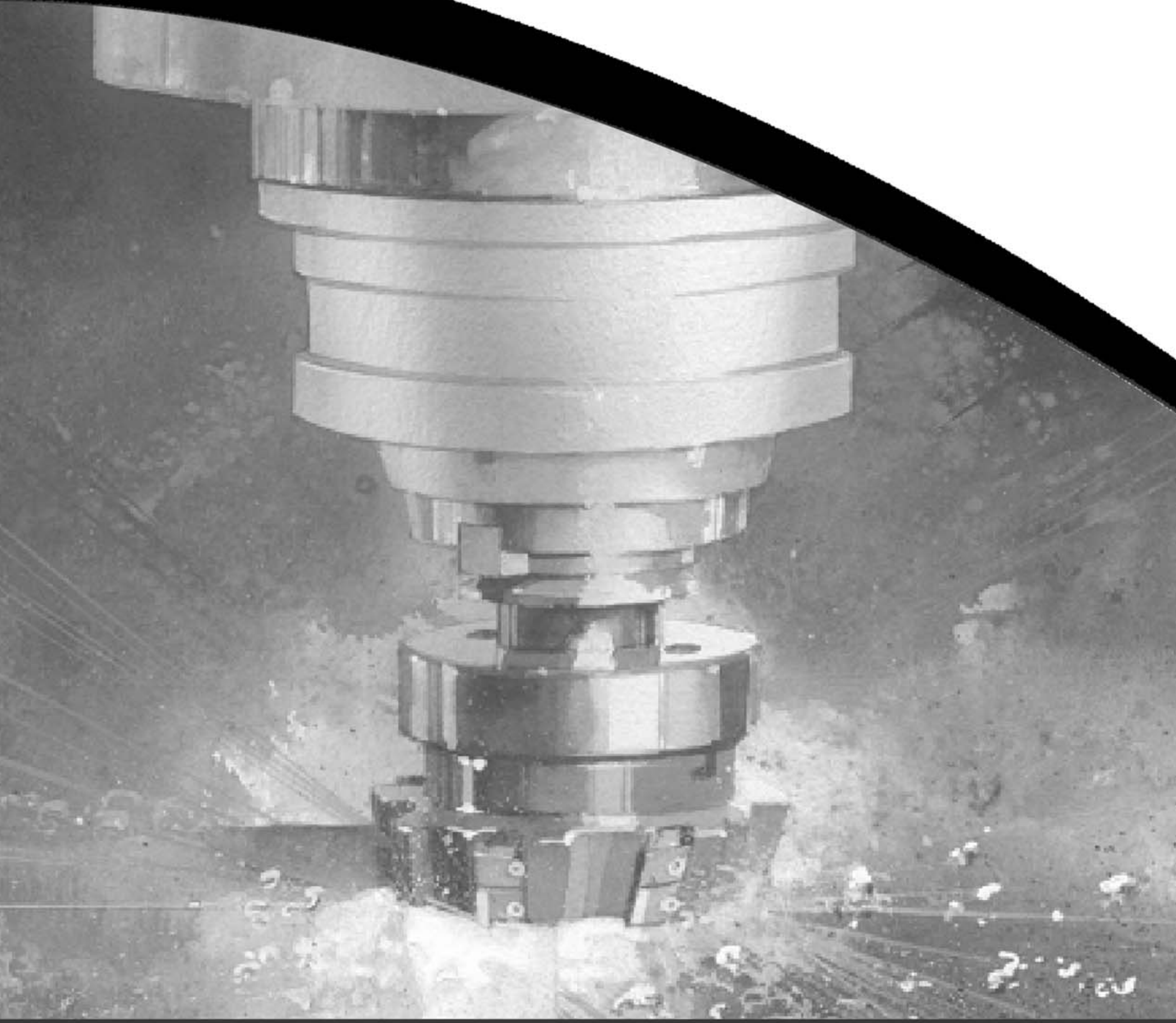
BOOK OF SPINDLES

Spindle component facts and engineering data



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DYNOMAX

Application Engineering Data
Part Two

Dynomax Information

Part Three

APPLICATION ENGINEERING DATA

1. SPINDLE SIZING

Power / Speed Requirements

For proper spindle sizing, the machining power and speed requirements must be known or determined. The optimum spindle size for a specific application is depended on the operating speed of the spindle and the power that needs to be transmited by the spindle to accomplish the machining operation.

A major factor in selecting the proper spindle for a specific machining application is the amount of power required to do the work. This power requirement, is defined as the Unit Power. The Unit Power utilizes published machining data, based on the machining operation and recommended cutting speeds and feed rates as determined by the material and hardness of the workpiece, and geometry of the cutter.

After determining the recommended cutting speed and feed rate, the next step is to find the forces, torque and power, which will be present at the desired machining.

Information provided in the **Design Data section**, has been compiled to assist in applying the DYNOMAX high speed precision spindles to specific application requirements. This information is provided as a guide for a quick and simple means of approximating machining application requirements.

Consult a cutting tool specialist to obtain best results for final machining requirements. The Design Data section contains machining data tables and equations to calculate approximata power, speed and feed rates.

For grinding applications it is recommended that a grinding wheel manufacturer be conctacted to determine the proper safe operating speeds and power requirements to ensure that the grinding wheel is not operated above the maximum rated speeds.

The Flowchart section, provides an overview with step-by-step procedure to calculate the required spindle speed and power.

A short Spindle Sizing rules are given in the **Sizing instruction section**, to help with the selecting of the right spindle from DYNOMAX Spindle Catalogue.

2. DESIGN DATA SECTION

Cutting Speeds and feeds

Table 1. Recommended values for precision boring/turning

Workpiece material	Hardness	Cutting speed - High speed steel				Cutting speed - Carbide uncoated				Feed rate per revolution			
	[Bhn]	Vc [feet/min]		Vc [m/min]		Vc [feet/min]		Vc [m/min]		f [inch]		f [mm]	
		MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	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	Cutting speed - High speed steel				Cutting speed - Carbide uncoated				Feed rate per tooth			
	[Bhn]	Vc [feet/min]		Vc [m/min]		Vc [feet/min]		Vc [m/min]		f_t [inch]		f_t [mm]	
		MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	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	Cutting material	Cutting speed				Feed rate per revolution			
	[Bhn]		Vc [feet/min]		Vc [m/min]		f [inch]		f [mm]	
			MIN	MAX	MIN	MAX	MIN	MAX	MIN	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

						Gun Drill Diameters [inch]											
Workpiece material	Hardness	Cutting speed				5/64" - 5/32"		5/32" - 1/4"		1/4" - 1/2"		1/2" - 3/4"		3/4" - 1"		1" - 2"	
	[Bhn]	Vc [feet/min]		Vc [m/min]		Feed - f [inch/revolution]											
		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	0,00015	0,00025	0,0003	0,0005		0,0006		0,001		0,001		0,002
Steel - Medium	200-325	225	450	69	137												
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	0,00015	0,00025	0,0003	0,001		0,003		0,005		0,008		0,01
Alum.Die casting			650		198												
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

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

Estimating Machining Power

Knowledge of the power required to perform machining operations is useful when planning new machining operations, for optimizing existing machining operations, and finally to perform a properly Spindle sizing.

The available power on any machine tool Spindle, places a limit on the size of the cut that it can take. When much metal must be removed from the workpiece it is advisable to estimate the cutting conditions that will utilize the maximum power on the machine. Many machining operations require only light cuts to be taken for which the machine obviously has ample power; in this event estimating the power required is a wasteful effort. Conditions in different shops may vary and machine tools are not all designed alike, so some variations between the estimated results and those obtained on the job are to be expected.

However, by using the methods provided in this section a reasonable estimate of the power required can be made, which will suffice in most practical situations.

The measure of power in customary inch units is the horsepower; in SI metric units it is the kilowatt, which is used for both mechanical and electrical power The power required to cut a material depends upon the rate at which the material is being cut and upon an experimentally determined **power constant K_p**, which is also called the unit horsepower, unit power or specific power consumption. The power constant is equal to the horsepower required to cut a material at a rate of one cubic inch per minute; in SI metric units the power constant is equal to the power in kilowatts required to cut a material at a rate of one cubic centimeter per second, or 1000 cubic millimeters per second (1 cm^3 = 1000 mm^3). Different values of the power constant are required for inch and for metric units, which are related as follows: to obtain the SI metric power constant multiply the inch power constant by 2.73; to obtain the inch power constant divide the SI metric power constant by 2.73 .

Table 5. Machining Power calculation:

$P_c\ [HP] = K_p[HP/\ in.^3/min] \times C \times Q[in.^3/min] \times W$	$P_c\ [kW] = K_p[kW/\ cm^3/s] \times C \times Q[cm^3/s] \times W$

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]	$N = 3.82 \dfrac{V_C[fpm]}{D[in.]}$	$N = 318{,}47 \dfrac{V_C[m/\min]}{D[mm]}$

The value of the power constant is essentially unaffected by the cutting speed, the depth of cut and the cutting tool material. Factors that do affect the value of the power constant and thereby the power required to cut a material include the hardness and microstructure of the work material the feed rate, the rake angle of the cutting tool and whether the cutting edge of the tool is sharp or dull. Values are given in the power constant tables for different material hardness levels, whenever this information is available. **Feed factors (C)** for the power constant are given in **Table 7**. All metal cutting tools wear but a worn cutting edge requires more power to cut than a sharp cutting edge.

Factors to provide for tool wear are given in **Table 8**. In this table, the extra-heavy-duty category for milling and turning occurs only on operations where the tool is allowed to wear more than a normal amount before it is replaced, such as roll turning. The effect of the rake angle usually can be disregarded. The rake angle for which most of the data in the power constant tables are given is positive 14 degrees. Only when the deviation from this angle is large is it necessary to make an adjustment Using a rake angle that is more positive reduces the power required approximately 1 per cent per degree; using a rake angle that is more negative increases the power required; again approximately 1 per cent per degree.

Many indexable insert cutting tools are formed with an integral chip breaker or other cutting edge modifications, which have the effect of reducing the power required to cut a material The extent of this effect cannot be predicted without a test of each design. Cutting fluids will also usually reduce the power required, when operating in the lower range of cutting speeds. Again, the extent of this effect cannot be predicted because each cutting fluid exhibits its own characteristics.

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

[a] Tuming-in/rev; milling-in./tooth; planing and shaping-in./stroke; broaching-in./tooth.
[b] Tuming-mm/rev; milling-mm/tooth; planing and shaping-mm/stroke; broaching-mm/tooth.

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

Note: For planing and shaping use values given for turning.

Power Constants K_p

Values of the power constant in **Tables 9, 10,** and **11** can be used for all machining operations except drilling and grinding. Values given are for sharp tools.

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	0.63	1.72
	100-120	0.66	1.80
	120-140	0.69	1.88
	140-160	0.74	2.02
	160-180	0.78	2.13
	180-200	0.82	2.24
	200-220	0.85	2.32
	220-240	0.89	2.43
	240-260	0.92	2.51
	260-280	0.95	2.59
	280-300	1.00	2.73
	300-320	1.03	2.81
	320-340	1.06	2.89
	340-360	1.14	3.11
Free Machining Steels			
AISI 1108, 1109, 1110, 1115, 1116, 1117,1118,1119, 1120, 1125, 1126, 1132	100-120	0.41	1.12
	120-140	0.42	1.15
	140-160	0.44	1.20
	160-180	0.48	1.31
	180-200	0.50	1.36
AISI 1137, 1138, 1139, 1140, 1141, 1144, 1145, 1146, 1148, 1151	180-200	0.51	1.39
	200-220	0.55	1.50
	220-240	0.57	1.56
	240-260	0.62	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	0.62	1.69
	160-180	0.65	1.77
	180-200	0.69	1.88
	200-220	0.72	1.97
	220-240	0.76	2.07
	240-260	0.80	2.18
	260-280	0.84	2.29
	280-300	0.87	2.38
	300-320	0.91	2.48
	320-340	0.96	2.62
	340-360	1.00	2.73
AISI 4130, 4320, 4615, 4620, 4626, 5120, 8615, 8617, 8620, 8622, 8625, 8630, 8720	140-160	0.56	1.53
	160-180	0.59	1.61
	180-200	0.62	1.69
	200-220	0.65	1.77
	220-240	0.70	1.91
	240-260	0.74	2.02
	260-280	0.77	2.10
	280-300	0.80	2.18
	300-320	0.83	2.27
	320-340	0.89	2.43
AISI 1330, I335, 1340, E52100	160-180	0.79	2.16
	180-200	0.83	2.27
	200-220	0.87	2.38
	220-240	0.91	2.48
	240-260	0.95	2.59
	260-280	1.00	2.73

Formulas for calculating the metal removal rate, **Q**, for different machining operations are given in **Table 12**. These formulas are used together with others given below. The following formulas can be used with either customary inch or with SI metric units.

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

Whenever possible the maximum power available on a machine tool should be use when heavy cuts must be taken.
The cutting conditions for utilizing the maximum power should be selected in the following order:
1) select the maximum depth of cut that can be used;
2) select the maximum feed rate that can be used;
3) estimate the cutting speed that will utilize the maximum power available on the machine.

This sequence is based on obtaining the longest tool life of the cutting tool and at the same time obtaining as much production as possible from the machine.
The life of a cutting tool is most affected by the cutting speed then by the feed rate, and least of all by the depth of cut. The maximum metal removal rate that a given machine is capable of machining from a given material is used as the basis for estimating the cutting speed that will utilize all the power available on the machine.

DRILLING

Estimating Drilling Thrust, Torque, and Power

Although the lips of a drill cut metal and produce a chip in the same manner as the cutting edges of other metal cutting tools, the chisel edge removes the metal by means of a very complex combination of extrusion and cutting. For this reason a separate method must be used to estimate the power required for drilling. Also, it is often desirable to know the magnitude of the thrust and the torque required to drill a hole. The formulas and tabular data provided in this section are based on information supplied by the National Twist Drill Division of Regal-Beloit Corp.

The values in **Tables 13** through **16** are for sharp drills and the tool wear factors are given in **Table 8**. For most ordinary drilling operations 1.30 can be used as the tool wear factor. When drilling most difficult-to-machine materials and when the drill is allowed to become very dull, 1.50 should be used as the value of this factor. It is usually more convenient to measure the web thickness at the drill point than the length of the chisel edge; for this reason, the approximate w/d ratio corresponding to each c/d ratio for a correctly ground drip is provided in **Table 14**. For most standard twist drills the c/d ratio is 0.18, unless the drill has been ground short or the web has been thinned. The c/d ratio of split point drills is 0.03.

The formulas given below can be used for spade drills as well as for twist drills.

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

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 the cutter	$P_c = M N / 63.025$ [HP]	$P_c = M N / 9550$ [kW]

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[a,b] 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

Twist drills are generally the most highly stressed of all metal cutting tools. They must not resist the cutting forces on the lips, but also the drill torque resulting from these forces and the very large thrust force required to push the drill through the hole. Therefore, often when drilling smaller holes, the twist drill places a limit on the power used and for very large holes, the machine may limit the power.

GRINDING

Grinding Forces, Torque and Power

Formulas to calculate the tangential cutting force, torque and required machining power are the same as for other metal cutting operations (see Estimating Machining Power Section), but the values of $\mathbf{K_C}$, specific cutting force or specific energy, are approximately 30 to 40 times higher in grinding than in turning, milling and drilling. This is primarily due to the fact that the ECT values in grinding are 1000 to 10000 times smalles, and also due to the negative rake angles of the grit. Average grinding rake angles are arround –35 to –45 degrees.

Another difference compared to turning is the influence of the negative rake angles, illustrated by the ratio of F_H/F_C, where F_H is the normal force and F_C the tangential grinding force acting in the wheel speed direction. F_H is much larger than the grinding cutting force.

Generally $\mathbf{F_H/F_C}$ ratio is approximately **2** to **4**.

It is apparent that both $\mathbf{K_C}$ and $\mathbf{F_H/F_C}$ attain maximum values for given small values of **ECT**. This fact illustrates that forces and wheel-life are closely linked. For example, wheel speed has a maximum for constant wheel-life at appoximately the same values of ECT. As a matter of fact, force relationships obey the same type of relationships as those of wheel-life.

The informations compiled in this section is intended as a guide in selecting the proper parameters for a particular grinding operation.
The process of selecting the proper power, speed feed wheel etc., should be based on experience and testing. There are no general equation that can adequately describe the selection process without use of test results for the particular application.

Grinding Power

The relationship for the Grinding power calculation can be expressed as:

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

Table 18. P_G –Grinding Power

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

The grinding cutting forces are relatively small because chip area is very small.

As in the other metal cutting operations, the forces vary with **ECT** - equivalent chip thickness and to a smaller extent with the weel speed **V**.

ECT – Equivalent chip thickness in Grinding

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

where: A- cross sectional area of cut (approximately = feed x depth of cut) – [mm^2] or [inch^2]

CEL – cutting edge length (tool contact rubbing length) – [mm] or [inch]

In turning, milling and drilling, ECT varies between 0.05 and 1 mm, and is always less than the feed/rev or feed/tooth; its value is usually about 0.7 to 0.9 times the feed.

ECT is much smaller in grinding than in milling, ranging from about 0.0001 to 0.001 mm (0.000004 to 0.00004 inch).

In turning and milling, ECT is defined as the volume of chips removed per unit cutting edge length per revolution of the work or cutter. In milling specifically, ECT is defined as the ratio of (number of teeth z x feed per tooth f, x radial depth of cut a_r x axial depth of cut a_a) and (cutting edge length CEL divided by πD) where D is the cutter diameter, thus,

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

In grinding, the same definition of ECT applies if we replace the number of teeth with the average number of grits along the wheel periphery, and replace the feed per tooth by the average feed per grit. This definition is not very practical, however, and ECT is better defined by the ratio of the specific metal removal rate - SMMR, and the wheel speed - V.
Keeping ECT constant when varying SMRR requires that the wheel speed must be changed proportionally.

In milling and turning ECT can also be redefined in terms of SMRR divided by the work and the cutter speeds respectively, because SMRR is proportional to the feed rate F_R.

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]

Terms and Definitions:

a_a = width of cut [mm] or [inch]
a_r = radial depth of cut [mm] or [inch]
C = fraction of grinding wheel width
CEL = cutting edge length, [mm] or [inch]
D = wheel diameter, [mm] or [inch]
DIST = grinding distance, [mm] or [inch]
d_W = work diameter [mm] or [inch]
F_R = feed rate, [mm/min] or [inch/min]
=f_S x RPM, for cylindrical grinding
=f_i x RPM, for plunge (in-feed) grinding
f_i = in-feed in plunge grinding [mm/rev of work]
f_S = side feed or engaged wheel width in cylindrical grinding [mm] or [inch]
f_S = C x Width = a_a approximately equal to the cutting edge length - CEL

SMRR = specific metal removal rate obtained by dividing MRR by the engaged wheel width $\mathbf{f_S}$
SMRR = 1000 x a_r x V_W [mm3/mm width/min]
100 [mm^3/mm/min] = 0.155 [in^3/in/min]
1 [in^3/in/min] = 645.16 [mm^3/mm/min]

Width = wheel width [mm]

Grindingratio = MRR/W* = SMRR x T / W* = 1000 x ECT x V x T /W*

T, T_U =wheel-life = Grinding ratio x W/(1000 x ECTx V) [minutes]

W^* =volume wheel wear [mm^3]

t_C = grinding time per pass = DIST/F_R [min]
= DIST/F_R + t_{SP} [min] - when spark-out time is included
= # Strokes x (DIST/F_R + t_{SP}) [min] when spark-out time and strokes are included
t_{SP} = spark-out time, [minutes]
V,V_U = wheel speed, [m/min] or [feet/min]
$V_{W,}V_{WU}$ = work speed = SMRR / (1000 x a_r) [m/min] or [feet/min]
W* = volume wheel wear [mm^3]
Width = wheel width [mm]
RPM = wheel speed = (1000 x V)/(D x π) [rpm] – for SI Metric Unit

RPM_W = work speed = (1000 x V_W)/(D_W x π) [rpm] – for SI Metric Unit

Basic Rules

Grinding data are scarely available in handbooks, which usually recommend a small range of depth and work speeds at constant wheel speed, including small variations in wheel and work material composition. Wheel life or grinding stiffness are seldom considered.

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

*Specific metal removal rate – **SMRR**, represents the rate of material removal per unit of wheel contact width

- Grinding stiffness is a major variable in determining wheel-life and spark out time. A typical value of system stiffness in outside-diameter grinding, for 10:1 length/diameter ratio, is approximately $K_{ST} = 30 – 50\ N/\mu m$. System stiffness K_{ST} is calculated from the stiffness of the part – K_W and the machine fixtures K_m. Machine values can be obtained from manufacturers, or can be measured using simple equipment along with the part stiffness.
- Generally a lower wheel hardness (soft wheel) is recommended when the system stiffness is poor or when a better finish is desired.

The primary parameters that determine wheel-life, forces and surface finish in grinding are:

- the wheel speed **V**
- equivalent chip thickness **ECT**

The following general rules and recommendations, using ECT, are based on extensive laboratory and industry tests both in Europe and USA. The relationships and shapes of curves pertaining to grinding tool-life, grinding time, and cost are similar to those of any metal cutting operation such as turning, milling and drilling. In turning and milling, the ECT theory says that if the product of feed times depth of cut is constant, the tool-life is constant no matter how the depth of cut or feed is varied, provided that the cutting speed and cutting edge length are maintained constant.

In grinding, wheel-life T remains constant for constant cutting speed V, regardless of how depth of cut a_r or work speed V, are selected as long as the specific metal removal rate

$SMMR = V_w \times a_r$ is held constant (neglecting the influence of grinding contact width).

Surface Finish– R_a

In cylindrical grinding, a reduction of side feed f_S improves R_a, as well. Small grit sizes are very important when very small finishes are required.

The finish is improved by decreasing the value of ECT. Because ECT is proportional to the depth of cut, a smaller depth of cut is favorable for reducing surface roughness when the work speed is constant.

Shorter wheel-life improves the surface finish, which means that either an increased wheel speed (wheel-life decreases) at constant ECT, or a smaller ECT at constant speed (wheel-life increases), will result in an improved finish. For a required surface finish, ECT and wheel-life have to be selected appropriately in order to also achieve an optimum grinding time or cost. In cylindrical grinding a reduction of side feed f_s, improves Ra as well.

In terms of specific metal removal rate, reducing SMRR will improve the surface finish $\mathbf{R_a}$.

Side Feed, Roughing and Finishing

In cylindrical grinding, the side feed: $f_s = C \times Width$

does impact on the feed rate F_R, where the fraction of the wheel width C is usually selected for roughing and in finishing operations, as shown in the following table

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

The depth of cut in rough grinding is determined by the allowance and usually set at
a_r = 0.01 to 0.025 mm (0.254 to0.635 inch).

The depth of cut for finishing is usually set at a_r = 0.0025 mm (0.0635 inch) and accompanied by higher wheel speeds in order to improve surface finish. However the most important criterion for critical parts is to increase the work speed in order to avoid thermal damage and surface cracks.

Grinding Data Selection

Work materials

The first estimate settings is based on dividing work materials into 10 groups, based on grindability, as given in next

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	

The grinding data machinability system is based on the basic parameters equivalent chip thickness ECT, and wheel speed V, and is used to determine specific metal removal rates SMRR and wheel-life T, including the work speed V_W, after the grinding depths for roughing and finishing are specified.

Maximum wheel speeds

The maximum peripheral speed of the wheels in regular High-Speed Cylindrical Grinding is generally 6500 feet per minute; the commonly used grinding wheels and machines are designed to operate efficiently at this speed.

Recently, efforts were made to raise the productivity of different grinding metbods, including cylindrical grinding, by increasing the peripheral speed of the grinding wheel to a substantially higher than traditional level such as 12,000 feet per minute or more. Such methods are designated by the distinguishing term of high-speed grinding.

For high-speed grinding, special grinding machines have been built with high dynamic stiffness and static rigidity, equipped with powerful drive motors, extra-strong spindles and bearings, reinforced wheel guards, etc, and using grinding wheel expressly made and tested for operating at high peripheral speeds. The higher stock-removal rate accomplished by high-speed grinding represents an advantage when the work configuration and material permit and the removable stock alowance warrants its application.

The general design of the grinding machines must ensure safe operation under normal conditions. The bearings and grinding wheel spindle must be dimensioned to withstand the expected forces and ample driving power should be provided to ensure maintenance of the rated spindle speed.

The **Table 25.** shows the permissible wheel speeds in surface feet per minute (sfpm) units and [m/min], whereas the tags on the grinding wheels state, for the convenience of the user, the maximum operating speed in revolutions per minute (rpm).

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 - l6-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)

[a] Source and reference ANSI B7.1-1988

[b] Nonstandard shape. For snagging wheels, 16 inch and larger-Type 1, internal wheels- Types 1 and 5, and mounted wheels, see ANSI B7.1-1988. Under no conditions should a wheel be operated faster than the maximum operating speed established by the manufacturer.

- Walues in this table are for general information only.

Special Speeds: Continuing progress in grinding methods has led to the recognition of certain advantages that can result from operating grinding wheels above, sometimes even higher than twice, the speeds considered earlier as the safe limits of grinding wheel operations Advantages from me application of high speed grinding are limited to specific processes, but the Standard admits, and offers code regulations for the use of wheels at special high speeds. These regulations define the structural requirements of the grinding machine and the responsibilities of the grinding wheel manufacturers, as well as of the users. High speed grinding should not be applied unless the machines particularly guards, spindle assemblies, and drive motors, are suitable for such methods. Also, appropriate grinding wheels expressly made for special high speeds must be used and, of course, the maximum operating speeds indicated on the wheel' s tag must never be exceeded.

Table 26. shows the formulas for calculating the rotational speed from the given peripheral (surface) speed - **V** and grinding wheel diameter - **D**.

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

Table 26. Formulas for calculating the rotational speed

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

where:

N = grinding wheel rotational speed [rpm]
V = peripheral (surface) wheel speed [feet/min] or [m/s]
D = grinding wheel diameter [inch] or [mm]

3. THE DRIVING MOTOR CHARACTERISTICS

The machine tool transmits the power from the driving motor to the workpiech where it is used to cut the material. The effectiveness of this transmission is measured by the **machine tool efficiency factor E**. Average values of this factor are given in **Table 28**.

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]

Electrical source parameters

When we know the required driving motor power, we need to calculate the appropriate electrical source characteristics. Some electrical formulas given below will be helpful in that task.

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:

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

IEC Protection Indexes

IEC has designation indicating the protection provided by motor's enclosure, spindles housing and connector housings.

Designation of the Protection Indexes:

-Protection against contact or approach to live and moving parts inside the enclosure
-Protection against ingress of solid foreign objects
-Protection against the harmful effects due to ingress of water

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.

For example:
IP 64 indicates Housing totally protected against dust and protected against water splashes from all directions.
IP 65 indicates Housing totally protected against dust and protected against jets of water from all directions.

IEC Cooling and Duty Cycle Indexes

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

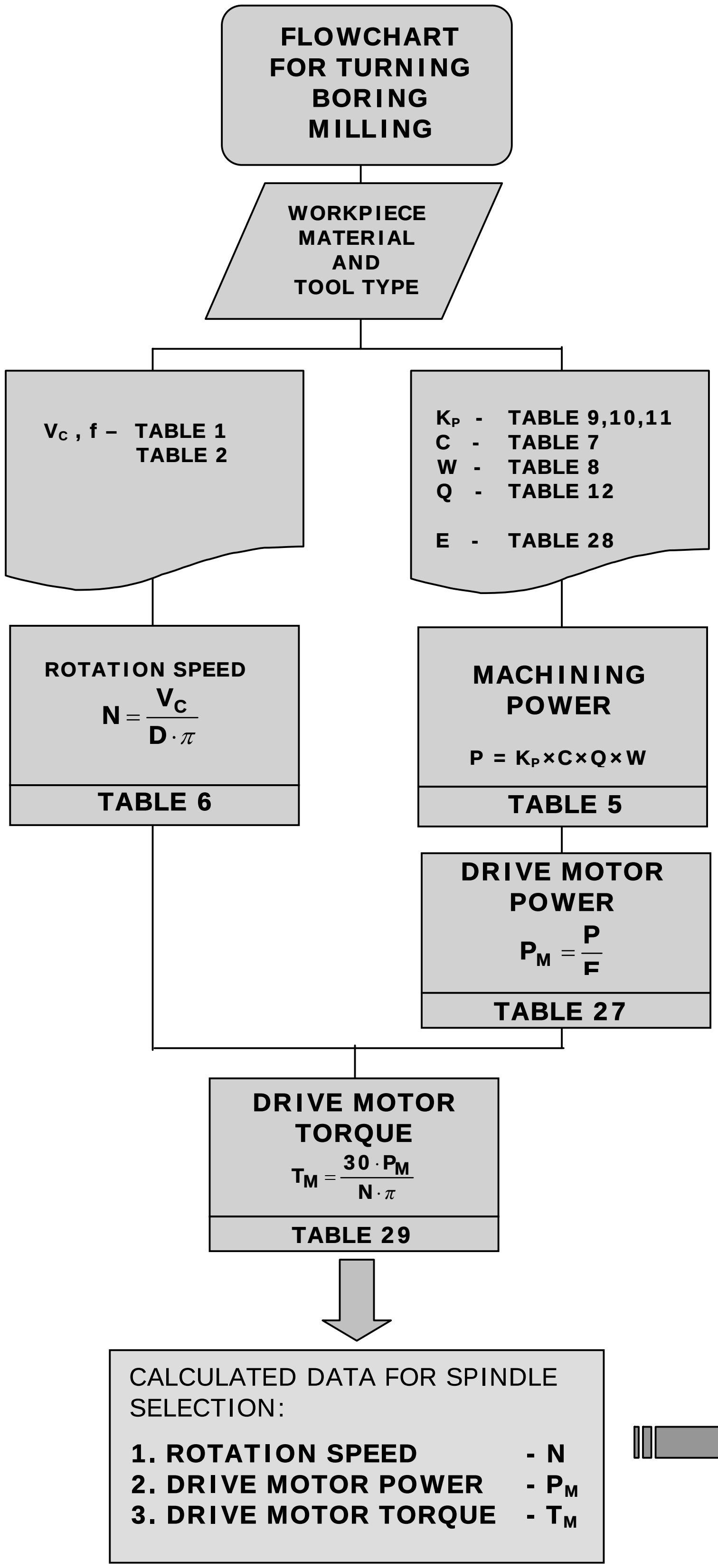
Designation	Cooling design
IC 01	Open design
IC 40	TENV -Totally Enclosed Non-Ventilated
IC 41	TEFC -Totally Enclosed Fan Cooled
IC 43	TEAO -Totally Enclosed Air Over

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

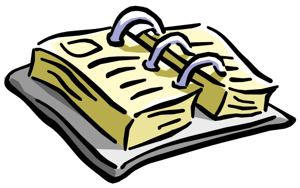
E - Machine Efficiency Factor

N - Rotation Speed

P - Machine Power

P_M - Drive Motor Power

T_M - Drive Motor Torque



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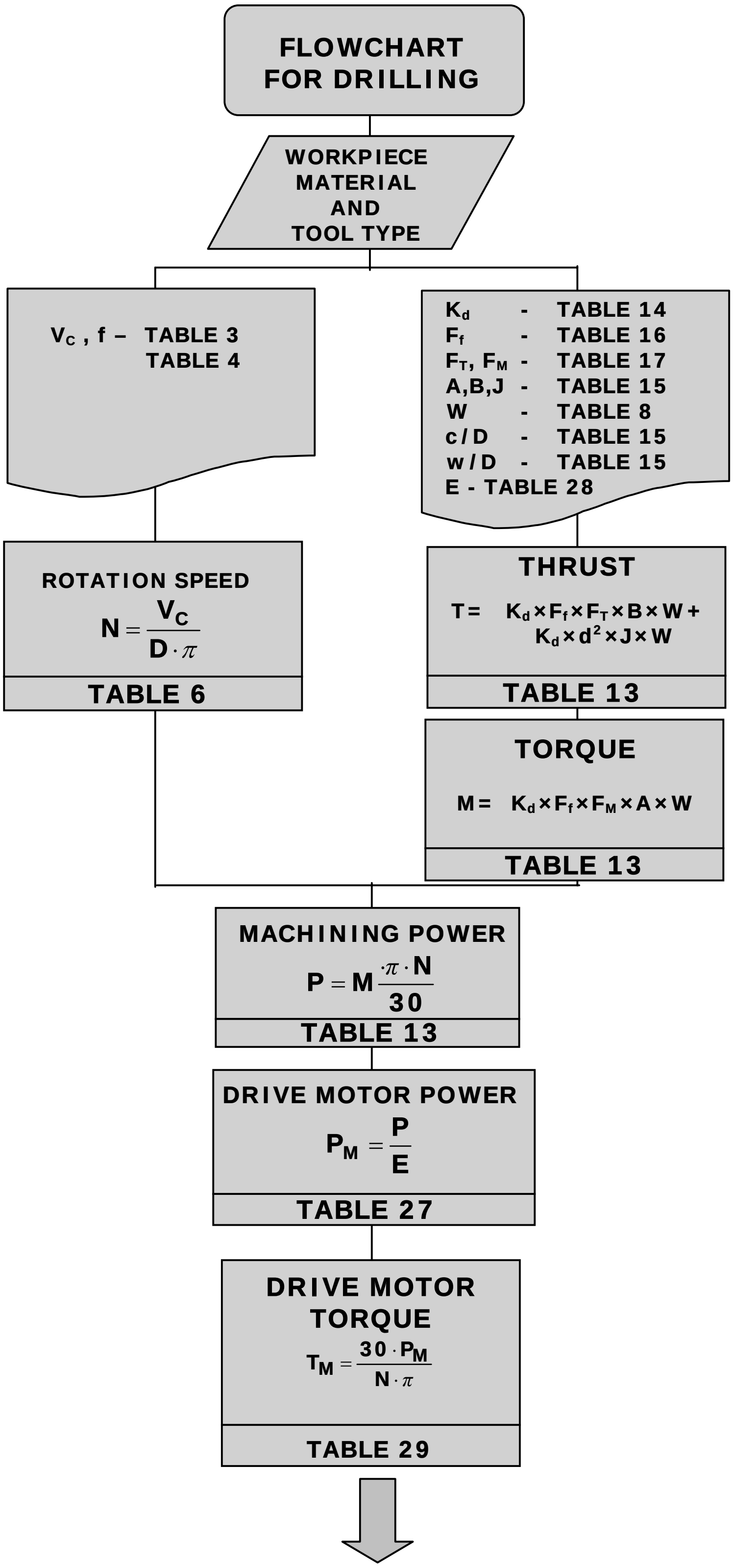
FLOWCHART FOR DRILLING



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

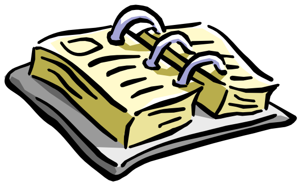
P - Machine Power

P_M - Drive Motor Power

T_M - Drive Motor Torque

CALCULATED DATA FOR SPINDLE SELECTION:

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



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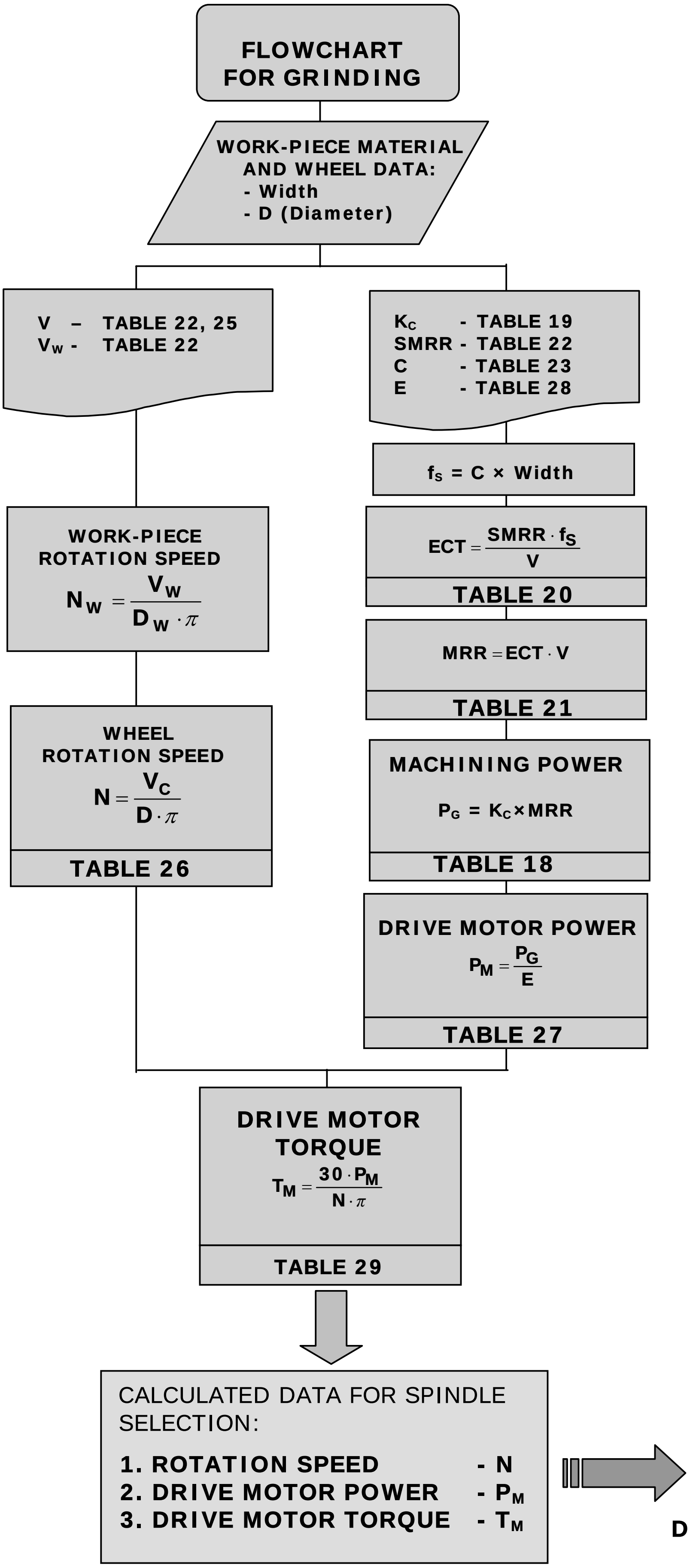
FLOWCHART FOR GRINDING



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

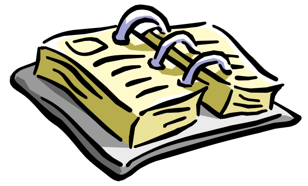
N - Wheel Rotation Speed

N_W - Work-piece Rotation speed

P_G - Grinding Power

P_M - Drive Motor Power

T - Drive Motor Torque



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5. SIZING INSTRUCTIONS

General rules for sizing

Proper spindle sizing is important to ensure a long and dependable life. To help in selecting the correct spindle the following factors should be considered.

1. Always select the largest spindle that will fit your particular space and comply with the speed requirements. This will give you the maximum spindle stiffness and longest life.

2. Keep tool overhang to a minimum, particularly when boring, and millling or nonsupported arbor milling. As you move further from the spindle bearings, bearing loads increase and spindle stiffness decreases. Use the specification charts to find the maximum overhang distance.

3. When boring, the spindle nose bearing bore should be approximately as large or larger than the hole being machined.

4. To minimize any shaft or bearing loading, keep within the maximum torque rating given on the specification charts.

5. Consider the environment in which the spindle is used. If the conditions are dusty, air purging is recommended. If there is heavy coolant or chips, it is advisable to suplly a deflector cover to keep coolant or chips from directly attacking the spindle. Contact seals should be used unless speed requirements do not allow.

6. Specify the correct bearing arrangement. For mostly radial loaded applications, use a bearing pair at the nose end. For high axial loads, combination axial and radial loading or heavy or interrupted cuts, use a triplex bearing set at the nose end.

7. Dynomax engineering and sales staff is always available to help in selecting the correct spindles for your applications. When asking for assistance, please supply the following information:
a) Type of operation and stock removal amounts
b) Tooling description
c) Part material specification
d) Spindle orientation
e) Environmental conditions
f) Space limitations
g) Horsepower and RPM required

Whenever possible, supply a part print along with any other information that may be useful in spindle selection.

"DN" Value

– the "DN" value plays a significant role in the overall design of high speed spindles. From the initial design stage to the finished product the "DN" value determines bearing precision, bearing mounting arrangement, machining tolerances, bearing preload, type and method of lubrication, material and heat treat process, balancing requirement, vibration acceptance level, and final inspection method that a spindle is processed.

The "DN" value is calculated as follows (using the largest bearing in the spindle):

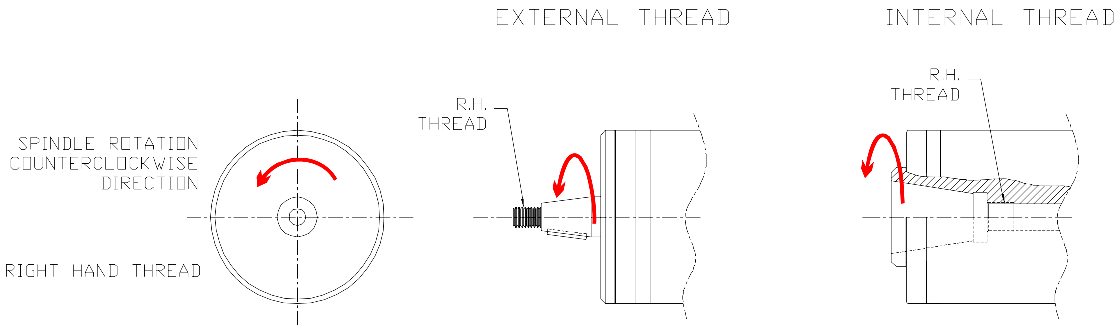
"DN" = Bearing Mean diameter [mm] × spindle RPM

*** See "The Spindle Book" - Part 1 for more information on DN numbers and limits.**

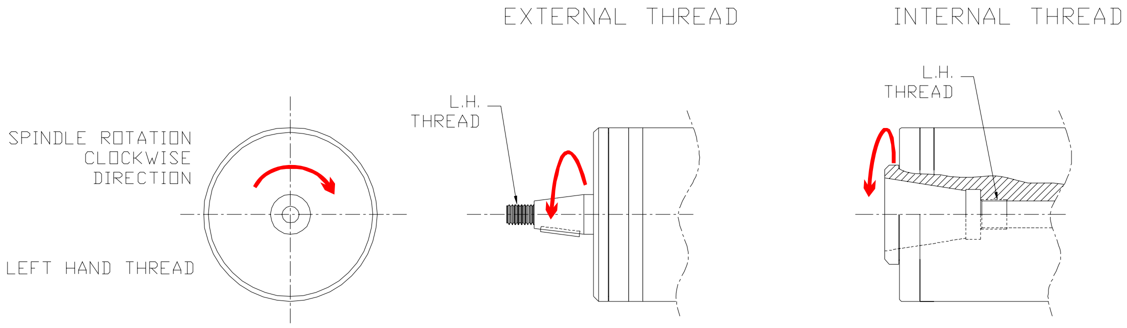
Threads Rotation Guide

Depending of the Spindle rotation direction, the proper threads direction should be select.
General rule for proper threads direction selection is given below:

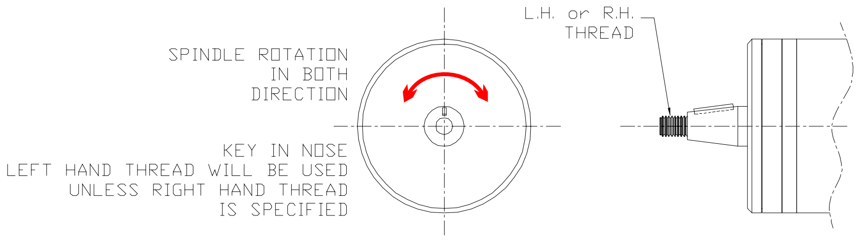
SPINDLE ROTATION COUNTERCLOCKWISE



SPINDLE ROTATION CLOCKWISE



SPINDLE ROTATION EITHER DIRECTION



6. MOST COMMON SPINDLE NOSE DESIGN

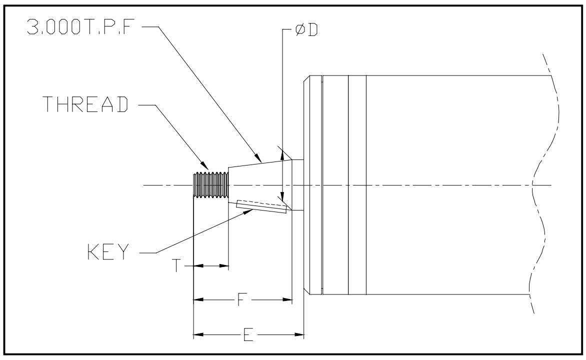
Generaly, the Machine Tool's spindles, and particularly Dynomax super precision spindles, ilustrated in The Spindle Book – Part 3, can accommodate various alternate spindle nose configurations. Described in this Section are the most common alternate spindle nose designs.

External Taper - G

External taper nose for adapting wheel holders in grinding applications. Standard thread is R.H. Collar nut furnished as standard with spindle.

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 – specifies guage diameter [inch]
** Minimum front bearing bore size [mm]

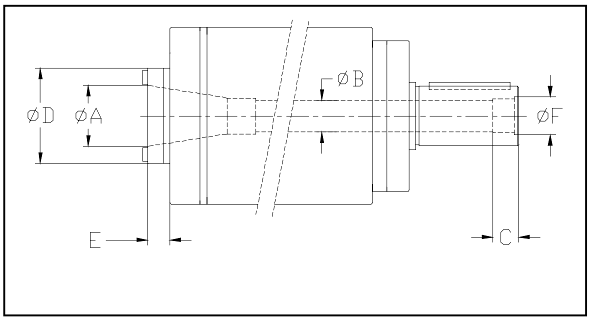


Milling Taper per ANSI B5.18 – M

Milling taper nose for adapting milling tool shanks in milling applications. Include drive keys and hole thru arbor for optional manual drawbar.

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]

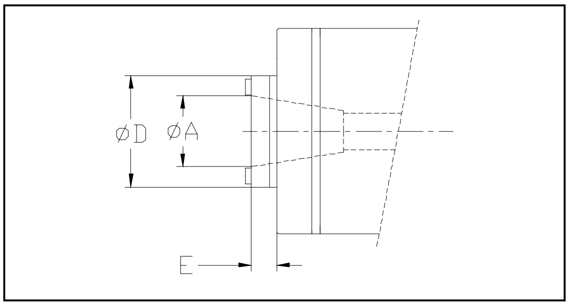


Milling Taper per ANSI B5.50 – MV

Milling taper nose for "V" flange tool shanks for machining centers with automatic tool changers. Includes drive key and machining of arbor to accept power drawbar.

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]

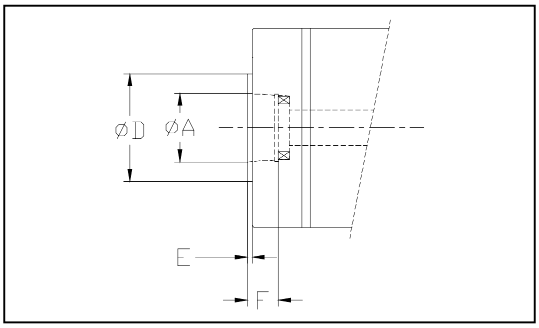


HSK per DIN 69893 - HA

HSK – A spindle nose contour for use with hollow shaft tooling for automatic tool change. Form A with internal keyways. Used with power drawbar.

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]

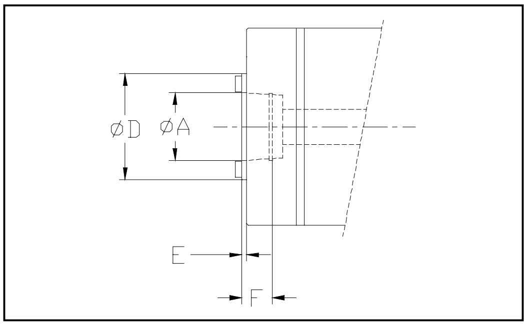


HSK per DIN 69893 - HB

HSK – B spindle nose contour for use with hollow shaft tooling for automatic tool change. Form B with external keyways. Used with power drawbar.

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]

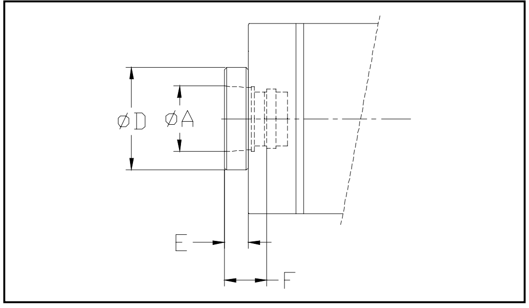


HSK per DIN 69893 - HC

HSK – C spindle nose contour for use with hollow shaft tooling. Form C machined to tool manufacturer's ,annual tool clamping cartridge specifications. Specify manufacturer of clamping cartridge at ordering.

						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]

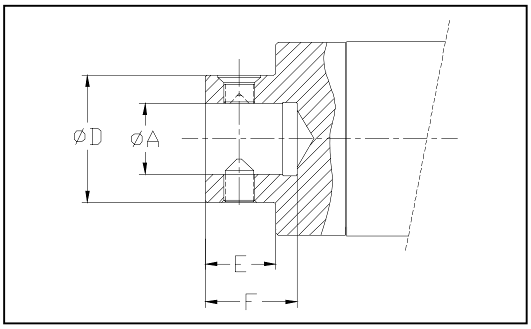


Komet ABS®Connection - K

Komet ABS tool holder systems for machining centers, FMS and dedicated machining systems. Includes thrust screw and receiving screw.

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]



Other common available spindle nose designs

In addition to the shown spindle nose designs, the other spindle nose designs can also be accomodated:

Universal Kwik-Switch®II (ACME Threads)
TM Smith "Tru-Taper"®
Air Gage "Fas-Loc"® Taper
Lathe Nose "Type B"
Jarno Internal Taper
Morse Internal Taper
Universal "Double Taper"® Collet
Erickson "Quick Change"®
Air Gage "Fas-Loc"® Taper
Adapter Plate
Flanged Grinding Nose
Loose Piece Pilot Nose
Kaiser® Tool Connectors
Universal Kwik-Switch®II ("V" - Threads)
Automotive Adapters
Lathe Nose "Type A"
DeVlieg "Flash Change"® Taper
Brown&Sharpe Internal Taper
Universal "Acura-Flex"® Collet
Erickson "Double Angle"® Collet
TM Smith "Super" Taper®
Standard "5C" Collet Nose
Straight Shaft with Threaded Nose
Extended Flanged Grinding Nose
Bridgeport® Collet Nose

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

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

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)

DYNOMAX INFORMATION

1. Corporate Overview

Established to offer manufactures high quality, customizable spindles to meet unique machining needs, Dynomax offers manufacturers the design, manufacturing and service of machine spindles. With more than 400 modular spindles each designed to offer countless options, Dynomax spindles are engineered to accommodate a variety of applications and environments. Offering spindles including belt and gear driven, integral motor, high speed and robotic, Dynomax is dedicated to spindles. An ISO 9001:2000 certified company, our spindles are found in industries ranging from aerospace to stone to medical.

Today, Dynomax operates within a 10,000 sq ft facility that provides the in-house equipment necessary to manufacture and service precision tolerance spindles.

2. Offering Overview

Dynomax's offering can be broken down into three distinct areas, each briefly introduced below.

2.1 Design Offering

As a niche focused spindle design, manufacturing and service facility, Dynomax has insight into all faucets of a spindle's life. We know what it takes to develop a spindle with integrity. Engineering a new spindle to meet a variety of specifications requires combining time-tested theories and new technologies, with careful consideration to practical application, to design a spindle for new or existing machinery.

In addition to designing new concepts, Dynomax, because of our modular designs, can customize standard spindles to meet special requirements without significantly increasing the delivery schedule. Working cooperatively with customers to design spindles that outperform the competition, Dynomax engineers review performance specifications and design limitations before engineering the ideal spindle. Our spindle design process includes:

- Application review/Application consulting
- Spindle Engineering
- New Spindle Design
- Design Approval
- Available finite element analysis (FEA)

Our experience has taught us that a good spindle is one that spins, but a great spindle is one that consistently spins, requires minimal maintenance and is quick and easy to restore when and if the time comes. Dynomax designs great spindles because we know spindles.

2.2 Manufacturing Overview

New robotic arm spindles. Spare cartridge spindles. High speed motorized spindles. When it comes to spindles, Dynomax does it all. Dynomax, an ISO 9001:2000 registered company, has invested heavily in the tools, talent and training necessary to manufacture new high quality spindles.

Dynomax's dedication to new spindle manufacturing has enabled us to better service our customers. Our experience has taught us how to determine the spindle best suited to customer requirements as well as how to manufacture that spindle to perform on the shop floor. We work with our customers to make sure they get the machine tool spindle they want, when they want it!

All new Dynomax spindles...

- Are manufactured to precision tolerances and assembled by trained technicians under controlled conditions
- Complete maximum speed run-in's to ensure the spindle meets performance requirements
- Complete balancing and vibration analysis testing
- Are processed and fully documented under ISO standards
- Come with a 1-year warrantee on craftsmanship and parts

Dynomax spindles are precision machine components. Dynomax has put rigorous standards in place to ensure spindles that leave our shop floor are ready to operate on yours. Dynomax offers more than 400 spindles, offering manufactures a variety of different sizes, styles and characteristics. Each spindle has been devloped to accomidate a variety of applications and tooling, offering our customers countless options.

Our extensive product line includes hundreds of standard spindles, each designed to allow customization with minimal impacts on delivery schedules. Our lines include:

- Block Spindles
- Cartridge Spindles
- Quill Spindles
- Motorized Spindles
- High Speed Spindles
- Robotic Spindles
- Dresser Spindles
- Speciality Spindles

Within each line we have spindles covering a large variety of operating characteristics, tooling set-ups and applications. Details on each spindle can be found on our website at www.dynospindles.com or our experienced engineering staff can help you determine the spinldle best suited to fit your needs.

2.3 Service Offering

Dynomax knows the quickest way back to maximum production is a timely, high quality service. Our step-by-step ISO 9001:2000 documented service processes are focused on detail with built-in quality control measures to ensure precision and quality craftsmanship. Experienced in spindle design, manufacturing and service. Dynomax applies fundamental spindle concepts and proven processes to service, regardless of application, in order to put value back into your machine tool spindle. Whether you need a complete spindle rebuild, a spindle repair or spindle enhancements, Dynomax has your solution. At Dynomax we make the best and repair the rest!

DYNOMAX
RFQ

Need a new spindle design?

For quote and more spindle information, please fill out the following and fax us at 847.680.8838 or complete online at www.dynospindles.com/rfq.html.
(If you do not have the answer to a question, please leave it blank and go to the next question.)

Company ______________________________
Name ______________________________
Address ______________________________
Email ______________________________
Phone ______________________________
Fax ______________________________

Date ______________
Quote needed by ______________
Spindle needed by ______________
Customer's Machine:
____

Type of Spindle *(Check One)*
☐ Belt Driven ☐ Motorized ☐ Other
- ☐ Base Mount
- ☐ Cartridge
- ☐ Flange Cartridge
- ☐ Block Style
- ☐ Other

Application
____
____
____
____

Operation to be performed
- ☐ Grinding
- ☐ Milling
- ☐ Turning
- ☐ Other
- ☐ Drilling
- ☐ Boring
- ☐ Facing

Axial Load: ______________
Radial Load: ______________
Radial Load (distance from the nose) ____________

Operating Characteristics
Operating RPM
- ☐ Horizontal
- ☐ Vertical
  - ☐ Nose Up
  - ☐ Nose Down
  - ☐ Angle to Horizontal ________°

Rotation of Spindle (Front View):
- ☐ Clockwise
- ☐ Counter Clockwise

Coolant
Type of coolant ____________ Pressure ____________

Type of Drive
Motorized:
H.P. __________ RPM __________ Voltage __________ Cycle __________ Phase ________
T.E.L.C. __________ T.E.F.C. __________ T.E.N.V. __________ Other __________
Belt Driven:
☐ Flat Belt ☐ "V" Belt ☐ Timing Belt ☐ Poly "V" Belt ☐ Other

Tooling interface
- ☐ HSK
- ☐ CAT
- ☐ Other ______________

Bearing Lubrication
- ☐ Grease Lube
- ☐ Oil Mist
- ☐ Air/Oil Lube

Define the requirements and any expectations you have for the spindle. Note any limiting factors such space or power.
____
____
____
____
____

Thank you for giving us the opportunity to work with you on your design project. We will contact you shortly.