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Table 1. Recommended values for precision boring/turning

Workpiece material	Hardness [Bhn]	Cutting speed - High speed steel Vc [feet/min] MIN	Vc [feet/min] MAX	Vc [m/min] MIN	Vc [m/min] MAX	Cutting speed - Carbide uncoated Vc [feet/min] MIN	Vc [feet/min] MAX	Vc [m/min] MIN	Vc [m/min] MAX	Feed rate per revolution f [inch] MIN	f [inch] MAX	f [mm] MIN	f [mm] MAX
Cast irons	190...320	16	197	5	60	33	492	10	150	0,003	0,020	0,080	0,500
Steel - plain carbon	85...200	49	394	15	120	197	919	60	280	0,003	0,020	0,080	0,500
Steel - alloys	35...50Rc	16	131	5	40	66	492	20	150	0,003	0,020	0,080	0,500
Steel - tool	50...58Rc	16	66	5	20	49	197	15	60	0,003	0,020	0,080	0,500
Steel - stainless	150...450	16	98	5	30	98	394	30	120	0,003	0,020	0,080	0,500
Aluminum alloys	30. . .150	492	1181	150	360	492	2625	150	800	0,003	0,020	0,080	0,500
Copper alloys	80...100Rb	98	591	30	180	164	1378	50	420	0,003	0,020	0,080	0,500
Nickel alloys	80. ..360	16	131	5	40	16	394	5	120	0,003	0,020	0,080	0,500
Titanium	250...375	16	98	5	30	33	328	10	100	0,003	0,020	0,080	0,500

Table 2. Recommended values for precision milling

Workpiece material	Hardness [Bhn]	Cutting speed - High speed steel Vc [feet/min] MIN	Vc [feet/min] MAX	Vc [m/min] MIN	Vc [m/min] MAX	Cutting speed - Carbide uncoated Vc [feet/min] MIN	Vc [feet/min] MAX	Vc [m/min] MIN	Vc [m/min] MAX	Feed rate per tooth f_t [inch] MIN	f_t [inch] MAX	f_t [mm] MIN	f_t [mm] MAX
Cast irons	190...320	16	197	5	60	33	492	10	150	0,005	0,012	0,120	0,300
Steel - plain carbon	85...200	49	394	15	120	197	919	60	280	0,005	0,012	0,120	0,300
Steel - alloys	35...50Rc	16	131	5	40	66	492	20	150	0,005	0,012	0,120	0,300
Steel - tool	50...58Rc	16	66	5	20	49	197	15	60	0,005	0,012	0,120	0,300
Steel - stainless	150...450	16	98	5	30	98	394	30	120	0,005	0,012	0,120	0,300
Aluminum alloys	30. . .150	492	1181	150	360	492	2625	150	800	0,005	0,012	0,120	0,300
Copper alloys	80...100Rb	98	591	30	180	164	1378	50	420	0,012	0,012	0,300	0,300
Nickel alloys	80...360	16	131	5	40	16	394	5	120	0,005	0,012	0,120	0,300
Titanium	250...375	16	98	5	30	33	328	10	100	0,005	0,012	0,120	0,300

Table 3. Recommended values for drilling

Workpiece material	Hardness [Bhn]	Cutting material	Cutting speed Vc [feet/min] MIN	Vc [feet/min] MAX	Vc [m/min] MIN	Vc [m/min] MAX	Feed rate per revolution f [inch] MIN	f [inch] MAX	f [mm] MIN	f [mm] MAX
Cast irons	190...320	High speed steel	33	295	10	90	0,002	0,008	0,050	0,200
Steel - plain carbon	85. . .200	High speed steel	49	148	15	45	0,002	0,008	0,050	0,200
Steel - alloys	35...50Rc	High speed steel	16	66	5	20	0,002	0,008	0,050	0,200
Steel - tool	50. . .58Rc	High speed steel	16	66	5	20	0,002	0,008	0,050	0,200
Steel - stainless	150...450	High speed steel	16	33	5	10	0,002	0,008	0,050	0,200
Aluminum alloys	30. . . 150	High speed steel	16	377	5	115	0,002	0,008	0,050	0,200
Copper alloys	80...100Rb	High speed steel	66	230	20	70	0,002	0,008	0,050	0,200
Nickel alloys	80...360	High speed steel	33	66	10	20	0,002	0,008	0,050	0,200
Titanium	250...375	High speed steel	16	49	5	15	0,002	0,008	0,050	0,200

Table 4. Recommended values for gun drilling – Carbide Tool

Workpiece material	Hardness [Bhn]	Cutting speed Vc [feet/min]		Vc [m/min]		Gun Drill Diameters [inch] – Feed - f [inch/revolution]: 5/64" - 5/32"		5/32" - 1/4"		1/4" - 1/2"		1/2" - 3/4"		3/4" - 1"		1" - 2"	
		MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
Cast irons- soft	120-220	250	350	76	107	0,00015	0,00025	0,0003	0,001	0,0015	0,001	0,003	0,002	0,005	0,003	0,007	0,003
Cast irons - hard	220-320	150	200	46	61			0,0003	0,0005								
Ductile Iron	140-260	200	300	61	91	0,00015	0,00025	0,0003	0,0005		0,0006		0,001		0,002		0,002
Malleable Iron	110-240	250	350	76	107	0,00015	0,00025	0,0003	0,0005		0,0006		0,001		0,002		0,002
Steel - soft	85...200	425	675	130	206												
Steel - Medium	200-325	225	450	69	137	0,00015	0,00025	0,0003	0,0005		0,0006		0,001		0,001		0,002
Steel - Hard	325-450	130	200	40	61												
Stainless Steel-Soft	135-275	250	300	76	91	0,00015	0,00025	0,0003	0,0005		0,0006		0,001		0,001		0,002
Stainless Steel-Hard	275-425	150	225	46	69												
Aluminum alloys- except Die casting			650		198												
Alum.Die casting			650		198	0,00015	0,00025	0,0003	0,001		0,003		0,005		0,008		0,01
Magnesium			650		198												
Brass and Bronze		500	600	152	183	0,00015	0,00025	0,0003	0,0005	0,001	0,003	0,003	0,005	0,005	0,008	0,008	0,01
Copper			350		107						0,001		0,003		0,005		0,008

Workpiece material	Hardness [Bhn]	Cutting speed Vc [feet/min]		Vc [m/min]		Gun Drill Diameters [inch] – Feed - f [mm/revolution]: 2,0 - 4,0		4,0 - 6,5		6,5 - 12,5		12,5 - 19,0		15,0 - 25,0		25,0 - 50,0	
		MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
Cast irons- soft	120-220	250	350	76	107			0,008	0,025								
Cast irons - hard	220-320	150	200	46	61	0,0038	0,0064	0,008	0,013	0,038	0,025	0,076	0,051	0,127	0,064	0,178	0,076
Ductile Iron	140-260	200	300	61	91	0,0038	0,0064	0,008	0,013		0,015		0,02		0,038		0,051
Malleable Iron	110-240	250	350	76	107	0,0038	0,0064	0,008	0,013		0,015		0,02		0,038		0,051
Steel - soft	85...200	425	675	130	206												
Steel - Medium	200-325	225	450	69	137												
Steel - Hard	325-450	130	200	40	61	0,0038	0,0064	0,008	0,013		0,015		0,02		0,025		0,038
Stainless Steel - Soft	135-275	250	300	76	91												
Stainless Steel - Hard	275-425	150	225	46	69	0,0038	0,0064	0,008	0,013		0,015		0,02		0,025		0,038
Aluminum alloys- except Die casting			650		198												
Alum.Die casting			650		198												
Magnesium			650		198	0,0038	0,0064	0,008	0,025		0,076		0,127		0,203		0,254
Brass and Bronze		500	600	152	183					0,025	0,076	0,076	0,127	0,127	0,203	0,203	0,254
Copper			350		107	0,0038	0,0064	0,008	0,013		0,025		0,076		0,127		0,203

Table 5. Machining Power calculation:

P_c [HP] = K_p[HP/ in.^{3}/min]×C×Q[in.^{3}/min]×W	P_c [kW] = K_p[kW/ cm^3/s]×C×Q[cm^3/s]×W

where: P_c = power at the cutting tool; HP, or kW
K_p = power constant, HP/ in.^{3}/min or kW/ cm^3/s (Tables 9, 10 and 11)
Q = metal removal rate; in.^{3}/min. or cm^3/s (Table 12)
C = feed factor for power constant (Table 7)
W = tool wear factor (Table 8)
V_c = cutting speed, fpm, or m/min (Table 1, 2, 3 and 4)
N = tool rotating speed, rpm or min^{-1}
f = feed rate for turning; in./rev. or mm/rev (Table 1)
f = feed rate for planing and shaping; in./stroke, or mm/stroke
f_t = feed per tooth; in./tooth, or mm/tooth (Table 2)
f_m = feed rate; in./min. or mm/min
d_t = maximum depth of cut per tooth: in. or mm
d = depth of cut; in. or mm
n_t = number of teeth on milling cutter
D = Tool diameter in inch or mm

Table 6. N- tool rotating speed calculation:

	Inch Units	SI Metric Units
N- Tool rotating speed [rpm]	$N = 3.82\frac{V_C[fpm]}{D[in.]}$	$N = 318{,}47\frac{V_C[m/\min]}{D[mm]}$

Table 7. Feed Factors, C, for Power Constants

Inch Unit				SI Metric Unit			
Feed in.[a]	C	Feed in.[a]	C	Feed mm.[b]	C	Feed mm.[b]	C
0.001	1.60	0.014	0.97	0.02	1.70	0.35	0.97
0.002	1.40	0.015	0.96	0.05	1.40	0.38	0.95
0.003	1.30	0.016	0.94	0.07	1.30	0.40	0.94
0.004	1.25	0.018	0.92	0.10	1.25	0.45	0.92
0.005	1.19	0.020	0.90	0.12	1.20	0.50	0.90
0.006	1.15	0.022	0.88	0.15	1.15	0.55	0.88
0.007	1.11	0.025	0.86	0.18	1.11	0.60	0.87
0.008	1.08	0.028	0.84	0.20	1.08	0.70	0.84
0.009	1.06	0.030	0.83	0.22	1.06	0.75	0.83
0.010	1.04	0.032	0.82	0.25	1.04	0.80	0.82
0.011	1.02	0.035	0.80	0.28	1.01	0.90	0.80
0.012	1.00	0.040	0.78	0.30	1.00	1.00	0.78
0.013	0.98	0.060	0.72	0.33	0.98	1.50	0.72

Table 8. Tool Wear Factors W

Type of Operation		W
For all operations with sharp cutting tools:		1.00
Turning	Finish turning (light cuts)	1.10
	Normal rough and semifinish turning	1.30
	Fxtra-heavy-duty rough turning	1.60 - 2.00
Milling	Slab milling	1.10
	End milling	1.10
	Light and medium face milling	1.10 - 1.25
Drilling	Extra-heavy-duty face milling	1.30 - 1.60
	Normal drilling	1.30
	Drilling hard-to-machine materials and drilling with a very dull drill	1.50
Broaching	Normal broaching	1.05 - 1.10
	Heavy-duty surface broaching	1.20 - 1.30

Power Constants K_p

Table 9. Power Constants K_p for Ferrous Cast Metals Using Sharp Cutting Tools

Material	Brinell Hardness Number	K_p Inch Unit	K_p SI Metric Unit	Material	Brinell Hardness Number	K_p Inch Unit	K_p SI Metric Unit
Gray Cast Iron	110-120	0.28	0.76	Malleable Iron			
	120-140	0.35	0.96	Ferritic	150-175	0.42	1.15
	140-160	0.38	1.04		175-200	0.57	1.56
	160-180	0.32	1.42	Pearlitic	200-250	0.82	2.24
	180-200	0.60	1.64		250-300	1.18	3.22
	200-220	0.71	1.94				
	220-240	0.91	2.48	Cast Steel	150-175	0.62	1.69
Alloy Cast Iron	150-175	0.30	0.82		175-200	0.78	2.13
	175-200	0.63	1.72		200-250	0.86	2.35
	200-250	0.92	2.51				

Table 10. Power Constant, K_P, for High-Temperature Alloys, Tool Steel Stainless Steel and Nonferrous Metal, Using Sharp Cutting Tools

Material	Brinell Hardness Number	K_p Inch Units	K_p Metric Units	Material	Brinell Hardness Number	K_p Inch Units	K_p Metric Units
High-Temp. Alloys				Stainless Steel	150-175	0.60	1.64
A 286	165	0.82	2.24		175-200	0.72	1.97
A 286	285	0.93	2.54		200-250	0.88	2.40
Chromology	200	0.87	3.22	Zinc Die Cast Alloys	…	0.25	0.68
Chromology	310	1.18	3.00	Pure Copper	…	0.91	2.48
Inco 700	330	1.12	3.06	Brass:			
Inco 702	230	1.10	3.00	Hard	…	0.83	2.27
Hastelloy-B	230	1.10	3.00	Medium	…	0.50	1.36
M-252	230	1.10	3.00	Soft	…	0.25	0.68
M-252	310	1.20	3.28	Leaded	…	0.30	0.82
Ti-150 A	340	0.65	1.77	Bronze:			
U-500	375	1.10	3.00	Hard	…	0.91	2.48
Monel Metal	…	1.00	2.73	Medium	…	0.50	1.36
Tool Steel	175-200	0.75	2.05	Aluminum:			
	200-250	0.88	2.40	Cast	…	0.25	0.68
	250-300	0.98	2.68	Rolled (Hard)	…	0.33	0.90
	300-350	1.20	3.28	Magnesium Alloys	…	0.10	0.27
	350-400	1.30	3.55				

Table 11. Power Canstants, K_p for Wrought Steels, Using Sharp Cutting Tools

Material	Brinell Hardness Number	K_p Inch Units	K_p SI Metric Units
Plain Carbon Steels			
All Plain Carbon Steels	80-100 100-120 120-140 140-160 160-180 180-200 200-220 220-240 240-260 260-280 280-300 300-320 320-340 340-360	0.63 0.66 0.69 0.74 0.78 0.82 0.85 0.89 0.92 0.95 1.00 1.03 1.06 1.14	1.72 1.80 1.88 2.02 2.13 2.24 2.32 2.43 2.51 2.59 2.73 2.81 2.89 3.11
Free Machining Steels			
AISI 1108, 1109, 1110, 1115, 1116, 1117,1118,1119, 1120, 1125, 1126, 1132	100-120 120-140 140-160 160-180 180-200	0.41 0.42 0.44 0.48 0.50	1.12 1.15 1.20 1.31 1.36
AISI 1137, 1138, 1139, 1140, 1141, 1144, 1145, 1146, 1148, 1151	180-200 200-220 220-240 240-260	0.51 0.55 0.57 0.62	1.39 1.50 1.56 1.69
Alloy Steels			
AISI 4023, 4024, 4027, 4028, 4032 4037, 4042, 4047, 4137, 4140, 4142 4145, 4147, 4150, 4340, 4640, 4815, 4817, 4820, 5130 5132 5135, 5140 5145, 5150, 6118, 6150, 8637, 8640, 8642, 8645, 8650, 8740	140-160 160-180 180-200 200-220	0.62 0.65 0.69 0.72	1.69 1.77 1.88 1.97

	220-240 240-260 260-280 280-300 300-320 320-340 340-360	0.76 0.80 0.84 0.87 0.91 0.96 1.00	2.07 2.18 2.29 2.38 2.48 2.62 2.73
AISI 4130, 4320, 4615, 4620, 4626, 5120, 8615, 8617, 8620, 8622, 8625, 8630, 8720	140-160 160-180 180-200 200-220 220-240 240-260 260-280 280-300 300-320 320-340	0.56 0.59 0.62 0.65 0.70 0.74 0.77 0.80 0.83 0.89	1.53 1.61 1.69 1.77 1.91 2.02 2.10 2.18 2.27 2.43
AISI 1330, I335, 1340, E52100	160-180 180-200 200-220 220-240 240-260 260-280	0.79 0.83 0.87 0.91 0.95 1.00	2.16 2.27 2.38 2.48 2.59 2.73

Table 12. Formulas for Calculating the Metal Removal Rate, Q

Operation	Metal Removal Rate	
	For Inch Units Only $Q = in.^3/min$	**For SI Metric Units Only** $Q = cm^3/s$
Single-Point Tools (Turning, planing, and Shaping)	$12\ V_C\ f\ d$	$\frac{V_C\ f\ d}{60}$
Milling	$f_m\ w\ d$	$\frac{f_m\ w\ d}{60{,}000}$
Surface Broaching	$12\ V_C\ w\ n_c\ d_t$	$\frac{V_C\ w\ n_c\ d_t}{60}$

n_c = number of teeth engaged in work
w = width of cut; in. or mm
V_c = cutting speed, fpm, or m/min (see **Table 1, 2, 3** and **4**)
f = feed rate for turning; in./rev. or mm/rev (see **Table 1**)
f = feed rate for planing and shaping; in./stroke, or mm/stroke
f_m = feed rate; in./min. or mm/min
d_t = maximum depth of cut per tooth: in. or mm
d = depth of cut; in. or mm

Table 13. Thrust, Torque and Power at Drilling with a Sharp Drill

	Inch Units	SI Metric Units
Thrust	$T = 2\ K_d\ F_f\ F_T\ BW + K_d\ d^2\ J\ W$ [lb]	$T = 0.05\ K_d\ F_f\ F_T\ B\ W + 0.007\ K_d\ d^2\ J\ W$ [N]
Torque	$M = K_d\ F_f\ F_M\ A\ W$ [in.-lb]	$M = 0.000025\ K_d\ F_f\ F_M\ A\ W$ [Nm]
Power at	$P_c = M\ N / 63.025$ [HP]	$P_c = M\ N / 9550$ [kW]

the cutter		

where:

P_c = Power at the cutter; hp, or kW
M = Torque; in.- Ib, or Nm
T = Thrust; Ib, or N
K_d = Work material factor (See **Table 14**)
F_f = Feed factor (See **Table 16**)
F_T = Thrust factor for drill diameter (See **Table 17**)
F_M = Torque factor for drill diameter (See **Table 17**)
A = Chisel edge factor for torque (See **Table 15**)
B = Chisel edge factor for thrust (See **Table 15**)
J = Chisel edge factor for thrust (See **Table 15**)
W = Tool wear factor (See **Table 8**)
N = Spindle speed; rpm
D = Drill diameter; in, or mm
c = Chisel edge length; in, or mm (See **Table 15**)
w = Web thickness at drill point; in, or mm (See **Table 15**)

Table 14. Work Material Factor, K_d for Drilling with a Sharp Drill

Work Material	Constant K_d
AISI 1117 (Resulfurized free machining mild steel)	12,000
Steel, 200 Bhn	24,000
Steel, 300 Bhn	31,000
Steel, 400 Bhn	34,000
cast Iron, 150 Bhn	14,000
Most Aluminum Alloys	7,000
Most Magnedum Alloys	4,000
Most Brasses	14,000
Leaded Brass	7,000
Austenitic Stainless Steel (Type 316)	24,000[a] for Torque
	35,000[a] for Thrust
Titanium Alloy T16A	18000[a] for Torque
	29,000[a] for Thrust
Rent 41	40,000[ab] min.
Hastelloy-c	30,000[a] for Torque
	37,000[a] for Thrust

[a]Values based upon a limited number of tests.
[b]Will increase with rapid wear

Table 15. Chisel Edge Factors for Torque and Thrust

c/d	Approx. w/d	Torque Factor A	Thrust Factor B	Thrust Factor J	c/d	Approx. w/d	Torque Factor A	Thrust Factor B	Thrust Factor J
0.03	0.025	1.000	1.100	0.001	0.18	0.155	1.085	1.355	0.030
0.05	0.045	1.005	1.140	0.003	0.20	0.175	1.105	1.380	0.040
0.08	0.070	1.015	1.200	0.006	0.25	0.220	1.155	1.445	0.065
0.10	0.085	1.020	1.235	0.010	0.30	0.260	1.235	1.500	0.090
0.13	0.110	1.040	1.270	0.017	0.35	0.300	1.310	1.575	0.120
0.15	0.130	1.080	1.310	0.022	0.40	0.350	1.395	1.620	0.160

Note:
For drills of standard design, use c/d = 0.18
For split point drills, use c/d= 0.03
c/d = Length of Chisel Edge / Drill Diameter
w/d= Web Thickness at Drill Point / Drill Diameter

Table 16. Feed Factors F_f for Drilling

Inch Units				SI Metric Units			
Feed inch/rev.	F_f	Feed inch/rev.	F_f	Feed mm/rev.	F_f	Feed mm/rev.	F_f
0.0005	0.0023	0.012	0.029	0.01	0.025	0.30	0.382
0.001	0.004	0.013	0.031	0.03	0.060	0.35	0.432
0.002	0.007	0.015	0.035	0.05	0.091	0.40	0.480
0.003	0.010	0.018	0.040	0.08	0.133	0.45	0.528
0.004	0.012	0.020	0.044	0.010	0.158	0.50	0.574
0.005	0.014	0.022	0.047	0.12	0.183	0.55	0.620
0.006	0.017	0.025	0.052	0.15	0.219	0.65	0.708
0.007	0.019	0.030	0.060	0.18	0.254	0.75	0.794
0.008	0.021	0.035	0.068	0.20	0.276	0.90	0.919
0.009	0.023	0.040	0.076	0.22	0.298	1.00	1.000
0.010	0.025	0.050	0.091	0.25	0.330	1.25	1.195

Table 17. Drill Diameter Factors: F_T for Thrust; F_M for Torque

Inch Units						SI Metric Units					
Drill Dia. inch	F_T	F_M	Drill Dia. inch	F_T	F_M	Drill Dia. mm	F_T	F_M	Drill Dia. mm	F_T	F_M
0.063	0.110	0.007	0.875	0.899	0.786	1.60	1.46	2.33	22.00	11.86	260.8
0.094	0.151	0.014	0.938	0.950	0.891	2.40	2.02	4.84	24.00	12.71	305.1
0.125	0.189	0.024	1.000	1.000	1.000	3.20	2.54	8.12	25.50	13.34	340.2
0.156	0.226	0.035	1.063	1.050	1.116	4.00	3.03	12.12	27.00	13.97	377.1
0.188	0.263	0.049	1.125	1.099	1.236	4.80	3.51	16.84	28.50	14.58	415.6
0.219	0.297	0.065	1.250	1.195	1.494	5.60	3.97	22.22	32.00	16.00	512.0
0.250	0.330	0.082	1.375	1.290	1.774	6.40	4.42	28.26	35.00	17.19	601.4
0.281	0.362	0.102	1.500	1.383	2.075	7.20	4.85	34.93	38.00	18.36	697.6
0.313	0.395	0.124	1.625	1.475	2.396	8.00	5.28	42.22	42.00	19.89	835.3
0.344	0.426	0.146	1.750	1.565	2.738	8.80	5.96	50.13	45.00	21.02	945.8
0.375	0.456	0.171	1.875	1.653	3.100	9.50	6.06	57.53	48.00	22.13	1062
0.438	0.517	0.226	2.000	1.741	3.482	11.00	6.81	74.90	50.00	22.86	1143
0.500	0.574	0.287	2.250	1.913	4.305	12.50	7.54	94.28	58.00	25.75	1493
0.563	0.632	0.355	2.500	2.081	5.203	14.50	8.49	123.1	64.00	27.86	1783
0.625	0.687	0.429	2.750	2.246	6.177	16.00	9.19	147.0	70.00	29.93	2095
0.688	0.741	0.510	3.000	2.408	7.225	17.50	9.87	172.8	76.00	31.96	2429
0.750	0.794	0.596	3.500	2.724	9.535	19.00	10.54	200.3	90.00	36.53	3293
0.813	0.847	0.689	4.000	3.031	12.13	20.00	10.98	219.7	100.00	39.81	3981

$$\mathbf{P_G = K_C \times MRR} \quad [HP] \text{ or } [kW]$$

Table 18. P_G –Grinding Power

	Inch Units	SI Metric Units
Grinding Power	$P_G = \frac{K_C \cdot MRR}{396{,}270}$ [HP]	$P_G = \frac{K_C \cdot MRR}{60{,}000{,}000}$ [kW]

where :

P_G = Grinding power at the grinding wheel; HP, or kW
K_C = specific cutting force [psi] or [N/mm²] – see **Table 19.**
MRR = metal removal rate [mm³/min] or [in³/min] – see **Table 21.**

Table 19. Approximately K_C can be taken in next ranges:

Material	K_C [N/mm²]	K_C [psi]
unhardened steel	50,000 to 70,000 N/mm²	7,250,000 to 10,150,000
hardened steel	150,000 to 200,000 N/mm²	21,750,000 to 29,000,000

ECT – Equivalent chip thickness in Grinding

The definition of ECT is: $ECT = \frac{A}{CEL}$ [mm] or [inch]

$$ECT = \frac{\pi \cdot D \cdot z \cdot f_z \cdot a_r \cdot a_a}{CEL}$$

ECT = equivalent chip thickness $=f(a_r, V, V_W, f_S)$ [mm] or [inch]

$$ECT = \frac{V_W f_S (a_r + 1)}{V} = approximately \ \frac{V_w \cdot a_r}{V}$$

Table 20. ECT = equivalent chip thickness

	Inch Units	SI Metric Units

ECT	$ECT = \frac{SMRR \cdot f_S}{V \cdot 12}$ [inch]	$ECT = \frac{SMRR \cdot f_S}{V \cdot 1000}$ [mm]

Table 21. MRR = metal removal rate

MRR = SMRR x f_s
MRR = (1000 x a_r x V_w) x f_s [mm^3/min] or [in^3/min]

	Inch Units	SI Metric Units
MRR	$MRR = ECT \cdot V \cdot 12$ [in^3/min]	$MRR = ECT \cdot V \cdot 1000$ [mm^3/min]

Table 22. Grinding parameter recommendations typically range as follows:

Recommended grinding parameter	SI- Metric Units	Inch Units
Wheel speed	1200 to 1800 m/min	4000 to 6000 fpm
Work speed	20 to 40 m/min	70 to 140 fpm
Depth of cut for roughing grinding	0.01 to 0.025 mm	0.0004 to 0.001 inch
Depth of cut for finish grinding	around 0.005 mm	around 0.0002 inch
Grit sizes for roughing grinding for easy-to-grind materials	46 to 60	
Grit sizes for roughing grinding for difficult-to-grind materials	> 80	
Internal griding grit sizes for small holes	100 to 320	
Specific metal removal rate – **SMRR** *	200 to 500 mm^3/mm width/min	0.3 to 0.75 in^3/inch width/min

Table 23. C- fraction of grinding wheel width

Work Material	Roughing, C	Finishing, C
Steel	2/3 – 3/4	1/3 – 3/8
Stainless Steel	1/2	1/4
Cast Iron	3/4	3/8
Hardened Steel	1/2	1/4

Table 24. Grindability Groups

Group	Examples
Group 1 Unhardened Steels	
Group 2 Stainless Steels	SAE 30201-30347, 51409-51501
Group 3 Cast iron	
Group 4 Tool Steels	M1, M8, T1, H, O, L, F 52100
Group 5 Tool Steels	M2, T2, T5, T6, D2, H41, H42, H43, M50
Group 6 Tool Steels	M3, M4, T3, D7
Group 7 Tool Steels	T15, M15
Group 8 Heat Resistaut Steels	Inconel, Rene etc.
Group 9 Carbide Materials	P30 Diamond Wheel
Group 10 Ceramic Materials	

Table 25. Max. Peripheral Speeds for Grinding Wheels- Based on ANSI B7.1-1988

Classification No.	Types of Wheels[a]	Maximum Operating Surface Speeds **sfpm –feet per minute** **(m/min)** Depending on Streingth of Bond	
		Inorganic Bonds	Organic Bonds
1	Straight wheels - Type 1, except classsifications 6, 7, 9, 10, 11, and 12 below Type 4[b] - Taper Side Wheels Types 5, 7, 20, 21, 22, 23, 24, 25, 26 Dish wheels - Type 12 Saucer wheels - Type 13 Cones and plugs - Types 16, 17, 18, 19	5,500 to 6,500 (1674 to 1980)	6,500 to 9,500 (1980 to 2898)
2	Cylinder wheels - Type 2 Segments	5,000 to 6,000 (1524 to 1830)	5,000 to 7,000 (1524 to 2136)
3	Cup shape tool grinding wheels – Types 6 and 11 (for fixed base machines)	4,500 to 6,000 (1374 to 1830)	6,000 to 8,500 (1830 to 2592)
4	Cup shape snagging wheels - Types 6 and 11 (for portable machines)	4,500 to 6,500 (1374 to 1980)	6,000 to 9,500 (1830 to 2898)
5	Abrasive disks	5,500 to 6,500 (1674 to 1980)	5,500 to 8,500 (1674 to 2592)
6	Reinforced wheels - except cutting-off wheels (depending on diameter and thickness)	…	9,500 to 16,000 (2898 to 4878)
7	Type 1 wheels for bench and pedestal grinders, Types 1 and 5 also in certain sizes for surface grinders	5,500 to 7,550 (1674 to 2304)	6,500 to 9,500 (1980 to 2898)
8	Diamond and cubic boron nitride wheels Metal bond Steel centered cutting off	to 6,500 (1980) to 12,000 (3660) to 16,000 (4878)	to 9,500 (2898) … to 16,000 (4878)
9	Cutting-offwheels -- Larger than 16-inch diameter ~ncL reinforced organic)	…	9,500 to 14,200 (2898 to 4326)
10	Cutting-offwheels - I6-inch diameter and smaller (incl. reinforced organic)	…	9,500 to 16,000 (2898 to 4878)
11	Thread and flute grinding wheels	8,000 to 12,000 (2436 to 3660)	8,000 to 12,000 (2436 to 3660)
12	Crankshaft and camshaft grinding wheels	5,500 to 8,500 (1674 to 2592)	6,500 to 9,500 (1980 to 2898)

Table 26. Formulas for calculating the rotational speed

	Inch Units	SI Metric Units
Rotational Speed N [RPM]	$N = \frac{12 \cdot V}{D \cdot \pi}$	$N = \frac{1000 \cdot V}{D \cdot \pi}$

Driving Motor Power

The Power at the Driving motor, for all kind of machining is given below:

Table 27. Driving Motor Power

	Inch Units	SI Metric Units
Driving Motor Power	$P_m = \frac{P[HP]}{E}[HP]$	$P_m = \frac{P[kW]}{E}[kW]$

where

P = power at the cutting tool; HP, or kW
P_m = power at the motor; HP, or kW
E = machine tool efficiency factor (see **Table 28**)

Table 28. Machine Tool Efficiency Factors E

Type of Drive	E
Direct and belt drive	0.90
Back Gear Drive	0.75
Geared Head Drive	0.70 – 0.80
Oil-Hydraulic Drive	0.60 – 0.90

Driving Motor Torque

Separate formulas are required for use with customary inch units and for SI metric units:

Table 29. Formulas for calculating of Driving Motor Torque

	Inch Units	SI Metric Units
Motor Torque at 100% Load	$T_m = \frac{63{,}025 \cdot P_m[HP]}{N[rpm]}$ [lb-in]	$T_m = \frac{9550 \cdot P_m[kW]}{N[rpm]}$ [Nm]

where:

T_m - motor torque [lb-in] or [Nm];
P_m - motor power [HP] or [kW];
N - motor rotational speed [rpm]

and some additional units combination:

$T_m = \frac{5{,}252 \cdot P_m[HP]}{N[rpm]}$ [lb-feet]	$T_m = \frac{84{,}454 \cdot P_m[kW]}{N[rpm]}$ [lb-in]	$T_m = \frac{7{,}127 \cdot P_m[HP]}{N[rpm]}$ [Nm]

Table 30. Electrical Formulas

To Find	Alternating Current		To Find	Alternating or Direct Current
	Single Phase	Three Phase		
Amperas when Horsepower is known	$I=\frac{HP\cdot 746}{V\cdot E\cdot pf}$	$I=\frac{HP\cdot 746}{1.73\cdot V\cdot E\cdot pf}$	Amperas when Voltage and Resistance are known	$I=\frac{E}{R}$ [A]
Amperas when Kilowatts are known	$I=\frac{KW\cdot 1000}{V\cdot pf}$	$I=\frac{KW\cdot 1000}{1.73\cdot V\cdot pf}$	Voltage when Resistance and Current are known	$V=I\cdot R$ [V]
Amperas when KVA are known	$I=\frac{KVA\cdot 1000}{V}$	$I=\frac{KVA\cdot 1000}{1.73\cdot V}$	Resistance when Voltage and Current are known	$R=\frac{E}{I}$ [Ohm]
Kilowatts	$\frac{I\cdot V\cdot pf}{1000}$	$\frac{1.73\cdot I\cdot V\cdot pf}{1000}$	General information (Approximation) at 100% Load: -at 575 V, 3-phase motor draws 1.0 A/HP -at 460 V, 3-phase motor draws 1.25 A/HP -at 230 V, 3-phase motor draws 2.5 A/HP -at 230 V, 1-phase motor draws 5.0 A/HP -at 115 V, 1-phase motor draws 10.0 A/HP	
KVA	$\frac{I\cdot V}{1000}$	$\frac{1.73\cdot I\cdot V}{1000}$		
Horsepower = (Output)	$\frac{I\cdot V\cdot E\cdot pf}{746}$	$\frac{1.73\cdot I\cdot V\cdot E\cdot pf}{746}$		
I- Current[A]; V= Voltage[V]; E= Efficiency- see Table 26.; pf= power factor- estimated at 80% for most motors; KVA=Kilovoltsamperes; KW=Kilowatts; R=Resistance[Ohm];			$RPM=\frac{120\times Frequency}{Number\ of\ poles}$	

Table 31. Motor Amps at Full Load:

HP	Alternating Current [A]			HP	Alternating Current [A]		
	Single-Phase	3-phase	DC [A]		Single-Phase	3-phase	DC [A]
0.5	4.9	2.0	2.7	25	...	60	92
1	8.0	3.4	4.8	30	...	75	110
1.5	10.0	4.8	6.6	40	...	100	146
2	12.0	6.2	8.5	50	...	120	180
3	17.0	8.6	12.5	60	...	150	215
5	28	14.4	20	75	...	180	268
7.5	40	21.0	29	100	...	240	355
10	50	26.0	38	125	...	300	443
15	...	38.0	56	150	...	360	534
20	...	50.0	74	200	...	480	712

Note: Values given in Table 31. are for all speeds and frequences at 230V. Amperas at voltage other than 230 Volts can be figured:

$$A=\frac{230\cdot Amp.fromTable}{NewVoltage}\quad [A]$$

Protection Against Solid Objects		**Protection Against Liquids**	
Number	**Definition**	**Number**	**Definition**
0	No protection	**0**	No protection
1	Protected against solid objects of over 50mm (e.g. accidental hand contact)	**1**	Protected against water vertically dripping (condensation).
2	Protected against solid objects of over 12mm (e.g.finger)	**2**	Protected against water dripping up to 15° from the vertical.
3	Protected against solid objects of over 2.5mm (e.g. tools, wire)	**3**	Protected against rain falling at up to 60° from the vertical.
4	Protected against solid objects of over 1mm (e.g. thin wire)	**4**	Protected against water splashes from all directions.
5	Protected against dust	**5**	Protected against jets of water from all directions.
6	Totally protected against dust	**6**	Protected against jets of water comparable to heavy seas.
		7	Protected against the effects of immersion to depths of between 0.15 and 1m.
		8	Protected against the effects of prolonged immersion at depth.

IEC has additional two digit designations indicating how a motor is cooled:

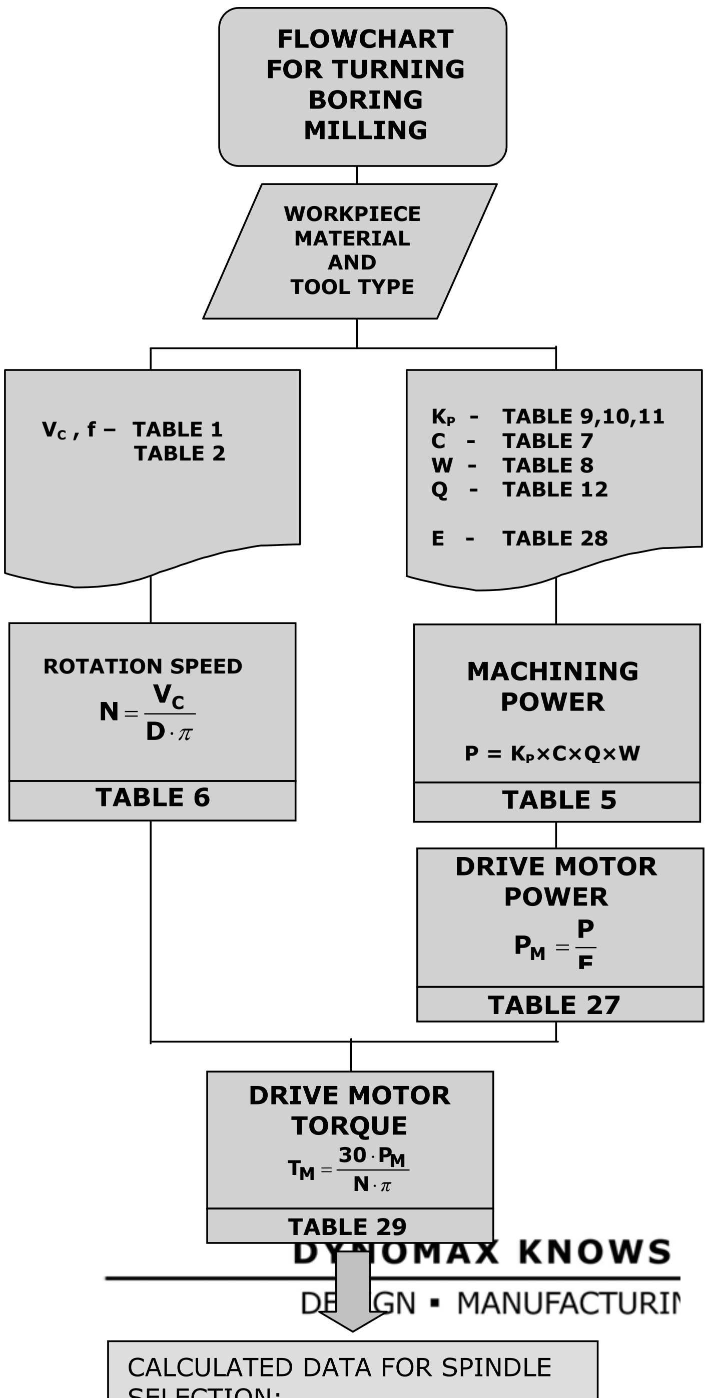
Designation	Cooling design
IC 01	Open design
IC 40	TENV -Totally Enclosed Non-Ventilated
IC 41	TEFC -Totally Enclosed Fan Cooled
IC 43	TEAO -Totally Enclosed Air Over

Duty cycles could be designated as continuous, intermittent, or special duty (typically expressed in minutes), IEC uses eight duty cycle designations.

Duty Cycle Designation	Description
S1	Continuous duty. The motor works at a constant load for enough time to reach temperature equilibrium.
S2	Short-time duty. The motor works at a constant load, but not long enough to reach temperature equilibrium, and the rest periods are long enough for the motor to reach ambient temperature.
S3	Intermittent periodic duty. Sequential, identical run and rest cycles with constant load. Temperature equilibrium is never reached. Starting current has little effect on temperature rise.
S4	Intermittent periodic duty with starting. Sequential, identical start, run and rest cycles with constant load. Temperature equilibrium is not reached, but starting current affects temperature rise.
S5	Intermittent periodic duty with electric braking. Sequential, identical cycles of starting, running at constant load, electric braking, and rest. Temperature equilibrium is not reached.
S6	Continuous operation with intermittent load. Sequential, identical cycles of running with constant load and running with no load. No rest periods.
S7	Continuous operation with electric braking. Sequential identical cycles of starting, running at constant load and electric braking. No rest periods.
S8	Continuous operation with periodic changes in load and speed. Sequential, identical duty cycles of start, run at constant load and given speed, then run at other constant loads and speeds. No rest periods.

4. FLOWCHARTS

FLOWCHART FOR TURNING, BORING AND MILLING



VARIABLES DEFINED:

V_C - Cutting Speed
f - Feed Rate

K_p - Power Constant
C - Feed Factor
W - Tool Wear Factor
Q - Metal Removal Rate

D - Tool or Work diameter

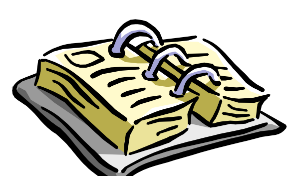
E - Machine Efficiency Factor

N - Rotation Speed

P - Machine Power

P_M - Drive Motor Power

T_M - Drive Motor Torque



FLOWCHART FOR DRILLING

FLOWCHART FOR DRILLING

WORKPIECE MATERIAL AND TOOL TYPE

V_C, f – TABLE 3, TABLE 4

ROTATION SPEED

$$N = \frac{V_C}{D \cdot \pi}$$

TABLE 6

K_d	-	TABLE 14
F_f	-	TABLE 16
F_T, F_M	-	TABLE 17
A,B,J	-	TABLE 15
W	-	TABLE 8
c/D	-	TABLE 15
w/D	-	TABLE 15
E	-	TABLE 28

THRUST

$$T = K_d \times F_f \times F_T \times B \times W + K_d \times d^2 \times J \times W$$

TABLE 13

TORQUE

$$M = K_d \times F_f \times F_M \times A \times W$$

TABLE 13

MACHINING POWER

$$P = M \frac{\pi \cdot N}{30}$$

TABLE 13

DRIVE MOTOR POWER

$$P_M = \frac{P}{E}$$

TABLE 27

DRIVE MOTOR TORQUE

$$T_M = \frac{30 \cdot P_M}{N \cdot \pi}$$

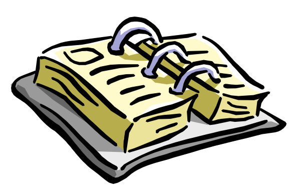
TABLE 29

CALCULATED DATA FOR SPINDLE SELECTION:

1. **ROTATION SPEED - N**
2. **DRIVE MOTOR POWER - P_M**
3. **DRIVE MOTOR TORQUE - T_M**

VARIABLES DEFINED:

V_C	-	Cutting Speed
f	-	Feed Rate
K_d	-	Work material factor
F_f	-	Feed factor
F_T	-	Thrust factor
F_M	-	Torque factor
A	-	Chisel edge factor for torque
B	-	Chisel edge factor for thrust
J	-	Chisel edge factor for thrust
W	-	Tool Wear Factor
c	-	Chisel edge length
w	-	Web thickness at drill point
D	-	Drill diameter
E	-	Machine Efficiency Factor
N	-	Rotation Speed
T	-	Thrust
M	-	Torque
P	-	Machine Power
P_M	-	Drive Motor Power
T_M	-	Drive Motor Torque



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FLOWCHART FOR GRINDING

FLOWCHART FOR GRINDING

WORK-PIECE MATERIAL AND WHEEL DATA:
- Width
- D (Diameter)

V – TABLE 22, 25
V_W - TABLE 22

K_C - TABLE 19
SMRR - TABLE 22
C - TABLE 23
E - TABLE 28

$f_S = C \times Width$

WORK-PIECE ROTATION SPEED

$$N_W = \frac{V_W}{D_W \cdot \pi}$$

$$ECT = \frac{SMRR \cdot f_S}{V}$$

TABLE 20

$$MRR = ECT \cdot V$$

TABLE 21

WHEEL ROTATION SPEED

$$N = \frac{V_C}{D \cdot \pi}$$

TABLE 26

MACHINING POWER

$$P_G = K_C \times MRR$$

TABLE 18

DRIVE MOTOR POWER

$$P_M = \frac{P_G}{E}$$

TABLE 27

DRIVE MOTOR TORQUE

$$T_M = \frac{30 \cdot P_M}{N \cdot \pi}$$

TABLE 29

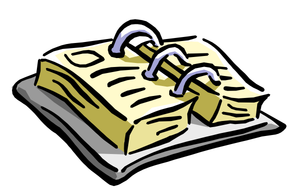
CALCULATED DATA FOR SPINDLE SELECTION:

1. **ROTATION SPEED - N**
2. **DRIVE MOTOR POWER - P_M**
3. **DRIVE MOTOR TORQUE - T_M**

VARIABLES DEFINED:

- **K_C - Specific cutting force**
- **SMRR- Specific Metal Removal Rate**
- **Width- Grinding wheel width**
- **D - Grinding wheel diameter**
- **D_W - Work-piece diameter**
- **V - Wheel speed**
- **V_W - Work-piece speed**
- **C - Fraction of grinding wheel width**
- **f_S - Side feed**
- **ECT - Equivalent chip thickness**
- **MRR - Metal Removal Rate**
- **E - Machine Efficiency Factor**

- **N - Wheel Rotation Speed**
- **N_W - Work-piece Rotation speed**
- **P_G - Grinding Power**
- **P_M - Drive Motor Power**
- **T - Drive Motor Torque**



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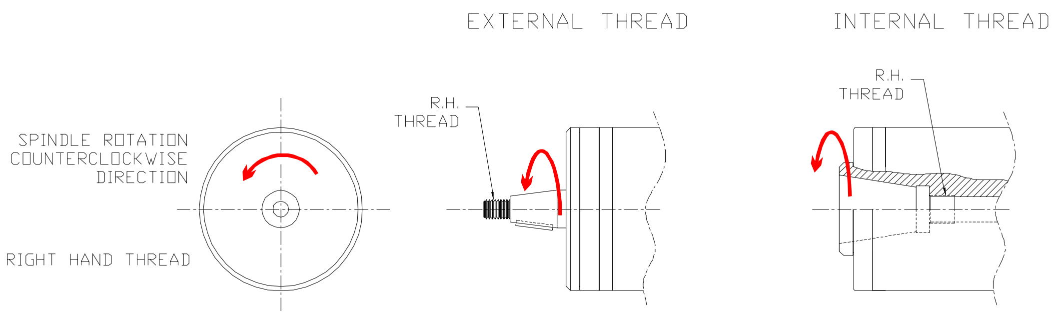
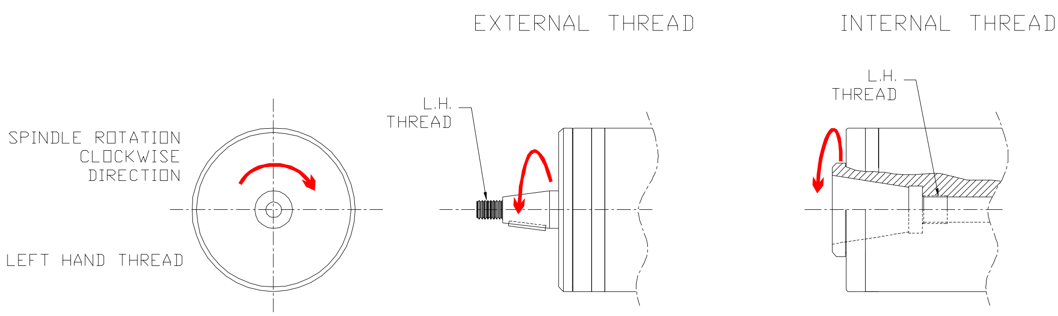
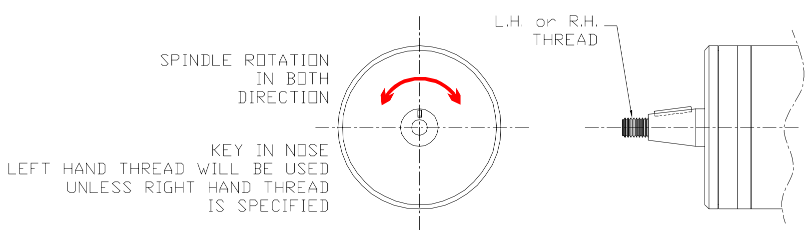
SPINDLE ROTATION COUNTERCLOCKWISE



SPINDLE ROTATION CLOCKWISE



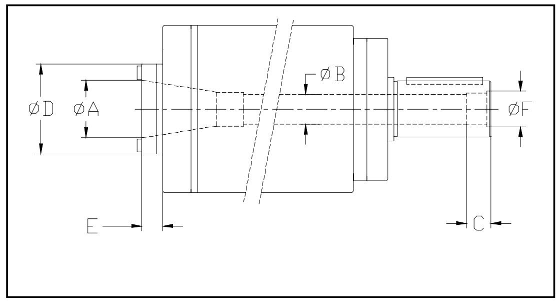
SPINDLE ROTATION EITHER DIRECTION



Size*	Bearing**	D	E	F	T	Thread	Key
1.00	30	25.400	47.00	44.00	13.00	.500-13	None
1.25	35	31.750	60.00	57.00	19.00	.500-13	6.35
1.62	45	41.275	74.00	71.00	27.00	.750-16	6.35
2.25	60	57.150	99.00	96.00	39.00	1.125-12	6.35
2.62	70	66.675	114.00	111.00	45.00	1.500-12	9.53
3.00	80	76.200	123.00	120.00	45.00	1.500-12	9.53
3.75	100	95.250	162.00	159.00	64.00	2.250-12	9.53
4.50	120	114.300	194.00	191.00	77.00	2.750-12	9.53
5.00	140	127.000	207.00	204.00	77.00	2.750-12	9.53

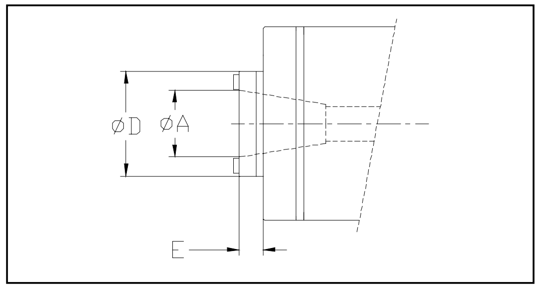
Size	Bearing*	A	D	E	B	F	C
30	40	31.750	69.832	13.00	14.29	15.88	12.70
40	50	44.450	88.882	16.00	17.50	19.05	12.70
45	70	57.150	101.582	18.00	20.00	25.40	15.88
50	80	69.850	128.569	20.00	27.00	31.75	15.88
60	120	107.950	221.437	38.00	36.00	38.10	19.05

* Minimum front bearing bore size [mm]

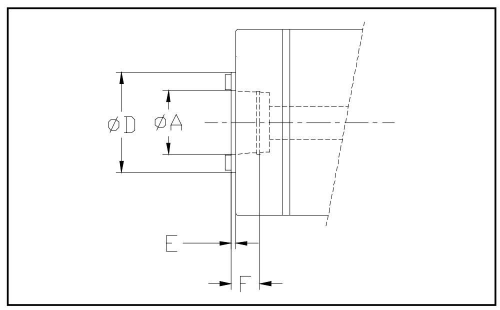


Size	Bearing*	A	D	E
30	40	31.750	50.00	13.00
40	50	44.450	65.00	16.00
45	70	57.150	85.00	18.00
50	80	69.850	100.00	20.00
60	120	107.950	160.00	38.00

* Minimum front bearing bore size [mm]



Size	Bearing*	A	D	F	E
HSK 25A	30	19.000	25.00	9.40	10.00
HSK 32A	40	24.000	32.00	11.40	12.00
HSK 40A	50	30.000	40.00	14.40	15.00
HSK 50A	60	38.000	50.00	17.90	18.00
HSK 63A	70	48.000	63.00	22.40	23.00
HSK 80A	90	60.000	80.00	28.40	29.00
HSK 100A	110	75.000	100.00	35.40	36.00
HSK 125A	130	95.000	125.00	44.40	45.00
HSK 160A	170	120.000	160.00	57.40	58.00



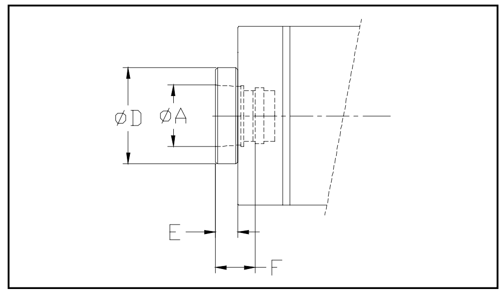
* Minimum front bearing bore size [mm]

Size	Bearing*	A	D	F	E
HSK 40B	50	24.000	40.00	20.50	21.00
HSK 50B	60	30.000	50.00	25.50	26.00
HSK 63B	70	38.000	63.00	25.50	26.00
HSK 80B	90	48.000	80.00	33.00	34.00
HSK 100B	110	60.000	100.00	41.00	42.00
HSK 125B	130	75.000	125.00	51.00	52.00
HSK 160B	170	95.000	160.00	64.00	65.00

* Minimum front bearing bore size [mm]

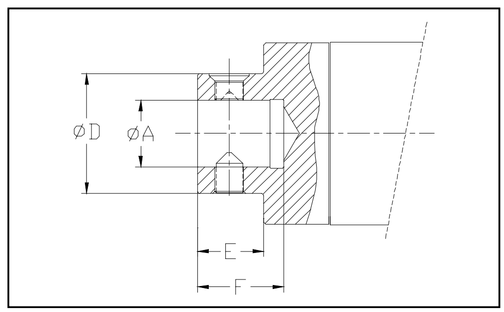
						Clamp Force (kN)	
Size	Bearing*	A	D	F	E	Guhring	Mapal
HSK 32C	40	24.000	32.00	11.40	12.00	9	11
HSK 40C	50	30.000	40.00	14.40	15.00	15	15
HSK 50C	60	38.000	50.00	17.90	18.00	23	21
HSK 63C	70	48.000	63.00	22.40	23.00	33	30
HSK 80C	90	60.000	80.00	28.40	29.00	50	38
HSK 100C	110	75.000	100.00	35.40	36.00	70	50

* Minimum front bearing bore size [mm]



Size	Bearing*	A	D	F	E
ABS 25	30	13.000	25.000	24.00	20.00
ABS 32	35	16.000	32.000	27.00	23.00
ABS 40	40	20.000	40.000	31.00	27.00
ABS 50	50	28.000	50.000	36.00	32.00
ABS 63	60	34.000	63.000	43.00	39.00
ABS 80	80	46.000	80.000	48.00	44.00
ABS 100	100	56.000	100.000	60.00	52.00
ABS 125	130	70.000	125.000	76.00	64.00
ABS 160	160	90.000	160.000	96.00	80.00
ABS 200	200	112.000	200.000	116.00	100.00

* Minimum front bearing bore size [mm]



7. Conversion Constants and Formulas for Metric and U.S. Units

Table 32. Length Conversion

[μm] micrometer × 0.00003937 = inches [in]	[in] Inches × 25,400.1 = micrometer [μm]
[mm] Milimeters × 0.039370 = inches. [in]	[in] Inches × 25.4001 = milimeters. [mm]
[m] Meters × 39.370 = inches. [in]	[in] Inches × .0254 = meters. [m]
[m] Meters × 3.2808 = feet. [ft]	[ft] Feet × .30480 = meters. [m]
[m] Meters × 1.09361 = yards. [yd]	[yd] Yard × .91440 = meters. [m]
[km] Kilometers × 3,280.8 = feet. [ft]	[ft] Feet × .0003048 = kilometers [km].
[km] Kilometers × .62137 = Statute Miles.	Statute Miles × 1.60935 = kilometers. [km]
[km] Kilometers × .53959 = Nautical Miles.	Nautical Miles × 1.85325 = kilometers. [km]

Table 33. Weight Conversion

[g] Grams × 981 = dynes.	Dynes × .0010193 = grams. [g]
[g] Grams × 15.432 = grains	Grains × .0648 = grams. [g]
[g] Grams × .03527 = ounces (Avd.). [oz]	[oz] Ounces (Avd.) × 28.35 = grams. [g]
[g]Grams × .033818 = fluid ounces (water). [oz]	[oz] Fluid Ounces (water) × 29.57 = grams. [g]
[kg] Kilograms × 35.27 = ounces (Avd.). [oz]	[ozg Ounces (Avd.) × .02835 = kilograms. [kg]
[fg] Kilograms × 2.20462 = pounds (Avd.). [lb]	[lb] Pounds (Avd.) × .45359 = kilograms. [kg]
Metric Tons (1000 kg.) × 1.10231 = Net Ton (2000 lb).	Net Ton (2000 lb) × .90719 = Metric Tons (1000 kg).
Metric Tons (1000 kg.) × .98421 = Gross Ton (2242 lb).	Gross Ton (2240 lb) × 1.01605 = Metric Ton (1000 kg)

Table 34. Area Conversion

[mm^2] Square Milimeters × .00155 = sqare inches. [in^2]	[in^2] Square Inches × 645.136 = square milimeters. [mm^2]
[cm^2]Square Centimeters × .155 = square inches. [in^2]	[in^2] Square Inches × 6.45163 = square centimeters. [cm^2
[m^2] Square Meters × 10.76387 = square feet. [ft^2]	[ft^2] Square Feet × .0929 = square meters. [m^2]
[m^2] Square Meters × 1.19599 = square yards. [yd^2]	[yd^2] Square Yards × .83613 = square meters. [m^2]
[ha] Hectares × 2.47104 = acres.	Acres × .40469 = hectares. [ha]
[km^2] Square Kilometers × 247.104 = acres.	Acres × .0040469 = square kilometers. [km^2]
[km^2] Square Kilometers × .3861 = square miles.	Square Miles × 2.5899 = square kilometers [km^2]

Table 35. Volume Conversion

[cm^3] Cubic centimeters × .033818 = fluid ounces.	Fluid Ounces × 29.57 = cubic centimeters. [cm^3]
[cm^3] Cubic centimeters × .061023 = cubic inches. [in^3]	[in^3]Cubic Inches × 16.387 = cubic centimeters. [cm^3]
[cm^3] Cubic centimeters × .271 = fluid drams.	Fluid Drams × 3.69 = cubic centimeters. [cm^3]
[l] Liters × 61.023 = cubic inches. [in^3]	[in^3]Cubic Inches × .016387 = liters. [l]
[l] Liters × 1.05668 = quarts.	Quarts × .94636 = liters. [l]
[l] Liters × .26417 = gallons.	Gallons × 3.78543 = liters. [l]
[l] Liters × .035317 = cubic feet. [ft^3]	[ft^3] Cubic Feet × 28.316 = liters. [l]
[hl] Hectoliters × 26.417 = gallons.	Gallons × .0378543 = hectoliters. [hl]
[hl] Hectoliters × 3. 5317 = cubic feet. [ft^3]	[ft^3] Cubic Feet × .28316 = hectoliters. [hl]
[hl] Hectoliters × 2.83794 = bushel (2150.42 cu. in.).	Bushels (2150.42 cu. in.) × .352379 = hectoliters. [hl]
[hl] Hectoliters ×.1308 = cubic yards. [yd^3]	[yd^3]Cubic Yards × 7.645 = hectoliters. [hl]
[m^3] Cubic Meters × 264.17 = gallons.	Gallons × .00378543 = cubic meters. [m^3]
[m^3] Cubic Meters × 35.317 = cubic feet. [ft^3]	[ft^3] Cubic Feet × .028316 = cubic meters. [m^3]
[m^3] Cubic Meters × .1308 = cubic yards. [yd^3]	[yd^3]Cubic Yards × 7.645 = cubic meters. [m^3]
[m^3] Cubic Meters × 61,023.76 = cubic inches. [in^3]	[in^3] Cubic Inches × 0.000016387 = cubic meters. [m^3]

Table 36. Force and Torque Conversion

[lb] pounds × 4.448 = Newton [N]	[N] Newton × 0.2248 = pounds [lb]
[lb-in] pound-inches × 0.11298 = Newton-meter [Nm]	[Nm] Newton-meters × 8.851 = pound-inches [lb-in]
[lb-ft] pound-feet × 1.356 = Newton-meter [Nm]	[Nm] Newton-meters × 0.7376 = pound-feet [lb-ft]
[oz-in] ounce-inches × 0.007062 = Newton-meter[Nm]	[Nm] Newton-meters × 141.60 = ounce-inches [oz-in]
[oz-in] ounce-inches × 0.005208 = pound-feet [lb-ft]	[lb-ft] pound-feet × 192 = ounce-inches [oz-in]
[oz-in] ounce-inches × 0.0625 = pound-inches [lb-in]	[lb-in] pound-inches × 16 = ounce-inches [oz-in]

Table 37. Power and Heat Conversion

[kW] Kilowatts × 1.341 = Horsepower. [HP]	Horsepower × 0.746 = kilowatts. [kW]
[kWh]Kilowatt Hours × 3415 = B.T.U.	B.T.U. × 0.00029282 = kilowatt hours. [kWh]
[Nm[Newton-meters × 8.851 = pound-inches. [lb-in]	Pound-Inches × 0.11298 = Newton-meters. [Nm]
[cal] Calorie × 0.003968 = B.T.U.	B.T.U. × 252 = calories. [cal]
[J]Joules × 0.7373 = pound-feet. [lb-ft]	Pound-Feet × 1.3563 = joules. [J]
Cheval Vapeur × 0.9863 = Horsepower. [HP]	Horsepower × 1.014 = Cheval Vapeur.

Table 38. Pressure Conversion

[Pa] Pascal × 1 = Newton per square meter [N/m^2]	[N/m^2] × 1 = [Pa]
[Pa] Pascal × 0.0001450=pounds per square inch [psi]	[psi] pounds per square inch × 6894.8= Pascal [Pa]
[Pa] Pascal × 0.02089= pounds per square foot [lb/ft^2]	[lb/ft^2] pounds per square foot × 47.8698= Pascal [Pa]
[atm] Atmosphere × 1 = [bar]	[bar] × 1 = Atmosphere [atm]
[atm] Atmosphere × 14.50 = [psi]	[psi]pound per square inch×0.0680 = Atmosp.[atm]
[atm] Atmosphere × 2116.8 = [lb/ft^2]	[lb/ft^2]pound per square foot×0.000472= Atmosp.[atm]
[atm] Atmosphere × 101325 = [Pa] or [N/m^2]	[Pa] Pascal × 0.000009869 = Atmosp.[atm]
[N/mm^2] × 145 = pounds per square inch [psi]	[psi]pound per square inch × 0.006897 = [N/mm^2]

Table 39. Temperature Conversion Table

$$\frac{°F - 32}{180} = \frac{°C}{100}$$

Locate known temperature in °C/°F column. Read converted temperature in °F or °C column.

°C	°C/°F	°F	°C	°C/°F	°F	°C	°C/°F	°F
-45.4	-50	-58	15.5	60	140	76.5	170	338
-42.7	-45	-49	18.3	65	149	79.3	175	347
-40	-40	-40	21.1	70	158	82.1	180	356
-37.2	-35	-31	23.9	75	167	85	185	365
-34.4	-30	-22	26.6	80	176	87.6	190	374
-32.2	-25	-13	29.4	85	185	90.4	195	383
-29.4	-20	-4	32.2	90	194	93.2	200	392
-26.6	-15	5	35	95	203	96	205	401
-23.8	-10	14	37.8	100	212	98.8	210	410
-20.5	-5	23	40.5	105	221	101.6	215	419
-17.8	0	32	43.4	110	230	104.4	220	428
-15	5	41	46.1	115	239	107.2	225	437
-12.2	10	50	48.9	120	248	110	230	446
-9.4	15	59	51.6	125	257	112.8	235	455
-6. 7	20	68	54.4	130	266	115.6	240	464
-3.9	25	77	57.1	135	275	118.2	245	473
-1.1	30	86	60	140	284	120.9	250	482
1.7	35	95	62.7	145	293	123.7	255	491
4.4	40	104	65.5	150	302	126.5	260	500
7.2	45	113	68.3	155	311	129.3	265	509
10	50	122	71	160	320	132.2	270	518
12.8	55	131	73.8	165	329	136	275	527

°F = (9/5 x °C) + 32 °C
°C= 5/9 (°F -32)