

Length, Germany, PTB (Physikalisch-Technische Bundesanstalt)



Calibration or Measurement Service			Measurand Level or Range			Measurement Conditions/Independent Variable		Expanded Uncertainty						
Class	Instrument or Artifact: Measurand	Instrument Type or Method	Minimum value	Maximum value	Units	Parameter	Specifications	Value	Units	Coverage Factor	Level of Confidence	Is the expanded uncertainty a relative one?	NMI Internal Service Identifier	Comments
Laser radiations	Stabilized He-Ne laser: vacuum wavelength	Optical beat frequency	633	633	nm	Temperature	(20 ± 5) °C	0.04	fm	2	95%	No	4.31/1	
Laser radiations	Stabilized He-Ne laser: absolute frequency	Optical beat frequency	474	474	THz	Temperature	(20 ± 5) °C	24	kHz	2	95%	No	4.31/1	
Laser radiations	Iodine-stabilized Nd-YAG, frequency doubled: vacuum wavelength	Optical beat frequency	532	532	nm	Temperature	(20 ± 5) °C	0.009	fm	2	95%	No	4.31/2	Approved on 04 May 2006
Laser radiations	Iodine-stabilized Nd-YAG, frequency doubled: absolute frequency	Optical beat frequency	563	563	THz	Temperature	(20 ± 5) °C	10	kHz	2	95%	No	4.31/2	Approved on 04 May 2006
Length instruments	Laser range finder (EDM) with flat reflector	50 m bench and laser interferometer	0	50	m			460	µm	2	95%	No	5.23/13	Approved on 22 March 2005
Length instruments	Laser range finder (EDM) with retroreflector	50 m bench and laser interferometer	0	50	m			102	µm	2	95%	No	5.23/14	Approved on 22 March 2005
Length instruments	Laser-interferometer system: error of indicated displacement with refractive index compensation $L$	Comparison with calibrated standards (laser interferometer, weather station)	0	5	m	Temperature	15 °C to 25 °C	$Q[0.015, 0.031L]$ , $L$ in m	µm	2	95%	No	5/0192	Approved on 01 April 2010
						Air pressure, humidity and CO <sub>2</sub> content	ambient pressure ± 30 hPa							

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Length instruments	Laser-interferometer system: error of indicated displacement with refractive index and thermal expansion compensation $L$	Comparison with calibrated standard (laser interferometer, weather station, body temperature sensors)	0	5	m	Temperature	15 °C to 25 °C	Q[0.015, 0.074 $L$ ], $L$ in m, for $\alpha = 11.5E-06$ 1/K	$\mu\text{m}$	2	95%	No	5/0193	Approved on 01 April 2010
						Air pressure, humidity and CO <sub>2</sub> content	ambient pressure $\pm 30$ hPa							
						$\alpha$	arbitrary							
End standards	Gauge blocks: central length $L$	Interferometry, exact fractions	0.5	200	mm			Q[20, 0.18 $L$ ], $L$ in mm	nm	2	95%	No	5.4/1	
End standards	Gauge blocks: thermal expansivity	Mechanical comparison	9.00E-06	1.30E-05	1/K	Length $L$	60 mm to 100 mm	Q[8.8E-06/ $L$ , 6.6E-08], $L$ in mm, values range from 1.1E-07 to 1.6E-07	1/K	2	95%	No	5.4/2	
						Temperature	15 °C to 25 °C						5.4/2	
End standards	Gauge blocks: central length $L$	Interferometry, exact fractions	100	1000	mm			Q[22, 0.066 $L$ ], $L$ in mm	nm	2	95%	No	5.4/3	
End standards	Gauge blocks: central length $L$	Mechanical comparison	200	1000	mm			Q[30, 0.12 $L$ ], $L$ in mm	nm	2	95%	No	5.4/4	
Line standards	Precision line scales: line spacing $L$	2-D optical mask comparator	0.01	280	mm			Q[10, 0.15 $L$ ], $L$ in mm	nm	2	95%	No	5.11/1	
Line standards	Stage micrometer: line spacing	2-D optical mask comparator	0.01	10	mm			50	nm	2	95%	No	5.11/2	
Line standards	Grid plates: grid point coordinates. Area	2-D optical mask comparator	(0.01x0.01)	(160x160)	mm <sup>2</sup>			Q[10, 0.2 $L$ ], $L$ center distance in mm	nm	2	95%	No	5.11/3	
Line standards	Grid plates: deviation from design grid coordinates	2-D optical mask comparator	(0.01x0.01)	(160x160)	mm <sup>2</sup>			10	nm	2	95%	No	5.11/4	

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Line standards	Grid plates: orthogonality	2-D optical mask comparator	89.95	90.05	°	Grid size	50 mm x 50 mm to 160 mm x 160 mm	0.05	"	2	95%	No	5.11/5	
Line standards	Photomask: linewidth	Optical microscope and interferometer	0.5	400	µm			0.02	µm	2	95%	No	4.22/1	
Line standards	(surveyor, engineer) tape, steel: line spacing $L$	50 m bench and laser interferometer	0	50	m	Support	multiple catenary, 0.4 m distance	$Q[13.4, 2.6L]$ , $L$ in m	µm	2	95%	No	5.23/2	Approved on 22 March 2005
Line standards	(surveyor, engineer) tape, steel: line spacing $L$	50 m bench and laser interferometer	50	100	m	Support	multiple catenary, 0.4 m distance	$Q[132, 2.6(L - 50 m)]$ , $L$ in m	µm	2	95%	No	5.23/3	Approved on 22 March 2005
Line standards	(surveyor, engineer) tape, invar: line spacing $L$	50 m bench and laser interferometer	0	50	m	Support	multiple catenary, 0.4 m distance	$Q[13.4, 0.72L]$ , $L$ in m	µm	2	95%	No	5.23/4	Approved on 22 March 2005
Line standards	(surveyor, engineer) tape, invar: line spacing $L$	50 m bench and laser interferometer	50	100	m	Support	multiple catenary, 0.4 m distance	$Q[41, 0.72(L - 50 m)]$ , $L$ in m	µm	2	95%	No	5.23/5	Approved on 22 March 2005
Line standards	Precision line scale, steel: line spacing $L$	50 m bench and laser interferometer	0.1	4	m			$Q[5.8, 1.8L]$ , $L$ in m	µm	2	95%	No	5.23/6	Approved on 22 March 2005
Line standards	Precision line scale, invar: line spacing $L$	50 m bench and laser interferometer	0.1	4	m			$Q[5.8, 0.4L]$ , $L$ in m	µm	2	95%	No	5.23/7	Approved on 22 March 2005
Line standards	Linear encoders: line spacing	1-D vacuum comparator	10	610	mm	Low thermal expansion substrate		$Q[1, 0.002L]$ , $L$ in mm	nm	2	95%	No	5.21/3	Approved on 19 May 2007
Line standards	Precision line scale: line spacing	1-D vacuum comparator, photoelectric microscope	0.01	610	mm	Surface flatness	< 1 µm, low thermal expansion substrate	$Q[9, 0.002L]$ , $L$ in mm	nm	2	95%	No	5.21/4	Approved on 19 May 2007

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Line standards	Photomask or wafer: linewidth	Scanning electron microscope and interferometer	0.2	1000	µm	Top linewidth		0.015	µm	2	95%	No	5.22-BS/10	Approved on 04 May 2006
Line standards	1-D grating: mean pitch	Laser diffractometer	0.14	4	µm	Grating area	> 0.1 mm <sup>2</sup>	20	pm	2	95%	No	4.22/2	Approved on 01 April 2010
Line standards	2-D grating: mean pitch	Laser diffractometer	0.14	4	µm	Grating area	> 0.1 mm <sup>2</sup>	20	pm	2	95%	No	4.22/2	Approved on 01 April 2010
Diameter standards	External cylinder (plug, piston, pin): diameter <i>L</i>	1-D comparator and contacting probe	0.5	190	mm			Q[48, 0.4 <i>L</i> ], <i>L</i> in mm	nm	2	95%	No	5.31/4	Approved on 22 March 2005
Diameter standards	External cylinder (plug, piston, pin): diameter <i>L</i>	1-D comparator and 2 contacting probes	2	185	mm			Q[10, 0.1 <i>L</i> ], <i>L</i> in mm	nm	2	95%	No	5.31/5	
Diameter standards	Internal cylinder (ring): diameter <i>L</i>	1-D comparator and contacting probe	2	200	mm			Q[48, 0.4 <i>L</i> ], <i>L</i> in mm	nm	2	95%	No	5.31/6	Approved on 22 March 2005
Diameter standards	Internal cylinder (ring): diameter <i>L</i>	1-D comparator and 2 contacting probes	10	170	mm			Q[14, 0.1 <i>L</i> ], <i>L</i> in mm	nm	2	95%	No	5.31/7	
Diameter standards	External sphere: diameter <i>L</i>	1-D comparator and 2 contacting probes	2	100	mm			Q[10, 0.1 <i>L</i> ], <i>L</i> in mm	nm	2	95%	No	5.31/8	Approved on 22 March 2005
Angle by circle dividers	Optical polygon: face angle	Angle comparator and autocollimator	3	72	faces			0.03	"	2	95%	No	5.22-BS/2	Approved on 04 May 2006
Angle by circle dividers	Index table: index angle	Cross calibration versus angle comparator or polygon and autocollimator	0	360	°			0.2	"	2	95%	No	5.22-BS/4	
Angle by circle dividers	Rotary encoder scale: position angle	Angle comparator	0	360	°			0.01	"	2	95%	No	5.22-BS/5	Approved on 04 May 2006

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Angle by circle dividers	Rotary table: position angle	Cross calibration versus angle comparator or polygon and autocollimator	0	360	°	Step size	5 °	0.1	"	2	95%	No	5.22-BS/6	Approved on 04 May 2006
Angle instruments	Autocollimator: error of indicated angle	Angle comparator		instrument specific	"	1 or 2 axes of measurement		0.01	"	2	95%	No	5.22-BS/8	Approved on 04 May 2006
Angle instruments	Electronic level: error of indicated inclination angle	Autocollimator	0	1000	"			0.3	"	2	95%	No	5.22-BS/9	Approved on 04 May 2006
Angle artefacts	Angle block: included angle	Angle comparator and autocollimator	0	180	°			0.05	"	2	95%	No	5.22-BS/1	Approved on 04 May 2006
Angle artefacts	90° square: squareness	Polygon, autocollimator and precision straightline motion	0	360	°	Orientation	horizontal	0.2	"	2	95%	No	5.22-BS/3	Approved on 04 May 2006
						Size	up to 1000 mm						5.22-BS/3	
Angle artefacts	90° cylinder square: squareness	Reversal method with reference on MFU8-PTB	0	500	µm/m	Length	up to 360 mm	3	"	2	95%	No	5.31/9	
						Diameter	up to 185 mm						5.31/9	
Flatness standard	Optical flat - flatness deviation over whole diameter	Tolanski multiple beam Fizeau interferometer	0	5	µm	Diameter of artefact	10 mm to 250 mm	10	nm	2	95%	No	4.21/1	
Roundness standards	Ring, plug, sphere, hemisphere: roundness $R$	Stylus-on-spindle roundness instrument	0	400	µm	Diameter	1 mm to 100 mm	Q[6, 10R], $R$ in µm	nm	2	95%	No	5.31/13	
Roundness standards	Magnification standard (e.g. flick standard): roundness $R$	Stylus-on-spindle roundness instrument	2	400	µm	Diameter	5 mm to 100 mm	Q[6, 10R], $R$ in µm	nm	2	95%	No	5.31/16	
Straightness standards	Straight edge: straightness $S$	Reversal method with reference on MFU8-PTB	0	100	µm	Length $L$	up to 400 mm	Q[50, 0.4L, 10S], $L$ in mm, $S$ in µm	nm	2	95%	No	5.31/17	

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Straightness standards	Straight edge with 2 parallel faces: parallelism $P$	Reversal method with reference on MFU8-PTB	0	100	$\mu\text{m}$	Length $L$	up to 400 mm	$Q[70, 0.6L, 14P]$ , $L$ in mm, $P$ in $\mu\text{m}$	nm	2	95%	No	5.31/18	
Straightness standards	Cylindrical straightness standard: straightness $S$	Reversal method with reference on MFU8-PTB	0	100	$\mu\text{m}$	External length $L$	up to 400 mm	$Q[50, 0.4L, 10S]$ , $L$ in mm, $S$ in $\mu\text{m}$	nm	2	95%	No	5.31/19	
						Internal length $L$	up to 200 mm						5.31/19	
Straightness standards	Cylindrical straightness standard: parallelism $P$	Reversal method with reference on MFU8-PTB	0	100	$\mu\text{m}$	External length $L$	up to 400 mm	$Q[70, 0.6L, 14P]$ , $L$ in mm, $P$ in $\mu\text{m}$	nm	2	95%	No	5.31/20	
						Internal length $L$	up to 200 mm						5.31/20	
Surface texture	Depth standard (ISO 5436-1 type A): profile depth	Interference microscope	0.01	10	$\mu\text{m}$	Maximum depth of profile, $Pt$	ISO 4287	$Q[6.5, 1.5Pt]$ , $Pt$ in $\mu\text{m}$	nm	2	95%	No	5.17/2	
Surface texture	Depth standard (ISO 5436-1 type A)	SFM	0.005	5	$\mu\text{m}$	Groove depth $d$	ISO 5436-1	$Q[1, 0.5d]$ , $d$ in $\mu\text{m}$	nm	2	95%	No	5.14/3	Approved on 22 March 2005
Surface texture	Roughness standard (ISO 5436-1 type C): ISO roughness parameters	Stylus instrument, ISO 3274	25	2500	$\mu\text{m}$	$RSm$	ISO 4287, ISO 4288, ISO 11562	0.5	$\mu\text{m}$	2	95%	No	5.17/3	Approved on 22 March 2005
Surface texture	Roughness standard (ISO 5436-1 type C, D): ISO roughness parameters	Stylus instrument, ISO 3274	0.02	4	$\mu\text{m}$	Average parameters, $Ra$ and $Rq$	ISO 4287, ISO 4288, ISO 11562	$Q[0.5, 10Ra]$ , $Ra$ in $\mu\text{m}$	nm	2	95%	No	5.17/4	Approved on 01 April 2010
Screw standards	Thread plug, plain: pitch diameter	CMM substitution	5	700	mm	Pitch	0.75 mm to 6 mm	2.0	$\mu\text{m}$	2	95%	No	5.32/1	
Screw standards	Thread plug, plain: lead, pitch	CMM	0.75	6	mm	Major diameter	5 mm to 700 mm	0.5	$\mu\text{m}$	2	95%	No	5.32/2	
Screw standards	Thread plug, plain: flank angle	CMM substitution	3	90	$^\circ$	Major diameter	5 mm to 700 mm	2.0	'	2	95%	No	5.32/3	

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Screw standards	Thread plug, tapered: pitch diameter	CMM substitution	5	700	mm	Pitch	0.75 mm to 6 mm	2.0	µm	2	95%	No	5.32/4	
Screw standards	Thread plug, tapered: lead, pitch	CMM	0.75	6	mm	Major diameter	5 mm to 700 mm	0.5	µm	2	95%	No	5.32/5	
Screw standards	Thread plug, tapered: flank angle	CMM substitution	3	90	°	Major diameter	5 mm to 700 mm	2.0	'	2	95%	No	5.32/6	
Screw standards	Thread plug, tapered: cone angle	CMM	0	15	°	Major diameter	5 mm to 700 mm	4	"	2	95%	No	5.32/7	
Screw standards	Thread ring, plain: pitch diameter	CMM substitution	5	600	mm	Pitch	0.75 mm to 6 mm	2.0	µm	2	95%	No	5.32/8	
Screw standards	Thread ring, plain: lead, pitch	CMM	0.75	6	mm	Minor diameter	5 mm to 600 mm	0.5	µm	2	95%	No	5.32/9	
Screw standards	Thread ring, plain: flank angle	CMM substitution	3	90	°	Minor diameter	5 mm to 600 mm	2.0	'	2	95%	No	5.32/10	
Screw standards	Thread ring, tapered: pitch diameter	CMM substitution	5	600	mm	Pitch	0.75 mm to 6 mm	2.0	µm	2	95%	No	5.32/11	
Screw standards	Thread ring, tapered: lead, pitch	CMM	0.75	6	mm	Minor diameter	5 mm to 600 mm	0.5	µm	2	95%	No	5.32/12	
Screw standards	Thread ring, tapered: flank angle	CMM substitution	3	90	°	Minor diameter	5 mm to 600 mm	2.0	'	2	95%	No	5.32/13	
Screw standards	Thread ring, tapered: cone angle	CMM	0	15	°	Minor diameter	5 mm to 600 mm	4	"	2	95%	No	5.32/14	
Gear standards	Spur gear: profile slope deviation	Standard involute measuring device	25	400	mm	Base diameter	25 mm to 400 mm	1.0 to 1.5	µm	2	95%	No	5.32/15	
Gear standards	Spur gear: helix slope deviation	Standard helix measuring device	0	45	°	Reference diameter	up to 300 mm	1.1 to 2.0	µm	2	95%	No	5.32/16	
Gear standards	Spur gear: pitch	Standard pitch measuring device	0.2	0.2	"	Reference diameter	up to 400 mm	0.2	µm	2	95%	No	5.32/17	
Gear standards	Bevel gear: form deviation	CMM		< 300	mm	Tip diameter	up to 300 mm	2.0	µm	2	95%	No	5.32/18	

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CMM artefacts	Ball plate: 2D centre coordinates	CMM with laser interferometer and reversal technique			mm	Ball plate size	< 960 mm x 960 mm	Q[0.4, 0.5L], L center distance in m	µm	2	95%	No	5.32/19	Approved on 01 April 2010
CMM artefacts	Ball bar: centre spacing L	CMM with laser interferometer			mm	Ball bar size	10 mm to 960 mm	Q[0.4, 0.5L], L in m	µm	2	95%	No	5.32/20	Approved on 01 April 2010
CMM artefacts	Reference software: Gaussian associated features for least square for circle, sphere, cylinder, plane, cone	Software test								2	95%	No	5.32/21	
Complex geometry	CMM	Ball plate calibration sphere			mm	CMM size	< 1000 mm x 1000 mm x 1000 mm	Q[0.6, 1.0L], L length in m	µm	2	95%	No	5.32/22	
Thermal expansivity	Thermal expansion artefact	Transfer standard	-5E-06	30E-06	1/K	Object size	< 1000 mm x 1000 mm x 500 mm	0.2E-06	1/K	2	95%	No	5.32/23	
Film thickness	Film thickness gauge	SFM	0.005	5	µm			Q[1, 0.5h], h thickness in µm	nm	2	95%	No	5.14/1	
End standards	Gauge blocks: thermal expansivity a	Interferometry, exact fractions	-2.0E-05	2.0E-05	1/K	Length L	60 mm to 1000 mm	Q[2.4E-06/L, 2.2E-09, 4.6E-04a], L in mm, a in 1/K	1/K	2	95%	No	5.4/5	Approved on 30 January 2009
						Temperature	15°C to 25°C							
End standards	Gauge blocks: thermal expansivity	Mechanical comparison	0.9E-05	1.3E-05	1/K	Length L	125 mm to 1000 mm	Q[2.4E-05/L, 2.7E-08], L in mm	1/K	2	95%	No	5.4/6	Approved on 30 January 2009
						Temperature	15 °C to 25 °C							
Surface texture	Depth standard (ISO 5436-1 type A): groove depth	Stylus instrument, ISO 3274	0.01	5	mm	Groove depth, d	ISO 5436-1	Q[22, 36d], d in mm	nm	2	95%	No	5.11/1	Approved on 30 January 2009
Surface texture	Depth standard (ISO 5436-1 type A): groove depth	Interference microscope	0.01	10	µm	Groove depth, d	ISO 5436-1	Q[2, d], d in µm	nm	2	95%	No	5.17/1	Approved on 30 January 2009

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Surface texture	Roughness standard (ISO 5436-1 type C, D): ISO roughness parameters	Stylus instrument, ISO 3274	0.1	20	µm	Peak parameters, $R_z$ , $R_p$ , $R_v$ , $R_t$ , $R_{z1max}$	ISO 4287, ISO 4288, ISO 11562	Q[3, 10 $R_z$ ], $R_z$ in µm	nm	2	95%	No	5.17/5	Approved on 30 January 2009
Surface texture	Roughness standard (ISO 5436-1 type D): ISO roughness parameters	Stylus instrument, ISO 3274	0.1	20	µm	$R_k$ parameters, $R_k$ , $Mr1$ , $Mr2$ , $Rpk$ , $Rvk$	ISO 13565-1, ISO 13565-2	Q[3, 10 $R_z$ ], $R_z$ in µm	nm	2	95%	No	5.17/6	Approved on 30 January 2009
Film thickness	Film thickness gauge	SEM	1	50	µm	Thickness $h$		(25 nm + 5E-03 $h$ ), $h$ in µm	nm	2	95%	No	5.14/2	Approved on 30 January 2009
Line standards	Precision line scales: mean pitch $p$	Metrological SFM	50	50000	nm			(0.002 + 3E-05 $p$ ), $p$ in nm	nm	2	95%	No	5.15/1	Approved on 30 January 2009
Line standards	Grating scales: mean pitch $p$	Metrological SFM	(50x50)	(50000 x 50000)	nm <sup>2</sup>			(0.002 + 3E-05 $p$ ), $p$ in nm	nm	2	95%	No	5.15/2	Approved on 30 January 2009
Line standards	Grating scales: orthogonality	Metrological SFM	89	90	°			0.0024	°	2	95%	No	5.15/3	Approved on 30 January 2009
End standards	Pairs of gauge blocks: length difference	Interferometry, exact fractions	0	20	µm	Length	0.5 mm to 100 mm	10 to 14	nm	2	95%	No	5.4/7	Approved on 30 January 2009
End standards	Specimen with parallel end faces (e.g. gauge blocks) thermal expansivity, length stability	Interferometry, exact fractions	-1.0E-04	1.0E-04	1/K	Length $L$	0.5 mm to 400 mm	2Q[5E-11/L, 1E-05 $\alpha$ /L], $L$ in m, $\alpha$ in 1/K	1/K	2	95%	No	5.4/8	Approved on 30 January 2009
						Parallelism	less than 10 µrad							
						Temperature	10 °C to 30 °C							
Straightness standards	Straight edge: straightness $S$	Reversal method with precision PTB straight guide	0	100	µm	Orientation	horizontal length up to 1000 mm	Q[50, 0.4 $L$ , 10 $S$ ], $L$ in mm, $S$ in µm	nm	2	95%	No	5/0119	Approved on 03 November 2009