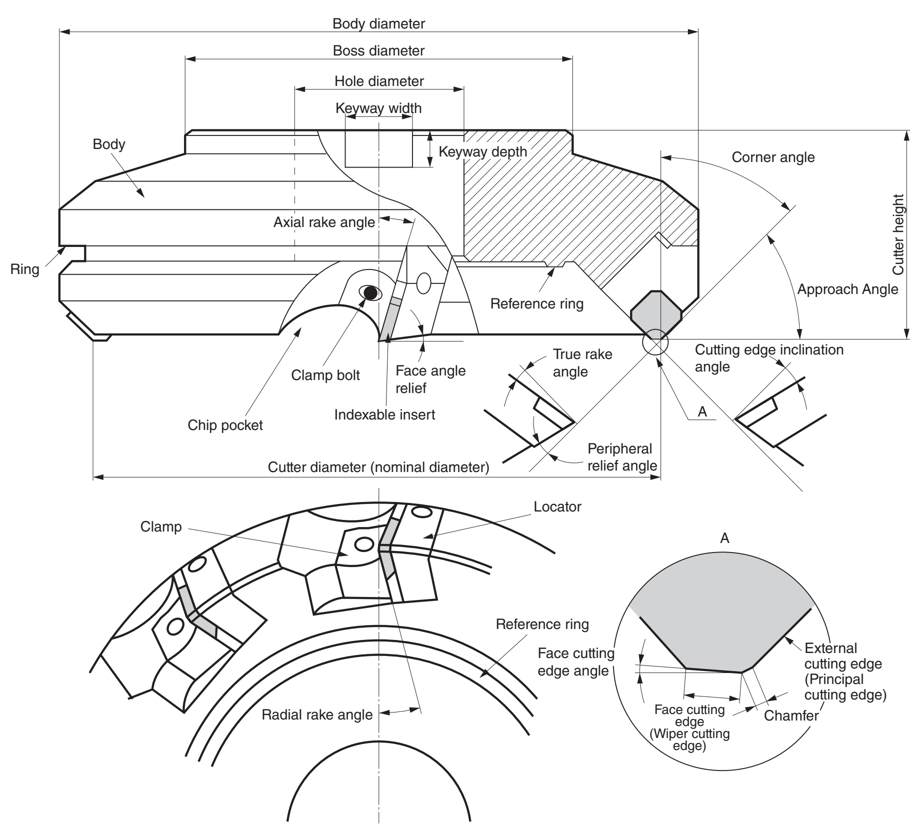
■ Parts of a Milling Cutter



■ Milling Calculation Formulas

● Calculating Cutting Speed

$$v_c = \frac{\pi \times DC \times n}{1{,}000}$$

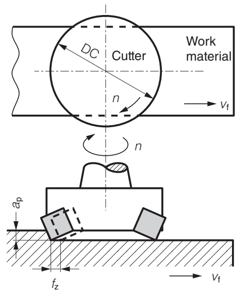
$$n = \frac{1{,}000 \times v_c}{\pi \times DC}$$

● Calculating Feed Rate

$$v_f = f_z \times z \times n$$

$$f_z = \frac{v_f}{z \times n}$$

v_c : Cutting speed (m/min)
π : ≈ 3.14
DC : Cutter diameter (mm)
n : Rotational speed (min^{-1})
v_f : Feed rate per minute (mm/min)
f_z : Feed rate per tooth (mm/t)
z : Number of teeth



● Power Requirement

$$P_c = \frac{a_e \times a_p \times v_f \times k_c}{60 \times 10^6 \times \eta} = \frac{Q \times k_c}{60 \times 10^3 \times \eta}$$

● Horsepower Requirement

$$H = \frac{P_c}{0.75}$$

● Chip Removal Amount

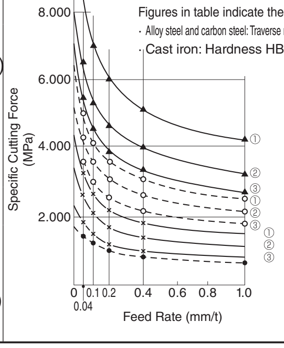
$$Q = \frac{a_e \times a_p \times v_f}{1{,}000}$$

P_c : Power requirement (kw)
H : Required horsepower (HP)
Q : Chip removal amount (cm^3/min)
a_e : Cutting width (mm)
v_f : Feed rate (mm/min)
a_p : Depth of cut (mm)
k_c : Specific cutting force (MPa)
Rough value (Steel: 2,500 to 3,000MPa
Cast iron: 1,500MPa
Aluminium: 800MPa)
η : Machine efficiency (about 0.75)

● Relation Between Feed Rate, Work Material, Specific Cutting Force

No. \ Work Material	Alloy Steel (▲)	Carbon Steel (○)	Cast Iron (×)	Aluminium Alloy (●)
(1)	1.8	0.8	200	—
(2)	1.4	0.6	160	—
(3)	1.0	0.4	120	—

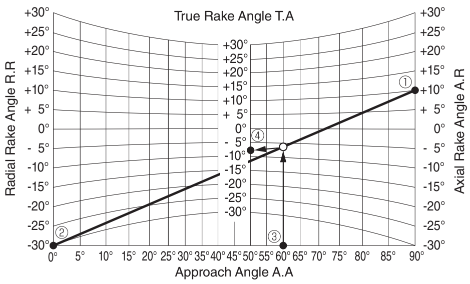
Figures in table indicate these characteristics.
· Alloy steel and carbon steel: Traverse rupture strength σ B(GPa)
· Cast iron: Hardness HB



Functions of the Various Cutting Angles

	Description	Symbol	Function	Effect
(1) (2)	Axial rake angle Radial rake angle	A.R. R.R.	Determines chip removal direction, built-up edge, cutting force	Available in positive to negative (large to small) rake angles; Typical combinations: Positive and Negative, Positive and Positive, Negative and Negative
(3)	Approach angle	A.A.	Determines chip thickness, chip removal direction	Large: Thin chips and small cutting force
(4)	True rake angle	T.A.	Effective rake angle	Positive (Large): Excellent machinability Low cutting edge strength. Negative (Small): Strong cutting edge and easy chip adhesion.
(5)	Cutting edge inclination angle	I.A.	Determines chip control direction	Positive (Large): Excellent chip control and small cutting force. Low cutting edge strength.
(6)	Face cutting edge angle	F.A.	Determines surface roughness	Small: Improved surface roughness.
(7)	Relief angle		Determines edge strength, tool life, chattering	

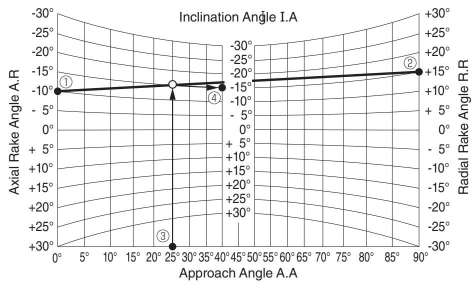
True Rake Angle Chart (T.A)



(Ex.) (1) A.R (Axial rake angle) = +10°
(2) R.R (Radial rake angle) = –30°
(3) A.A (Approach angle) = 60°
-> T.A. (True rake angle) = –8° (4)

<Formula> tan T.A=tan R.R · cos A.A + tan A.R · sin A.A

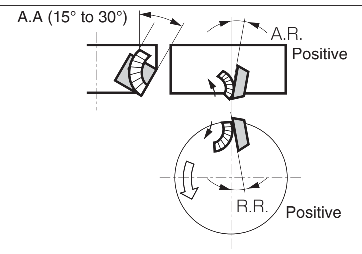
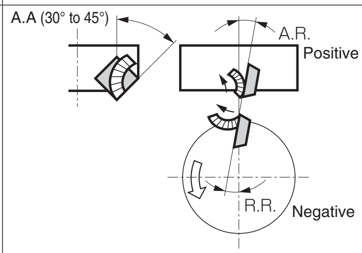
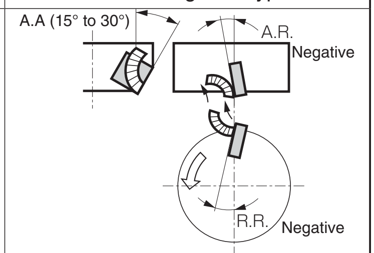
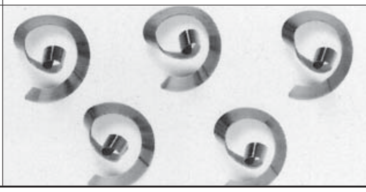
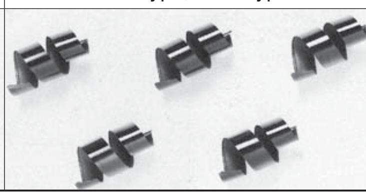
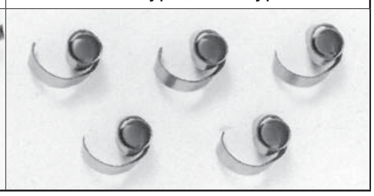
Inclination Angle (I.A) Chart



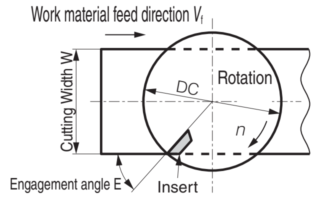
(Ex.) (1) A.R (Axial rake angle) =–10°
(2) R.R (Radial rake angle) =+15°
(3) A.A (Approach angle) = 25°
-> I (Inclination angle) =–15° (4)

<Formula> tan I.R=tan A.R · cos A.A – tan R.R · sin A.A

Rake Angle Combination

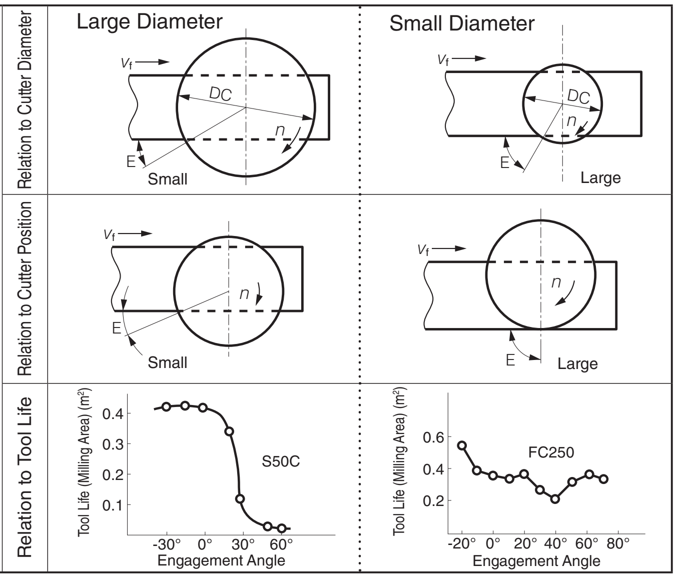
	Double Positive Type	Negative - Positive Type	Double Negative Type
Edge Combination and Chip Removal A.R: Axial rake angle R.R: Radial rake angle A.A: Approach angle : Chip and removal direction : Rotation			
Advantages	Good cutting action	Excellent chip removal and cutting action	Double-sided inserts can be used and higher cutting edge strength
Disadvantages	Lower cutting edge strength and only single-sided inserts can be used	Only single-sided inserts can be used	Dull cutting action
Application	For general milling of steel and low rigidity work piece	For Steel, Cast iron, Stainless steel, Alloy steel	For light milling of cast iron and steel
Series	DPG Type	WGX Type, UFO Type	DGC Type, DNX Type
Chips (Ex.) · Work material: SCM435 · v_c=130m/min f_z=0.23mm/t a_p=3mm			

■ Relation Between Engagement Angle and Tool Life



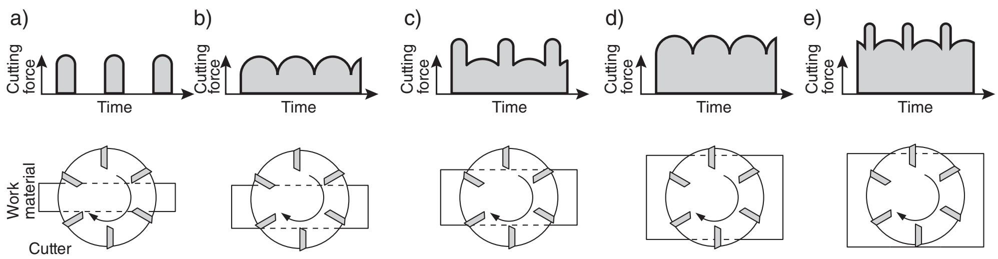
The Engagement angle denotes the angle at which the full length of the cutting edge comes in contact with the work material, with reference to the feed direction.

· The larger E is, the shorter the tool life.
· To change the value of E:
 1) Increase the cutter size.
 2) Shift the position of the cutter.



● Relation between the number of simultaneously engaged cutting edges and cutting force:

Normally, cutting width is considered to be appropriate with 70 to 80% of the cutter diameter engaged as shown in example d). However, this may not apply due to the actual rigidity of the machine or work piece, and machine horsepower.



a) · 0 or 1 edge in contact at same time.
b) · Only 1 edge in contact at any time.
c) · 1 or 2 edges in contact.
d) · 2 edge in contact at any time.
e) · 2 to 3 edges in contact.

■ To Improve Surface Roughness

(1) Inserts with wiper flat

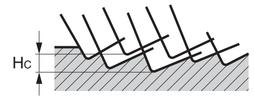
When all the cutting edges have wiper flats, a few teeth are intentionally elevated to play the role of a wiper insert.

· Insert equipped with straight wiper flat (Face angle: 15' - 1°)
· Insert equipped with curved wiper flat (Curvature ≈ R500 (example))

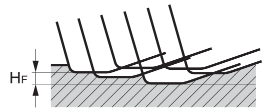
(2) Wiper insert assembling system

A system to protrude one or two inserts (wiper inserts) with a smooth curved edge just a little beyond the other teeth to wipe the milled surface. (Applies to WGC, RF types, etc.)

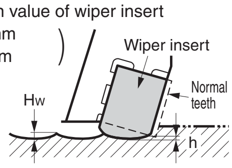
● Surface roughness without wiper flat



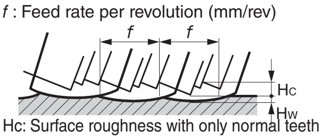
● Surface roughness with straight wiper flat



h: Projection value of wiper insert
(Fc: 0.05mm
Al: 0.03mm)

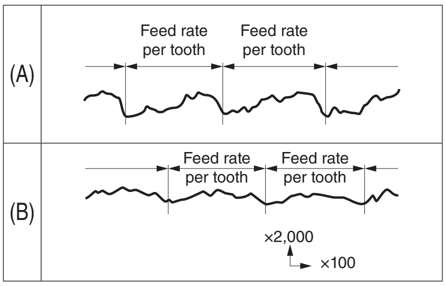


f : Feed rate per revolution (mm/rev)



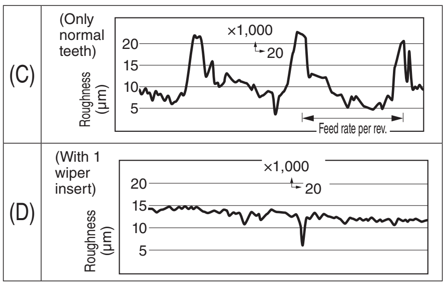
Hc: Surface roughness with only normal teeth
Hw: Surface roughness with wiper insert

● Influence of different face angles on surface finish



· Work : SCM435
· Cutter: DPG5160R (Single tooth)
· v_c = 154m/min
 f_z = 0.234mm/t
 a_p = 2mm
· Face Cutting Edge Angle
 (A): 28'
 (B): 6'

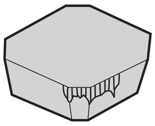
● Effects of having wiper insert (example)

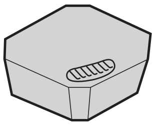


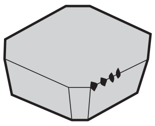
· Work : FC250
· Cutter: DPG4100R
· Insert : SPCH42R
· Face run-out : 0.015mm
· Radial run-out: 0.04mm
· v_c = 105m/min
 f_z = 0.29mm/t
 (1.45 mm/rev)
(C) : Only normal teeth
(D) : With 1 wiper insert

Technical Guidance
Troubleshooting for Milling

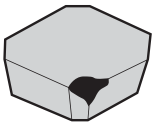
■ Tool Failure and Remedies

<table>
<tr><th colspan="2">Failure</th><th colspan="2">Basic Remedies</th><th>Remedy Examples</th></tr>
<tr><td rowspan="4">Cutting Edge Failure</td><td>Excessive Flank Wear
</td><td>Tool Material

Cutting Conditions</td><td>· Select a more wear resistant grade.
Carbide (P30 → P20, K20 → K10) → { Coated, Cermet
· Reduce cutting speeds. Increase feed rate.</td><td>· Recommended insert grades<table><tr><th></th><th>Steel</th><th>Cast Iron</th><th>Non-Ferrous Alloy</th></tr><tr><td>Finishing</td><td>T250A, T4500A (Cermet)</td><td>ACK100 (Coated Carbide)
BN7000 (SUMIBORON)</td><td>DA1000 (SUMIDIA)</td></tr><tr><td>Roughing</td><td>ACP100 (Coated Carbide)</td><td>ACK200 (Coated Carbide)</td><td>DL1000 (Coated Carbide)</td></tr></table></td></tr>
<tr><td>Excessive Crater Wear
</td><td>Tool Material

Cutting Conditions</td><td>· Select a crater-resistant grade.
· Reduce cutting speeds. Reduce depth-of-cut and feed rate.</td><td>· Recommended insert grades<table><tr><th></th><th>Steel</th><th>Cast Iron</th><th>Non-Ferrous Alloy</th></tr><tr><td>Finishing</td><td>T250A, T4500A (Cermet)</td><td>ACK100 (Coated Carbide)</td><td>DA1000 (SUMIDIA)</td></tr><tr><td>Roughing</td><td>ACP100 (Coated Carbide)</td><td>ACK200 (Coated Carbide)</td><td>DL1000 (Coated Carbide)</td></tr></table></td></tr>
<tr><td>Chipping
</td><td>Tool Material

Tool Design

Cutting Conditions</td><td>· Change to tougher grades.
P10 → P20 → P30
K01 → K10 → K20
· Select a negative-positive cutter configuration with a large peripheral cutting edge angle (small approach angle).
· Reinforce the cutting edge (Honing).
· Select a strong edge insert (G → H).
· Reduce feed rates.</td><td>· Recommended insert grades<table><tr><th></th><th>Steel</th><th>Cast Iron</th></tr><tr><td>Finishing</td><td>ACP200 (Coated Carbide)</td><td>ACK200 (Coated Carbide)</td></tr><tr><td>Roughing</td><td>ACP300 (Coated Carbide)</td><td>ACK300 (Coated Carbide)</td></tr></table>· Recommended cutter: SEC-WaveMill WGX Type
· Cutting conditions: Refer to H20</td></tr>
<tr><td>Breakage
</td><td>Tool Material

Tool Design

Cutting Conditions</td><td>· If it is due to excessive low speeds or very low feed rates, select an adhesion resistant grade.
· If it is due to thermal cracking, select a thermal impact resistant grade.
· Select a negative-positive (or negative) cutter configuration with a large peripheral cutting edge angle (small approach angle).
· Reinforce the cutting edge (Honing).
· Select a stronger chipbreaker (G → H)
· Increase insert size (Thickness in particular).
· Select appropriate conditions with regards to the particular application.</td><td>· Recommended insert grades<table><tr><th></th><th>Steel</th><th>Cast Iron</th></tr><tr><td>Roughing</td><td>ACP300 (Coated Carbide)</td><td>ACK300 (Coated Carbide)</td></tr></table>· Recommended cutter: SEC-WaveMill WGX Type
· Insert thickness: 3.18 → 4.76mm
· Insert type: Standard → Strong edge type
· Cutting conditions: Refer to H20</td></tr>
<tr><td rowspan="5">Others</td><td>Unsatisfactory Machined Surface Finish</td><td>Tool Material

Tool Design

Cutting Conditions</td><td>· Select an adhesion resistant grade.
Carbide → Cermet
· Improve axial runout of cutting edges.
(Use a cutter with less runout, Attach correct inserts.)
· Use wiper inserts.
· Use special purpose cutters designed for finishing.
· Increase cutting speeds</td><td>· Recommended insert grades<table><tr><th colspan="2"></th><th>Steel</th><th>Cast Iron</th><th>Non-Ferrous Alloy</th></tr><tr><td>General Purpose</td><td>Cutter Insert</td><td>WGX type*
ACP200
(Coated Carbide)</td><td>DGC type
ACK200
(Coated Carbide)</td><td>RF type*
H1 (Carbide)
DL1000 (Coated Carbide)</td></tr><tr><td>Finishing</td><td>Cutter Insert</td><td>WGX type
T4500A (Cermet)</td><td>FMU type
BN7000 (SUMIBORON)</td><td>RF type
DA1000 (SUMIDIA)</td></tr></table>* marked cutters can be fitted with wiper inserts.</td></tr>
<tr><td>Chattering</td><td>Tool Design

Cutting Conditions
Others</td><td>· Select a cutter with sharp cutting edges.
· Use an irregular pitched cutter.
· Reduce feed rates.
· Improve workpiece and cutter clamp rigidity.</td><td>· Recommended cutter
For Steel: SEC-WaveMill WGX Type
For Cast Iron: SEC-Sumi Dual Mill DGC Type
For Non-Ferrous Alloy: High Speed cutter for Aluminium RF type</td></tr>
<tr><td>Unsatisfactory Chip Control</td><td>Tool Design</td><td>· Select cutter with good chip removal features.
· Reduce number of teeth.
· Enlarge chip pocket.</td><td>· Recommended cutter: SEC-WaveMill WGX Type</td></tr>
<tr><td>Edge Chipping On Workpiece</td><td>Tool Design

Cutting Conditions</td><td>· Increase the peripheral cutting edge angle (decrease the approach angle).
· Select a stronger chipbreaker (G → L).
· Reduce feed rates.</td><td>· Recommended cutter: SEC-WaveMill WGX Type</td></tr>
<tr><td>Burr On Workpiece</td><td>Tool Design
Cutting Conditions</td><td>· Select a cutter with sharp cutting edges.
· Increase feed rates.
· Select an insert designed for low burr.</td><td>· Recommended cutter: SEC-WaveMill WGX Type + FG Breaker
DGC Type + FG Breaker</td></tr>
</table>