CLEVELAND TWIST DRILL

End Mills

Selection of Proper End Mill and Machine

Tool Material

Cleveland end mills are available in a variety of tool materials; regular high speed steel, two varieties of high speed steel with cobalt, (premium cobalt and PM/Plus for higher production rates), carbide-tipped and sub micron grain solid carbide. The choice of tool material will depend on the following factors:

1. Machinability of the workpiece
2. Hardness and structure of the workpiece
3. Shape and conditions of the workpiece
4. Number of workpieces to be processed

Several of the chief characteristics of high speed steel end mills as compared to carbide tipped or solid carbide mills are their low initial cost and general purpose versatility. End mills of high speed steel with cobalt have proven most effective in titanium alloys, alloy steels, Rc-40-50, high strength stainless steels, and thermal and heat resistant materials such as nickel or cobalt base alloys.

The PM/Plus end mills utilizing a special cobalt high speed steel coupled with a heat treatment and special mechanical designs, are capable of greater than normal feed rates and longer tool life in these same material groups.

For high production jobs in non-ferrous, non-metallic or highly abrasive substances it is more economical to use solid carbide MicroPlus end mills or carbide tipped mills. The carbide used in each type of mill has been specifically selected to match the application of the mill. The bodies of the carbide tipped mills have been heat treated to withstand both the bending and torsional loads encountered in milling.

Number of Flutes

To determine selection of either a two-flute or a multiple-flute end mill, several basics need to be considered.

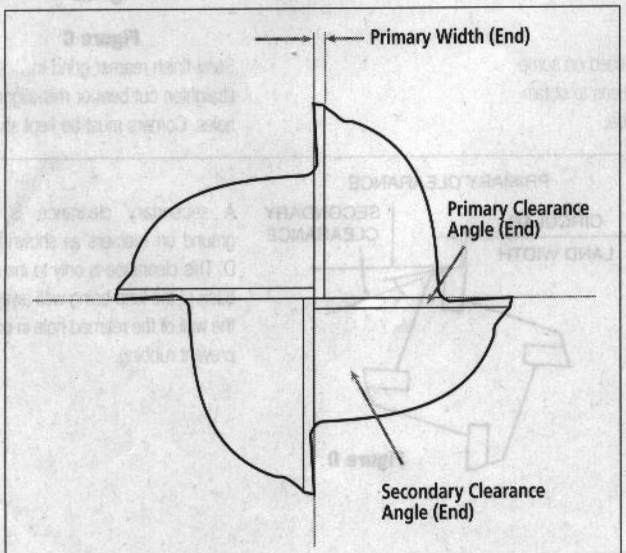
1. Type of cut
2. Chip space required
3. Production rate desired
4. Surface finish required

Two-fluted end mills have greater chip handling capacity than multiple fluted end mills. In order for an end mill to axially plunge-cut (drill), it must be manufactured as a center cutting tool. All two-flute end mills are center cutting. Multiple-flute end mills are available with center cutting or non-center cutting features.

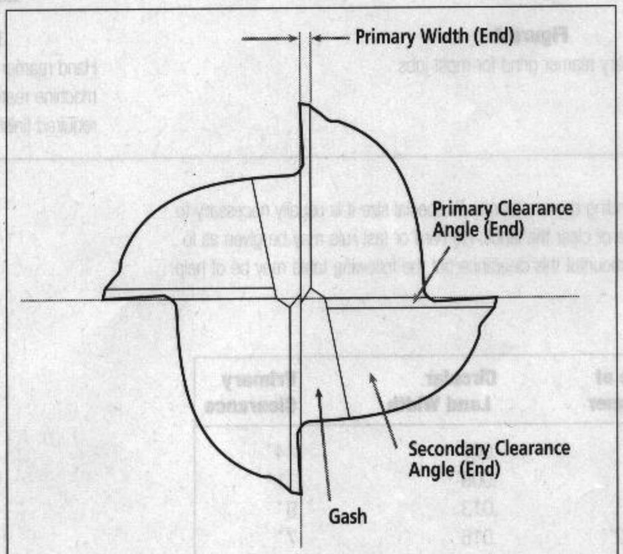
When two-flute end mills and multiple-flute end mills are run at the same feed rate (inches per minute), multiple-flute end mills may produce finer finishes and longer tool life than two-flute end mills, owing to a lighter chip load per tooth. Some caution must be exercised to insure that the chip load does not become so light as to cause excessive wear. Generally for production runs where either a two-flute or multiple flute end mill would be applicable, it is more economical to use the multiple-flute end mill.

Roughing end mills are designed to be used in a variety of materials and to remove more cubic inches of material in the same period of time than conventional end mills. In order to achieve these rates of material removal, as well as to obtain full tool life, the feed rates employed must be heavier than with conventional end mills.

The Cleveland "Select-A-Mill" system shown on pages 130 and 131 has been designed to aid in the selection of the proper end mill based upon type operation and workpiece material.



End View - Non Center Cutting Style



End View - Center Cutting Style

Ferrous MaterialsMachine & Job Set-Up Considerations

The milling machine being used for an application should never be underpowered. The power being expended on the milling operation must be below that of the rated capacity of the machine. Inconsistencies in material or line voltage will actually decrease the spindle speed, resulting in increased chip load per tooth and premature cutting edge failure. Scored or battered end mill shanks, adapter holes, or adapter shanks all contribute to lack of concentricity between the milling machine spindle and the cutting portion of the end mill.

In most milling operations, the end mill is subjected to side forces acting normal to mill axis. The projection of the tool from the holder results in beam loading with the fulcrum point being the end of the holder or the holder screw. Continued use leads to a bell mouth condition of the holder as evidenced by brown ring(s) being formed on the end mill shank during use. Maintenance and use of good quality holders are important elements in achieving consistent end mill performance.

General Considerations

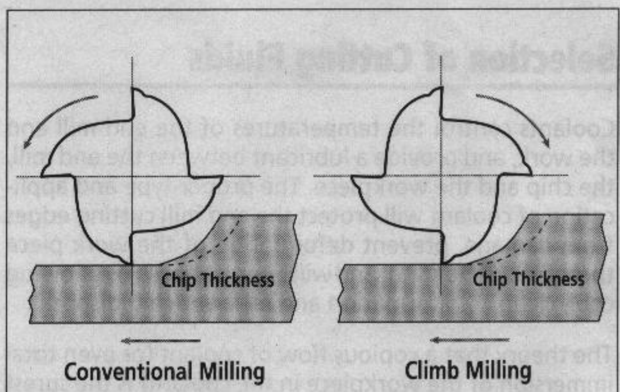
An end mill of proper design must be used whenever possible, with the shortest necessary flute length projecting from the milling machine spindle. In addition, the end mill being used must be sharp, with correct relief and rake angles for the material being milled, and must be as concentric with the milling machine spindle as possible. Worn or misaligned machine spindles can also contribute to a lack of concentricity. Non-concentric set-ups lead to premature wear, rough surface finish and excessive oversize cutting action. Rigidity of the set-up is extremely critical to obtaining satisfactory end mill performance. The best aligned spindle-holder-end mill combination is ineffective if the set-up is too light, workpiece insecurely clamped or improperly supported.

Mode of Milling

In peripheral milling operations where the radial width of cut is less than half the end mill diameter, two options are available relative to the direction of rotation of the end mill and direction of movement of the workpiece as noted below.

Originally the "conventional" milling procedure of feeding the workpiece material into the counter rotating end mill was the standard practice. To some degree this was dictated by the quality of the milling machines available and their lack of back lash eliminators. In this system of cutting the thickness of the chip constantly increases as the tooth of the end mill moves through the cut. Before actually engaging into the cut, the tooth has a tendency to slide along until enough pressure is built up to cause the cutting edge to penetrate into the material. This sliding action both dulls the cutting edge as well as generates heat. It also has an undesirable effect on those materials which have a tendency to work harden. "Conventional" milling is still applicable for those applications involving workpieces with hard, scaly surfaces or machines with poor back lash characteristics.

With the general quality of milling machines in use today, the preferred method of milling in most instances is to have both the direction of rotation and direction of the feed of the workpiece to be in the same direction. Known as the "Climb Milling" this procedure allows the mill tooth to take a full cut as it penetrates into the workpiece, without any substantial rubbing or dragging on the surface. The thickness of the chip decreases as the face moves through its cut. This results is lower cutting temperatures, finer workpiece finish and generally longer tool life. One additional advantage is that "climb milling" forces the workpiece into the table, providing for a more rigid situation during cutting, whereas, the "conventional milling" mode tends to lift the workpiece away from the table. Such action results in an unstable condition for cutting, where the workpieces are thin or poorly clamped.

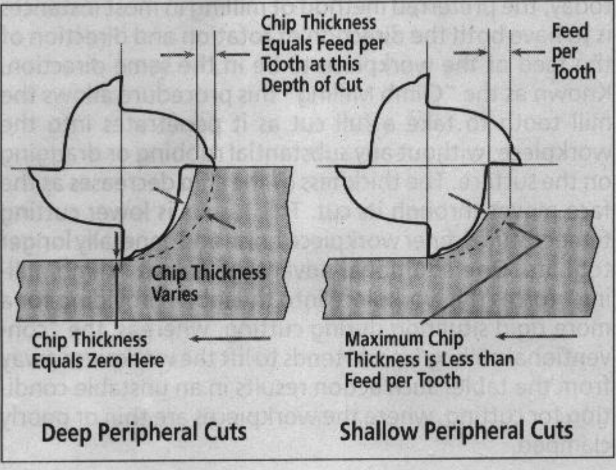


Chip Thickness

Chip thickness is one of the more important factors affecting tool life in milling operations. Very thin or feather-edge chips dull cutting edges more rapidly than thick chips. Chip thickness is governed by the size and shape of the end mill and workpiece. Chip thickness is

End Mills

also affected by the position of cutter axis to resultant milled surface as illustrated below for several conditions; It emphasizes that careful thought must be given to feed per tooth, to mill size and design and location relative to the work.



Selection of Cutting Fluids

Coolants control the temperatures of the end mill and the work, and provide a lubricant between the end mill, the chip and the workpiece. The proper type and application of coolant will protect the end mill cutting edges from damage, prevent deformation of the work piece through overheating, and will improve finish by allowing cool, clean chip formation and efficient chip disposal.

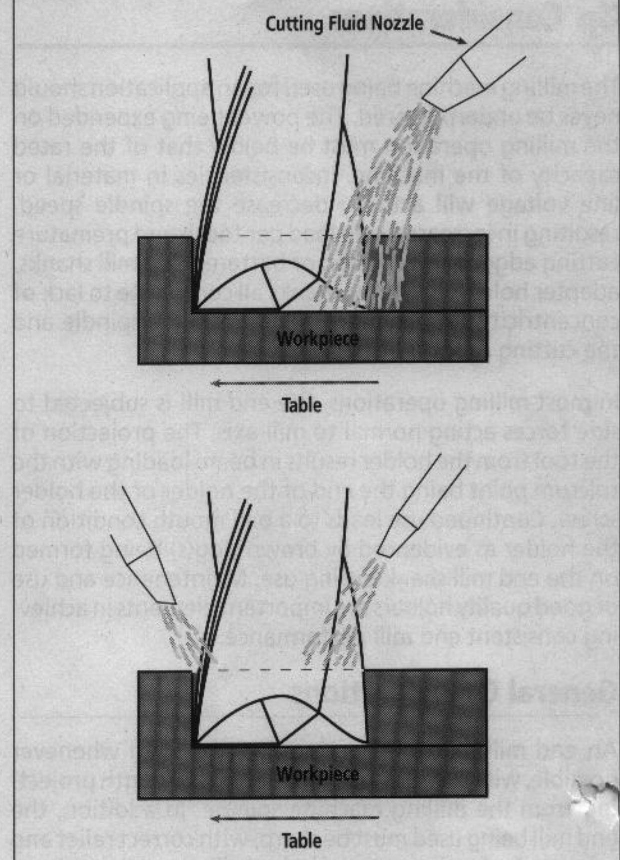
The theory that a copious flow of coolant (or even total immersion of the workpiece in the coolant) is the surest way to provide proper cooling and lubrication, is not necessarily true. Recent tests have shown that multiple streams or jets of coolant, directed at strategic locations of the end mill rotating in or against the work, have greater cooling effects than a slow-moving copious flow.

The optimum application of coolant is achieved by the use of coolant feeding end mills. These end mills are designed and manufactured to meet your specific need.

When using coolant, care should always be taken to insure that coolant lines are clean and free of obstructions, and that the coolant is both clean and free of fines.

No matter how well the cutting fluid is directed between the end mill and the work, a dull end mill will generate more heat than can be dissipated by adequate cooling. Proper cutting fluid application will protect a sharp cutting edge to insure maximum tool life per grind. An interrupted flow of cutting fluid can cause rapid damage to the cutting edges in a few revolutions of the end mill.

It is always wise to consult a cutting fluid supplier when experiencing problems of an unusual nature.



High Speed Steel End Mills

A cutting fluid or coolant is required when using high speed steel end mills for milling steel. For milling with high speed end mills, water emulsified cutting oil generally is considered the least expensive and most applicable coolant for nearly all materials except those that are milled dry. Some of the harder steel forgings and die steels may be milled with somewhat better results when mineral or lard oils, or sulfurized oils are used. Plastics and cast iron should be milled dry or with a jet of air, while aluminum and aluminum alloys are best milled with water emulsified cutting oil, either in a properly directed jet stream, or in a mist.

Carbide Tipped & Solid Carbide End Mills

Most carbide milling applications may be run dry. Often a jet of air is used which also serves to remove chips from the cutting area.

If a coolant is used, it should be applied carefully so that the direction of flow is not partially blocked by the workpiece or fixtures. Intermittent heating and quenching of carbide, such as caused by an interrupted flow of coolant, will result in cracked carbide and tool failure. In cases where coolant is used, it generally is a soluble oil or light cutting oil.

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.

Regular High Speed Steel & Premium Cobalt High Speed Steel

Conventional Style End Mills

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	Feed	Speed 10-15 SFM	Feed	Speed 15-20 SFM	Feed	Speed 20-40 SFM	Feed	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	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.

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%.

Regrinding of End Mills

In any manufacturing plant today, both large and small, an effective, organized end mill regrinding program is essential. No matter how large or small the end mill usage may be, an organized regrinding system will pay dividends in greater production per end mill.

End mills should be removed from the machine at the end of a predetermined production run, or when dull.

If possible, a predetermined amount of stock should be removed on dull end mills (normal stock removal is .005 or .010 for each regrind) and color coding or size etching might be marked on the end mill to indicate its size. After several regrinds (this, too, can be predetermined) the end mill will tend to lose its effective rake angle and flute depth, and, at this point, the end mill must be scrapped.

Charts and data for the correct relief angles, relief widths, and rake angles for regrinding end mills are shown on page 297 and 298.

After regrinding and inspection, all end mills should be dipped in rust-preventative oil, and, if suitable cartons are not available, they should be dipped in plastic coating for the full flute length. They should be stored in their original container, in separate bins or wooden containers. Small wooden containers that can be carried about are usually better than ordinary bin storage, as rough handling, in some cases, ruins more cutting edges than the actual milling operation.

The basic requirements for efficient end mill regrinding are:

- Tool grinding equipment in good condition.
- Adequate information for particular applications with reference to correct reliefs and rake angles.
- A workable tool conservation program.
- Adequate storage facilities and efficient handling techniques.

Nothing decreases the usable tool life of an end mill more than continued use of a dull end mill. The cutting action of a dull end mill is such that all the shearing qualities are gone and the material being milled is actually pushed on ahead of the individual cutting edges. This results in drawing the temper of the individual high-speed steel cutting edges, poorer finishes and accelerated wear. Continued use of dull end mill makes it necessary to remove much more stock at regrinding to make the end mill usable once again. In the case of carbide end mills excessive dullness will chip and crater the cutting edges and will often cause breakage.

The point in the milling operation at which an end mill begins to dull can be determined in several ways. A dull end mill begins to spring or chatter, causes finishes to become poorer, and glazes or smears some materials. In addition, a wear land begins to form on the top of each individual cutting edge. Many milling machine operators can determine the first signs of end mill dulling by the sound of the cutting action, or by slight variations in machine vibrations.

Generally, an end mill is ready for resharpening when a wear land is visible on the top of the cutting edge. For smaller diameter end mills, and when milling some of the harder, ferrous materials, a wear land of approximately .005 may be used as an indication of the maximum allowable wear prior to resharpening. When using larger diameter end mills, and when milling in other classes of materials, a wider wear land may be used as an end point prior to regrinding.

In the final analysis, the many variables of each individual end mill application will determine the amount of cutting edge wear or degree of end mill dullness allowable before regrinding.

Regrinding Equipment

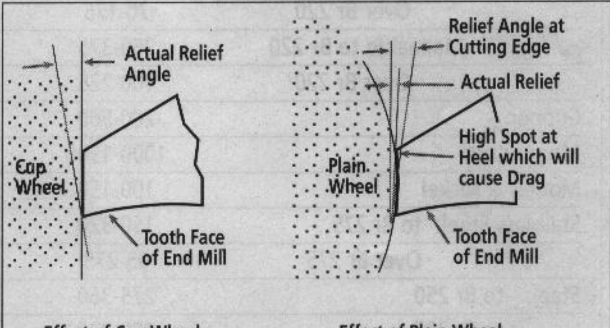
The tool cutter grinders on the market today are extremely versatile, and are capable of end mill regrinding between centers or off-the-shank. Tool and cutter grinders specifically designed for this type of work are easy to set up, operate and maintain, and versatile enough to regrind many types of cutting tools other than end mills. For large volume of regrinding work some facilities utilize NC or CNC grinding equipment which maintains uniformity of reground mills at each regrinding.

Wheel Selection for Regrinding

High Speed Steel End Mills

Efficient end mill regrinding is possible without the necessity of stocking a large inventory of various wheel types. For general purpose regrinding, aluminum oxide wheels of 46 to 80 grit are usually satisfactory, although, for finer finishes, finer grit wheels many be used. When using wheels with a grit finer than 80, and particularly when resharpening thin cutting edges, approximately .002 should be the maximum amount of stock removal. Heavier cuts than .002 with fine grit wheels usually cause wheel loading and cutting edge burning. CBN wheels are recommended for minimum heat generation and may allow greater stock removal on roughing operations.

Two basic types of wheels may be used; plain or cupped. The cutting edge sections shown below are those which will be produced on the end mill cutting edges by each of these wheels. For a conventional type of regrinding, cup-shaped wheels are often preferred. This preference is no doubt caused by the fact that regrinding with a plain wheel tends to leave a high heel portion on the cutting edge, which might cause drag. If the heel portion is too high, it must be cleared also, requiring an additional regrinding setup and operation. Then too, the relief ground on an end mill cutting edge with a cupped wheel is easier to measure, as this type of regrinding leaves a flat, angular relief.



Effect of Cup Wheel Shape on Relief Angle

Effect of Plain Wheel Shape on Relief Angle

Solid or Tipped Carbide End Mills

Resinoid bond diamond wheel of 200 grit to 300 grit should be used for resharpening solid carbide or carbide tipped end mills. The wheel should be rotated so that it cuts from the lip face to the back of the land to minimize any tendency of the carbide to flake. The same consideration on use of plain wheels versus cup wheel shape stated above applies.

Regrinding of End Mills (Sides)

Producing the correct relief angle on an end mill is accomplished by establishing the proper location of the wheel and the end mill. On NC or CNC equipment, this relationship is established through use of a probe or other locating type device. On tool and cutter grinding