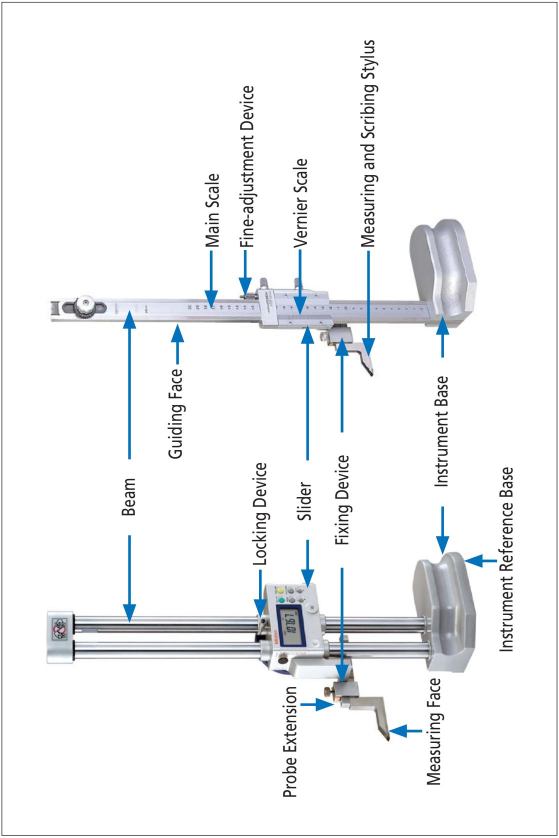
Nomenclature Internal gear gauging



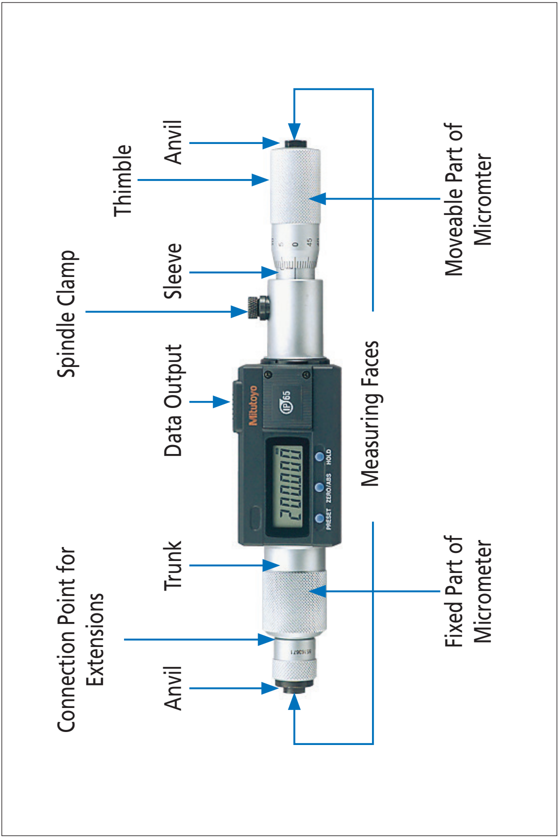
Nomenclature Gauge Blocks



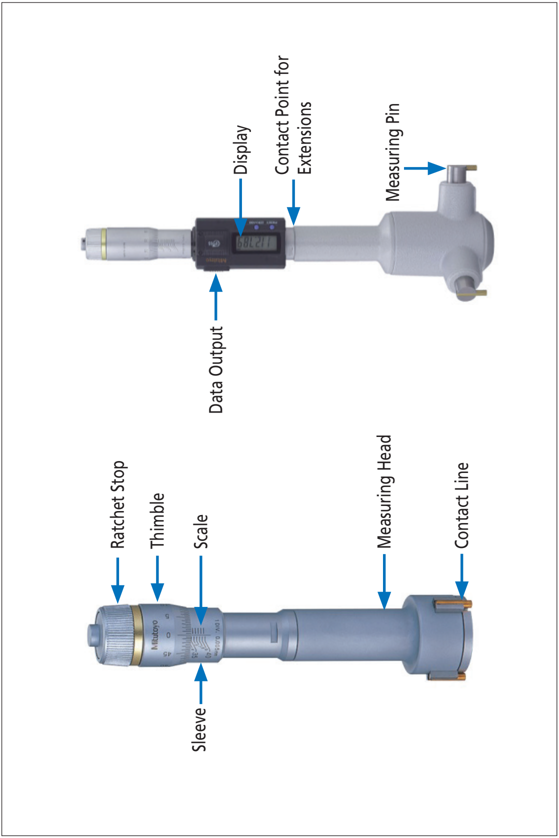
Nomenclature Height Gauges



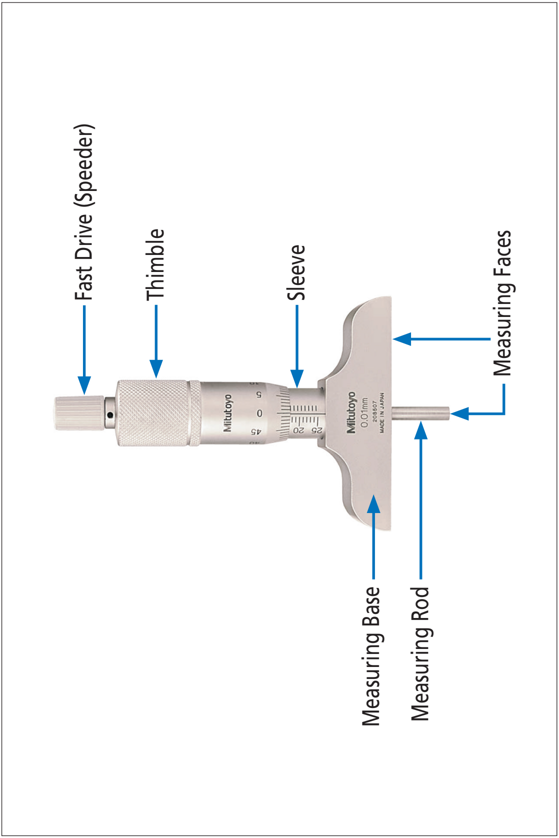
Nomenclature 2-Point Inside Micrometer



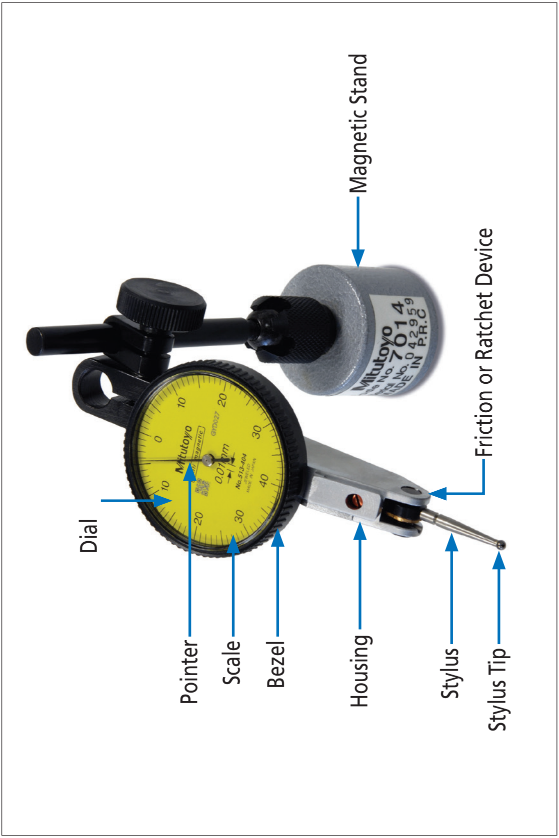
Nomenclature 3-Point Inside Micrometer



Nomenclature Depth Micrometer

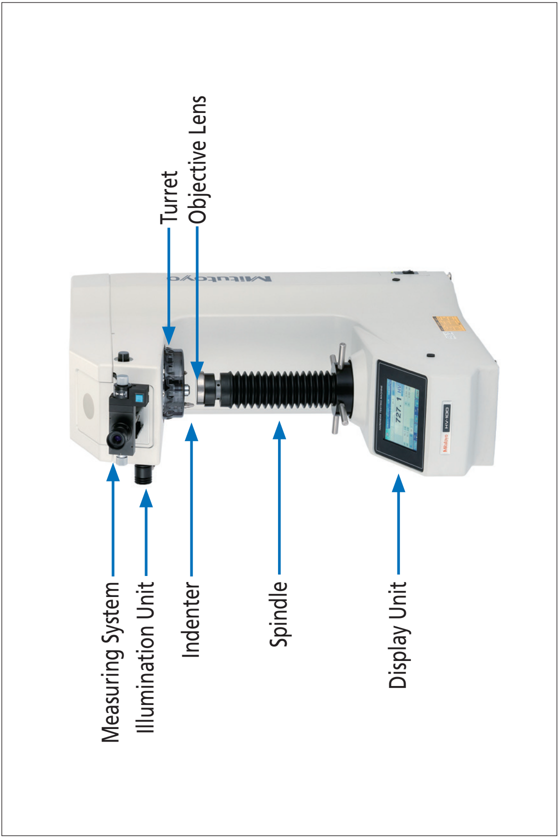


Nomenclature Dial Test Indicator

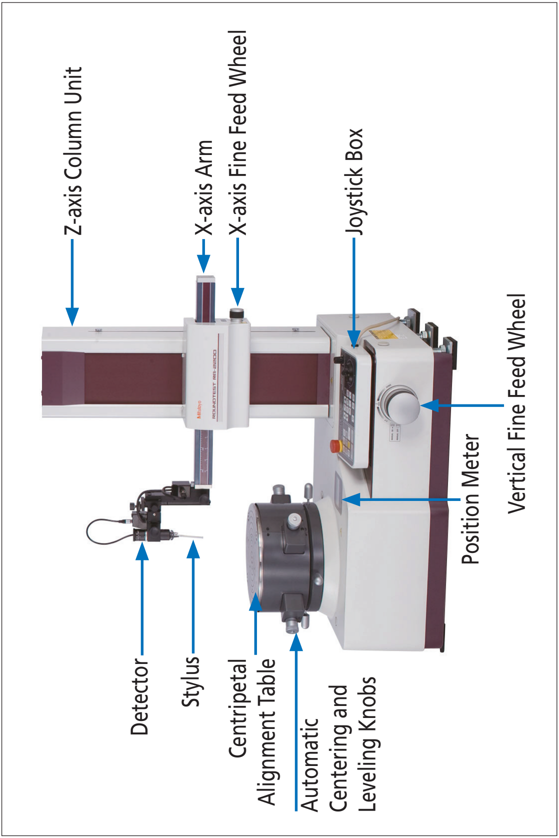


Nomenclature Micrometer Head

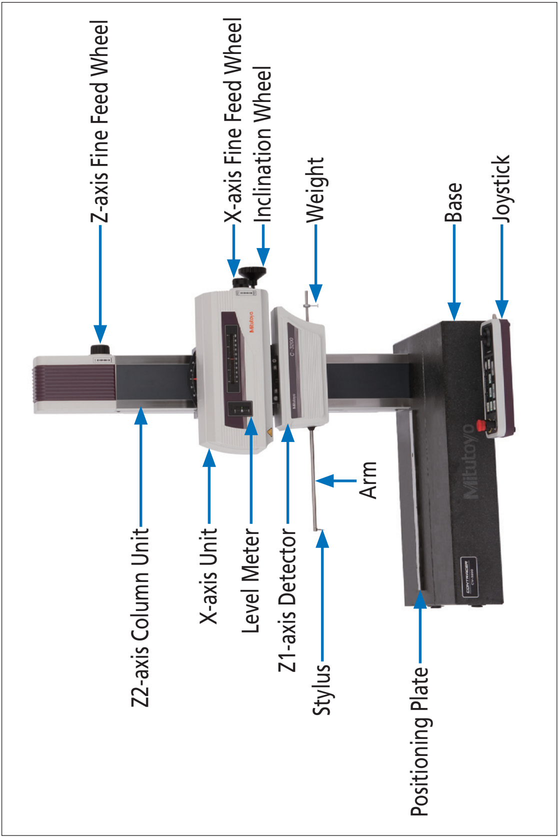
Nomenclature Hardness Testing



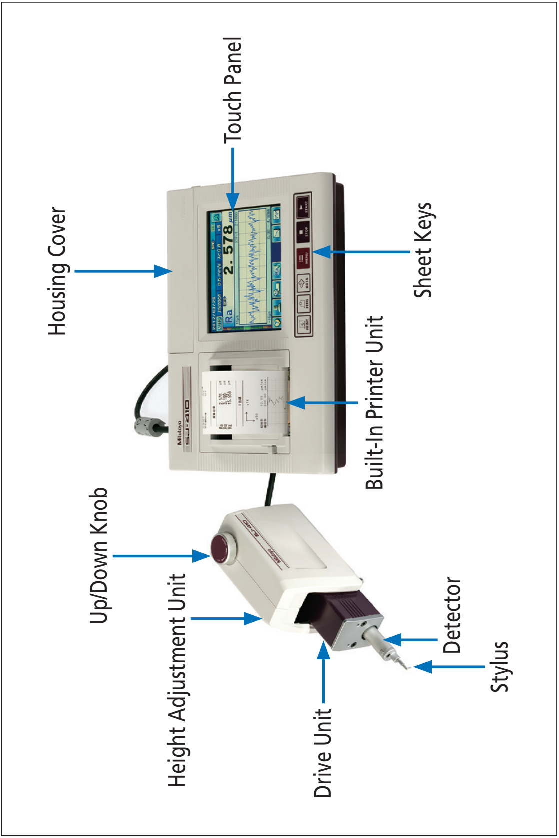
Nomenclature for Roundness and Cylindricity Measuring Machine



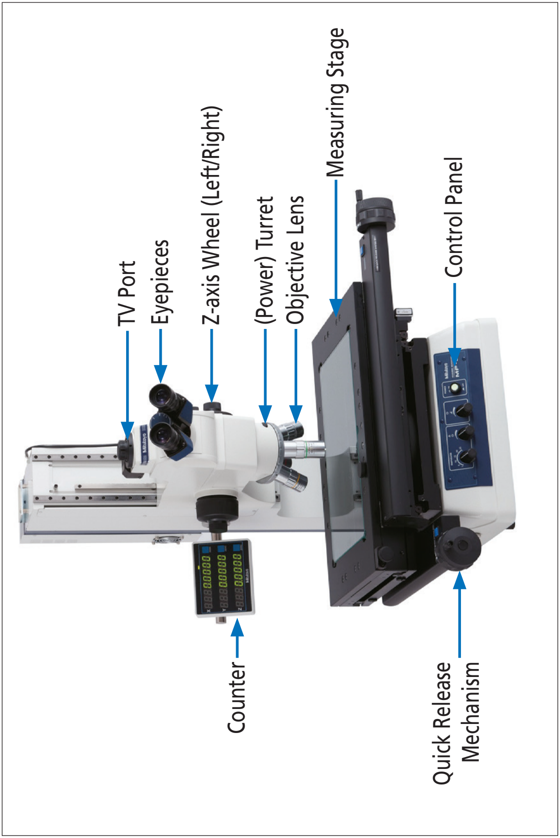
Nomenclature for Contour Measuring Machine



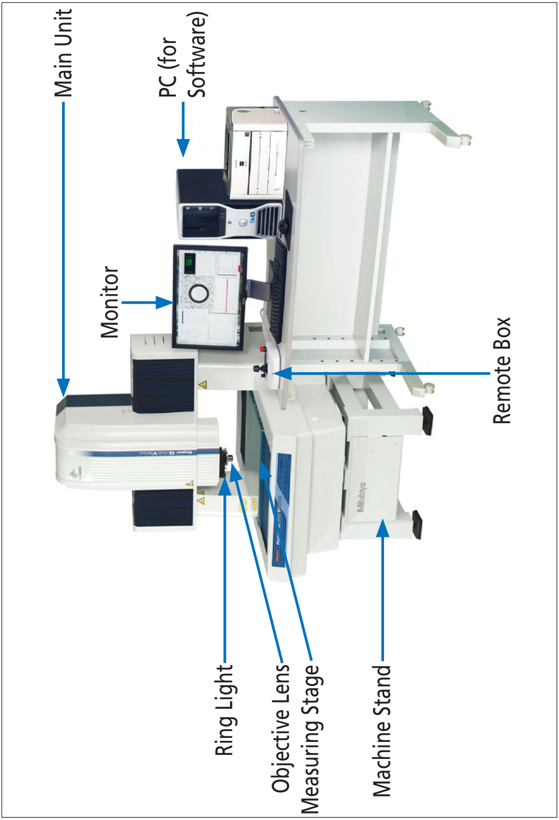
Nomenclature for Surface Roughness Tester



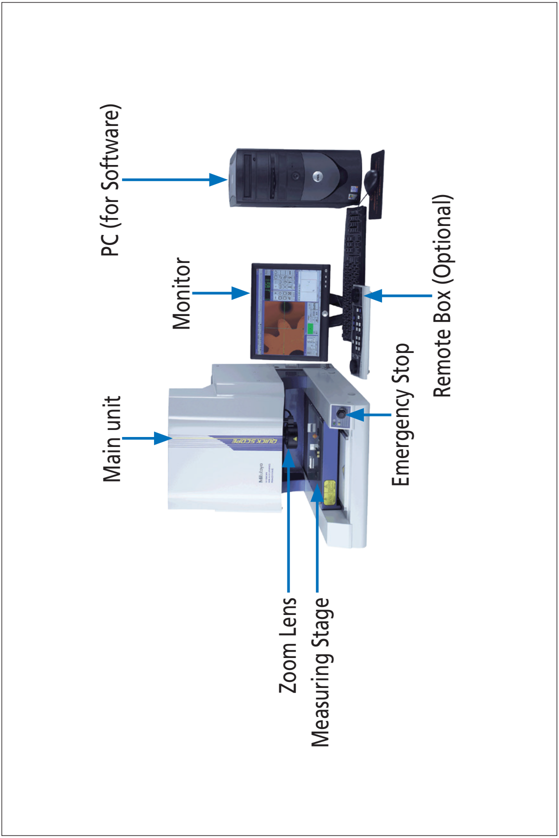
Nomenclature Measuring Microscope



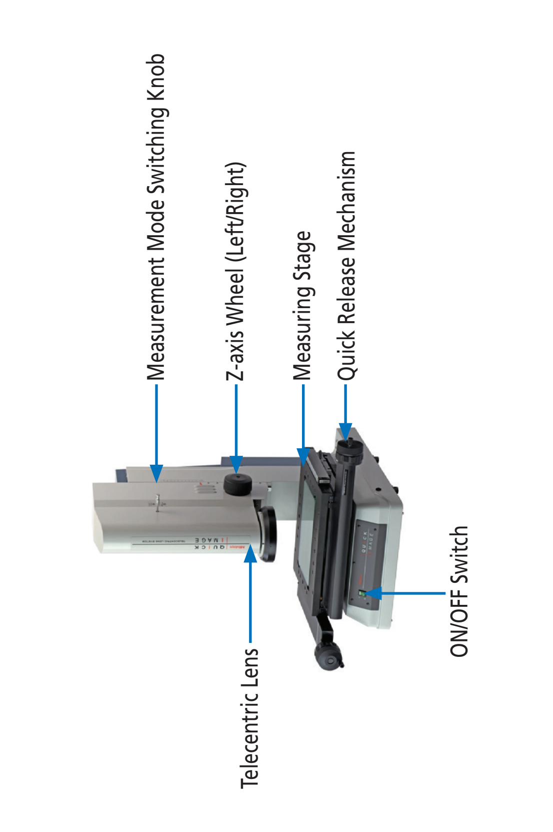
Nomenclature 3-D Vision Measuring System



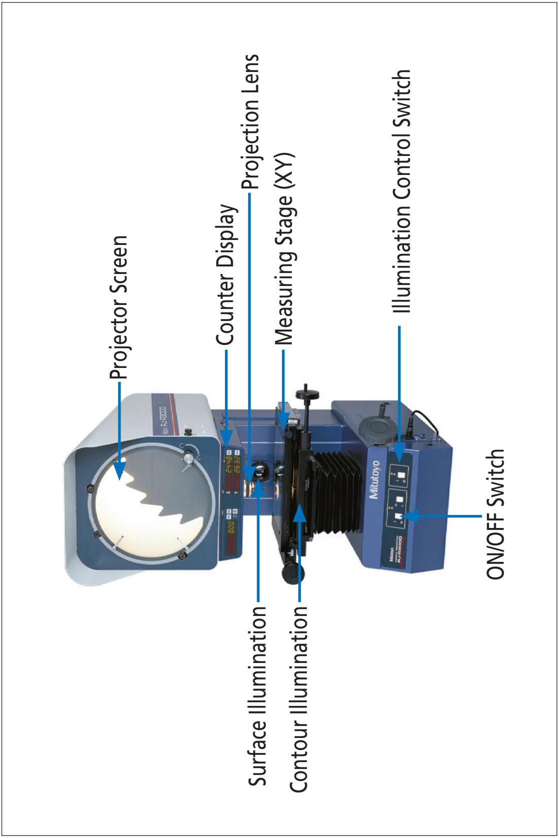
Nomenclature 3-D Vision Measuring System with Colour Camera



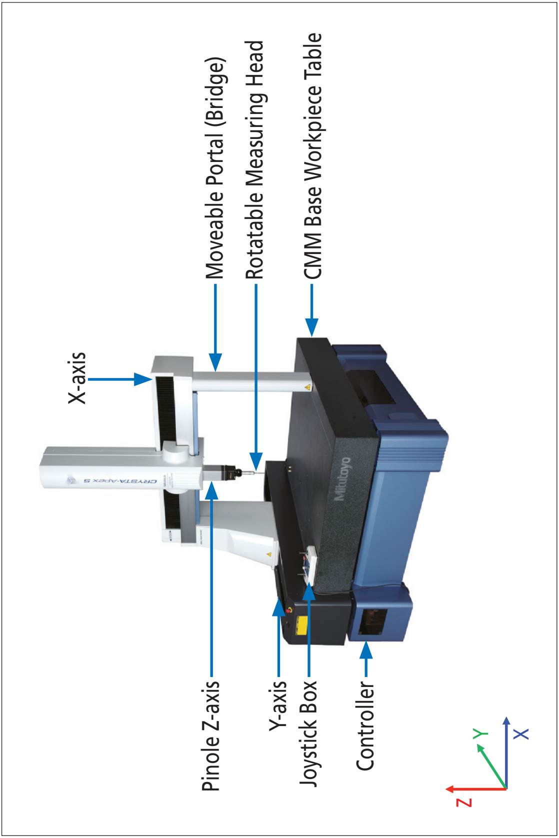
Nomenclature Manual
2-D Vision Measuring System



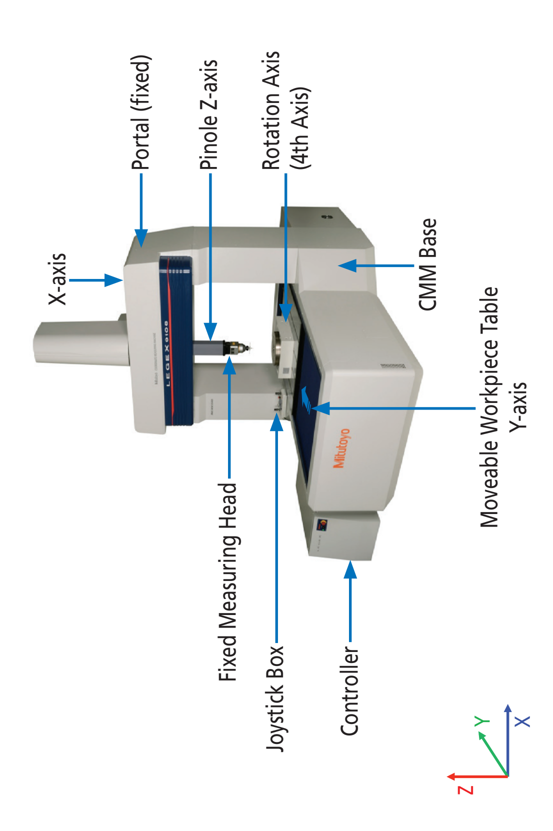
Nomenclature Projector



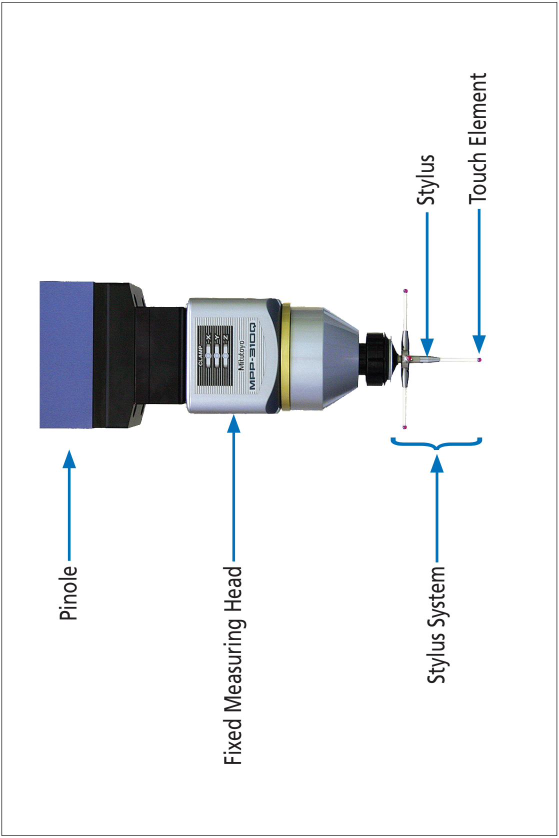
Coordinate Measuring Machine with Moveable Portal



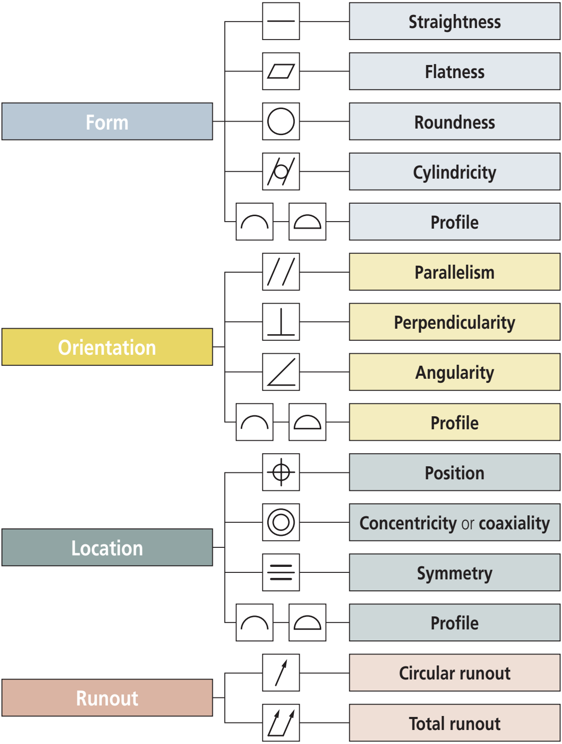
Coordinate Measuring Machine with Fixed Portal



Coordinate Measuring Machine: Fixed Measuring Head



Geometric Tolerancing Symbols

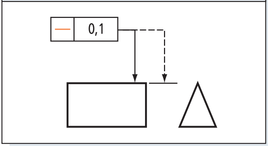


Note:
EN ISO 1101 Geometrical Product Specifications (GPS). Geometrical tolerancing. Tolerances of form, orientation, location and run-out should be consulted for full details.

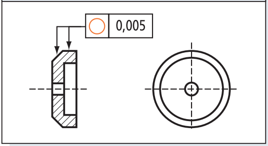
Geometric Tolerancing Symbols

Examples of use

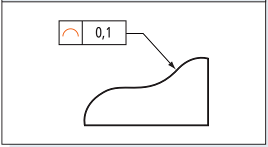
Straightness



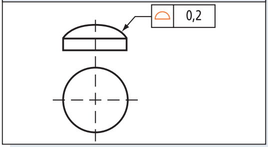
Roundness



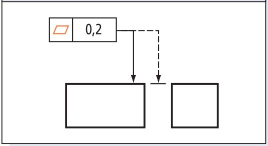
Profile of any line



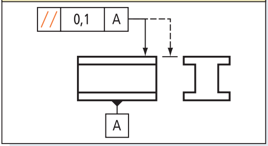
Profile of any surface



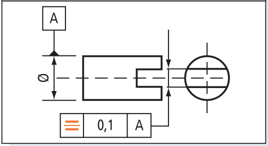
Flatness



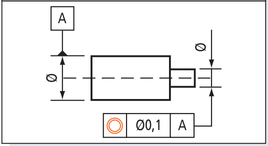
Parallelism



Symmetry



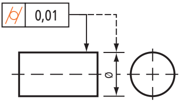
Concentricity or coaxiality



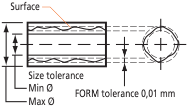
Geometric Tolerancing Symbols

Examples of interpretation

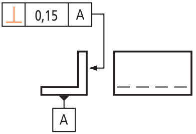
Cylindricity



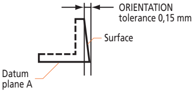
Interpretation:
surface to lie within 2 concentric cylinders 0,01 mm different in radius



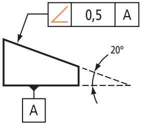
Perpendicularity



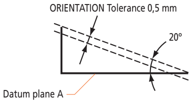
Interpretation:
surface to lie within 2 parallel planes 0,15 mm apart set perpendicular to datum A



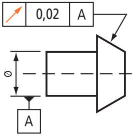
Angularity



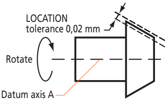
Interpretation:
surface to lie within 2 parallel planes 0,5 mm apart set at 20 degrees to datum A



Circular runout



Interpretation:
any line on surface to lie within 2 circles concentric with datum A and 0,02 mm apart in the direction normal to the surface

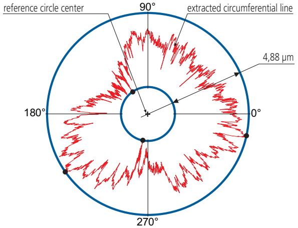


Defining Roundness

Deviation from perfect roundness is defined by the difference in radii of two coplanar and concentric reference circles whose sizes and center position are constructed by one of four methods (described below) after the circumferential line has been extracted. The diagrams show how the deviation value obtained is affected by the method used.

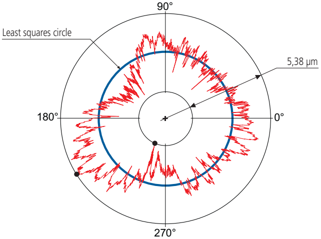
Minimum Zone Circle (MZCI)

The size and position of two concentric circles that touch and together enclose the extracted circumferential line are adjusted until their radial difference is a minimum.



Least Squares Circle (LSCI)

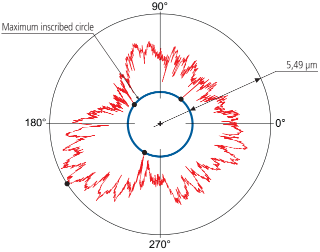
The size and position of a circle from which the sum of the squares of the radial deviations of the extracted circumferential line are a minimum is constructed. Two concentric circles coaxial with this circle are then constructed that touch and together enclose the extracted circumferential line.



Defining Roundness

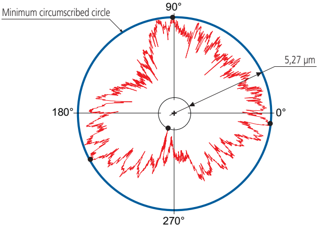
Maximum Inscribed Circle (MICI)

An inscribing circle of the maximum size to touch the extracted circumferential line is constructed. A second circle concentric with the first is then constructed to touch and, together with the first circle, enclose the extracted circumferential line.



Minimum Circumscribed Circle (MCCI)

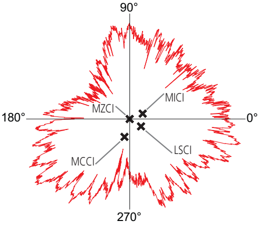
A circumscribing circle of the minimum size to touch and enclose the extracted circumferential line is constructed. A second circle concentric with the first is then constructed to touch and, together with the first circle, enclose the extracted circumferential line.



Defining Roundness

Important axes for roundness/cylindricity measurement

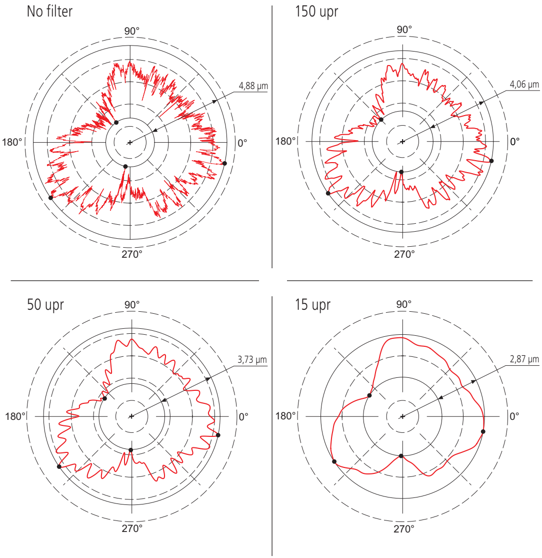
The position of the center of the concentric circles defines the center of the extracted circumferential line and therefore the location of the circular feature measured. Each of the methods described above results in different center positions for the reference circles, as shown.



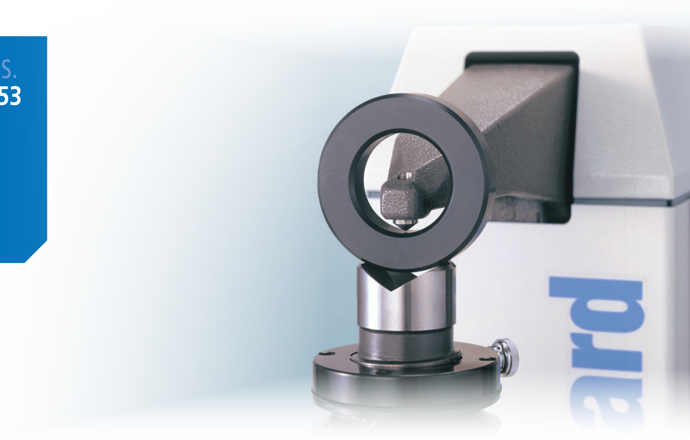
Defining Roundness

Filtering

Extracted lines can be low-pass filtered in various ways to reduce or eliminate unwanted detail, with a cut-off value set in terms of undulations per revolution (upr). The effect of different upr settings is shown in the diagrams below, for a phase-corrected 50% Gaussian filter, which illustrate how the measured roundness value decreases as lower upr settings progressively smooth out the extracted line.



Hardness Scales



All hardness measurements are method-dependent. However, the tables below indicate the approximate equivalence between the various hardness scales in common use. (Mitutoyo specification)

> Hardened steel and hard alloys

VICKERS HV 10	ROCKWELL diamond HR A	HR C	HR D	ROCKWELL SUPERFICIAL diamond HR 15N	HR 30N	HR 45N	BRINELL HBW 10/3000	TENSILE strength N/mm²
240	60,7	20,3	40,3	69,6	41,7	19,9	224	770
245	61,2	21,3	41,1	70,1	42,5	21,1	230	785
250	61,6	22,2	41,7	70,6	43,4	22,2	236	800
255	62,0	23,1	42,2	71,1	44,2	23,2	242	820

Hardness Scales

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VICKERS HV 10	ROCKWELL HR A	ROCKWELL HR C diamond	ROCKWELL HR D	ROCKWELL SUPERFICIAL HR 15N	ROCKWELL SUPERFICIAL HR 30N diamond	ROCKWELL SUPERFICIAL HR 45N	BRINELL HBW 10/3000	TENSILE strength N/mm²
260	62,4	24,0	43,1	71,6	45,0	24,3	247	835
265	62,7	24,8	43,7	72,1	45,7	25,2	252	850
270	63,1	25,6	44,3	72,6	46,4	26,2	257	865
275	63,5	26,4	44,9	73,0	47,2	27,1	261	880
280	63,8	27,1	45,3	73,4	47,8	27,9	266	900
285	64,2	27,8	46,0	73,8	48,4	28,7	271	915
290	64,5	28,5	46,5	74,2	49,0	29,5	276	930
295	64,8	29,2	47,1	74,6	49,7	30,4	280	950
300	65,2	29,8	47,5	74,9	50,2	31,1	285	965
310	65,8	31,0	48,4	75,6	51,3	32,5	295	995
320	66,4	32,2	49,4	76,2	52,3	33,9	304	1030
330	67,0	33,3	50,2	76,8	53,6	35,2	314	1060
340	67,6	34,4	51,1	77,4	54,4	36,5	323	1095
350	68,1	35,5	51,9	78,0	55,4	37,8	333	1125
360	68,7	36,6	52,8	78,6	56,4	39,1	342	1155
370	69,2	37,7	53,6	79,2	57,4	40,4	352	1190
380	69,8	38,8	54,4	79,8	58,4	41,7	361	1220
390	70,3	39,8	55,3	80,3	59,3	42,9	371	1225
400	70,8	40,8	56,0	80,8	60,2	44,1	380	1290
410	71,4	41,8	56,8	81,4	61,1	45,3	390	1320
420	71,8	42,7	57,5	81,8	61,9	46,4	399	1350
430	72,3	43,6	58,2	82,3	62,7	47,4	409	1385
440	72,8	44,5	58,8	82,8	63,5	48,4	418	1420
450	73,3	45,3	59,4	83,2	64,3	49,4	428	1455
460	73,6	46,1	60,1	83,6	64,9	50,4	437	1485
470	74,1	46,9	60,7	83,9	65,7	51,3	447	1520
480	74,5	47,7	61,3	84,3	66,4	52,2	(456)	1555
490	74,9	48,4	61,6	84,7	67,1	53,1	(466)	1595
500	75,3	49,1	62,2	85,0	67,7	53,9	(475)	1630

Hardness Scales

VICKERS HV 10	ROCKWELL HR A	ROCKWELL HR C diamond	ROCKWELL HR D	ROCKWELL SUPERFICIAL HR 15N	ROCKWELL SUPERFICIAL HR 30N diamond	ROCKWELL SUPERFICIAL HR 45N	BRINELL HBW 10/3000	TENSILE strength N/mm²
510	75,7	49,8	62,9	85,4	68,3	54,7	(485)	1665
520	76,1	50,5	63,5	85,7	69,0	55,6	(494)	1700
530	76,4	51,1	63,9	86,0	69,5	56,2	(504)	1740
540	76,7	51,7	64,4	86,3	70,0	57,0	(513)	1775
550	77,0	52,3	64,8	86,6	70,5	57,8	(523)	1810
560	77,4	53,0	65,4	86,9	71,2	58,6	(532)	1845
570	77,8	53,6	65,8	87,2	71,7	59,3	(542)	1880
580	78,0	54,1	66,2	87,5	72,1	59,9	(551)	1920
590	78,4	54,7	66,7	87,8	72,7	60,5	(561)	1955
600	78,6	55,2	67,0	88,0	73,2	61,2	(570)	1995
610	78,9	55,7	67,5	88,2	73,7	61,7	(580)	2030
620	79,2	56,3	67,9	88,5	74,2	62,4	(589)	2070
630	79,5	56,8	68,3	88,8	74,6	63,0	(599)	2105
640	79,8	57,3	68,7	89,0	75,1	63,5	(608)	2145
650	80,0	57,8	69,0	89,2	75,5	64,1	(618)	2180
660	80,3	58,3	69,4	89,5	75,9	64,7	—	—
670	80,6	58,8	69,8	89,7	76,4	65,3	—	—
680	80,8	59,2	70,1	89,8	76,8	65,7	—	—
690	81,1	59,7	70,5	90,1	77,2	66,2	—	—
700	81,3	60,1	70,8	90,3	77,6	66,7	—	—
720	81,8	61,0	71,5	90,7	78,4	67,7	—	—
740	82,2	61,8	72,1	91,0	79,1	68,6	—	—
760	82,6	62,5	72,6	91,2	79,7	69,4	—	—
780	83,0	63,3	73,3	91,5	80,4	70,2	—	—
800	83,4	64,0	73,8	91,8	81,1	71,0	—	—
820	83,8	64,7	74,3	92,1	81,7	71,8	—	—
840	84,1	65,3	74,8	92,3	82,2	72,2	—	—
860	84,4	65,9	75,3	92,5	82,7	73,1	—	—
880	84,7	66,4	75,7	92,7	83,1	73,6	—	—

Hardness Scales

VICKERS HV 10	ROCKWELL HR A	ROCKWELL HR C diamond	ROCKWELL HR D	ROCKWELL SUPERFICIAL HR 15N	ROCKWELL SUPERFICIAL HR 30N diamond	ROCKWELL SUPERFICIAL HR 45N	BRINELL HBW 10/3000	TENSILE strength N/mm²
900	85,0	67,0	76,1	92,9	83,6	74,2	—	—
920	85,3	67,5	76,5	93,0	84,0	74,8	—	—
940	85,6	68,0	76,9	93,2	84,4	75,4	—	—

> Unhardened steel and most non-ferrous metals

ROCKWELL HR B 1,5875 mm ball	ROCKWELL HR A diamond	ROCKWELL HR F 1,5875 mm ball	ROCKWELL HR E 3,175 mm ball	ROCKWELL SUPERFICIAL HR 15T 1,575 mm ball	ROCKWELL SUPERFICIAL HR 30T 1,575 mm ball	ROCKWELL SUPERFICIAL HR 45T 1,575 mm ball	VICKERS HV/10	BRINELL HBW 10/3000
100	61,5	—	—	93,1	83,1	72,9	240	224
99	60,9	—	—	92,8	82,5	71,9	234	218
98	60,2	—	—	92,5	81,8	70,9	228	212
97	59,5	—	—	92,1	81,1	69,9	222	208
96	58,9	—	—	91,8	80,4	68,9	216	205
95	58,3	—	—	91,5	79,8	67,9	210	201
94	57,6	—	—	91,2	79,1	66,9	205	196
93	57,0	—	—	90,8	78,4	65,9	200	193
92	56,4	—	—	90,5	77,8	64,8	195	189
91	55,8	—	—	90,2	77,1	63,8	190	182
90	55,2	—	—	89,9	76,4	62,8	185	177
89	54,6	—	—	89,5	75,8	61,8	180	172
88	54,0	—	—	89,2	75,1	60,8	176	165
87	53,4	—	—	88,9	74,4	59,8	172	165
86	52,8	—	—	88,6	73,8	58,8	169	163
85	52,3	—	—	88,2	73,1	57,8	165	160
84	51,7	—	—	87,9	72,4	56,8	162	157
83	51,1	—	—	87,6	71,8	55,8	159	155

Hardness Scales

ROCKWELL HR B 1,5875 mm ball	ROCKWELL HR A diamond	ROCKWELL HR F 1,5875 mm ball	ROCKWELL HR E 3,175 mm ball	ROCKWELL SUPERFICIAL HR 15T 1,575 mm ball	ROCKWELL SUPERFICIAL HR 30T 1,575 mm ball	ROCKWELL SUPERFICIAL HR 45T 1,575 mm ball	VICKERS HV/10	BRINELL HBW 10/3000
82	50,6	—	—	87,3	71,1	54,8	156	153
81	50,0	—	—	86,9	70,4	53,8	153	151
80	49,5	—	—	86,6	69,7	52,8	150	149
79	48,9	—	—	86,3	69,1	51,8	147	146
78	48,4	—	—	86,0	68,4	50,8	144	144
77	47,9	—	—	85,6	67,7	49,8	141	141
76	47,3	—	—	85,3	67,1	48,8	139	139
75	46,8	99,6	—	85,0	66,4	47,8	137	137
74	46,3	99,1	—	84,7	65,7	46,8	135	135
73	45,8	98,5	—	84,3	65,1	45,8	132	132
72	45,3	98,0	—	84,0	64,4	44 ,8	130	130
71	44,8	97,4	100,0	83,7	63,7	43,8	127	128
70	44,3	96,8	99,5	83,4	63,1	42,8	127	127
69	43,8	96,2	99,0	83,0	62,4	41,8	125	125
68	43,3	95,6	98,0	82,7	61,7	40,8	123	123
67	42,8	95,1	97,5	82,4	61,0	39,8	121	121
66	42,3	94,5	97,0	82,1	60,4	38,7	119	119
65	41,8	93,9	96,0	81,8	59,7	37,7	117	117
64	41,4	93,4	95,5	81,4	59,0	36,7	116	116
63	40,9	92,8	95,0	81,1	58,4	35,7	114	114
62	40,4	92,2	94,5	80,8	57,7	34,7	112	110
61	40,0	91,7	93,5	80,5	57,0	33,7	110	107
60	39,5	91,1	93,0	80,1	56,4	32,7	108	106
59	39,0	90,5	92,5	79,8	55,7	31,7	107	104
58	38,6	90,0	92,0	79,5	55,0	30,7	106	102
57	38,1	89,4	91,0	79,2	54,4	29,7	104	99
56	37,7	88,8	90,5	78,8	53,7	28,7	103	—
55	37,2	88,2	90,0	78,5	53,0	27,7	101	—
54	36,8	87,7	89,5	78,2	52,4	26,7	100	—

Hardness Scales

ROCKWELL				ROCKWELL SUPERFICIAL			VICKERS	BRINELL
HR B 1,5875 mm ball	HR A diamond	HR F 1,5875 mm ball	HR E 3,175 mm ball	HR 15T 1,575 mm ball	HR 30T	HR 45T	HV/10	HBW 10/3000
53	36,3	87,1	89,0	77,9	51,7	25,7	—	—
52	35,9	86,5	88,0	77,5	51,0	24,7	—	—
51	35,5	86,0	87,5	77,2	50,3	23,7	—	—
50	35,0	85,4	87,0	76,9	49,7	22,7	—	—
49	34,6	84,8	86,5	76,6	49,0	21,7	—	—
48	34,1	84,3	85,5	76,2	48,3	20,7	—	—
47	33,7	83,7	85,0	75,9	47,7	19,7	—	—
46	33,3	83,1	84,5	75,6	47,0	18,7	—	—
45	32,9	82,6	84,0	75,3	46,3	17,7	—	—
44	32,4	82,0	83,5	74,9	45,7	16,7	—	—
43	32,0	81,4	82,5	74,6	45,0	15,7	—	—
42	31,6	80,8	82,0	74,3	44,3	14,7	—	—
41	31,2	80,3	81,5	74,0	43,7	13,6	—	—
40	30,7	79,7	81,0	73,6	43,0	12,6	—	—
39	30,3	79,1	80,0	73,3	42,3	11,6	—	—
38	29,9	78,6	79,5	73,0	41,6	10,6	—	—
37	29,5	78,0	79,0	72,7	41,0	9,6	—	—
36	29,1	77,4	78,5	72,3	40,3	8,6	—	—
35	28,7	76,9	78,0	72,0	39,6	7,6	—	—
34	28,2	76,3	77,0	71,7	39,0	6,6	—	—
33	27,8	75,7	76,5	71,4	38,3	5,6	—	—
32	27,4	75,2	76,0	71,0	37,6	4,6	—	—
31	27,0	74,6	75,5	70,7	37,0	3,6	—	—
30	26,6	74,0	75,0	70,4	36,3	2,6	—	—

Note:
Caution is necessary when comparing hardness values because the form and type of workpiece can affect the measurement. For example, a case hardened steel workpiece may be sensitive to indentation depth. Therefore the method of measuring hardness specified in product documentation should not be replaced by an alternative method without reference to the design authority for that product.

Quick Guide to Surface Texture Measurement

1. Surface profiles

Actual profile

The profile resulting from the intersection of the workpiece surface and a plane normal to that surface and in a direction that maximises the surface roughness value (usually in the direction normal to the surface lay).

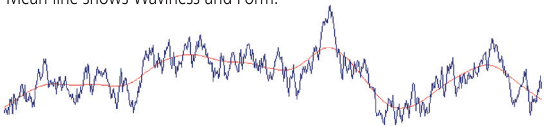
Measured profile

The profile resulting from scanning the actual profile with a mechanical probe which filters this profile depending on the probe tip radius and, if fitted, by the skid of the probe system. Scratch and dent components are removed as they are not part of the profile.

Primary profile (P-profile)

The profile resulting from filtering the measured profile to remove any wavelength data too short to be relevant for surface texture analysis. Parameters are designated by Psuffix (Pa, Pc, Pt, Pz, etc).

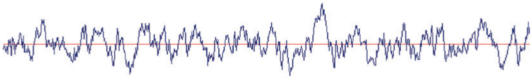
> Mean line shows Waviness and Form.



Roughness profile (R-profile)

The surface profile resulting from filtering the primary profile to remove Waviness and Form wavelengths. Parameters are designated by Rsuffix (Ra, Rc, Rt, Rz, etc).

> Waviness and Form filtered out, leaving only Roughness.



Waviness profile (W-profile)

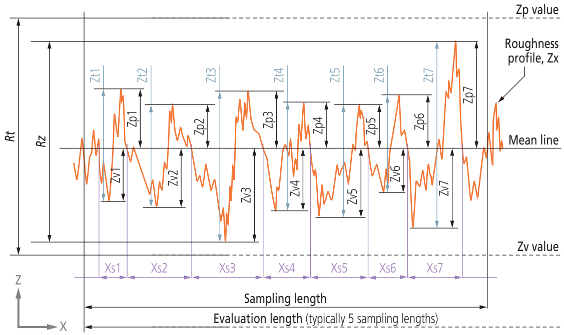
The surface profile resulting from filtering the primary profile to remove Roughness and Form wavelengths. Parameters are designated by Wsuffix (Wa, Wc, Wt, Wz, etc).

> First-stage filtering removes Roughness leaving Waviness and Form.

> Second-stage filtering removes Form leaving only Waviness.

2. Some common parameters

> A typical profile (roughness).



Arithmetical mean deviation of the profile: Pa**,** Ra **or** Wa
The arithmetical mean of the absolute profile Z(x) values within a sampling length.

$$Pa, Ra, Wa = \frac{1}{l}\int_0^l \left|Z(x)\right| dx$$

l = lp, lr or lw accordingly for primary, roughness or waviness profile

Root-mean-square deviation of the profile: Pq**,** Rq **or** Wq
The root-mean-square of the profile Z(x) values within a sampling length.

$$Pq, Rq, Wq = \sqrt{\frac{1}{l}\int_0^l \left|Z^2(x)\right| dx}$$

l = lp, lr or lw accordingly for primary, roughness or waviness profile

Total height of the profile: Pt**,** Rt **or** Wt
The sum of the highest peak Zp, and the deepest valley Zv, within the evaluation length.

Maximum height of the profile: Pz**,** Rz **or** Wz
The sum of the highest peak Zp, and the deepest valley Zv, within a sampling length.

Mean width of profile elements: PSm**,** RSm **or** WSm
The mean value of the profile element widths Xs within a sampling length.

$$PSm, RSm, WSm = \frac{1}{m}\sum_{i=1}^{m} Xs_i$$

If not otherwise specified, the minimum height of elements to be included is 10% of Pz, Rz or Wz, respectively, with a minimum spacing of 1% of the sampling length.

Mean height of profile elements: Pc, Rc **or** Wc
The mean value of the profile element heights Zt within a sampling length.

$$Pc, Rc, Wc = \frac{1}{m}\sum_{i=1}^{m} Zt_i$$

If not otherwise specified, the minimum height of elements to be included is 10% of Pz, Rz or Wz, respectively, with a minimum spacing of 1% of the sampling length.

3. Roughness value / grade number

The relationship between surface roughness values and grade numbers, as per ISO 1302, is shown in the table below.

Roughness value		Roughness grade number
Micrometre (µm)	Microinch (µinch)	
50	2000	N12
25	1000	N11
12,5	500	N10
6,3	250	N9
3,2	125	N8
1,6	63	N7
0,8	32	N6
0,4	16	N5
0,2	8	N4
0,1	4	N3
0,05	2	N2
0,025	1	N1

Quick Guide to Surface Texture Measurement

Setups for roughness measurement (EN ISO 4288)

Non-periodic profiles		Periodic profiles	Measuring conditions according to EN ISO 4288 and EN ISO 3274			
Grinding, honing, lapping, EDM		Turning, milling, hobbing	**r_{tip}** Maximum probe tip radius **lr** Sampling length **ln** Evaluation length **lt** Stylus travel (evaluation length plus start and finish lengths)			
Rt, Rz µm	Ra µm	RSm mm	**r_{tip}** µm	**λ_c = lr** mm	**ln** mm	**lt** mm
> 0,025...0.1	> 0,006...0.02	> 0,013...0.04	2	0,08	0,4	0,48
> 0,1...0.5	> 0,02...0.1	> 0,04...0.13	2	0,25	1,25	1,5
> 0,5...10	> 0,1...2	> 0,13...0.4	2*	0,8	4	4,8
> 10...50	> 2...10	> ,04...1.3	5	2,5	12,5	15
> 50...200	> 10...80	> 1,3...4	10	8	40	48

* When Rz > 3 µm or Ra > 0.5 µm a probe tip radius (**r_{tip}**) = 5 µm may be used.

Note:
This section is based on EN ISO 4287,
which should be consulted for detailed explanation.

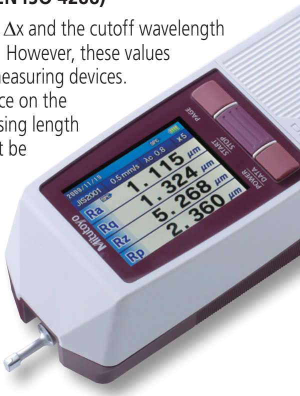
Roughness Measuring Conditions

Roughness measuring conditions (EN ISO 4288)

In addition, the measuring point distance Δx and the cutoff wavelength λs of the low-pass filter are standardised. However, these values have already been set in the roughness measuring devices.

Practical tip 1: If there is insufficient space on the workpiece surface for the required traversing length **lt**, the number of evaluation lengths must be reduced and indicated in the drawing.

Practical tip 2: If there is still insufficient space, the total height of the primary profile **Pt** is measured over the available length instead of **Rt** or **Rz**. **Pt** is still equal to **Rt**, but defined at the primary profile, and the measurement value is always larger.



Evaluation of roughness measurements (EN ISO 4288)

Roughness measurement values, particularly the vertical parameters **Rt**, **Rz**, **Rz1max** and **Ra**, have a spread between -20 % and +30 %. A single measurement value can therefore not provide a complete statement with regard to compliance with the permissible parameter tolerances. The following procedure is specified in the EN ISO 4288 Appendix A:

Max rule

All roughness parameters with the addition of **„max"** as the maximum of the mean value from the five sampling lengths: Measure at least three points on the surface where the highest values are expected; the stated limit must not be exceeded at any point.

Roughness Measuring Conditions

16% rule

All roughness parameters without the addition of „max" as the mean value from the five sampling lengths:
16% of the measured values may exceed the stated limit; the step-by-step procedure is as follows:

1. If the first measured value is less than 70% of the stated limit, this is considered compliant.
2. If the result is otherwise, two additional measurements are taken at other locations on the surface; if all three measured values are less than the stated limit, this is considered compliant.
3. If the result is otherwise, nine additional measurements are taken at other locations on the surface; if no more than two of the measured values exceed the stated limit, this is considered compliant.

Roughness Measuring Conditions

Examples	Explanation
Rz 5	No material removal allowed, default transmission band, **R** profile, 16% rule, mean roughness depth 5 µm (upper limit)
0,2 Rzmax 3	Material removal allowed, default transmission band, **R** profile, max rule, maximum roughness depth 3 µm (upper limit); machining allowance 0,2 mm
Rz3 4 C	Material removal permitted, default transmission band, **R** profile, evaluation length of 3 sampling lengths, 16% rule, mean roughness depth 4 µm (upper limit); concentric surface grooves
Rz 5 Ra 1	Material removal allowed, default transmission band, **R** profile, 16% rule, mean roughness depth 5 µm; arithmetic average roughness value 1 µm (upper limit)
U Rz 3 L Rz 1	Material removal allowed, default transmission band, **R** profile, 16% rule, mean roughness depth between 1 µm (lower limit) and 3 µm (upper limit)
Pt 25	Material removal allowed, default transmission band for λs, no λc filter, **P** profile, evaluation length equals workpiece length, 16% rule, total height of primary profile 25 µm (upper limit)
0,8 - 25 / Wt5 10	Material removal allowed, default transmission band 0,8 (=λc) 25 (=λf=**lw**) mm, W profile, evaluation length of 5 sampling lengths **ln**=5***lw**=125 mm), 16% rule, total height of profile 10 µm (upper limit)
Rt 1 Rmr (c=0,3) 90%	Material removal allowed, default transmission band, **R** profile, 16% rule, total height of roughness profile 1 µm (upper limit); material portion of profile is 90% in cutting height c =0,3 µm (lower limit)
U RSm 0,3 L RSm 0,1	Material removal allowed, default transmission band, **R** profile, mean groove width between 0,1 mm (lower limit) and 0,3 mm (upper limit)
y = y Rz 10	Explanation of the meaning (right) of simplified benchmarking (left), if space is limited.

Coefficient of Thermal Expansion (CTE)

The table below lists the typical Coefficient of Thermal Expansion (CTE) values for a selection of 50 engineering materials at moderate temperatures.

Material	α in 10^{-6}/ °C	Material	α in 10^{-6}/ °C
Alumina ceramics	6 – 7	Nickel and its alloys	12 – 17
Aluminium and its alloys	21 – 25	Nickel alloy, low expansion	10
Beryllium	11	Nitriding steel	12
Beryllium copper	17	Platinum	9
Brass	18 – 21	Stainless steel, age hardenable	10 – 15
Bronze, aluminium (cast)	16 – 17	Stainless steel, austenitic	14 – 18
Bronze, phosphor-silicon	17 – 18	Stainless steel, cast	11 – 19
Bronze, tin (cast)	18	Stainless steel, ferritic	10 – 11
Cast iron, nodular or ductile	10 – 19	Stainless steel, martensitic	10 – 12
Cermet, alumina	8 – 9	Steel, alloy	11 – 15
Cermet, chromium carbide	10 – 11	Steel, alloy, cast	14 – 15
Cermet, titanium carbide	8 –13	Steel, carbon, free cutting	15
Cermet, tungsten carbide	4 – 7	Steel, high temperature	11 – 14
Copper	17	Steel, ultra-high strength	10 – 14
Cupro-nickel and nickel silver	16 – 17	Superalloys, cobalt based	12 – 17
		Superalloys, Cr-Ni-Co-Fe	17 – 19
Diamond	1	Superalloys, Cr-Ni-Fe	14 – 16
Gauge block, CERA block*	9,3 ± 0,5	Superalloys, nickel based	14 – 18
Gauge block, steel	10,8 ± 0,5	Tantalum carbide	8
Gauge block, tungsten carbide	5,5 ± 1	Tin and its alloys	23
		Titanium and its alloys	9 – 13
Glass, fused quartz	0,55 – 0,59	Titanium carbide	7
Glass, pyrex	3,3	Tungsten	4
Iron, grey cast	11	Zerodur®, glass ceramic**	0,05 ± 0,10
Magnesium alloys	25 – 28	Zinc and its alloys	19 – 35
Molybdenum and its alloys	5 – 6	Zirconium and its alloys	5,5 – 6

* Zirconia ceramic.
** Used for the XYZ scales of ultra-high accuracy CMMs, such as Mitutoyo's LEGEX series.

Coefficient of Thermal Expansion (CTE)

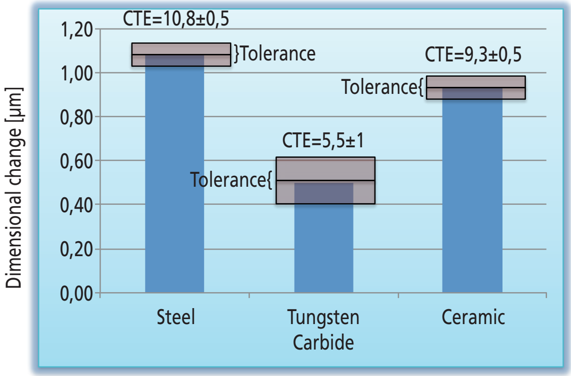
Most solids expand with rising and contract with decreasing temperature. This response to temperature change is expressed as their coefficient of thermal expansion (CTE).

$$\Delta l = l1 \cdot \alpha(t2 - t1)$$

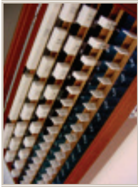
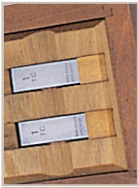
Δl= dimensional change
α= coefficient of thermal expansion
l1= dimension at 20°C
t2= temperature after change
t1= temperature before change. Reference temperature (20°C) for metrology (refer to EN ISO1).

> Example:

Dimensional change of a 100 mm gauge block with +1°C temperature to reference temperature (20°C). Mitutoyo material specification.



Material Characteristics of Gauge Blocks

	 CERA-Block ZrO_2	 Steel	 Tungsten Carbide
Vickers Hardness (HV)	1350	800	1650
Coefficient of thermal expansion (10^{-6}/°C)	9,3 ± 0,5	10,8 ± 0,5	5,5 ± 1
Flexural strength (N/mm^2=MPa)	1270	1960	1960
Fracture toughness K_{Ic} ($MPa \cdot m^{1/2}$)	7	120	12
Young's modulus (N/mm^2=MPa)	206000	206000	618000
Poisson ratio	0,3	0,3	0,2
Specific gravity (g/cm^3=kg/dm^3)	6	7,8	14,8
Thermal conductivity (W/m·K)	2,9	54,4	79,5
Dimensional stability	+++	+	++
Corrosion resistance	+++	+	++
Wear resistance	+++	+	++
Costs	high	low	high

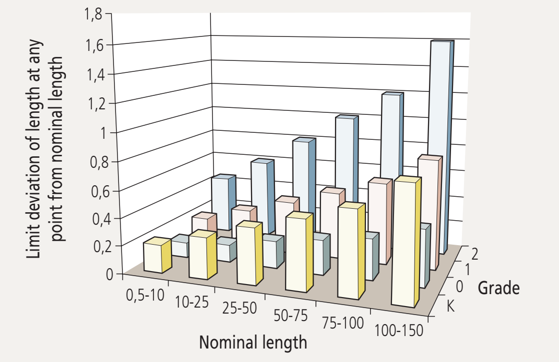
Gauge Block Grades

The grades specify the metrological characteristics (grades of accuracy). The following table can be used to select the correct gauge block grade for the diverse purposes (specified by EN ISO 3650, BS4311, and JIS B 7506).

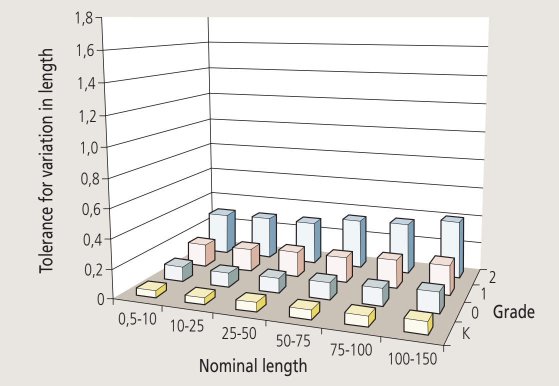
	Application	Grade
Workshop use	• Mounting tools and cutters	2
	• Calibration of instruments • Manufacturing gauges	1 or 2
Inspection use	• Setup of measuring devices	1 or 2
	• Checking the accuracy of gauges • Calibration of instruments	0 or 1
Calibration use	• Checking the accuracy of gauge blocks for workshops • Checking the accuracy of gauge blocks for inspection • Checking the accuracy of instruments	K or 0
Reference use	• Checking the accuracy of gauge blocks for calibration • Academic research	K

Gauge Block Grades

> Deviation limits of gauge blocks to EN ISO 3650

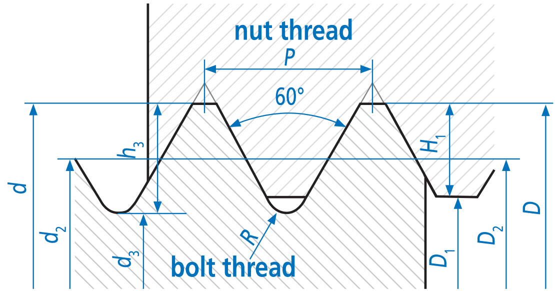


> Tolerances of gauge blocks to EN ISO 3650



Thread sizes – metric ISO-threads

$d = D$	Nominal diameter
P	Pitch
h_3	Thread depth of the bolt thread
H_1	Thread depth of the nut thread
R	Roundness
d_2	Pitch-Ø
d_3	Core Ø of the bolt thread
D_1	Core Ø of the nut thread
$d – P$	Core drill Ø
60°	flank angles



Thread sizes – metric ISO threads

Metric ISO-standard thread DIN 13-1
The metric ISO-thread is a worldwide standardized thread. It replaces older metric threads and most inch threads. The designation consists of the letter M and a number indicating the outer Ø. The flank angle is 60°

Standard thread-Ø in mm	Pitch in mm
M 2,5	0,45
M 3,0	0,50
M 3,5	0,60
M 4,0	0,70
M 4,5	0,75
M 5,0	0,80
M 6,0	1,00
M 7,0	1,00
M 8,0	1,25
M 9,0	1,25
M 10,0	1,50
M 11,0	1,50
M 12,0	1,75
M 14,0	2,00
M 16,0	2,00
M 18,0	2,50

Thread sizes – metric ISO threads

Metric fine pitch thread DIN 13-3
Compared to the standard thread, the fine thread has a smaller pitch, which increases the load capacity. Typical applications include adjusting screws on measuring devices, as it allows more precise adjustment.
The designation consists of the letter M and a number indicating the outer Ø. The flank angle is 60°.

Fine pitch thread-Ø in mm	Pitch in mm
M 3,5	0,35
M 4,0	0,50
M 4,5	0,50
M 5,0	0,35
M 6,0	0,75
M 7,0	0,75
M 8,0	0,75
M 8,0	1,00
M 9,0	0,75
M 9,0	1,00
M 10,0	0,75
M 10,0	1,00
M 11,0	1,00
M 12,0	1,00
M 12,0	1,25
M 12,0	1,50

Thread sizes – metric ISO threads

Metric fine pitch thread DIN 13-3

[Continuation of the table]

Fine pitch thread-Ø in mm	Pitch in mm
M 14,0	1,00
M 14,0	1,25
M 14,0	1,50
M 16,0	1,00
M 16,0	1,25
M 18,0	1,00
M 18,0	1,50
M 18,0	2,00

Notes

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