Speed, Feed and Power Calculations

To Find	Known Values	Formulae
Peripheral Cutting Speed - SFM	Mill Diameter, D Rotational Speed RPM	SFM=.262 x RPM xD SFM(est) = $\frac{RPM \times D}{4}$
Rotational Speed - RPM	Peripheral Cutting Speed,SFM Mill Diameter, D	RPM = $\frac{SFM}{.262 \times D}$ RPM(est) = $\frac{4 \times SFM}{D}$
Machine Feed Rate - IPM	Rotational Speed, RPM Number of Flutes (Teeth), T Feed per Tooth, IPT	IPM= T x IPT x RPM
Feed per Tooth - IPT	Machine Feed Rate, IPM Rotational Speed, RPM Number of Teeth, T	IPT = $\frac{IPM}{RPM \times T}$
Feed per Revolution - IPR Rotational Speed, RPM	Machine Feed Rate, IPM	IPR = $\frac{IPM}{RPM}$
Cutting Power Input - HP	Width of Cut, WOC Depth of Cut, DOC Machine Feed Rate, IPM Work Piece Material Power Constant, K	HP = WOC x DOC x IPM x K

Operating Conditions for End Milling

Speeds and Feeds

Speeds and feeds are the most important factors to consider for best results in milling. Improper feeds and speeds often cause low production, poor work quality and unnecessary damage to the cutter. Too high a speed or too light a feed leads to rapid wear and dulling of the cutter, thus reducing tool life.

In milling, SPEED is measured in peripheral feet per minute. Often times, SPEED is referred to as "cutting speed", "surface speed", or "peripheral speed". The relationship of this peripheral speed to the diameter of the end mill and the rotational speed of the machine spindle are indicated in the following table.

FEED is normally measured and stated in inches per minute (IPM). It is, as shown below, the product of the number of cutting teeth in the end mill times the feed per tooth times the revolutions per minute. In establishing operating conditions, all feed rates should be calculated from the chip load or feed per tooth. The individual cutting tooth must be able to sustain the load or feed applied to it without fracturing regardless of the number of teeth in the mill. Because feed per tooth affects thickness, it is a very important factor in tool life.

Highest possible feed per tooth will usually give longer tool life between grinds and greater production per grind. Excessive feeds may overload the mill teeth and cause breakage or chipping of the cutting edge. Reasonable safe starting feeds for end mills under 1/2" diameter range from .0002 - .002 inch per tooth and .002 - .003 for end mills 1/2" diameter and greater.

The following are some important relationships for the end milling operation.

Definition of Symbols and Measurement Units

Quantity	Symbol	Measurement Unit
Cutting Speed	SFM	Surface feet per minute
Rotational Speed	RPM	Revolutions per minute
End Mill Diameter	D	Inches
Feed Per Tooth	IPT	Inches per tooth
Machine Feed Rate	IPM	Inches per minute
Feed Per Revolution	IPR	Inches per revolution
Cutting Power Input	HP	Horsepower
Power Constant	K	Horsepower/Cubic Inch/Minute
Width of Cut	WOC	Inches
Depth of Cut	DOC	Inches
Number of Teeth	T	

Speed, Feed and Power Calculations

To Find	Known Values	Formulae
Peripheral Cutting Speed - SFM	Mill Diameter, D Rotational Speed RPM	SFM=.262 x RPM xD SFM(est) = $\frac{RPM \times D}{4}$
Rotational Speed - RPM	Peripheral Cutting Speed,SFM Mill Diameter, D	RPM = $\frac{SFM}{.262 \times D}$ RPM(est) = $\frac{4 \times SFM}{D}$
Machine Feed Rate - IPM	Rotational Speed, RPM Number of Flutes (Teeth), T Feed per Tooth, IPT	IPM= T x IPT x RPM
Feed per Tooth - IPT	Machine Feed Rate, IPM Rotational Speed, RPM Number of Teeth, T	IPT = $\frac{IPM}{RPM \times T}$
Feed per Revolution - IPR Rotational Speed, RPM	Machine Feed Rate, IPM	IPR = $\frac{IPM}{RPM}$
Cutting Power Input - HP	Width of Cut, WOC Depth of Cut, DOC Machine Feed Rate, IPM Work Piece Material Power Constant, K	HP = WOC x DOC x IPM x K

End Mills

Power Constants* For Use in Power Calculations

Work Material	K (Constant)	Work Material	K (Constant)	Work Material	K (Constant)
Aluminum	0.3	**High Temperature Alloys**		**High Tensile Alloys**	
Magnesium	0.3	Ferritic	1.7	180,000 - 220,000 psi	2.0
Copper	0.5	Austenitic	2.0	220,000 - 260,000 psi	2.5
Brass	0.4	Nickel Base	2.5	260,000 - 300,000 psi	3.3
Bronze	0.5	Cobalt Base	2.5	**Titanium**	
Cast Irons		**Steel**		under 100,000 psi	1.3
Ferritic	0.7	up to 150 Brinell	1.4	100,000 - 135,000 psi	1.7
Pearlitic	1.0	up to 300 Brinell	1.7	135,000 psi & over	2.5
Chilled	1.7	up to 400 Brinell	2.0	**Stainless Steel**	
Malleable Iron	1.0	up to 500 Brinell	2.5	Free Machining	1.0
				Others	1.7

*Horsepower required to remove one cubic inch of material per minute assuming a 60% power efficiency at the spindle nose and a 25% allowance for dulling of the end mill.

Starting Points

All of the speeds and feeds presented in the following tables by tool material, work piece material and diameter and types of end mill are suggested starting points. These may be increased or decreased dependent upon variables such as finish desired, condition of the milling machine, magnitude of the cut, rigidity of the part, use of coolant, power available, etc. Some points to consider in selecting speeds and feeds from within the ranges stated are:

Speed	
Use lower speeds for:	Use higher speeds for:
Hard Materials	Softer materials
Tough Materials	Better finishes
Abrasive Materials	Small diameter mills
Heavy Cuts	Light cuts
Minimum Tool Wear	Frail work piece or set-ups
Maximum Mill Life	Maximum production rates
	Non metallics

Feed	
Use higher feeds for:	Use lighter feeds for:
Heavy roughing cuts	Light and finishing cuts
Rigid set-ups	Frail set-ups
Easy to machine work materials	Hard to machine work materials
Rugged heavy duty mills	Deep slots
High tensile strength materials	Frail and small diameter mills
Coarse tooth mills	Low tensile strength materials
	Abrasive materials

Troubles and Corrective Actions

The following is a listing of some of the more common troubles experienced during end milling and corrective actions involving variations in speeds and feeds which may be taken to offset them:

Lack of rigidity:	Increase speed, decrease feed.
Excessive abrasion of the tool:	Decrease speed, increase feed.
Chipping of the cutting edge:	Decrease feed per tooth.
Burning of the cutting edge:	Decrease speed.
Cratering of carbide:	Decrease speed and feed.
Chatter:	Use other combinations of speed and feed.

Speed & Feed Data - Applications in various materials

Materials ➤	Heat-Resistant Cobalt Base Alloys, High Tensile Steels (50-55C)	Heat-Resistant Austenitic Alloys, High Tensile Steels (46-50C)	Heat-Resistant Nickel Base Alloys, High Strength Stainless Steels, High Strength Titanium Alloys	High Strength Stainless Steels, High Tensile Steels (40-46C) Medium Strength Titanium Alloys	Heat-Resistant Ferritic Base Alloys, Medium Strength Stainless Steels, Unalloyed Titanium Tool Steels (30-40C)	Machine Steel, Hard Brass & Bronze Electrolytic Copper, Mild Steel Forgings (20-30C)	Cast Iron, Mild Steel, Half-Hard Brass & Bronze	Brass, Bronze, Alloyed Aluminium, Abrasive Plastics	Aluminium, Plastics, Wood
Types & Styles of End Mills ➤	Premium Cobalt, High Speed Steel, 2 or More Flute	Premium Cobalt, High Speed Steel, 2 or More Flute	Premium Cobalt, High Speed Steel, 2 or More Flute	High Speed Steel End Mills or Premium Cobalt, High Speed Steel Types, 2 or More Flute	High Speed Steel End Mills, 2 or More Flute	High Speed Steel End Mills, 2 or More Flute	High Speed Steel End Mills, 2 or More Flute. Surface Treatment Helpful in C.I. Applications	1 to 6 Flute, High Speed Steel End Mills of High Helix Type	1 to 6 Flute, High Speed Steel End Mills of High Helix Type

	Speed 5-10 SFM		Speed 10-15 SFM		Speed 15-20 SFM		Speed 20-40 SFM		Speed 40-60 SFM		Speed 60-80 SFM		Speed 80-100 SFM		Speed 100-200 SFM		Speed 200-600 SFM	
Dia. of End Mill	RPM	Chip Load per Tooth	RPM	Chip Load per Tooth	RPM	Chip Load per Tooth	RPM	Chip Load per Tooth	RPM	Chip Load per Tooth	RPM	Chip Load per Tooth	RPM	Chip Load per Tooth	RPM	Chip Load per Tooth	RPM	Chip Load per Tooth
1/16	*	*	*	*			1222-2444	.0002-.0005	2444-3667	.0002-.0005	3667-4888	.0002-.0005	4888-6111	.0002-.0005	6111-12222	.0002-.0005	12222 Up	.0002-.0005
3/32	*	*	*	*	611-815	.0002-.0005	815-1629	"	1629-2750	"	2750-3259	"	3259-4073	"	4073-8146	"	8146 Up	"
1/8	*	*	*	*	456-611	"	611-1222	"	1222-1833	"	1833-2440	.0002-.001	2440-3056	.0002-.001	3056-6112	.0002-.001	6112 Up	.0002-.001
3/16	*	*	204-306	.0002-.0005	306-407	"	407-815	"	815-1222	"	1222-1625	"	1625-2037	"	2037-4074	"	4074-12222	"
1/4	76-153	.0002-.001	153-230	.0002-.001	229-306	.0002-.001	306-611	.0002-.001	611-917	.0002-.001	917-1222	.0005-.002	1222-1528	.0005-.002	1528-3056	.0005-.002	3056-9168	.0005-.002
5/16	61-122	"	122-183	"	183-244	"	244-489	"	489-733	"	733-978	"	978-1222	"	1222-2444	"	2444-7332	"
3/8	51-102	"	102-153	"	153-203	"	203-407	.0005-.002	407-611	.0005-.002	611-815	.001-.003	815-1019	.001-.003	1019-2038	.0005-.003	2038-6114	"
7/16	44-88	.0005-.001	88-132	.0005-.001	131-175	.0005-.002	175-349	"	349-524	"	524-698	"	698-873	"	873-1746	"	1746-5238	"
1/2	38-76	"	76-115	"	115-153	"	153-306	.0005-.003	306-458	.001-.003	458-611	"	611-764	"	764-1528	"	1528-4584	"
9/16	34-68	.0005-.002	68-104	.0005-.002	104-136	"	136-272	"	272-412	"	412-543	.001-.004	543-678	.001-.004	678-1356	.0005-.004	1356-4071	.0005-.003
3/8	31-61	"	61-92	"	92-122	"	122-244	.001-.004	244-367	.001-.004	367-489	"	489-611	"	611-1222	"	1222-3666	"
11/16	28-56	"	56-84	"	84-111	"	111-222	"	222-337	"	337-444	"	444-555	"	555-1110	"	1110-3330	"
3/4	26-51	"	51-76	"	76-102	.001-.004	102-203	"	203-306	"	306-407	"	407-509	.002-.006	509-1018	.001-.006	1018-3054	.001-.004
13/16	24-47	.001-.003	47-71	.001-.003	71-94	"	94-189	"	189-284	"	284-379	.002-.006	379-469	"	469-938	"	938-2814	"
7/8	22-44	"	44-65	"	65-87	"	87-175	"	175-262	.002-.006	262-349	"	349-436	"	436-872	"	872-2616	"
15/16	20-40	"	40-62	"	62-81	"	81-163	"	163-246	"	246-326	"	326-407	"	407-814	"	814-2442	"
1	19-38	"	38-58	"	58-76	"	76-153	.002-.006	153-229	"	229-306	"	306-382	"	382-764	.002 Up	764-2292	.002 Up
1-1/8	34	.0015-.004	34-51	.0015-.004	51-68	.0015-.005	68-136	"	136-204	"	204-272	"	272-340	.003 Up	340-680	"	680-2040	"
1-1/4	31	"	31-46	"	46-61	"	61-122	"	122-183	"	183-244	.003 Up	244-306	"	306-612	"	612-1836	"
1-3/8	28	"	28-42	"	42-55	"	55-111	"	111-167	.003 Up	167-222	"	222-278	"	278-556	"	556-1668	"
1-1/2	26	"	26-38	"	38-51	.002 Up	51-102	.003 Up	102-153	"	153-204	"	204-255	"	255-510	.003 Up	510-1530	"
1-5/8	24	.002 Up	35	.002 Up	35-47	"	47-94	"	94-141	"	141-188	"	188-235	"	235-470	"	470-1410	"
1-3/4	22	"	32	"	32-43	"	43-87	"	87-131	"	131-175	"	175-218	"	218-436	"	436-1308	"
1-7/8	20	"	30	"	30-40	.003 Up	40-81	"	81-122	"	122-163	"	163-204	"	201-408	"	408-1224	.003 Up
2	19	"	29	.003 Up	29-38	"	38-76	"	76-115	"	115-153	"	153-191	"	191-382	"	382-1146	"
2-1/8	18	.003 Up	28	"	36	"	36-72	"	72-108	"	108-144	"	144-179	"	179-358	"	358-1074	"
2-1/4	17	"	26	"	34	"	34-68	"	68-102	"	102-136	"	136-170	"	170-340	"	340-1020	"
2-3/8	16	"	25	"	32	"	32-64	"	64-97	"	97-128	"	128-161	"	161-322	"	322-966	"
2-1/2	15	"	23	"	30	"	30-61	"	61-92	"	92-122	"	122-153	"	153-306	"	306-918	"
2-5/8	15	"	22	"	29	"	29-58	"	58-88	"	88-116	"	116-145	"	145-290	"	290-870	"
2-3/4	14	"	21	"	28	"	28-56	"	56-83	"	83-111	"	111-139	"	139-278	"	278-834	"
2-7/8	14	"	20	"	27	"	27-53	"	53-80	"	80-106	"	106-132	"	132-264	"	264-792	"
3	13		19		26	"	26-51	"	51-76	"	76-102	"	102-127	"	127-254	"	254-762	"

Note: All the speeds and feeds shown are suggested starting points. They may be increased or decreased, dependent upon such variables as finish desired, condition of milling machine, magnitude of cut, coolant, etc. In many cases they may be increased slightly. The above speeds and feed are applicable for slotting cuts, one (1) diameter deep. For deeper slotting cuts or cavity applications, feeds should be decreased. * Solid Carbide End Mills should be used in small diameter applications, in materials harder than 46C.

Regular High Speed Steel & Premium Cobalt High Speed Steel

Speed & Feed Data - Applications in various materials

Materials ➤	Heat-Resistant Ferritic Base Alloys, Medium Strength Stainless Steels, Unalloyed Titanium Tool Steels (30-40C)		Machine Steel, Hard Brass & Bronze Electrolytic Copper, Mild Steel Forgings (20-30C)		Cast Iron, Mild Steel, Half-Hard Brass & Bronze		Brass, Bronze, Alloyed Aluminium, Abrasive Plastics		Aluminium, Plastics, Wood	
Types & Styles of End Mills ➤	High Speed Steel End Mills, 2 or More Flute		High Speed Steel End Mills, 2 or More Flute		High Speed Steel End Mills, 2 or More Flute. Surface Treatment Helpful in C.I. Applications		1 to 6 Flute, High Speed Steel End Mills of High Helix Type		1 to 6 Flute, High Speed Steel End Mills of High Helix Type	
5	Speed 40-60 SFM	Feed	Speed 60-80 SFM	Feed	Speed 80-100 SFM	Feed	Speed 100-200 SFM	Feed	Speed 200-600 SFM	Feed
Dia. of End Mill	RPM	Chip Load per Tooth	RPM	Chip Load per Tooth	RPM	Chip Load per Tooth	RPM	Chip Load per Tooth	RPM	Chip Load per Tooth
1/16	2444-3667	.0002-.0005	3667-4888	.0002-.0005	4888-6111	.0002-.0005	6111-12222	.0002-.0005	12222 Up	.0002-.0005
3/32	1629-2750	"	2750-3259	"	3259-4073	"	4073-8146	"	8146 Up	"
1/8	1222-1833	"	1833-2440	.0002-.001	2440-3056	.0002-.001	3056-6112	.0002-.001	6112 Up	.0002-.001
3/16	815-1222	"	1222-1625	"	1625-2037	"	2037-4074	"	4074-12222	"
1/4	611-917	.0002-.001	917-1222	.0005-.002	1222-1528	.0005-.002	1528-3056	.0005-.002	3056-9168	.0005-.002
5/16	489-733	"	733-978	"	978-1222	"	1222-2444	"	2444-7332	"
3/8	407-611	.0005-.002	611-815	.001-.003	815-1019	.001-.003	1019-2038	.0005-.003	2038-6114	"
7/16	349-524	"	524-698	"	698-873	"	873-1746	"	1746-5238	"
1/2	306-458	.001-.003	458-611	"	611-764	"	764-1528	"	1528-4584	"
9/16	272-412	"	412-543	.001-.004	543-678	.001-.004	678-1356	.0005-.004	1356-4071	.0005-.003
3/8	244-367	.001-.004	367-489	"	489-611	"	611-1222	"	1222-3666	"
11/16	222-337	"	337-444	"	444-555	"	555-1110	"	1110-3330	"
3/4	203-306	"	306-407	"	407-509	.002-.006	509-1018	.001-.006	1018-3054	.001-.004
13/16	189-284	"	284-379	.002-.006	379-469	"	469-938	"	938-2814	"
7/8	175-262	.002-.006	262-349	"	349-436	"	436-872	"	872-2616	"
15/16	163-246	"	246-326	"	326-407	"	407-814	"	814-2442	"
1	153-229	"	229-306	"	306-382	"	382-764	.002 Up	764-2292	.002 Up

End Mills

Regular High Speed Steel & Premium Cobalt High Speed Steel

Roughing Style End Mills

Speed & Feed Data - Applications in various materials

Material	SFM	*Feed Increase
Aluminum Alloys	125-250	50%
Magnesium	125-250	50
Copper	75-100	40
Brass	85-110	40
Bronze	75-100	40
Cast Iron	100-125	30
Cast Steel	75-100	20
Malleable Iron	80-120	30
Stainless Steel		
Free Machining	75-90	20
Other	50-75	20

Material	SFM	*Feed Increase
Steel		
Annealed	100-125	30
Rc 18-24	75-100	25
Rc 32-37	40-90	20
Titanium		
to Rc 30	38-75	25
Rc 30+	19-25	20
High Temperature Alloys		
Austenetic	13-19	20
Ferritic	50-75	20
Nickel Base	18-25	15
Cobalt Base	8-13	10

* Feed Increase over chip load per tooth currently in use with convential style end mills.

PM/Plus Cobalt

Conventional & Roughing Style End Mills

Speed & Feed Data - Applications in various materials

Material	Hardness BHN	Surface Feet Per Minute SFM	Chip Load Per Tooth by Cutting Diameter 1/8"	1/4"	1/2"	1"
Titanium**	300	60-75	.0015	.0025	.005	.007
Annealed Alloys**	340	30-45	.001	.002	.004	.006
Sol. trtd. & Aged**	400	15-30	.0007	.0015	.002	.004
High Temp. Alloys**	300	30-45	.002	.0025	.004	.006
Inconel, Monel, Hastelloy**	400	10-24	.0015	.002	.003	.005
Tool Steels	370	40-55	.0005	.0007	.0012	.002
	450	20-30	.0003	.0005	.0007	.001
Free Machining Steel	200	90-120	.001	.002	.004	.006
Alloyed & UnAlloyed	275	75-90	.0007	.0012	.003	.005
Alloy Steels - Medium to Hard	400	40-50	.001	.0015	.002	.004
Stainless Steel						
Work Hardening	Various	55-75	.0005	.0007	.0012	.002
Precipitation Hardening	Various	35-50	.0005	.0007	.0012	.002
Copper Alloys Short Chip	250	180-240	.001	.002	.004	.006

** List number 552, 553, 554, 575 and 579 only.

List number 503, 505 and 578 Roughing Mills - Applicable to materials other than Titanium and High Temperature Alloys. For carbon steels over 300 BHN use at feed rates stated above. All other applications, a 25% increase in feed rate over chip load listed above is recommended.

NOTE: All of the speeds and feeds shown are suggested starting points. They may be increased or decreased, dependent upon such variables as finish desired, condition of milling machine, magnitude of cut, coolant, etc. In many cases they may be increased slightly. The above speeds and feeds are applicable for slotting cuts, one (1) diameter deep. For deeper slotting cuts or cavity applications, feed should be decreased.

MicroPlus Carbide End Mills

Speed & Feed Data - Application in various materials

Material	Speed SFM	Chip Load Per Tooth by Cutting Diameter 1/4"	1/2"	3/4"	1-2"
Aluminum & Aluminum	800-1300	.0015	.004	.005	.006
Aluminum - High Silicon	300-800	.002	.004	.005	.006
Brass/Bronze	250-400	.002	.003	.004	.005
Cast Iron: Gray to Br 220	235-500	.0015	.002	.004	.0055
Over Br 220	100-240	.0008	.0013	.002	.0035
Ductile to Br 220	225-325	.0014	.002	.004	.005
Over Br 220	70-175	.0005	.0015	.003	.004
Malleable to Br 220	250-375	.0013	.002	.003	.004
Over Br 220	100-225	.0007	.0012	.002	.003
Copper	200-500	.0012	.002	.004	.005
Magnesium	1000-1300	.0015	.004	.006	.008
Monels & Nickel	100-150	.0007	.0015	.002	.003
Stainless Steel: to Br 275	150-320	.0004	.001	.002	.003
Over Br 275	65-275	.0004	.001	.002	.003
Steel: to Br 250	275-360	.0013	.002	.004	.005
to Br 325	190-320	.0007	.0015	.0035	.0045
to Br 425	115-200	—	.001	.0025	.0035
to Rc 52	45-60	—	.0007	.0015	.002
Titanium & Ti Alloys: to Br 250	50-280	.0009	.0015	.004	.006
Over Br 250	45-130	.0005	.001	.004	.006
High Temperature Alloys: Cobalt Base	35-60	—	—	.0010	.0015
Nickel Base	20-60	—	.0007	.0015	.002
Iron Base	60-90	—	.0007	.0015	.002

Note: For slotting cuts - reduce lowest speed by approximately 20%.

Power Constants* For Use in Power Calculations

Work Material	K (Constant)	Work Material	K (Constant)	Work Material	K (Constant)
Aluminum	0.3	**High Temperature Alloys**		**High Tensile Alloys**	
Magnesium	0.3	Ferritic	1.7	180,000 - 220,000 psi	2.0
Copper	0.5	Austenitic	2.0	220,000 - 260,000 psi	2.5
Brass	0.4	Nickel Base	2.5	260,000 - 300,000 psi	3.3
Bronze	0.5	Cobalt Base	2.5	**Titanium**	
Cast Irons		**Steel**		under 100,000 psi	1.3
Ferritic	0.7	up to 150 Brinell	1.4	100,000 - 135,000 psi	1.7
Pearlitic	1.0	up to 300 Brinell	1.7	135,000 psi & over	2.5
Chilled	1.7	up to 400 Brinell	2.0	**Stainless Steel**	
Malleable Iron	1.0	up to 500 Brinell	2.5	Free Machining	1.0
				Others	1.7