Efficient milling with the correct strategies
使用正確的方式進行高效率銑削加工

GTC milling strategies
鈷領擺線銑削加工應用

These milling strategies belong to the state-of-the-art and most effective application methods for current solid carbide milling tools. When applied, an enormously high metal removal rate ensures a considerable increase in productivity. Very high cutting parameters can be achieved even with less powerful machines or unstable machining conditions. With difficult-to-machine materials or unfavourable diameter-length-ratios of the tools a massive increase of process reliability can be achieved.

這些銑削策略的應用屬於當前全鎢鋼銑刀的最新技術和最有效的應用方法。使用時，極高的金屬移除率可確保生產效率的顯著提升，即使在功率較小的機台或是工況不穩定的條件下，也可以實現非常高的切削參數。即使加工難切削材，或是刀具的直徑長度比不理想，也是可以大大提高加工過程的穩定性。

GTC
GÜHRING TROCHOIDAL CUTTING

HPC

HIGH PERFORMANCE CUTTING 高性能切削加工（最高的金屬移除率）

max. metal removal rate/time → stable conditions; short de-clamping; high performance; good cooling
單位時間內最高的金屬移除率 → 工況條件穩定、快速換模上下料；高性能；冷卻條件優良

HSC

HIGH SPEED CUTTING 高速度加工（用於模具類球刀、圓鼻銑刀成形銑削）

at high speed/high feed rate → high dynamics; low cutting widths ＆depths ; low drive power
高轉速/ 高進給 → 高動能；低切寬、低切深；主軸馬力低

Principles and objectives 銑削加工的大原則和目標

Maximum tool utilisation
- utilisation of entire cutting edge length
- full power delivery
- increased tool life
- balanced wear

最大限度地利用刀具
- 盡量利用全部切削刃長度
- 機台全功率輸出利用
- 延長刀具壽命
- 刀具磨損磨耗均勻

Modification of cutting distribution
- low cutting widths a_e
- high cutting depths a_p

切削參數調整分配
- 低切割寬度 ae
- 高切削深度 ap

High process reliability
- low tool wrapping
- improved thermal conditions at tool cutting edge
- low mechanical stress

高加工的穩定性
- 刀具纏屑情況低
- 改善刀具刃口的散熱
- 工件加工面低的機械應力產生

Maximum metal removal rate
- saving time/machine costs

最大金屬移除率
- 節省時間與機器成本

Foundations for economically efficient milling 經濟效益高的銑削加工基礎

Peripheral requirements

Applicable in every material group

- P K H M S N
- easy to machine materials = increase in productivity
- difficult to machine materials = increase in process reliability

High-dynamic machining centres

- short acceleration distances
- higher speed range
- small to medium tool diameters

Heavy machines

- stable feed axes
- high spindle torque
- medium to large tool diameters

Unstable to stable workpiece clamping

- stable = vibration-free machining = maximum metal removal rate
- unstable = reduction of radial forces = increased process reliability

周邊外圍需求的考量因素

適用於每個物料群組

- P K H M S N
- 容易加工的材料 = 提高生產率
- 難加工的材料 = 提高加工過程的穩定性

高轉速加工中心機

- 加速距離短
- 更高的切削速度範圍
- 盡量使用小、中尺寸直徑的刀具

重型機器

- 穩定的進給軸向控制
- 高主軸扭力
- 盡量使用中大尺寸直徑刀具

不穩定或是穩定的工件夾持狀況

- 穩定 = 無振動的加工 = 最大金屬去除率
- 不穩定 = 減少徑向力 = 提高加工過程穩定性

Application parameters 加工參數應用

Low cutting width a_e to 0.33 x D 低的切削寬度ae 到 0.33x D

- low angle of engagement <70° 低切削嚙合角<70°
- short time of contact between cutting edge and component
  切削刃與工件之間的接觸時間短

Very high tooth feed f_z 極高進給率fz

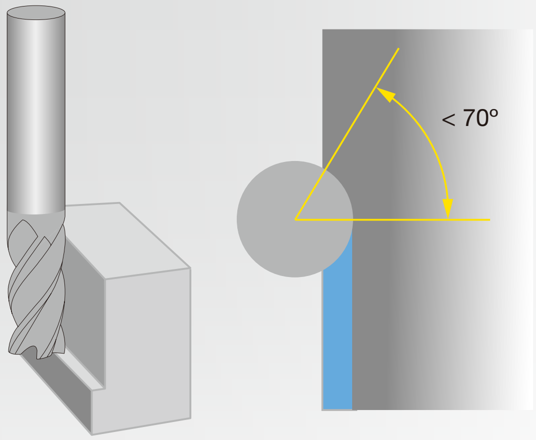
- reduced chip thickness allows considerably higher f_z
  切屑厚度減少、可顯著提高 fz

Very high cutting speed v_c 非常高的切削速度vc

- reduced heating up and prolonged cooling down allow very high v_c values
  高切削速度時減少加工時熱的產生、並延長冷卻時間

High cutting depth a_p 高切削深度ap

- improved leverage effect 改善槓桿效應
- high metal removal rate 高金屬移除率
- increase in contact points between tool and component
  增加刀具與零件之間的接觸點



Tool angle of engagement & tool contact time

刀具切削嚙合角度 & 刀具接觸時間

Metal removal rate 金屬移除率（單位時間內材料切除的體積）

The metal removal rate specifies how high the actual chip removal is per minute.
It is especially suitable for comparing different machining strategies.

金屬移除率是指每分鐘實際去除切屑的量，特別適合用於比較不同的加工策略。

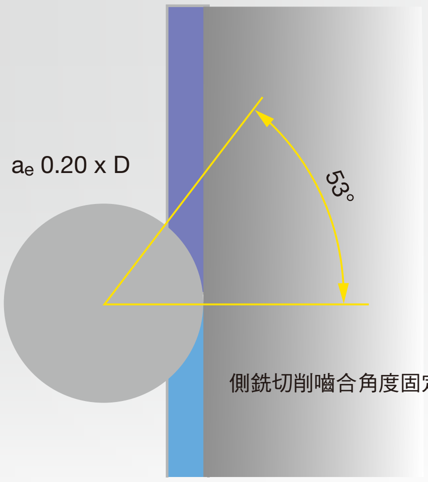
$$a_p\ (mm) \times a_e\ (mm) \times v_f\ (m/min) = Q\ (cm^3/min)$$

切深ap　切寬ae　每分鐘進給　每分鐘移除量cm³

Influence on process through tool engagement
刀具切削與工件的接觸嚙合角度對加工過程的影響

Angle of engagement 切削嚙合角度

The angle of engagement inscribes the cutting range of the tool from start of chip formation to exit from the material. With these parameters the stress impacting on the tool can be assessed. With straight milling paths the angle is constant, with concave milling paths it increases and with convex milling paths it decreases.
嚙合角度確定了從切屑形成開始到從退出材料時刀具的切削範圍。
利用這些參數，可以評估影響刀具的受力。在直線銑削路徑中，角度是恆定的；
在凹形銑削路徑中，角度是逐漸增大的；而在凸形銑削路徑中，角度則是減小。

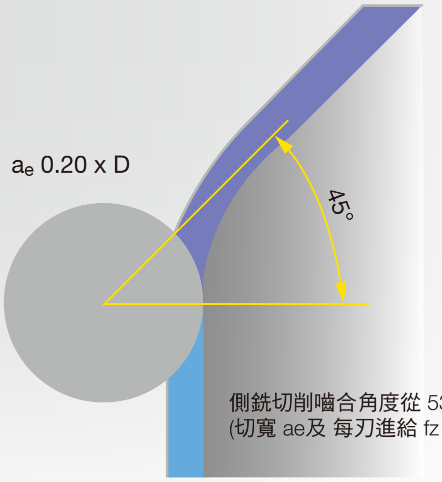


Straight milling path 直線銑削路徑
- constant angle of engagement 嚙合角度固定
- constant tool stress 刀具的受力固定

Example: a_e 0.20 x D = 53° engagement 切寬ae 0.2D=53°嚙合角
Engagement remains a constant 53° 53°固定的嚙合角度

Angle of engagement with convex contour radii
外凸形繞銑嚙合角度變化

Convex milling path 外凸形繞銑路徑
- decreasing angle of engagement 嚙合角度減少
- reduced tool stress 刀具的受力減少

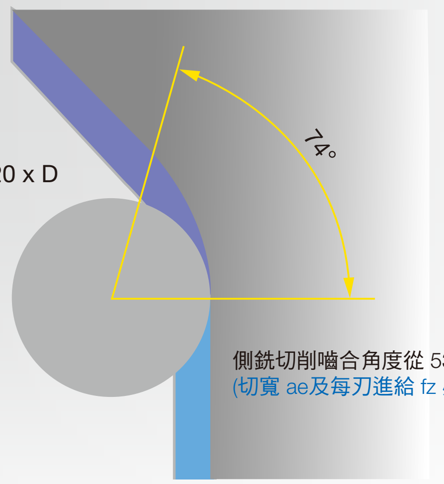


Example: a_e 0.20 x D = 53° engagement 切寬ae 0.2D=53°嚙合角
Engagement reduces to 45° 嚙合角度減少至45°

Measures: 調整方式
a_e may be increased
f_z can be increased
切寬 ae及每刃進給 fz 可以增加

Angle of engagement with concave contour radii
內凹形繞銑嚙合角度變化

Concave milling path 內凹形繞銑路徑
- increasing angle of engagement 嚙合角度增加
- increased tool stress 刀具的受力增加



Example: a_e 0.20 x D = 53° engagement 切寬ae 0.2D=53°嚙合角
Engagement increases to 74° 嚙合角度增加至74°

Measures: 調整措施
a_e must be reduced
f_z must be reduced in radius
切寬 ae及每刃進給 fz 必須減少

Influence on process through tool engagement
刀具切削與工件的 "接觸嚙合角度" 對加工過程的影響

Angle of engagement with 90° corner radii 90°內凹圓形繞銑嚙合角度變化

Tool radius = Corner radius 刀具半徑＝工件圓弧半徑

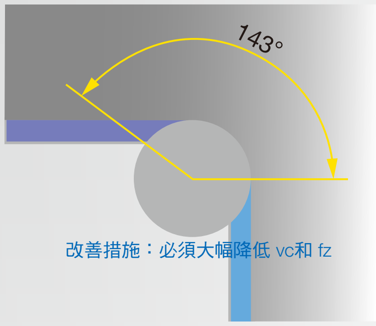
- very unfavourable for tool dynamics 非常不利的刀具動態路徑
- change of stress direction 刀具的受力改變
- abrupt increase in tool stress 刀具受力突然增加

Example: Increase of engag. angle from 53° to 143° (270°)
接觸嚙合角度由 53°增加至 143°

Measures: v_c and f_z must be heavily reduced
改善措施：必須大幅降低 vc和 fz

a_e 0.20 x D

接觸嚙合角度由 53°增加至 143°



Tool radius < Corner radius 刀具半徑< 工件圓弧半徑

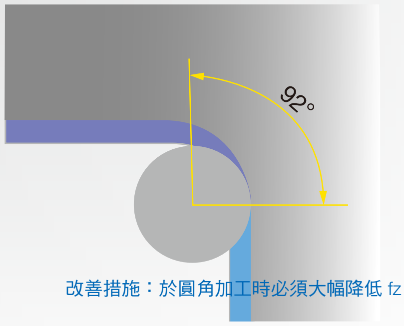
- machine can interpolate the path 機器可以插補路徑
- no “impact” on tool 對刀具無 “影響”
- lower increase of tool stress 降低刀具受力

Example: Increase of engag. angle from 53° to 92° (174°)
接觸嚙合角度由 53°增加至 92°

Measures: a_e must be reduced 切寬 ae必須減少
改善措施： f_z must be heavily reduced in radius
fz每刃進給於圓角加工時必須大幅降低

a_e 0.20 x D

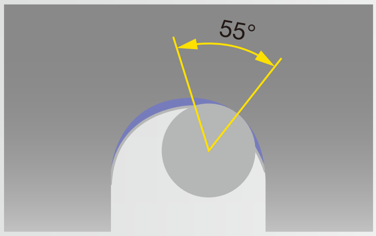
接觸嚙合角度由 53°增加至 92°



Ratio of flute width to tool diameter with trochoidal milling
擺線銑削時槽寬與刀具直徑之比

Flute width 1.7 – 2.0 x D 槽寬 1.7~2.0 x D

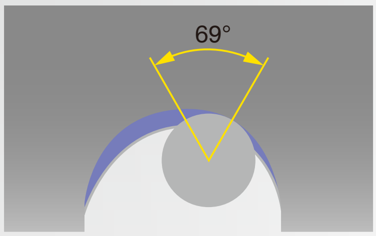
- cut in C arc C形圓弧切削
- a_e max. 0.10 x D (theor. 37°) 切寬 ae最多 0.10D（理論上嚙合37°）
- increase of angles of engagement by up to 50%
  切削嚙合角度增加最多至 50%。（37°x 1.5=55.5°）



接觸嚙合角度由 37°增加至 55°

Flute width 2.1 – 3.0 x D 槽寬 2.1~3.0 x D

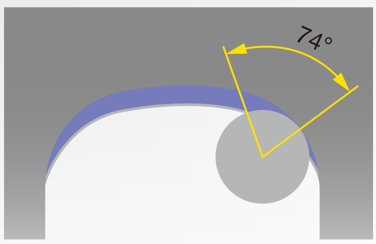
- cut in C arc C形圓弧切削
- a_e max. 0.15 x D (theor. 46°) 切寬 ae最多 0.15D（理論上嚙合46°）
- increase of angles of engagement by up to 50%
  切削嚙合角度增加最多至 50%。（46°x 1.5=69°）



接觸嚙合角度由 46°增加至 69°

Flute width from 3.1 x D 槽寬 3.1 x D

- cut in D arc C形圓弧切削
- a_e max. 0,20 x D (theor. 53°) 切寬 ae最多 0.20 D（理論上嚙合53°）
- increase of angles of engagement by up to 40%
  切削嚙合角度增加最多至 40°。（53°x 1.4=74.2°）



接觸嚙合角度由 53°增加至 74°

GTC HPC HSC

建議參數，用於在切削刃長最大為 **3xD** 的情況下增加切削值

Guide values for increasing the cutting values with cutting edge lengths up to 3 x D

GTC HPC HSC Roughing and HSC finishing 粗、精銑

Material 工件材質	Application 銑削方式	radial feed in % of Ø 徑向進給切寬%	v_c factor * 切削速度 係數	f_z factor * 每刃進給 係數	Angle of engagement 切削嚙合角度
	Slotting	**100 %**	**1**	**1**	**180°**
N	HPC Roughing	33 %	1.5	1.3	70°
N P	HPC Roughing	25 %	1.6	1.5	60°
N P K	HPC Roughing	20 %	1.7	1.6	53°
N P K M	HPC Roughing	15 %	1.8	1.9	46°
N P K M S	HSC Roughing	10 %	1.9	2.3	37°
N P K M S	HSC Roughing	8 %	2.0	2.5	31°
N P K M S	HSC Roughing	5 %	2.1	2.5	26°
N P K	HSC Finishing	3 %	2.0	1.2	20°
N P K M S	HSC Finishing	2 %	2.0	1.1	18°
N P K M S	HSC Finishing	1 %	2.0	1.0	11°
N P K M S	HSC Fine finishing	0.5 %	2.2	0.9	8°

* Base value for the calculation with v_C and f_Z factors is the value specified in the Gühring Navigator for “slotting” in the respective material group.

使用的 vc和 fz 係數進行計算的基本值是以 Gühring Navigator 中為相對應材料群組中的 “開槽” 指定的值

Base cutting values slotting – RF 100 tools – smooth cutting
開槽基準切削值 – RF 100銑刀 – 平順切削

Material 工件材質	Hardness 抗拉強度	Application 銑削方式	v_C 切削速度	f_z (mm/z) with nom. Ø 每刃進給/ 刃徑 3	4	5	6	8	10	12	16	20	25
P1	≤ 850 N/mm²	Slotting	180	0.015	0.020	0.025	0.030	0.040	0.060	0.072	0.096	0.120	0.150
P2	850-1200 N/mm²	Slotting	160	0.014	0.019	0.024	0.029	0.038	0.055	0.066	0.088	0.110	0.138
P3	850-1400 N/mm²	Slotting	135	0.014	0.018	0.023	0.027	0.036	0.050	0.060	0.080	0.100	0.125
M1	< 750 N/mm²	Slotting	120	0.014	0.018	0.023	0.027	0.036	0.050	0.060	0.080	0.100	0.125
M2	750-850 N/mm²	Slotting	80	0.012	0.016	0.020	0.024	0.032	0.045	0.054	0.072	0.090	0.113
M3	> 850 N/mm²	Slotting	70	0.011	0.014	0.018	0.021	0.028	0.040	0.048	0.064	0.080	0.100
S-Ni	≤ 1300 N/mm²	Slotting	30	0.008	0.011	0.014	0.017	0.022	0.032	0.038	0.051	0.064	0.080
S-Ti	≤ 1300 N/mm²	Slotting	60	0.012	0.016	0.020	0.024	0.032	0.045	0.054	0.072	0.090	0.113
K1	≤ 240 HB	Slotting	160	0.017	0.022	0.028	0.033	0.044	0.065	0.078	0.104	0.130	0.163
K2	> 240 HB	Slotting	140	0.015	0.020	0.025	0.030	0.040	0.055	0.066	0.088	0.110	0.138
Wr. al.alloy	≤ 5 % Si	Slotting	500	0.020	0.026	0.033	0.039	0.052	0.075	0.090	0.120	0.150	0.188
Cast al. alloy	> 5 % Si	Slotting	230	0.017	0.022	0.028	0.033	0.044	0.060	0.072	0.096	0.120	0.150
Non-fer.metals	≤ 850 N/mm²	Slotting	250	0.017	0.022	0.028	0.033	0.044	0.060	0.072	0.096	0.120	0.150

Metal removal rate 移除率 (單位時間內材料切除的體積)

$$a_p\ (mm) \times a_e\ (mm) \times v_f\ (m/min) = Q\ (cm^3/min)$$

切深ap 切寬ae 每分鐘進給 每分鐘移除量cm³

Example 範例	HPC roughing: 15% a_e ; 2 x D a_p ; C45 中碳鋼
Tool 銑刀	RF 100 U Ø12 mm – 4 flutes
Feed 進給	radial feed a_e 1.8 mm = 15% of D
Base value slotting 切削基礎值	v_c slotting = 180 m/min, f_z slotting= 0.072 mm
Conversion 切削係數	v_c factor = 1.8 ➞ v_c: 180 m/min x 1.8 = v_c 324 m/min f_z factor = 1.9 ➞ f_z: 0.072 mm x 1.9 = f_z 0.137
Increased values 係數增加後之切削參數	v_c: 324 m/min / f_z: 0.137 mm n: 8594 U/min / v_f: 4710 mm/min
Metal removal rate 移除率	Q = 203 cm³/min

GENERAL RECOMMENDATION TOOL COOLING

Steel P
Cast iron K
Hardened H

Dry machining, compressed air, MQL:

- avoid thermal shock 避免熱產生對刀具的衝擊
- dissipate machining temperature via chip 切屑把熱帶走
- supporting chip removal 幫助排屑

Stainless M
Special alloy S

Emulsion; oil:

- cooling of tool cutting edge 切削刃口冷卻
- preventing built-up edgex 避免刃口沾黏積屑
- supporting chip removal 幫助排屑

Non-ferrous metals N

Emulsion; MQL:

- preventing built-up edges 避免刃口沾黏積屑
- supporting chip removal 幫助排屑

EXCEPTIONS FOR MATERIAL RANGES 材料範圍以外的注意事項

P K

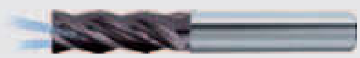
When coolant is not available the cutting speed v_c and/or the radial feed a_e should be reduced.
The resulting reduced temperature reduces the risk of thermal shock.
如果冷卻條件不佳，則應該降低切削速度（vc）及降低切寬（ae），這樣才能降低溫度，降低熱對刀刃的衝擊
If there are chip removal problems the application of coolant should be taken into consideration, because poor removal of chips can lead to massive tool wear and even tool breakage.
如果排屑不良，則應使用冷卻液，排屑不良會大大導致刀刃磨損甚至斷刀。
In the case of component heating by chip nests, it should be checked whether the component chips can be removed by a specifically aligned „coolant jet“ without hitting the cutting area.
Alternatively, the application of coolant for the entire machining operation is recommended.
當排屑不良而產生熱能時應檢查是否可以使用冷卻液，透過使用專門的 "冷卻液噴嘴" ，可以將冷卻液供應到堵塞處而不會碰到切削區域， 另外，建議在整個加工過程中使用冷卻液。

OTHER NOTES 其他注意事項

Finishing 精銑削
The application of coolant is principally an advantage as a better surface finish can be achieved.
使用冷卻液原則上是一個優勢，因為可以實現更好的表面光潔度

Very long tools 長刃型銑削
Coolant can result in a smoother process, as the lubricant has a vibration-reducing effect.
使用冷卻液可以使加工過程更順暢，因為潤滑劑具有減振作用

Alignment of coolant 冷卻液對準加工區域



- as acurate as possible in the cutting area from at least three directions
- no flushing back of small chips to the cutting area

至少有三個方向的切削液噴嘴，需對準切削區域噴射 不要將小切屑衝回切削區域

Solid carbide milling cutter with internal cooling

- optimal chip removal, very good cutting edge cooling, very effective against built-up edges
- to be recommended especially for larger tool diameters and tough materials

最佳的排屑性，非常好的切削刃口冷卻，避免刃口沾黏積屑非常有效
特別推薦用於較大尺寸的刀具和堅韌的難切削材銑削

Peripheral cooling / Gührojet Guhrojet 刀具周邊外圍冷卻
Best external option: Optimal tool cooling and chip removal thanks to the direct route from coolant exit to cutting area
由於冷卻液直接噴到切削區域，達到最佳的刀具冷卻和排屑性

GÜHROJET

ISO code

P	Steel, high-alloyed steel
M	Stainless steel
K	Grey cast iron, spheroidal graphite ion and malleable cast iron
N	Aluminium and other non-ferrous metals
S	Special-, super- and titanium-alloys
H	Hardened steel and chilled cast iron

Tool recommendations regarding the suitability for application groups or specifications of max. tensile strength and hardness can be found in the product pages:

● optimal suitability 最適用

○ limited suitability 使用有限制

適用的刀具推薦，關於工件材料的最大抗拉強度和硬度，可在產品頁面中找到：

Coatings

○ bright finish　　Ⓨ Signum

Pictograms

Tool material	VHM Solid carbide ultrafine grain (carbide UF)
Shank form	HA, ~HA, HB, ~HB to DIN 6535
Type	DIN 6527 K, DIN 6527 L to DIN WN to Guhring standard
Type	N, NH
Applications	Slotting, Roughing, Ramping, Helix, Drilling, Finishing, Copying
Milling conditions	HPC maximum volume HSC maximum speed MTC unstable conditions 工況不佳，例如： 機台馬力不足、機台轉速與進給有限制； 工件形狀特殊、夾持不穩固容易震動位移。 請盡量使用小尺寸銑刀、降低銑削時的力量並降低轉速與進給
Length	short (DIN), long (DIN)
No. of cutting edges	3, 4 no. of cutting lips
Helix angle	36° 38° 37°, 41° 43° 45° Size of helix angle / no. of different helix angles
Helix angle	7° helix angle of circumference cutting edges
Cutting edge form	45° corner chamfer
Feed	for lateral feed for lateral feed and oblique plunging 用於橫向進給切削和斜向切削 for lateral feed, for oblique plunging and drilling 用於橫向進給切削、斜向切削及鑽孔