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# **THE MITUTOYO ENGINEERS REFERENCE BOOK**

**FOR MEASUREMENT AND QUALITY CONTROL**

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**EQUIVALENTS  
CONVERSIONS  
FORMULAE**

**TERMINOLOGY & DEFINITIONS**

**HARDNESS COMPARISONS**

**GEOMETRIC TOLERANCE SYMBOLS**

**AREA GEOMETRY**

**SPC CHARTS & FORMULAE**

**Mitutoyo**

## A RANGE OF PRODUCTS FOR EVERY APPLICATION

**M**itutoyo has always placed great emphasis on offering the widest range of quality measuring instruments possible. From small hand tools to the largest CMM's, the Mitutoyo quality is inherent in every product, with a wide number of measuring ranges and options for most items. Integration is a key feature of our electronic instruments. Powerful SPC systems enable a comprehensive quality management package to be integrated into the production process.



**1** Statistical Process Control products connect to a vast range of Digimatic instruments. The data processors can perform a variety of statistical functions and output results.



**2** Mitutoyo are the world's largest manufacturer of Micrometers with an instrument for every application. Digimatic Micrometers can output results to SPC systems.



**3** Calipers are available in digimatic, Dial and Vernier form in a host of different models and sizes. The Digimatic gauges can also be linked to Mitutoyo SPC systems.



**4** Height gauges are available for every application in Vernier and Digimatic form. The Linear Height allows complete 2D Coordinate Measuring.



**5** A Complete range of Dial Gauges and Dial Test Indicators, including SPC gauges, ensures exactly the right instrument can be chosen for the task in hand.



**6** From combination sets to Black Granite Surface Plates, from Pocket Comparators to Thickness Gauges; a full range of engineers' precision tools is available.



**7** Laser, Surface and Profile Gauging systems are the solution for precision measuring in the workshop or inspection room today, with output to SPC a key feature.



**8** Digital Readout Systems and Linear scales produced by Mitutoyo incorporate the very latest technology and are used by OEM's and end-users alike.



**9** Optical Projectors and Microscopes facilitate close visual inspection of workpieces. Projectors can be linked to Quadra Chek DRO's for advanced functions.



**10** Mitutoyo's range of Hardness Testers offer high precision and superb value in Rockwell, Brinell, Vickers and Micro Vickers type systems, with a full range of accessories.



**11** As the largest producer of CMM's, Mitutoyo can supply anything from low cost manual machines to ultra high accuracy CNC machines with excellent software packages.

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WHILST EVERY EFFORT HAS BEEN MADE TO ENSURE THE ACCURACY OF DATA WITHIN THIS HANDBOOK, MITUTOYO DOES NOT TAKE RESPONSIBILITY FOR ANY INACCURACIES THAT MAY HAVE OCCURRED WITHIN.

## INTRODUCTION

From supplying new equipment, to providing Technical support for its customers, Mitutoyo makes the most of its 60+ years of experience in the field of measurement technology.

Our dedication to personal and product development is more than matched by investments in plant and equipment, such as the 18 acre factory development in Telford and the new Metrology Institute extension in Warwick.

Services now offered include NAMAS Calibration, Metrology Institute for Training Facilities, Field Service, Spares and Repairs and a Contract Measurement Service.

Mitutoyo supports customers from six regional Metrology Centres in Andover, East Kilbride, Leeds, Warwick, and Cardiff.

Our full colour catalogue covering thousands of products is available by calling (01264) 353123.



## HELPFUL FORMULAE

RPM = Revolution per minute  
 F(R) = Feed per revolution  
 D = Diameter  
 S = Surface speed per minute  
 F(M) = Feed per minute  
 DC = Depth of cut  
 T = Machining time

	Metric	Imperial
	mm	inch
	mm	inch
	M	Feet
	mm	inch
	mm	inch

Known Data	To Find	Metric	Imperial
Diameter	RPM	$\frac{S \times 1000}{D \times 3.142}$	$\frac{S \times 12}{D \times 3.142}$
Surface Speed	RPM	$\frac{S \times 1000}{D \times 3.142}$	$\frac{S \times 12}{D \times 3.142}$
Diameter	S	$\frac{RPM \times D \times 3.142}{1000}$	$\frac{RPM \times D \times 3.142}{12}$
RPM	S	$\frac{RPM \times D \times 3.142}{1000}$	$\frac{RPM \times D \times 3.142}{12}$
Diameter	F(R)	$\frac{F(M) \times D \times 3.142}{S \times 1000}$	$\frac{RPM \times D \times 3.142}{S \times 12}$
Surface speed	F(R)	$\frac{F(M) \times D \times 3.142}{S \times 1000}$	$\frac{RPM \times D \times 3.142}{S \times 12}$
Feed/Minute	F(R)	$\frac{F(M)}{RPM}$	$\frac{F(M)}{RPM}$
RPM	F(R)	$\frac{F(M)}{RPM}$	$\frac{F(M)}{RPM}$
Feed/Minute	F(R)	$\frac{F(M)}{RPM}$	$\frac{F(M)}{RPM}$
Feed/Rev	F(M)	RPM x F(R)	RPM x F(R)
RPM	F(M)	RPM x F(R)	RPM x F(R)
Depth of cut	T	$\frac{DC}{F(M)}$	$\frac{DC}{F(M)}$
Feed/minute	T	$\frac{DC}{F(M)}$	$\frac{DC}{F(M)}$

## CONVERSION FACTORS

### LENGTH

1 cm = 0.3937 in	1 in = 25.4 mm
1 m = 3.2808 ft	1 ft = 0.3048 m
1 km = 0.6214 mile	1 mile = 1.6093 km

### WEIGHT

1 g = 0.0353 oz	1 oz = 28.35 g
1 kg = 2.2046 lb	1 lb = 0.4536 kg
1 tonne = 0.9842 ton	1 ton = 1.016 tonne

### AREA

1 m <sup>2</sup> = 1.196 yard <sup>2</sup>	1 in <sup>2</sup> = 645.2 mm <sup>2</sup>
1 hectare = 2.471 acre	1 yard <sup>2</sup> = 0.8361 m <sup>2</sup>
	1 acre = 0.4047 hectare
	1 sq mile = 259 hectare

## CONVERSION TABLE

### English to metric

inches (ins.).....X	25.4 = millimetres (mm)
feet (ft) .....X	0.3 = metres (m)
yards (yds.).....X	0.9 = metres (m)
miles (mi.) .....X	1.6 = kilometres (km)
sq.inch (in <sup>2</sup> ) .....X	6.5 = sq. centimetres (cm <sup>2</sup> )
sq. feet (ft <sup>2</sup> ).....X	0.09 = sq. metres (m <sup>2</sup> )
sq. yard (yd <sup>2</sup> ).....X	0.8 = sq. metres (m <sup>2</sup> )
acre (a) .....X	0.4 = hectares (ha)
cu. in. (in <sup>3</sup> ).....X	16.0 = cu.centimetres (cm <sup>3</sup> )
cu. ft. (ft <sup>3</sup> ) .....X	0.03 = cu. metres (m <sup>3</sup> )
cu. (yd <sup>3</sup> ).....X	0.8 = cu. metres (m <sup>3</sup> )
(liq) quart (qt).....X	0.9 = litre (l)
gallon (gal).....X	0.004 = cu. metre (m <sup>3</sup> )
(avdp) ounce (oz).....X	28.3 = grams (g)
(avdp) pound (lb).....X	0.45 = kilogram (kg)
horsepower (h.p.) .....X	0.75 = kilowatt (kW)
ft. per sec. (ft/s).....X	0.304 = met. per sec. (m/s)
ounce-force (ozf).....X	0.278 = newtons (N)
pounds-force (lbf) .....X	4.448 = newtons (N)
foot-pounds (ft. lb) .....X	1.355 = newton-metres (N.m.)
foot-pounds (ft. lb) .....X	1.355 = joules (J)
in.-pounds (in.lb).....X	0.112 = newton-metres (N.m)
lb. per foot (lb/ft).....X	14.593 = new. per metre (N/m)
cycles per sec. (cps).....X	1.0 = hertz (Hz)
Brit. therm unit (Btu).....X	1055.06 = joules (J)
Degrees Fah.(F).....X	5/9 after sub. 32 = deg. Celsius (C)

### Metric to English

mm X 0.04 = ins.
m X 3.3 = ft
m X 1.1 = yds.
km X 0.6 = mi.
cm <sup>2</sup> X 0.16 = in <sup>2</sup>
m <sup>2</sup> X 11.00 = ft <sup>2</sup>
m <sup>2</sup> X 1.2 = yd <sup>2</sup>
ha X 2.5 = a
cm <sup>3</sup> X 0.06 = in <sup>3</sup>
m <sup>3</sup> X 35.0 = ft <sup>3</sup>
m <sup>3</sup> X 1.3 = yd <sup>3</sup>
l X 1.05 = qt
m <sup>3</sup> X 264.2 = gal
g X 0.035 = oz
kg X 2.20 = lb
kW X 1.34 = h.p.
m/s X 3.280 = ft/s
N X 3.597 = ozf
N X 0.224 = lbf
N.m X 0.737 = ft. lb
J X 0.737 = ft. lb
N.m X 8.850 = in.lb
N.m X 0.068 = lb/ft
Hz X 1.0 = cps
J X 0.00094 = Btu
C X 9/5 then add 32 = F

**Note:** Conversion from inches to millimetres (ins. X 25.4) is exact. Conversion from millimetres to inches (mm X 0.04) is approximate (mm X 0.039 370 1) is accurate to six significant figures for mm/in. Converted units should be rounded off to values consistent with the original accuracy.

## TERMINOLOGY AND DEFINITIONS

Quantity	Name of Unit symbol	Unit	Definition
Frequency	hertz	Hz	1 Hz = 1 s <sup>-1</sup>
Force	newton	N	1 N = 1 kg m/s <sup>2</sup>
Pressure	pascal	Pa	1 Pa = 1 N/m <sup>2</sup>
Energy	joule	J	1 J = 1 Nm
Power	watt	W	1 W = 1 J/S
Electricity (Quantity)	coulomb	C	1 C = 1 As
Electric potential/force	volt	V	1 V = 1 J/C
Electrical capacitance	farad	F	1 F = 1 C/V
Electrical resistance	ohm	Ω	1 Ω = 1 V/A
Electrical conductance	siemens	S	1 S = 1 Ω <sup>-1</sup>
Inductance	henry	H	1 H = 1 Wb/A <sup>2</sup>
Luminous flux	lumen	lm	1 lm = 1 cd • sr
Illuminance	lux	lx	1 lx = 1 lm/m <sup>2</sup>

## MATHEMATICAL SYMBOLS

+	plus or positive	≥	greater than or equal to
-	minus or negative	≤	less than or equal to
±	plus or minus, positive or negative	≪	much greater than
×	multiplied by	≲	much less than
÷	divided by	∞	square root
=	equal to	∞	infinity
≡	identically equal to	∝	proportional to
≠	not equal to	∏	sum of
≇	not identically equal to	∏	product of
≈	approximately equal to	Δ	difference
~	of the order of	∠	therefore
∝	similar to	∠	angle
>	greater than	∥	parallel to
<	less than	⊥	perpendicular to
≧	not greater than	∴	is to
≦	not less than		

## HARDNESS COMPARISONS

VICKERS HARDNESS 10kg	ROCKWELL HARDNESS						BRINELL HARDNESS 3000Kgf	TENSILE HARDNESS N/mm <sup>2</sup>
	A 60 Kgf Diamond	C 150Kgf Diamond	D 100Kgf Diamond	15N 15Kgf Diamond	30N 30Kgf Diamond	45N 45Kgf Diamond		
240	60.7	20.3	40.3	69.6	41.7	19.9	228	770
245	61.2	21.3	41.1	70.1	42.5	21.1	233	785
250	61.6	22.2	41.7	70.6	43.4	22.2	238	800
255	62.0	23.1	42.2	71.1	44.2	23.2	242	820
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	1255
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

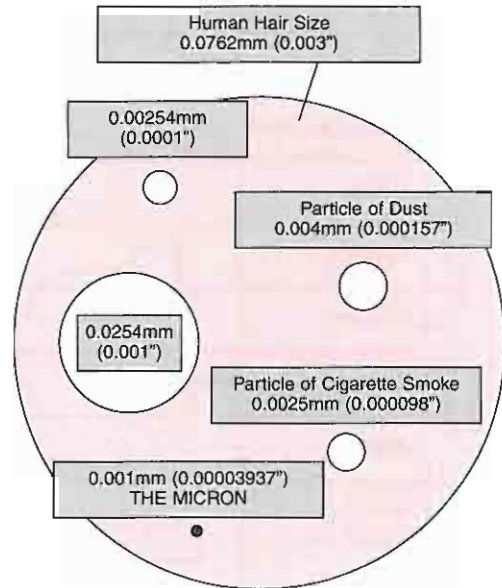
## HARDNESS COMPARISONS *continued*

ROCKWELL B 1/16" Ball	ROCKWELL A 60 Kgf Diamond	ROCKWELL F 1/16" Ball	ROCKWELL E 100Kgf 1/16" BALL	SUPERFICIAL ROCKWELL			VICKERS HARDNESS NUMBER	BRINELL 3000Kgf 10mm Ball
				15T 15Kgf 1/16" Ball	30T 30Kgf 1/16" Ball	45T 45Kgf 1/16" Ball		
100	61.5	-	-	93.1	83.1	72.9	240	240
99	60.9	-	-	92.8	82.5	71.9	234	234
98	60.2	-	-	92.5	81.8	70.9	228	228
97	59.5	-	-	92.1	81.1	69.9	222	222
96	58.9	-	-	91.8	80.4	68.9	216	216
95	58.3	-	-	91.5	79.8	67.9	210	210
94	57.6	-	-	91.2	79.1	66.9	205	205
93	57.0	-	-	90.8	78.4	65.9	200	200
92	56.4	-	-	90.5	77.8	64.8	195	195
91	55.8	-	-	90.2	77.1	63.8	190	190
90	55.2	-	-	89.9	76.4	62.8	185	185
89	54.6	-	-	89.5	75.8	61.8	180	180
88	54.0	-	-	89.2	75.1	60.8	176	176
87	53.4	-	-	88.9	74.4	59.8	172	172
86	52.8	-	-	88.6	73.8	58.8	169	169
85	52.3	-	-	88.2	73.1	57.8	165	165
84	51.7	-	-	87.9	72.4	56.8	162	162
83	51.1	-	-	87.6	71.8	55.8	159	159
82	50.6	-	-	87.3	71.1	54.8	156	156
81	50.0	-	-	86.9	70.4	53.8	153	153
80	49.5	-	-	86.6	69.7	52.8	150	150
79	48.9	-	-	86.3	69.1	51.8	147	147
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	83.7	63.7	43.8	127	127
70	44.3	96.8	99.5	83.4	63.1	42.8	125	125
69	43.8	96.2	99.0	83.0	62.4	41.8	123	123
68	43.3	95.6	98.0	82.7	61.7	40.8	121	121

VICKERS HARDNESS 10kg	ROCKWELL HARDNESS					BRINELL HARDNESS 3000Kgf	TENSILE HARDNESS N/mm <sup>2</sup>
	A 60 Kgf Diamond	C 150Kgf Diamond	D 100Kgf Diamond	15N 15Kgf Diamond	30N 30Kgf Diamond		
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	- -
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	- -

## MAKING SENSE OF MICRONS

ROCKWELL B 10Kgf 1/16" Ball	ROCKWELL A 60 Kgf Diamond	ROCKWELL F 60Kgf 1/16" Ball	ROCKWELL E 100Kgf 1/16" BALL	SUPERFICIAL ROCKWELL			VICKERS HARDNESS NUMBER	BRINELL 3000Kgf 10mm Ball
				15T 15Kgf 1/16" Ball	30T 30Kgf 1/16" Ball	45T 45Kgf 1/16" Ball		
67	42.8	95.1	97.5	82.4	61.0	39.8	119	119
66	42.3	94.5	97.0	82.1	60.4	38.7	117	117
65	41.8	93.9	96.0	81.8	59.7	37.7	116	116
64	41.4	93.4	95.5	81.4	59.0	36.7	114	114
63	40.9	92.8	95.0	81.1	58.4	35.7	112	112
62	40.4	92.2	94.5	80.8	57.7	34.7	110	110
61	40.0	91.7	93.5	80.5	57.0	33.7	108	108
60	39.5	91.1	93.0	80.1	56.4	32.7	107	107
59	39.0	90.5	92.5	79.8	55.7	31.7	106	106
58	38.6	90.0	92.0	79.5	55.0	30.7	104	104
57	38.1	89.4	91.0	79.2	54.4	29.7	103	103
56	37.7	88.8	90.5	78.8	53.7	28.7	101	101
55	37.2	88.2	90.0	78.5	53.0	27.7	100	100
54	36.8	87.7	89.5	78.2	52.4	26.7	-	-
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	-	-



A 100mm (4") iron rod will change in length by 0.012mm (0.00047") at a temperature change of 10 degrees °C

NOT SHOWN TO SCALE

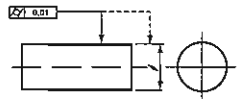
# GEOMETRIC TOLERANCE SYMBOLS

		Characteristic	Symbol
Form Tolerances	Single Features	Straightness	
		Circularity (Roundness)	
		Profile of any line	
		Profile of any surface	
		Flatness	
		Cylindricity	
	Related Features	Parallelism	
		Perpendicularity (Squareness)	
		Angularity	
		Runout	
Tolerances of Location	Position		
	Symmetry		
	Concentricity & Coaxiality		
		Maximum Material Condition	
		Diameter (PHI)	

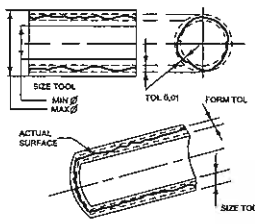
# CHARACTERISTICS

<p><b>Straightness</b> Example:</p>	<p><b>Circularity (Roundness)</b> Example:</p>
<p><b>Profile of Any line</b> Example:</p>	<p><b>Profile of Any Surface</b> Example:</p>
<p><b>Flatness</b> Example:</p>	<p><b>Parallelism</b> Example:</p>
<p><b>Symmetry</b> Example:</p>	<p><b>Concentricity &amp; Coaxiality</b> Example:</p>

## Cylindricity

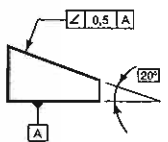


Interpretation: 2 concentric cylinders

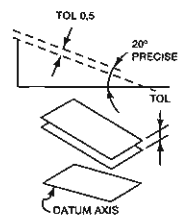


## Angularity

Example:

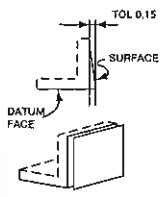
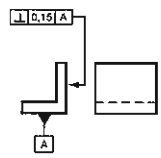


Interpretation: 2 parallel planes



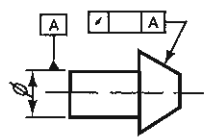
## Perpendicularity (Squareness)

Example:

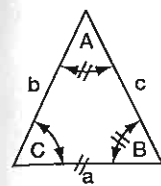
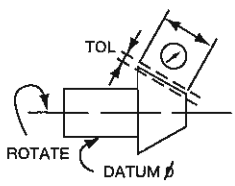


## Runout

Example:

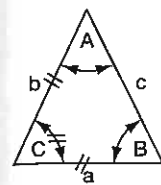


Interpretation:



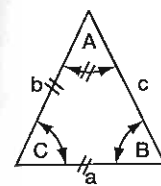
ANY ONE SIDE & ANY TWO ANGLES KNOWN  
For Example: denote the known side a and the angle A and B.

Then:  $C = 180^\circ - (A+B)$   
 $b = \frac{a \sin B}{\sin A}$        $c = \frac{a \sin C}{\sin A}$   
 Area =  $\frac{a \times b \times \sin C}{2}$



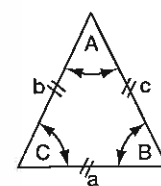
TWO SIDES & THE INCLUDED ANGLE  
For Example: denote the known sides a & b and the angle C.

Then:  $\tan A = \frac{a \sin C}{b - a \cos C}$   
 $b = \frac{a \sin B}{\sin A}$        $c = \frac{a \sin C}{\sin A}$   
 Area =  $\frac{a \times b \times \sin C}{2}$



TWO SIDES & THE OPPOSITE ANGLE  
For Example: Let the angle be A and the sides a & b.

Then:  $\sin B = \frac{b \sin A}{a}$   
 $b = \frac{a \sin C}{\sin A}$        $C = 180^\circ - (A+B)$   
 Area =  $\frac{a \times b \times \sin C}{2}$

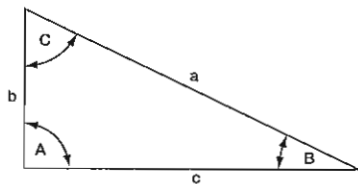


ALL SIDES GIVEN  
For Example: Let the sides be a, b & c and the angles opp. A, B & C.

Then:  $\cos A = \frac{b^2 + c^2 - a^2}{2bc}$   
 $\sin B = \frac{b \sin A}{A}$        $C = 180^\circ - (A+B)$   
 Area =  $\frac{a \times b \times \sin C}{2}$

NB: // = signifies data known

# SOLUTION OF THE RIGHT ANGLED TRIANGLE



a = HYPOTENUSE  
b = PERPENDICULAR  
c = BASE

TAN  $B = \frac{b}{c}$   
SINE  $B = \frac{b}{a}$   
COS  $B = \frac{c}{a}$

COTAN  $B = \frac{c}{b}$   
COSEC  $B = \frac{a}{b}$   
SEC  $B = \frac{a}{c}$

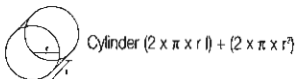
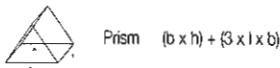
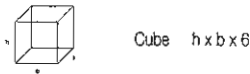
## AREA GEOMETRY

Geometry of area  
ABBREVIATIONS  
a = length of top  
b = length of base  
h = perpendicular height  
r = length or radius

$$\pi = 3.1416$$

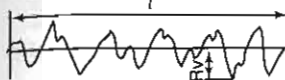
Geometry of surface area  
ABBREVIATIONS  
b = breadth of base  
h = perpendicular height  
l = length of base  
r = length of radius

$$\pi = 3.1416$$



# QUICK GUIDE TO SURFACE ROUGHNESS MEASUREMENT

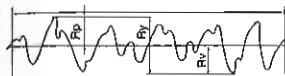
- **Maximum profile valley depth, Rv**  
The distance between the lowest point of the profile and the mean line.



- **Mean profile valley depth, Rvm**  
The arithmetic mean of the maximum profile valley depths (Rvi) determined for five sampling lengths.

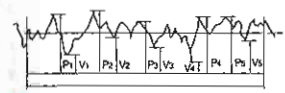
$$R_{pvm} = \frac{1}{5} \sum_{i=1}^5 R_{vi}$$

- **Maximum peak-to-valley height, Ry**  
The distance between the maximum peak height (Rp) and the maximum valley depth (Rv).



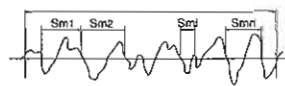
- **Ten-point height of irregularities, Rz**  
The difference between the average height of the five highest peaks and average height of the five deepest valleys.

$$R_{pzm} = \frac{1}{5} \sum_{i=1}^5 P_i - \frac{1}{5} \sum_{i=1}^5 V_i$$



- **Mean spacing of profile irregularities, Sm**  
The arithmetic mean of the spacing (Smj) between peaks and adjacent valleys.

$$S_m = \frac{1}{n} \sum_{j=1}^n S_{mj}$$

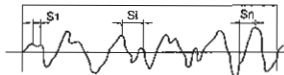


- **Peak count, Pc**  
The number of profile peaks per unit length (10mm or 1 inch).

$$P_c = \frac{1}{S_m}$$

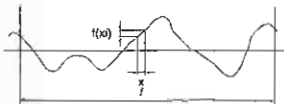
- **Mean spacing of local peaks of the profile, S**  
The arithmetic mean of the spacing (Si) between adjacent local peaks.

$$S = \frac{1}{n} \sum_{i=1}^n S_i$$

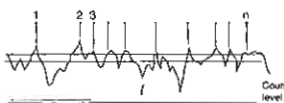


- **Arithmetic mean slope of the profile**  
The arithmetic mean of the absolute values of the rate of change of the profile departures determined for small intervals.

$$\Delta a = \frac{1}{7} \int_0^7 \left| \frac{df(x)}{dx} \right| dx = \frac{1}{n} \sum_{i=1}^n \left| \frac{\Delta f(x)}{\Delta x} \right|$$



- **High spot count, HSC**  
The number of peaks per unit length (10 mm or 1 inch), that project above a specified count level which is parallel to the mean line.



# QUICK GUIDE TO SURFACE ROUGHNESS MEASUREMENT

## 1. Measurement curves

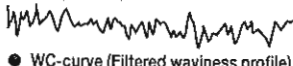
### ● P-curve (Unfiltered profile)

The P-curve is a profile resulting from the intersection of a surface with a plane normal to the surface, and unless otherwise specified, the intersecting plane must be orientated in the direction in which the roughness of the surface profile is the maximum value of the surface roughness. Generally it is in the direction normal to the surface lay.



### ● R-curve (Roughness profile)

The R-curve is obtained from the P-curve by removing the long wavelength components (waviness components).



### ● WC-curve (Filtered waviness profile)

The WV-curve is obtained from the P-curve by removing the short wavelength components (roughness components).

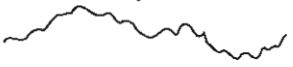


### ● WCA-curve (Filtered centre line waviness profile)

The WCA-curve is obtained from the P-curve by removing the long wavelength components (such as out-of-straightness components) and the short wavelength components (roughness components).

### ● WE-curve (Rolling circle waviness profile)

A locus made by the center of a circle of fixed radius when it traces the unfiltered profile. This circle is called the rolling circle.



### ● WEA-curve (Rolling circle centre line waviness curve)

The WEA-curve is obtained from the WE-curve by removing the long wavelength components (such as out-of-straightness components).

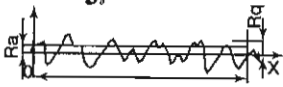


## 2. Parameters

### ● Roughness average (Arithmetic mean deviation of roughness profile), Ra

The arithmetic mean of the absolute values of the departures of the profile from the mean line.

$$R_a = \frac{1}{l} \int_0^l |f(x)| dx = \frac{1}{n} \sum_{i=1}^n |f(x_i)|$$



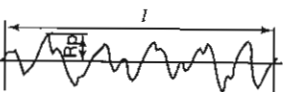
### ● Root-mean square deviation of the profile, Rq

The root-mean square sum of the profile departure from the mean line.

$$R_q = \sqrt{\frac{1}{l} \int_0^l |f(x)|^2 dx} = \sqrt{\frac{1}{n} \sum_{i=1}^n |f(x_i)|^2}$$

### ● Maximum profile peak height, Rp

The distance between the highest point of the profile and the mean line.



### ● Mean profile peak height, Rpm

The arithmetic mean of the maximum profile peak heights (Rpi) determined for five sampling lengths.

$$R_{pm} = \frac{1}{5} \sum_{i=1}^5 R_{pi}$$

# RESULTS OF CALCULATION

Item	Symbol	Formula
Number of measurements	N	-
Maximum value	MAX	-
Minimum value	MIN	-
Range	R	$R = \text{MAX} - \text{MIN}$
Average	$\bar{X}$	$\bar{X} = \frac{\sum X_i}{N}$
Deviation	$\bar{X} - R$ $\bar{X} - S$ $X - R_s$	$\hat{\sigma}(\bar{X}) = R/\sqrt{2}$ $\hat{\sigma}(\bar{S}) = S/\sqrt{2}$ $\sigma(n-1) = \sqrt{\frac{N \sum X_i^2 - (\sum X_i)^2}{N(N-1)}}$
Process capability index	Cp	$C_p = \frac{USL - LSL}{6\hat{\sigma}}$ (Case of $\bar{X}-R, \bar{X}-S$ ) $C_p = \frac{USL - LSL}{6\hat{\sigma}(n-1)}$ (Case of $X-R_s$ )
Process capability index	Cpk	$C_{pk} = \frac{Z_{min}}{3}$ <sup>2, 4, 5</sup>
Machine capability index	Cm	$C_m = \frac{USL - LSL}{6\sigma(n-1)}$ (Case of $\bar{X}-R, \bar{X}-S$ ) $C_m = \frac{USL - LSL}{6\sigma(n-1)}$ (Case of $X-R_s$ ) <sup>1, 4</sup>
Machine capability index	Cmk	$C_{mk} = \frac{Z_{min}}{3}$ (Case of $\bar{X}-R, \bar{X}-S$ ) $C_{mk} = \frac{Z_{min}}{4}$ (Case of $X-R_s$ ) <sup>2, 4, 5</sup>
Fraction defective	P	$P = \frac{(+NG) + (-NG)}{N} \times 100$ <sup>3</sup>
Estimated fraction defective	Pe	Calculated from $Z_{USL}$ , $Z_{LSL}$ , and normal distribution chart <sup>4, 5</sup>
± 3SD		SD: The mean of $\sigma(n-1)$

\*1: USL: Upper tolerance limit, LSL: Lower tolerance limit

\*2: Zmin: ZUSL or ZLSL whichever the smaller

$$Z_{USL} = \frac{USL - \bar{X}}{\hat{\sigma} \text{ or } \sigma(n-1)}, Z_{LSL} = \frac{\bar{X} - LSL}{\hat{\sigma} \text{ or } \sigma(n-1)}$$

\*3: +NG or -NG is the number of defectives.

\*4: " \* \* \* " is plotted for Cp, Cpk, Cm, Cmk and Pe when  $\sigma(\bar{X})$ ,  $\sigma(S)$ ,  $\sigma(n-1) = 0$

\*5: Cpk, Cmk, and Pe values are not guaranteed in the case of  $X > USL$  or  $X < LSL$

## FORMULAS CONTROL CHARTS

Item (symbol)	Formula		
	$\bar{X}$ -R	X-S	$\bar{X}$ -Rs
$\bar{X}$	$\bar{\bar{X}} = \frac{\sum X_k}{n}$ <sup>1</sup>		$\bar{\bar{X}} = \frac{\sum Xk}{m}$
R,S, or Rs	$R = \text{MAX}(\bar{X}) - \text{MIN}(\bar{X})$	$S = \sqrt{\frac{n \sum X_k^2 - (\sum X_k)^2}{n(n-1)}}$	$R_{Sk} = Xk + 1 - Xk$
$\bar{\bar{X}}$	$\bar{\bar{X}} = \frac{\sum Xk}{m}$		
R,S, or Rs	$\bar{R} = \frac{\sum Rk}{m}$	$\bar{S} = \frac{\sum S_k}{m}$	$\bar{R}_S = \frac{\sum R_{Sk}}{m-1}$
X-UCL X-LCL	$\bar{X} - \text{UCL} = \bar{\bar{X}} + A_2 \bar{R}$	$\bar{X} - \text{UCL} = \bar{\bar{X}} + A_3 \bar{S}$	$X - \text{UCL} = \bar{X} + 2.659 \bar{R}_S$
X-LCL X-LCL	$\bar{X} - \text{LCL} = \bar{\bar{X}} + A_2 \bar{R}$	$\bar{X} - \text{LCL} = \bar{\bar{X}} + A_3 \bar{S}$	$X - \text{LCL} = \bar{X} + 2.659 \bar{R}_S$
R-UCL S-UCL Rs-UCL	$R - \text{UCL} = D_4 \bar{R}$	$S - \text{UCL} = B_4 \bar{S}$	$RS - \text{UCL} = 3.267 \bar{R}_S$
R-LCL S-LCL	$R - \text{LCL} = D_3 \bar{R}$ <sup>2</sup>	$S - \text{LCL} = B_3 \bar{S}$ <sup>3</sup>	---

\*1: n = sample size

m = number of subgroups

j = between 1 and n

k = between 1 and m

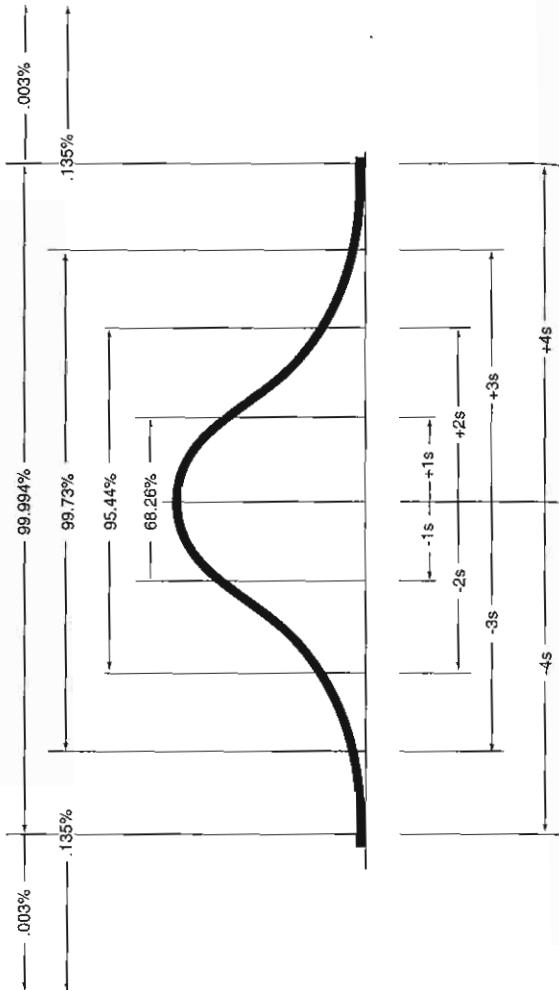
\*2: R-LCL is calculated when sample size is greater than 7.

\*3: S-LCL is calculated when sample size is greater than 6.

## TABLE OF CONSTANTS FOR CONTROL CHARTS

Sample size n	$\bar{X}$ -R				$\bar{X}$ -S			
	A2	d2	D3	D4	A3	C4	B3	B4
2	1.880	1.128	-	3.267	2.659	0.7979	-	3.267
3	1.023	1.693	-	2.574	1.954	0.8862	-	2.568
4	0.729	2.059	-	2.282	1.628	0.9213	-	2.266
5	0.577	2.326	-	2.114	1.427	0.9400	-	2.089
6	0.483	2.534	-	2.004	1.287	0.9515	0.030	1.970
7	0.419	2.704	0.076	1.924	1.182	0.9594	0.118	1.882
8	0.373	2.847	0.136	1.864	1.099	0.9650	0.185	1.815
9	0.337	2.970	0.184	1.816	1.032	0.9693	0.239	1.761
10	0.308	3.078	0.223	1.777	0.975	0.9727	0.284	1.716
11	0.285	3.173	0.256	1.744	0.927	0.9754	0.321	1.679
12	0.266	3.258	0.283	1.717	0.886	0.9776	0.354	1.646
13	0.249	3.336	0.307	1.693	0.850	0.9794	0.382	1.618
14	0.235	3.407	0.328	1.672	0.817	0.9810	0.406	1.594
15	0.223	3.472	0.347	1.653	0.789	0.9823	0.428	1.572
16	0.212	3.532	0.363	1.637	0.763	0.9835	0.448	1.552
17	0.203	3.588	0.378	1.622	0.739	0.9845	0.466	1.534
18	0.194	3.640	0.391	1.608	0.718	0.9854	0.482	1.518
19	0.187	3.689	0.403	1.597	0.698	0.9862	0.497	1.503
20	0.180	3.735	0.415	1.585	0.680	0.9869	0.510	1.490
21	0.173	3.778	0.425	1.575	0.663	0.9876	0.523	1.477
22	0.167	3.819	0.435	1.566	0.647	0.9882	0.534	1.466
23	0.162	3.858	0.443	1.557	0.633	0.9887	0.545	1.455
24	0.157	3.895	0.451	1.548	0.619	0.9892	0.555	1.445
25	0.153	3.931	0.459	1.541	0.606	0.9896	0.565	1.435

## PERCENTAGES OF THE NORMAL DISTRIBUTION



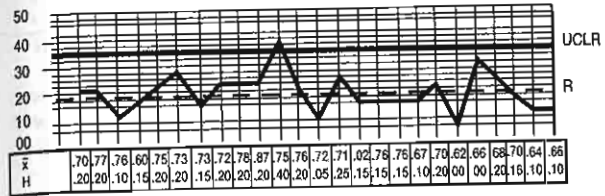
## PROCESS CONTROL $\bar{X}$ & R

Record 25 sets of 5 consecutive readings at regular intervals, calculate  $\bar{X}$  & R for each set of readings.

### To interpret range chart for control

Plot 25 Range (R) Points on the range chart

Calculate  $\bar{R} = \frac{\text{SUM of 25 Ranges (R)}}{25}$



### Ranges

$$\bar{R} = \frac{4.45}{25} = .178$$

### Calculate control limits for range

$$UCL_R = D_4 \times \bar{R}$$

$$LCL_R = D_3 \times \bar{R}$$

Sampled Size	2	3	4	5	6	7	8	9	10
$D_4$	3.27	2.57	2.28	2.11	2.00	1.92	1.86	1.82	1.78
$D_3$	0	0	0	0	0	0.08	0.14	0.18	0.22

N.B. For sample size 2 to 6 the  $LCL_R = 0$

$$UCL_R = 2.11 \times .178 = .376$$

Plot  $\bar{R}$ ,  $UCL_R$  &  $LCL_R$  on chart

### Interpret chart for control by applying the following test

- 1) No Points outside control limits
- 2) 2/3 of points in middle 1/3 of control limits
- 3) Not a run of 7 consecutive points all above or below  $\bar{R}$  Line
- 4) Not a run of 8 consecutive points upwards or downwards

If any of the above (4) test fail, process is out of control for range. Investigate for special causes and correct

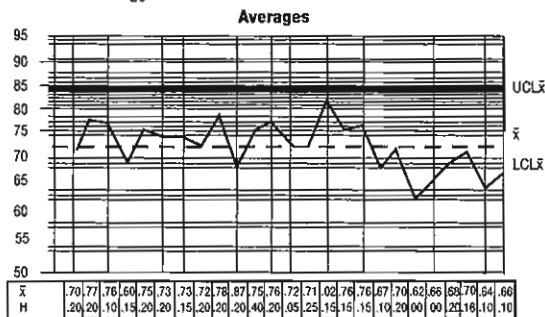
If all (4) tests pass, interpret for control on  $\bar{x}$  chart

## PROCESS CONTROL $\bar{X}$ & R

### To interpret averages ( $\bar{x}$ ) chart for control

Plot 25 averages ( $\bar{x}$ ) points on the average chart

$$\text{Calculate } \bar{x} = \frac{\text{SUM of 25 Ranges } (\bar{x})}{25}$$



$$x = \frac{17.90}{25} = .716$$

### Calculate control limits for averages

Sampled Size	2	3	4	5	6	7	8	9	10
A2	1.88	1.02	0.73	0.58	0.48	0.42	0.37	0.34	0.31

$$UCL_x = \bar{x} + (A_2 \times R)$$

$$LCL_x = \bar{x} - (A_2 \times R)$$

$$UCL_x = .716 + (0.58 \times 1.78) = .819$$

$$LCL_x = .716 + (0.58 \times 1.78) = .819$$

Plot  $\bar{x}$ , UCL, & LCL, On Chart

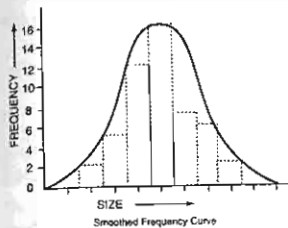
### Interpret Chart for Control by Applying the Following Test

- 1) No Points outside control limits
- 2) 2/3 of points in middle 1/3 of control limits
- 3) Not a run of 7 consecutive points all above or below X Line
- 4) Not a run of 8 consecutive points upwards or downwards

If any of the above (4) test fail, process is out of control for averages. investigate for special causes and correct

If all (4) tests pass, process is in control for average and range

## UNDERSTANDING VARIATION



Histograms show quickly whether the variation in the results is forming a definite pattern. If we draw a smooth curve through the top of each box of the histogram, we get a "bell-shaped" pattern

### Process Capability

Providing the process is in control for both X and R or X and S the process deviation  $\sigma$  can be calculated either:

$$\text{For } \bar{R} - R \quad \hat{\sigma} = \frac{\bar{R}}{C_R} = \frac{.178}{2.33} = 0.0764$$

$$\text{For } \bar{S} - S \quad \hat{\sigma} = \frac{\bar{S}}{C_S}$$

$$C_p - \text{Process Capability} = \frac{USL - LSL}{6 \hat{\sigma}}$$

$$C_p - \text{Capability index} = \text{Lower of } \frac{USL - \bar{X}}{3 \hat{\sigma}} \text{ and } \frac{\bar{X} - USL}{3 \hat{\sigma}}$$

A process with a Cpk of 1 = Process capable to  $\pm 3 \hat{\sigma}$

A process with a Cpk of 1.33 = Process capable to  $\pm 4 \hat{\sigma}$

### VARIABLE CONTROL CHARTS

$$\text{Sub group mean } \bar{X} = \frac{X_1 + X_2 + \dots + X_n}{n}$$

$$\text{Sub group range } R = X_{\text{highest}} - X_{\text{lowest}}$$

$$\text{Sub group std. deviation } \bar{s} = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}}$$

(X is the measured value, n is the number of values)

$$\text{Process mean } \bar{\bar{X}} = \frac{\bar{X}_1 + \bar{X}_2 + \dots + \bar{X}_m}{m}$$

$$\text{Mean range } \bar{R} = \frac{R_1 + R_2 + \dots + R_m}{m}$$

$$\text{Mean std. dev } \bar{s} = \frac{S_1 + S_2 + \dots + S_m}{m}$$

(m is the number of sub groups)

$$UCL_{\bar{X}}, LCL_{\bar{X}} = \bar{\bar{X}} \pm (A_2) \bar{R}$$

$$UCL_R = (D_4) \bar{R}$$

$$LCL_R = (D_3) \bar{R} \text{ (if } n > 6)$$

$$UCL_s = (B_4) \bar{s}$$

$$LCL_s = (B_3) \bar{s} \text{ (if } n > 5)$$

## UNDERSTANDING VARIATION

Patterns of variation which follow the principles of normal distribution can be described by their LOCATION and SPREAD as follows:



Figure 1

In figure 1 The pattern of variation in the two "bell shaped" curves A and B is identical. However, the central value or most frequently occurring size in each curve is different.

$\bar{X}$  Varying  
R Constant

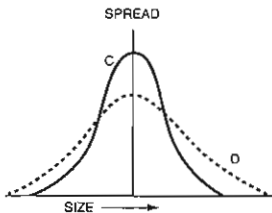


Figure 2

In figure 2 The central value of the two "bell shaped" curves C and D is the same but the spread of the variation of curve D is greater than curve C.

$\bar{X}$  Varying  
R Constant

TABLE OF CONSTANTS: used for many SPC formulae.

Sample

size	A2	B3	B4	C4	D2	D3	D4
2	1.880		3.267	0.7979	1.13		3.267
3	1.023		2.568	0.8862	1.69		2.574
4	0.729		2.266	0.9213	2.06		2.282
5	0.577		2.089	0.9400	2.33		2.114
6	0.483	0.030	1.970	0.9515	2.53		2.004
7	0.419	0.118	1.882	0.9594	2.70	0.076	1.924
8	0.373	0.185	1.815	0.9650	2.85	0.136	1.864
9	0.337	0.239	1.761	0.9693	2.97	0.184	1.816
10	0.308	0.284	1.716	0.9727	3.08	0.233	1.777

## SOLVING GEOMETRIC FIGURES

The **Diameter of a Circle equal in area to a given Square**, multiply one side of the Square by 1.12838

The **Side of a Hexagon inscribed in a Circle**, multiply the Circle Diameter by .5

The **Diameter of a Circle inscribed in a Hexagon**, multiply one side of the Hexagon by 1.7321

The **Side of an Equilateral Triangle inscribed in a Circle**, multiply the Circle Diameter by .866

The **Diameter of a Circle inscribed in an Equilateral Triangle**, multiply one Side of the Triangle by .57735

The **Area of a Square or Rectangle**, multiply the base by the height

The **Area of a Triangle**, multiply the Base by half the Perpendicular

The **Area of a Trapezoid**, multiply half the sum of Parallel sides by the Perpendicular

The **Area of a Regular Hexagon**, multiply the square of one side by 2.598

The **Area of a Regular Octagon**, multiply the square of one side by 4.828

The **Area of a Regular Polygon**, multiply half the sum of Sides by the Inside Radius

The **Circumference of a Circle**, multiply the Diameter by 3.1416

The **Diameter of a Circle**, multiply the Circumference by .31831

The Square Root of the Area of a Circle x 1.12838 = **the Diameter**

The Circumference of a Circle x .159155 = **the Radius**

The Square Root of the area of a Circle x .56419 = **the Radius**

The **Area of a Circle**, multiply the Square of the Diameter by .7854

The Square of the Circumference of a circle x .07958 = **the Area**

Half the circumference of a Circle x half its diameter = **the Area**

The **Area of the Surface of a Sphere**, multiply the Diameter Squared by 3.1416

The **Volume of a Sphere**, multiply the Diameter Cubed by .5236

The **Area of an Ellipse**, multiply the Long Diameter by the Short Diameter by .78540

To find the **Side of a Square inscribed in a Circle**, multiply the Circle Diameter by .7071

To find the **Side of a Square Equal in Area to a given Circle**, multiply the Diameter by .8862

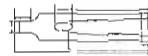
# DECIMAL EQUIVALENTS

Frac.	mm	Gauge	Inch	Frac.	mm	Gauge	Inch	Frac.	mm	Gauge	Inch
	.30		.0118	.940	63	.0370		2.083	45	.0820	
	.32		.0126	.95		.0374		2.10		.0827	
	.343	80	.0135	.965	62	.0380		2.15		.0846	
	.35		.0138	.98		.0386		2.184	44	.0860	
	.368	79	.0145	.991	61	.0390		2.20		.0866	
	.38		.0150	1.00		.0394		2.25		.0886	
$\frac{1}{16}$	.397		.0156	1.016	60	.0400		2.261	43	.0890	
	.40		.0157	1.041	59	.0410		2.30		.0906	
	.406	78	.0160	1.05		.0413		2.35		.0925	
	.42		.0165	1.067	58	.0420		2.375	42	.0935	
	.45		.0177	1.092	57	.0430	$\frac{3}{32}$	2.381		.0938	
	.457	77	.0180	1.10		.0433		2.40		.0945	
	.48		.0189	1.15		.0453		2.438	41	.0960	
	.50		.0197	1.181	56	.0465		2.45		.0965	
	.508	76	.0200	$\frac{3}{16}$	1.191	.0469		2.489	40	.0980	
	.52		.0205	1.20		.0472		2.50		.0984	
	.533	75	.0210	1.25		.0492		2.527	39	.0995	
	.55		.0217	1.30		.0512		2.55		.1004	
	.572	74	.0255	1.321	55	.0520		2.578	38	.1015	
	.58		.0228	1.35		.0532		2.60		.1024	
	.60		.0236	1.397	54	.0550		2.642	37	.1040	
	.610	73	.0240	1.40		.0551		2.65		.1043	
	.62		.0244	1.45		.0571		2.70		.1063	
	.635	72	.0250	1.50		.0591		2.705	36	.1065	
	.65		.0256	1.511	53	.0595		2.75		.1083	
	.660	71	.0260	1.55		.0610	$\frac{1}{16}$	2.778		.1094	
	.68		.0268	$\frac{1}{16}$	1.588	.0625		2.794	35	.1100	
	.70		.0276	1.60		.0630		2.80		.1102	
	.711	70	.0280	1.613	52	.0635		2.819	34	.1110	
	.72		.0283	1.65		.0650		2.85		.1122	
	.742	69	.0292	1.70		.0669		2.870	33	.1130	
	.75		.0295	1.702	51	.0670		2.90		.1142	
	.78		.0307	1.75		.0689		2.946	32	.1160	
	.787	68	.0310	1.778	50	.0700		2.95		.1161	
$\frac{1}{32}$	.794		.0312	1.80		.0709		3.00		.1181	
	.80		.0315	1.85		.0728		3.048	31	.1200	
	.813	67	.0320	1.854	49	.0730		3.10		.1220	
	.82		.0323	1.90		.0748	$\frac{1}{8}$	3.175		.1250	
	.838	66	.0330	1.930	48	.0760		3.20		.1260	
	.85		.0335	1.95		.0768		3.25		.1280	
	.88		.0346	$\frac{1}{16}$	1.984	.0781		3.264	30	.1285	
	.889	65	.0350	1.994	47	.0785		3.30		.1299	
	.90		.0354	2.00		.0787		3.40		.1339	
	.914	64	.0360	2.05		.0807		3.454	29	.1360	
	.92		.0362	2.057	46	.0810		3.50		.1378	

Frac.	mm	Gauge	Inch	Frac.	mm	Gauge	Inch	Frac.	mm	Gauge	Inch
	3.569	28	.1405		5.309	4	.2090		7.671	N	.3020
$\frac{1}{64}$	3.572		.1406		5.40		.2126		7.70		.3032
	3.60		.1417		5.410	3	.2130		7.75		.3051
	3.658	27	.1440		5.50		.2165		7.80		.3071
	3.70		.1457	$\frac{1}{32}$	5.556		.2188		7.90		.3110
	3.734	26	.1470		5.60		.2205	$\frac{1}{16}$	7.938		.3125
	3.75		.1476		5.613	2	.2210		8.00		.3150
	3.797	25	.1495		5.70		.2244		8.026	O	.3160
	3.80		.1496		5.75		.2264		8.10		.3189
	3.861	24	.1520		5.791	1	.2280		8.20		.3228
	3.90		.1535		5.80		.2283		8.204	P	.3230
	3.912	23	.1540		5.90		.2323		8.25		.3248
$\frac{1}{16}$	3.969		.1562	$\frac{1}{32}$	5.944	A	.2340		8.30		.3268
	3.988	22	.1570	$\frac{1}{16}$	5.953		.2344	$\frac{1}{16}$	8.334		.3281
	4.00		.1575		6.00		.2362		8.40		.3307
	4.039	21	.1590		6.045	B	.2380		8.433	Q	.3320
	4.089	20	.1610		6.10		.2402		8.50		.3346
	4.10		.1614		6.147	C	.2420		8.60		.3386
	4.20		.1654		6.20		.2441		8.611	R	.3390
	4.216	19	.1660		6.248	D	.2460		8.70		.3425
	4.25		.1673		6.25		.2461	$\frac{1}{32}$	8.731		.3438
	4.30		.1693		6.30		.2480		8.75		.3445
	4.305	18	.1695	$\frac{1}{4}$	6.350	E	.2500		8.80		.3465
$\frac{1}{32}$	4.366		.1719		6.40		.2520		8.839	S	.3480
	4.394	17	.1730		6.50		.2559		8.90		.3504
	4.40		.1732		6.528	F	.2570		9.00		.3543
	4.496	16	.1770		6.60		.2598		9.093	T	.3580
	4.50		.1772		6.629	G	.2610		9.10		.3583
	4.572	15	.1800		6.70		.2638	$\frac{3}{16}$	9.128		.3594
	4.60		.1811	$\frac{1}{16}$	6.747		.2656		9.20		.3622
	4.623	14	.1820		6.75		.2657		9.25		.3642
	4.70	13	.1850		6.756	H	.2660		9.30		.3661
	4.75		.1870		6.80		.2677		9.347	U	.3680
$\frac{1}{16}$	4.762		.1875		6.90		.2717		9.40		.3701
	4.80	12	.1890		6.909	I	.2720		9.50		.3740
	4.851	11	.1910		7.00		.2756	$\frac{1}{4}$	9.525		.3750
	4.90		.1929		7.036	J	.2770		9.576	V	.3770
	4.915	10	.1935		7.10		.2795		9.60		.3780
	4.978	9	.1960		7.137	K	.2810		9.70		.3819
	5.00		.1968	$\frac{1}{32}$	7.144		.2812		9.75		.3239
	5.055	8	.1990		7.20		.2835		9.80		.3858
	5.10		.2008		7.25		.2854		9.804	W	.3860
	5.105	7	.2010		7.30		.2874		9.90		.3898
$\frac{1}{16}$	5.159		.2031		7.366	L	.2900	$\frac{3}{16}$	9.922		.3906
	5.182	6	.2040		7.40		.2913		10.00		.3937
	5.20		.2047		7.493	M	.2950		10.084	X	.3970
	5.220	5	.2055		7.50		.2953		10.10		.3976
	5.25		.2067	$\frac{1}{16}$	7.541		.2969		10.20		.4016
	5.30		.2087		7.60		.2992		10.25		.4035

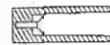
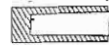
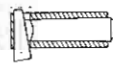
Frac.	mm	Gauge	Inch	Frac.	mm	Gauge	Inch	Frac.	mm	Gauge	Inch
	10.262	Y	.4040	13.70	Z	.5394	<sup>19</sup> / <sub>16</sub>	20.638	Z		.8125
	10.30		.4055	13.75		.5413		20.75			.8169
<sup>19</sup> / <sub>32</sub>	10.319		.4062	13.80		.5433		21.00			.8268
	10.40		.4094	<sup>35</sup> / <sub>64</sub>	13.891	.5469	<sup>35</sup> / <sub>64</sub>	21.034			.8281
	10.490	Z	.4130	13.90		.5472		21.25			.8366
	10.50		.4134	14.00		.5512	<sup>27</sup> / <sub>32</sub>	21.431			.8438
	10.60		.4173	14.25		.5610		21.50			.8465
	10.70		.4213	<sup>3</sup> / <sub>16</sub>	14.288	.5625		21.75			.8563
<sup>27</sup> / <sub>64</sub>	10.716		.4219	14.50		.5709	<sup>35</sup> / <sub>64</sub>	21.828			.8594
	10.75		.4232	<sup>37</sup> / <sub>64</sub>	14.684	.5781		22.00			.8661
	10.80		.4252	14.75		.5807	<sup>7</sup> / <sub>8</sub>	22.225			.8750
	10.90		.4291	15.00		.5906		22.25			.8760
	11.00		.4331	<sup>13</sup> / <sub>16</sub>	15.081	.5938		22.50			.8858
	11.10		.4370	15.25		.6004	<sup>57</sup> / <sub>64</sub>	22.622			.8906
<sup>7</sup> / <sub>16</sub>	11.112		.4375	<sup>39</sup> / <sub>64</sub>	15.478	.6094		22.75			.8957
	11.20		.4409	15.50		.6102		23.00			.9056
	11.25		.4429	15.75		.6201	<sup>29</sup> / <sub>32</sub>	23.019			.9062
	11.30		.4449	<sup>3</sup> / <sub>8</sub>	15.875	.6250		23.25			.9154
	11.40		.4488	16.00		.6299	<sup>59</sup> / <sub>64</sub>	23.416			.9219
	11.50		.4528	16.25		.6398		23.50			.9252
<sup>29</sup> / <sub>32</sub>	11.509		.4531	<sup>11</sup> / <sub>16</sub>	16.272	.6406		23.75			.9350
	11.60		.4567	16.50		.6496	<sup>15</sup> / <sub>16</sub>	23.812			.9375
	11.70		.4606	<sup>21</sup> / <sub>32</sub>	16.669	.6562		24.00			.9449
	11.75		.4626	16.75		.6594	<sup>13</sup> / <sub>16</sub>	24.209			.9531
	11.80		.4646	17.00		.6693		24.25			.9547
	11.90		.4685	<sup>47</sup> / <sub>64</sub>	17.066	.6719		24.50			.9646
<sup>13</sup> / <sub>16</sub>	11.906		.4688	17.25		.6791	<sup>31</sup> / <sub>32</sub>	24.606			.9668
	12.00		.4724	<sup>11</sup> / <sub>8</sub>	17.462	.6875		24.75			.9744
	12.10		.4764	17.50		.6890		25.00			.9843
	12.20		.4803	17.75		.6988	<sup>61</sup> / <sub>64</sub>	25.003			.9844
	12.25		.4823	<sup>45</sup> / <sub>64</sub>	17.859	.7031		25.25			.9941
	12.30		.4843	18.00		.7087	1	25.400			1.0000
<sup>31</sup> / <sub>64</sub>	12.303		.4844	18.25		.7185		25.50			1.0039
	12.40		.4882	<sup>29</sup> / <sub>32</sub>	18.256	.7188		25.75			1.0138
	12.50		.4921	18.50		.7283	<sup>11</sup> / <sub>16</sub>	25.797			1.0156
	12.60		.4961	<sup>47</sup> / <sub>64</sub>	18.653	.7344		26.00			1.0236
<sup>1</sup> / <sub>2</sub>	12.70		.5000	18.75		.7382	<sup>11</sup> / <sub>16</sub>	26.194			1.0312
	12.75		.5020	19.00		.7480		26.25			1.0335
	12.80		.5039	<sup>3</sup> / <sub>4</sub>	19.050	.7500		26.50			1.0433
	12.90		.5079	19.25		.7579	<sup>13</sup> / <sub>16</sub>	26.591			1.0469
	13.00		.5118	<sup>47</sup> / <sub>64</sub>	19.447	.7656		26.75			1.0531
<sup>35</sup> / <sub>64</sub>	13.097		.5156	19.50		.7677	<sup>11</sup> / <sub>16</sub>	26.988			1.0625
	13.10		.5157	19.75		.7776		27.00			1.0630
	13.20		.5197	<sup>29</sup> / <sub>32</sub>	19.844	.7812		27.25			1.0728
	13.25		.5217	20.00		.7874		27.25			1.0728
	13.30		.5236	<sup>31</sup> / <sub>64</sub>	20.241	.7969	<sup>13</sup> / <sub>16</sub>	27.384			1.0781
	13.40		.5276	20.25		.7972		27.50			1.0827
<sup>11</sup> / <sub>32</sub>	13.494		.5312	20.422		.8040		27.75			1.0925
	13.50		.5315	20.50		.8071	<sup>13</sup> / <sub>16</sub>	27.781			1.0938
	13.60		.5354								

## MORSE TAPER SLEEVES



A - No. Morse taper outside B - No. Morse Taper Inside

A	B	C	D	E	F	G	H	I	K	L	M
2	1	<sup>3</sup> / <sub>16</sub>	0.700	<sup>1</sup> / <sub>4</sub>	<sup>1</sup> / <sub>4</sub>	<sup>7</sup> / <sub>16</sub>	<sup>2</sup> / <sub>16</sub>	0.475	<sup>2</sup> / <sub>16</sub>	<sup>1</sup> / <sub>4</sub>	.213
3	1	<sup>3</sup> / <sub>16</sub>	0.938	<sup>1</sup> / <sub>4</sub>	<sup>7</sup> / <sub>16</sub>	<sup>7</sup> / <sub>16</sub>	<sup>2</sup> / <sub>16</sub>	0.475	<sup>2</sup> / <sub>16</sub>	<sup>1</sup> / <sub>4</sub>	.213
3	2	<sup>4</sup> / <sub>16</sub>	0.938	<sup>1</sup> / <sub>4</sub>	<sup>7</sup> / <sub>16</sub>	<sup>7</sup> / <sub>16</sub>	<sup>2</sup> / <sub>16</sub>	0.700	<sup>2</sup> / <sub>16</sub>	<sup>1</sup> / <sub>4</sub>	.260
4	1	<sup>4</sup> / <sub>16</sub>	1.231	<sup>1</sup> / <sub>4</sub>	<sup>15</sup> / <sub>32</sub>	<sup>7</sup> / <sub>8</sub>	<sup>2</sup> / <sub>16</sub>	0.475	<sup>2</sup> / <sub>16</sub>	<sup>1</sup> / <sub>4</sub>	.213
4	2	<sup>4</sup> / <sub>16</sub>	1.231	<sup>1</sup> / <sub>4</sub>	<sup>15</sup> / <sub>32</sub>	<sup>7</sup> / <sub>8</sub>	<sup>2</sup> / <sub>16</sub>	0.700	<sup>2</sup> / <sub>16</sub>	<sup>1</sup> / <sub>4</sub>	.260
4	3	<sup>5</sup> / <sub>16</sub>	1.231	<sup>1</sup> / <sub>4</sub>	<sup>15</sup> / <sub>32</sub>	<sup>7</sup> / <sub>8</sub>	<sup>3</sup> / <sub>4</sub>	0.938	<sup>3</sup> / <sub>16</sub>	<sup>1</sup> / <sub>16</sub>	.322
5	1	<sup>6</sup> / <sub>16</sub>	1.748	<sup>1</sup> / <sub>4</sub>	<sup>7</sup> / <sub>8</sub>	<sup>7</sup> / <sub>8</sub>	<sup>2</sup> / <sub>16</sub>	0.475	<sup>2</sup> / <sub>16</sub>	<sup>1</sup> / <sub>4</sub>	.213
5	2	<sup>6</sup> / <sub>16</sub>	1.748	<sup>1</sup> / <sub>4</sub>	<sup>7</sup> / <sub>8</sub>	<sup>7</sup> / <sub>8</sub>	<sup>2</sup> / <sub>16</sub>	0.700	<sup>2</sup> / <sub>16</sub>	<sup>1</sup> / <sub>4</sub>	.260
5	3	<sup>6</sup> / <sub>16</sub>	1.748	<sup>1</sup> / <sub>4</sub>	<sup>7</sup> / <sub>8</sub>	<sup>7</sup> / <sub>8</sub>	<sup>4</sup> / <sub>16</sub>	1.231	<sup>3</sup> / <sub>16</sub>	<sup>1</sup> / <sub>4</sub>	.478
5	4	<sup>6</sup> / <sub>16</sub>	1.748	<sup>1</sup> / <sub>4</sub>	<sup>7</sup> / <sub>8</sub>	<sup>7</sup> / <sub>8</sub>	<sup>4</sup> / <sub>16</sub>	1.231	<sup>3</sup> / <sub>16</sub>	<sup>1</sup> / <sub>4</sub>	.478
6	1	<sup>8</sup> / <sub>16</sub>	2.494	<sup>3</sup> / <sub>8</sub>	<sup>7</sup> / <sub>8</sub>	<sup>1</sup> / <sub>8</sub>	<sup>2</sup> / <sub>16</sub>	0.475	<sup>2</sup> / <sub>16</sub>	<sup>1</sup> / <sub>4</sub>	.213
6	2	<sup>8</sup> / <sub>16</sub>	2.494	<sup>3</sup> / <sub>8</sub>	<sup>7</sup> / <sub>8</sub>	<sup>1</sup> / <sub>8</sub>	<sup>2</sup> / <sub>16</sub>	0.700	<sup>2</sup> / <sub>16</sub>	<sup>1</sup> / <sub>4</sub>	.260
6	3	<sup>8</sup> / <sub>16</sub>	2.494	<sup>3</sup> / <sub>8</sub>	<sup>7</sup> / <sub>8</sub>	<sup>1</sup> / <sub>8</sub>	<sup>3</sup> / <sub>4</sub>	0.938	<sup>3</sup> / <sub>16</sub>	<sup>1</sup> / <sub>16</sub>	.322
6	4	<sup>8</sup> / <sub>16</sub>	2.494	<sup>3</sup> / <sub>8</sub>	<sup>7</sup> / <sub>8</sub>	<sup>1</sup> / <sub>8</sub>	<sup>4</sup> / <sub>16</sub>	1.231	<sup>3</sup> / <sub>16</sub>	<sup>1</sup> / <sub>4</sub>	.478
6	5	<sup>8</sup> / <sub>16</sub>	2.494	<sup>3</sup> / <sub>8</sub>	<sup>7</sup> / <sub>8</sub>	<sup>1</sup> / <sub>8</sub>	<sup>5</sup> / <sub>4</sub>	1.748	<sup>4</sup> / <sub>16</sub>	<sup>1</sup> / <sub>2</sub>	.635
7	3	<sup>11</sup> / <sub>16</sub>	3.270	<sup>1</sup> / <sub>2</sub>	<sup>1</sup> / <sub>8</sub>	<sup>1</sup> / <sub>8</sub>	<sup>3</sup> / <sub>16</sub>	0.938	<sup>3</sup> / <sub>16</sub>	<sup>1</sup> / <sub>16</sub>	.322
7	4	<sup>11</sup> / <sub>16</sub>	3.270	<sup>1</sup> / <sub>2</sub>	<sup>1</sup> / <sub>8</sub>	<sup>1</sup> / <sub>8</sub>	<sup>4</sup> / <sub>16</sub>	1.231	<sup>3</sup> / <sub>16</sub>	<sup>1</sup> / <sub>4</sub>	.478
7	5	<sup>11</sup> / <sub>16</sub>	3.270	<sup>1</sup> / <sub>2</sub>	<sup>1</sup> / <sub>8</sub>	<sup>1</sup> / <sub>8</sub>	<sup>5</sup> / <sub>4</sub>	1.748	<sup>4</sup> / <sub>16</sub>	<sup>1</sup> / <sub>2</sub>	.635
7	6	<sup>12</sup> / <sub>16</sub>	3.270	<sup>1</sup> / <sub>2</sub>	<sup>1</sup> / <sub>4</sub>	<sup>1</sup> / <sub>8</sub>	<sup>7</sup> / <sub>8</sub>	2.494	7	<sup>1</sup> / <sub>4</sub>	.760



MORSE TAPER SHANK

Taper No.	Dia. of Small End	Dia. at End of Socket	SHANK		Depth of Bore	Standard Plug Depth	TONGUE		KEYWAY		End of Socket to Keyway	Cutter Radius	Taper per Foot
			Whole Length	Depth			Thickness	Length	Width	Length			
	D	A	B	S	H	P	t	T	W	L	K	R	
0	.252	.356	<sup>2</sup> / <sub>16</sub>	<sup>2</sup> / <sub>16</sub>	<sup>2</sup> / <sub>16</sub>	2	<sup>3</sup> / <sub>16</sub>	<sup>1</sup> / <sub>4</sub>	.160	<sup>1</sup> / <sub>16</sub>	<sup>1</sup> / <sub>16</sub>	<sup>1</sup> / <sub>16</sub>	.6246
1	.369	.475	<sup>2</sup> / <sub>16</sub>	<sup>2</sup> / <sub>16</sub>	<sup>2</sup> / <sub>16</sub>	<sup>1</sup> / <sub>16</sub>	<sup>3</sup> / <sub>16</sub>	<sup>3</sup> / <sub>16</sub>	.213	<sup>3</sup> / <sub>4</sub>	<sup>2</sup> / <sub>16</sub>	<sup>1</sup> / <sub>16</sub>	.5986
2	.572	.700	<sup>3</sup> / <sub>16</sub>	<sup>2</sup> / <sub>16</sub>	<sup>2</sup> / <sub>16</sub>	<sup>2</sup> / <sub>16</sub>	<sup>1</sup> / <sub>4</sub>	<sup>7</sup> / <sub>16</sub>	.260	<sup>1</sup> / <sub>8</sub>	<sup>2</sup> / <sub>16</sub>	<sup>1</sup> / <sub>4</sub>	.5994
3	.778	.938	<sup>3</sup> / <sub>16</sub>	<sup>3</sup> / <sub>16</sub>	<sup>3</sup> / <sub>16</sub>	<sup>3</sup> / <sub>16</sub>	<sup>7</sup> / <sub>16</sub>	<sup>7</sup> / <sub>16</sub>	.322	<sup>1</sup> / <sub>16</sub>	<sup>3</sup> / <sub>16</sub>	<sup>7</sup> / <sub>16</sub>	.6023
4	1.020	1.231	<sup>4</sup> / <sub>16</sub>	<sup>4</sup> / <sub>16</sub>	<sup>4</sup> / <sub>16</sub>	<sup>4</sup> / <sub>16</sub>	<sup>15</sup> / <sub>32</sub>	<sup>7</sup> / <sub>8</sub>	.478	<sup>1</sup> / <sub>4</sub>	<sup>3</sup> / <sub>16</sub>	<sup>7</sup> / <sub>16</sub>	.6233
5	1.475	1.748	<sup>6</sup> / <sub>16</sub>	<sup>5</sup> / <sub>16</sub>	<sup>5</sup> / <sub>16</sub>	<sup>5</sup> / <sub>16</sub>	<sup>7</sup> / <sub>8</sub>	<sup>3</sup> / <sub>4</sub>	.635	<sup>1</sup> / <sub>2</sub>	<sup>4</sup> / <sub>16</sub>	<sup>7</sup> / <sub>8</sub>	.6315
6	2.116	2.494	<sup>8</sup> / <sub>16</sub>	<sup>8</sup> / <sub>16</sub>	<sup>7</sup> / <sub>8</sub>	<sup>7</sup> / <sub>8</sub>	<sup>3</sup> / <sub>4</sub>	<sup>1</sup> / <sub>8</sub>	.760	<sup>1</sup> / <sub>4</sub>	7	<sup>1</sup> / <sub>4</sub>	.6256

TAN - Taper per Foot divided by 24

and then multiplied by 2

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