High Speed Machining (HSM) & 5-Axis Machining

CONTENTS

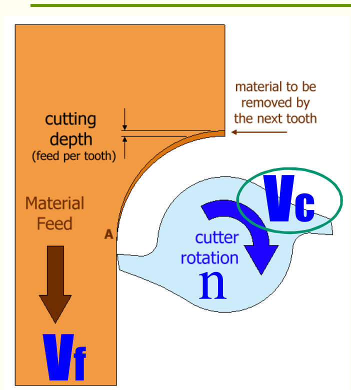
- Introduction of HSM
- Advantages
- Disadvantages
- Cutting Parameters
- HSM Techniques
- Machine
- Semi-Finishing Toolpaths
- HSM versus HPM
- Introduction of 5-Axis Machining
- Types of 5-Axis Machines

Introduction of HSM

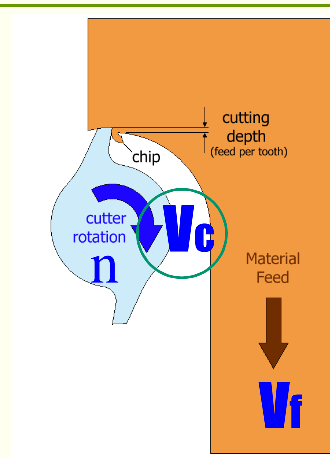
- High cutting speed machining, V_c
- High rotational speed machining, n
- High feed machining, V_f
- High productive machining

- Achieving high metal removal rates with quick milling passes
  - Leaving a surface finish good enough to call finished in one pass

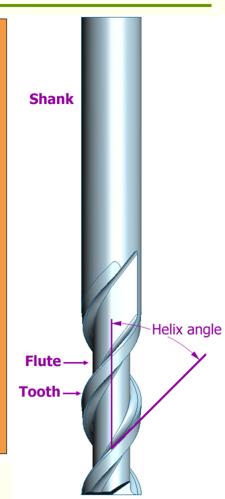
Introduction of HSM



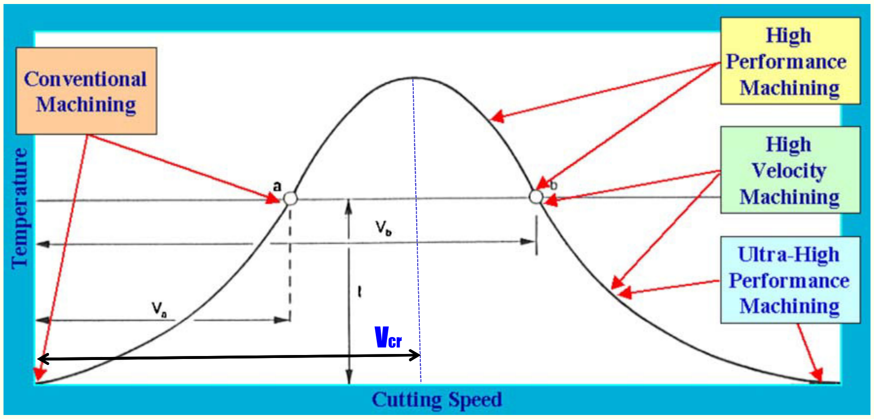
Conventional Milling



Climb Milling

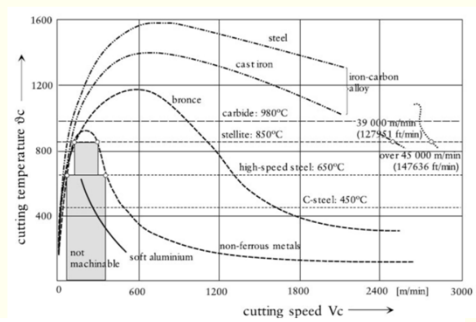


Introduction of HSM

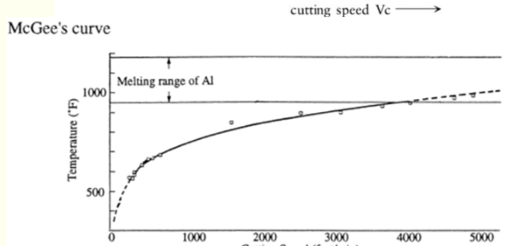


Introduction of HSM

- C. Salomon, 1931



- F.J. McGee, 1979



Introduction of HSM

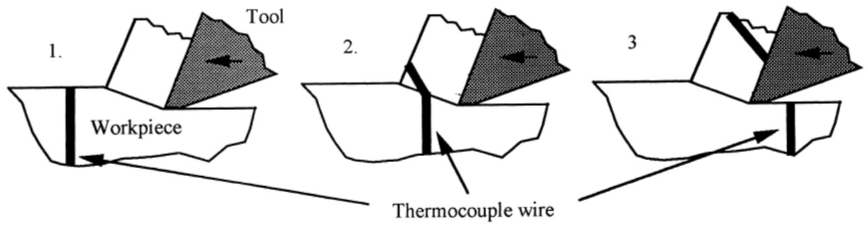
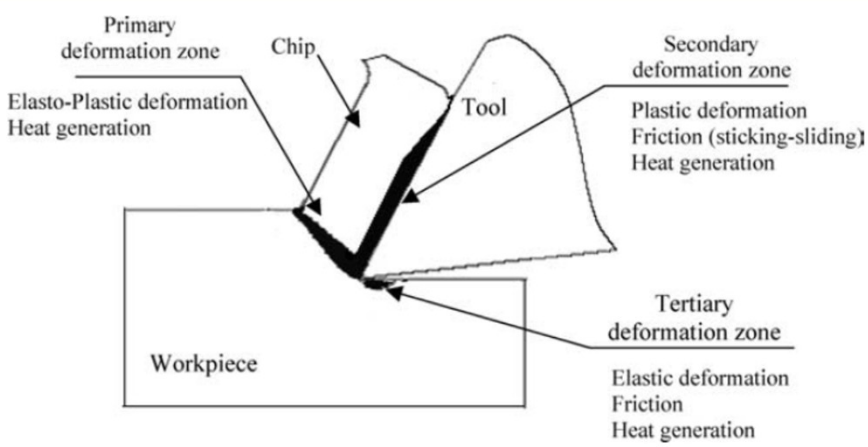


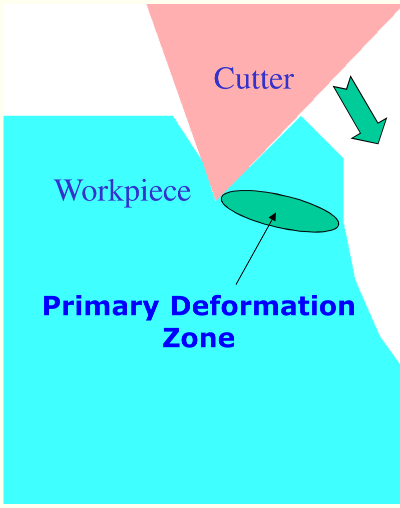
Fig. 2. Machining sequence when using the implanted workpiece thermocouple [12].

Introduction of HSM



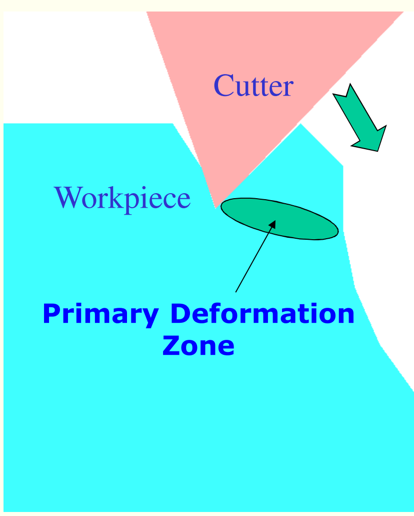
Sources of heat generation in the orthogonal cutting process.

Introduction of HSM



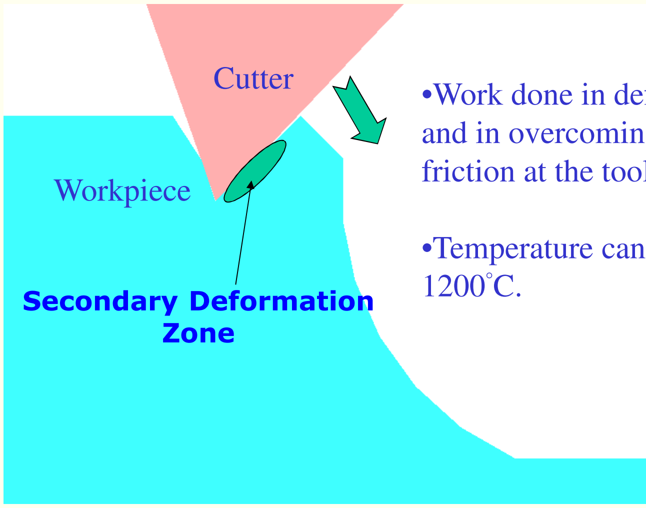
- Very high internal shear stress.
- Induces high temperature due to friction between dislocated molecules.
- High stress and high temperature has transformed the materials from elastic to plastic in a rapid manner, and so produces high deformation.
- The plastic deformed materials will pack up layer by layer and sliding along the tool geometry, and creating the chip.

Introduction of HSM



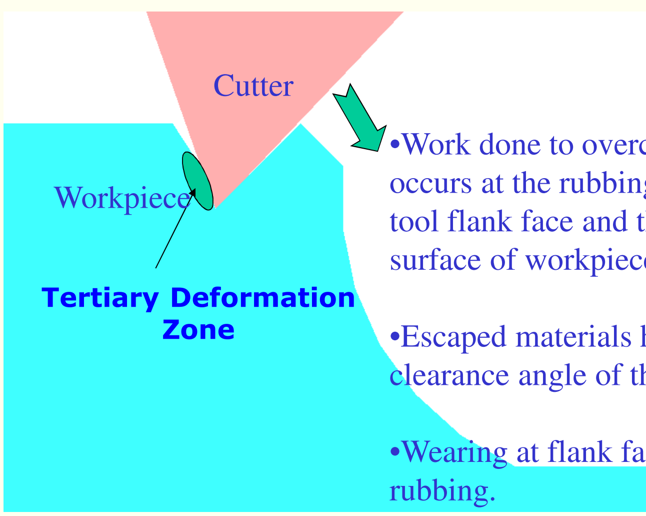
- Cutting metals at high speeds results in highly localized temperatures, stresses and strain rates, and so resulting in a decrease in chip thickness and a corresponding decrease in cutting forces
- Machined surface temperature decreases at higher cutting speeds

Introduction of HSM



- Work done in deforming the chip and in overcoming the sliding friction at the tool-chip interface.
- Temperature can be raised to 1200°C.

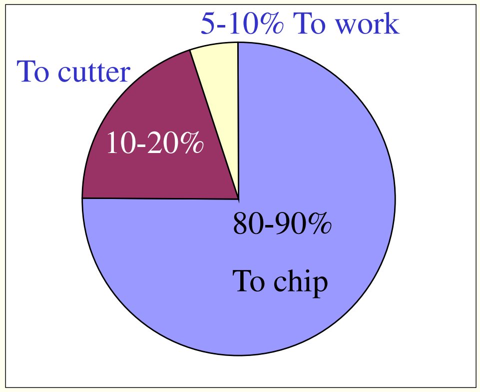
Introduction of HSM



- Work done to overcome friction which occurs at the rubbing contact between the tool flank face and the newly machined surface of workpiece.
- Escaped materials has spring-back at the clearance angle of the tool flank face.
- Wearing at flank face is occurred due to rubbing.

Introduction of HSM

•Heat absorption at HSM



Advantages

FEATURES	EFFECTS
Reduced heat transfer to the work piece	Minimal workpiece distortion Eliminates the need of coolant
Reduction of cutting forces	Part accuracy Surface quality Machining of very thin walls
Increased cutting speed	Stability of rotating cutting tool feed rate Increased material removal

Disadvantages

FEATURES	EFFECTS
Increased cutting speed	High tool wear Expensive tool materials Balanced tooling Precision tool-holder tapers Expensive spindles Costly machine tools and control systems

Cutting Parameters

- a_p: Axial depth of cut or Stepdown (mm)
- a_e: Radial depth of cut or Stepover (mm)

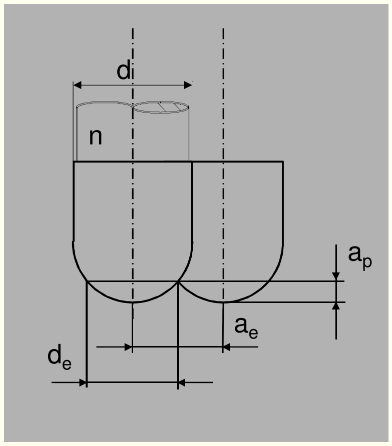
- n: Spindle rotational speed (rpm)

- V_c: Cutting speed (m/min)

- f_z: Feed per tooth per revolution (mm)
- z : Number of tooth or flute or cutting edge
- V_f: Feed rate or table feed (mm/min)

- Q: Material removal rate (mm^3/min)

Cutting Parameters



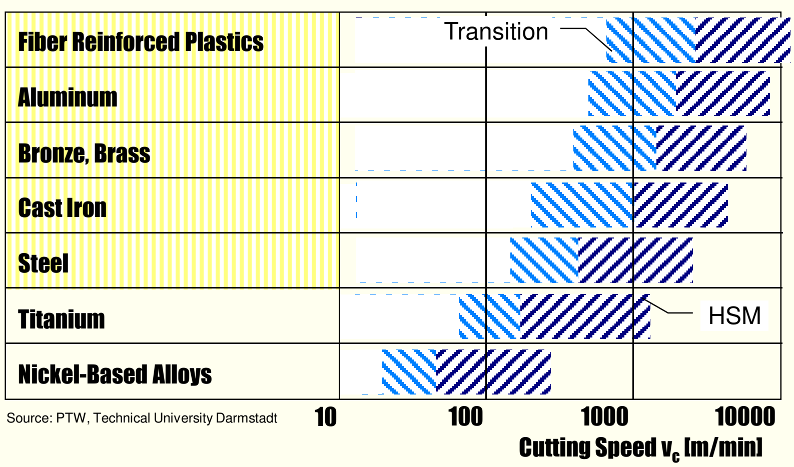
$$Q = a_p \times a_e \times V_f \quad [mm^3/min]$$

$$V_f = f_z \times n \times z \quad [mm/min]$$

$$d_e = 2 \times \sqrt{a_p (d - a_p)} \quad [mm]$$

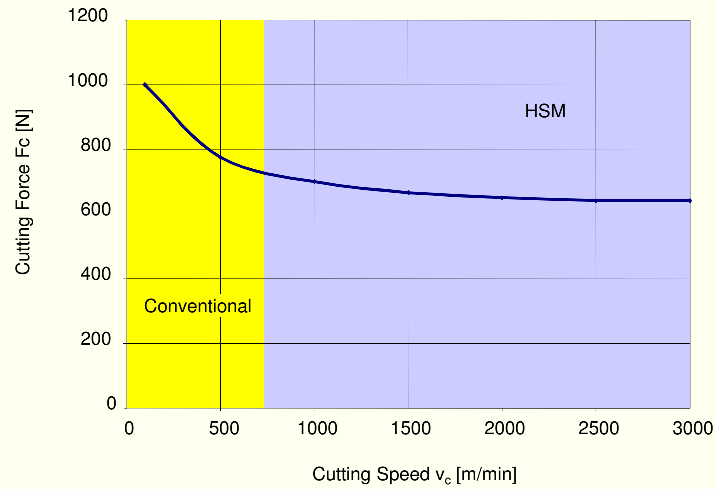
$$V_c = \frac{\pi \times n \times d_e}{1000} \quad [m/min]$$

Cutting Parameters



Source: PTW, Technical University Darmstadt

Cutting Parameters



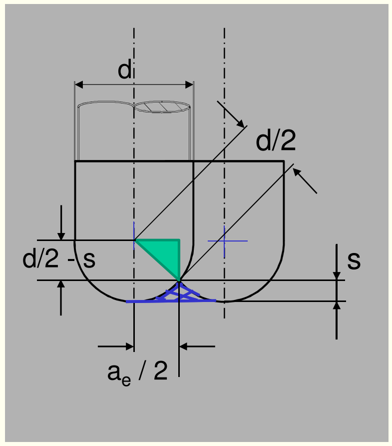
Cutting Parameters

Determine Feeds & Speeds:

- By experience, or use rules of thumb
  - Judge feeds and speeds by sound and experience
  - Hand on the machine's handwheels
  - Cutter engagement angle?
    - Difficult to maintain with handwheels
    - Feedrates were generally a lot slower
  - Today we have CNC ➔ much higher speeds
    - CNC machines have no ability to sense much about what's going on in the cut.
- Rely on manufacturer's recommendations
  - Over aggressive (great MRR, lower tool life) / Over conservative (great tool life, lower MRR)?
  - Coupled with own environment / knowledge-base
    - Used machining strategy, CNC machines, clamping system, etc.
- Rely on their CAM software
  - Most CAM software have some sorts of feeds and speeds calculator
  - Coupled with own environment / knowledge-base

Cutting Parameters

- Cusp (scallop) height s and Stepover a_e can be related by:

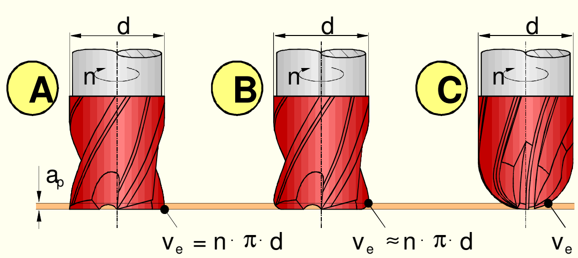


$$s = \frac{d}{2} - \sqrt{\frac{d^2 - a_e^2}{4}} \qquad [mm]$$

for $s << d$,

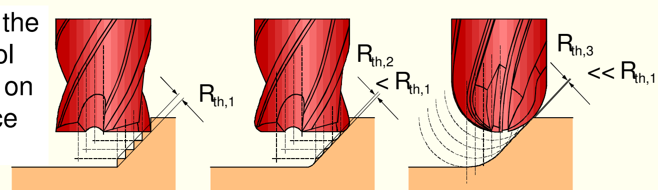
$$a_e \cong \sqrt{4sd}$$

Cutting Parameters

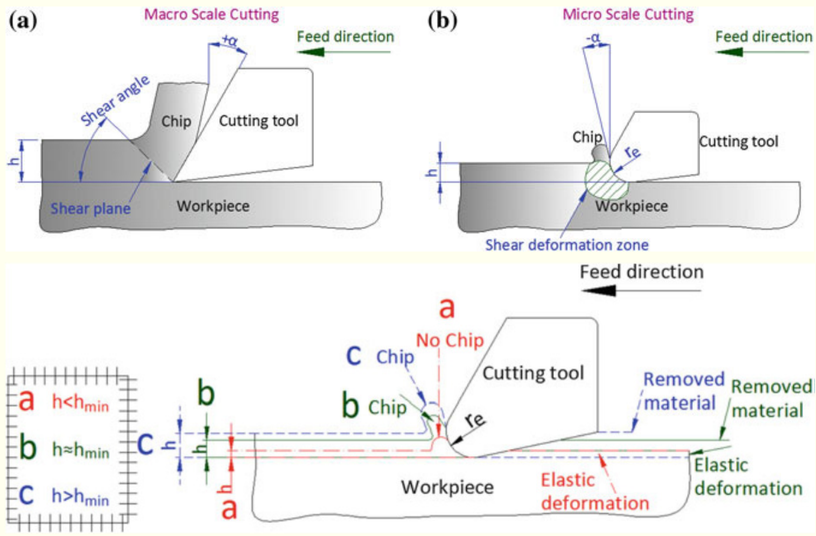


Impact of the cutting tool geometry on the effective cutting speed

Impact of the cutting tool geometry on the surface finish

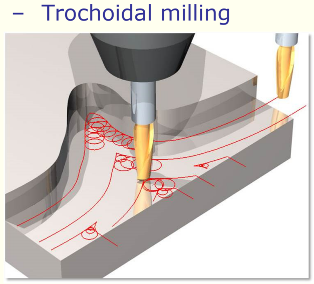


Cutting Parameters



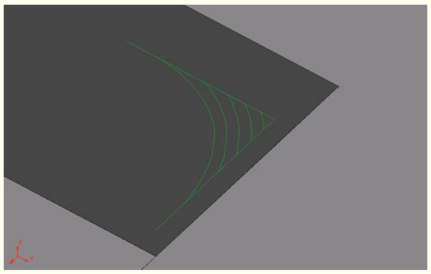
HSM Techniques

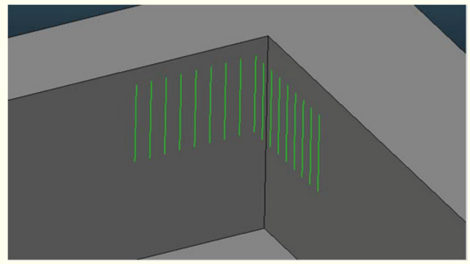
- Low radial cut width (i.e. a_e, 10-15% of TDU, or even 5%), allows better chip clearance.
- Increase cut depth (i.e. a_p), allows more flute length to come into play instead just wearing out the bottom of the mill.
- Use toolpath strategy that avoid heavy tool load
  - Trochoidal milling



HSM Techniques

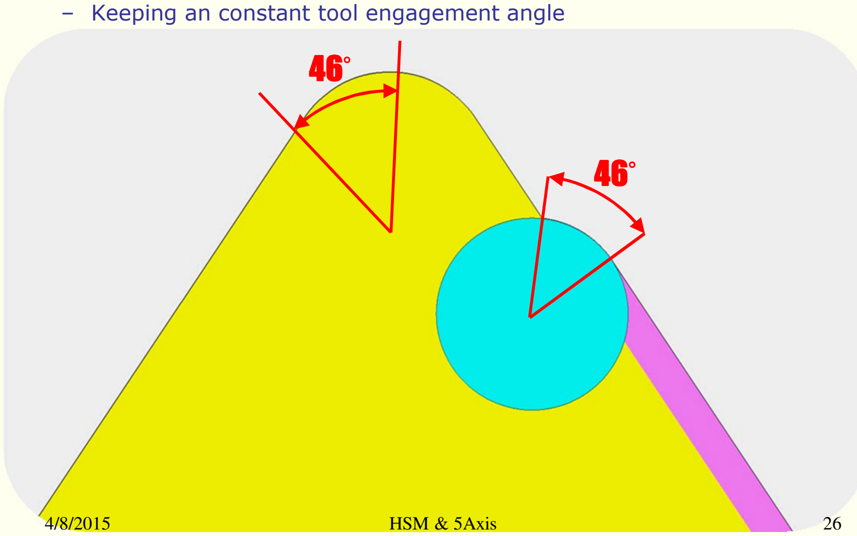
- Use toolpath strategy that avoid heavy tool load
  - Slicing or peeling of corners.





HSM Techniques

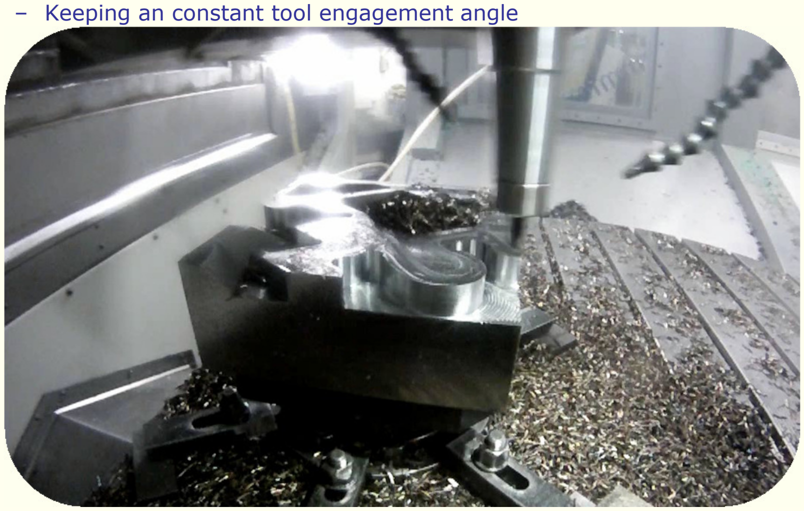
- Use toolpath strategy that avoid heavy tool load
  - Keeping an constant tool engagement angle



Design & Manufacturing Services Facility

HSM Techniques

- Use toolpath strategy that avoid heavy tool load
  - Keeping an constant tool engagement angle



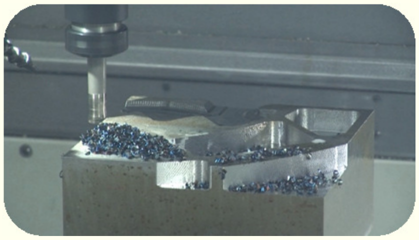
Design & Manufacturing Services Facility

HSM Techniques

- Can see the chip appearance and tell the difference …

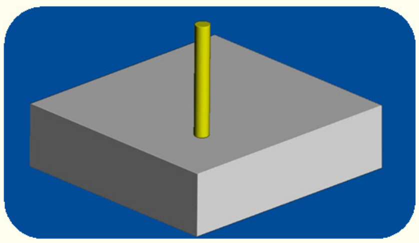
HSM Techniques

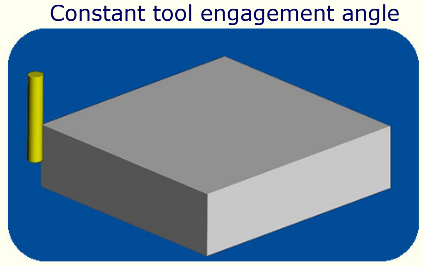
- Can listen to the sound and tell the difference …



- Conventional

Constant tool engagement angle





HSM Techniques Low Speed Spindle

- Maximize horsepower! In roughing, aim to take advantage of as much of the spindle's horsepower as possible.
  - Use high power cutting, i.e. heavy cutting, to increase materials removal rate
  - Use plunge roughing for rigid machine
- Finishing pass
  - Use as many flutes as possible, so that the cutting speed can be increased, and so the removal rate.
- Machine internal corners prior to finishing ribs

DESIGN & MANUFACTURING SERVICES FACILITY

Machine

- Spindle speed (n >20000 rpm)
- Spindle power (>10 KW)
- Feed rate (Vf ~ 40-60 m/min)
- Rapid travels (<90 m/min)
- Block processing speed (1-20 ms)
- High thermal stability and rigidity in spindle
- Air blast/coolant through spindle
- Advanced look ahead function in the CNC

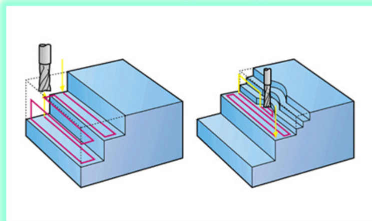
DESIGN & MANUFACTURING SERVICES FACILITY

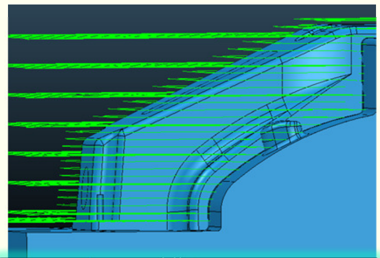
Semi-Finishing Toolpaths

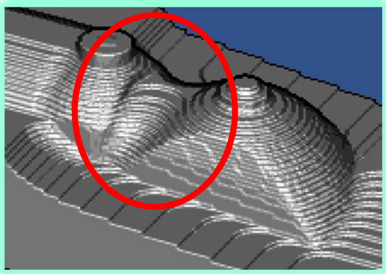
- To realize finishing operation that can produce an optimum surface quality, accuracy and cutting tool life:
  - **constant stock material** is required on all surfaces to be finished.
- Semi-finishing operation in more than one step of:
  - Various cutting tools with decreasing diameter
  - Specific toolpath strategies for rest roughing

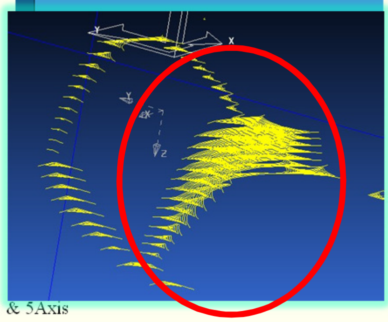
Semi-Finishing Toolpaths

- Rest roughing:





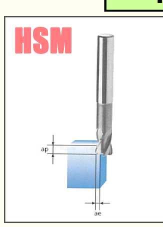




HSM versus HPM

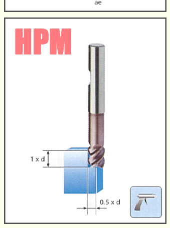
Material: Hardened Tool Steel 52 - 56 HRc (fraisa)

HSM



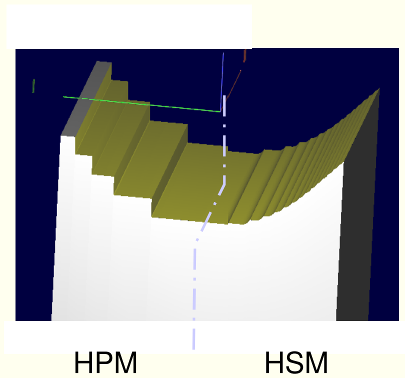
Ø	z	v_c	f_z	a_p	a_e	n	v_f	Q
[mm]	[-]	[m/min]	[mm]	[mm]	[mm]	[min^{-1}]	[mm/min]	[mm^3/min]
6	4	120	0.10	0.60	0.80	6370	2550	1'224
8	4	120	0.10	0.80	0.90	4770	1910	1'375
10	4	120	0.10	1.00	1.00	3820	1530	1'530
12	4	120	0.12	1.20	1.10	3180	1525	2'013
16	4	120	0.14	1.50	1.20	2390	1340	2'412

HPM



Ø	z	v_c	f_z	a_p	a_e	n	v_f	Q
[mm]	[-]	[m/min]	[mm]	[mm]	[mm]	[min^{-1}]	[mm/min]	[mm^3/min]
6	4	45	0.020	6.00	3.00	2120	170	3'100
8	4	45	0.027	8.00	4.00	1590	170	5'400
10	4	45	0.033	10.00	5.00	1270	170	8'500
12	4	45	0.040	12.00	6.00	1190	190	13'700
16	4	45	0.053	16.00	8.00	900	190	24'300

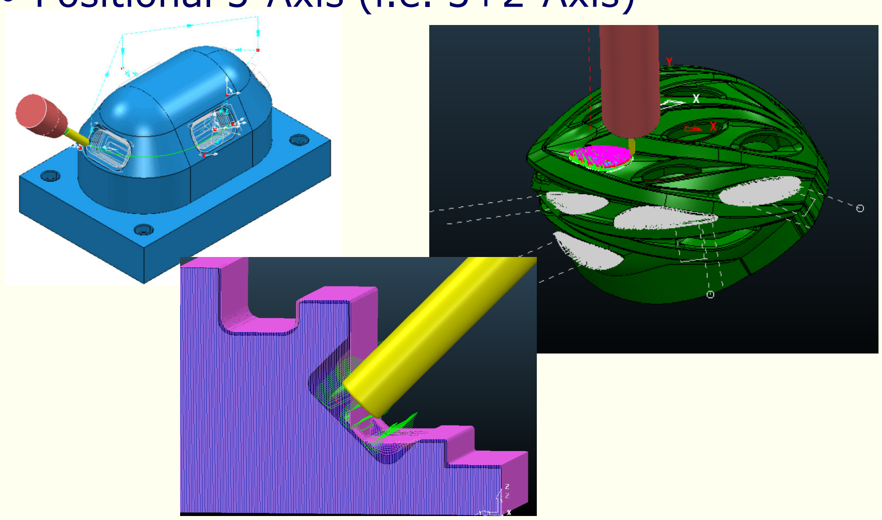
HSM versus HPM



- Benefit of HPM versus HSM for faster roughing of
  - large cavities
  - cavities with steep walls
- Drawback of HPM versus HSM for roughing of
  - small cavities
  - cavities with shallow walls
- Semifinish operation is required after HPM to remove the excess material left after the roughing operation
- HSM roughing gets closer to the final geometry

Introduction of 5-Axis Machining

- Positional 5-Axis (i.e. 3+2-Axis)



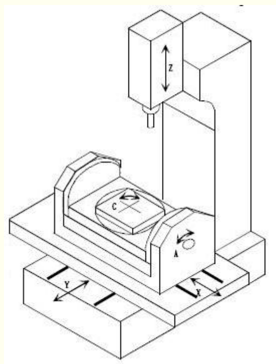
Introduction of 5-Axis Machining

- Continuous 5-Axis

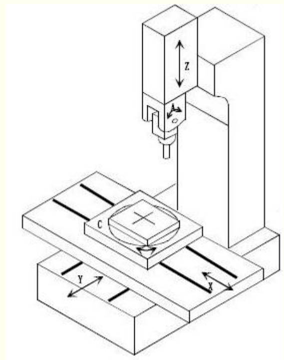
Introduction of 5-Axis Machining

- Positional 4-Axis (i.e. 3+1-Axis)
- Continuous 4-Axis
- Rotary 4-Axis

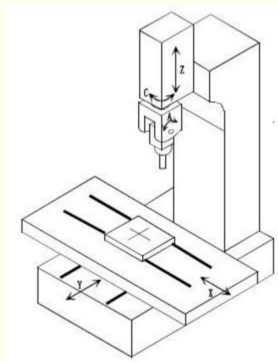
Types of 5-Axis Machines



Table/Table



Table/Head



Head/Head

Types of 5-Axis Machines

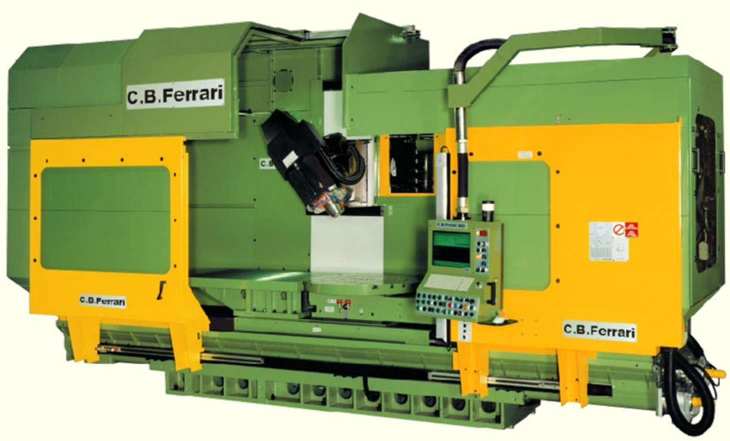
- Table / Table

Types of 5-Axis Machines

- Table / Table

Types of 5-Axis Machines

- Head / Table

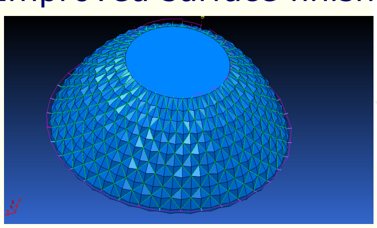


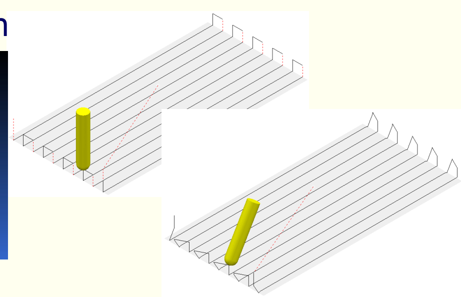
Types of 5-Axis Machines

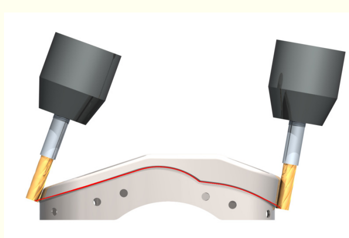
- Head / Head

Advantages of 5-Axis Machining

- Improved surface finish

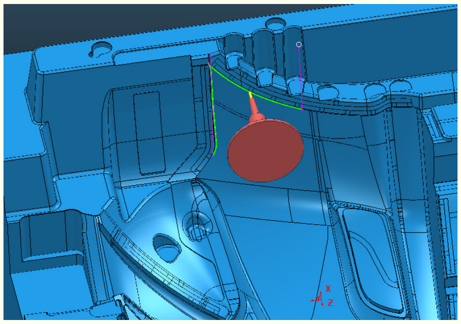


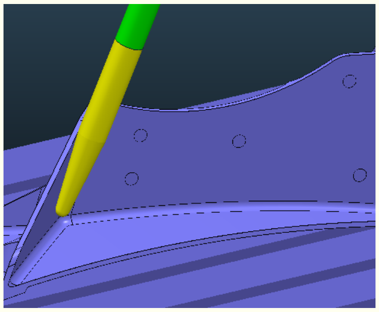




Advantages of 5-Axis Machining

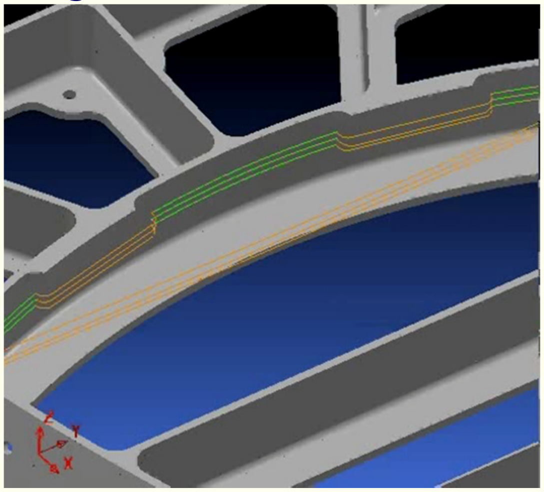
- Reduce post-machining operation





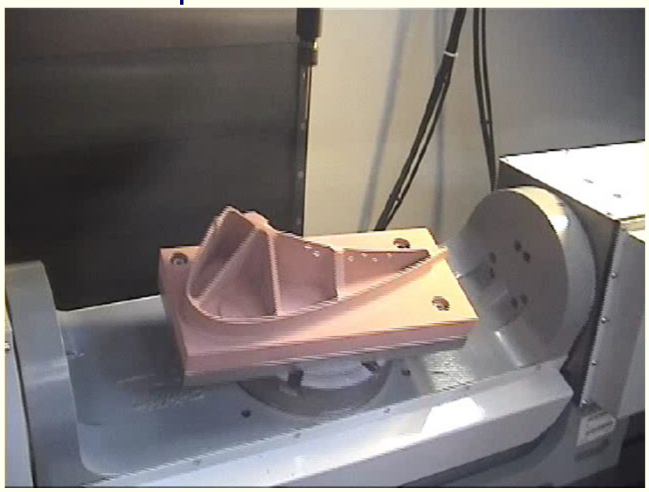
Advantages of 5-Axis Machining

- Auto tilting to avoid collision



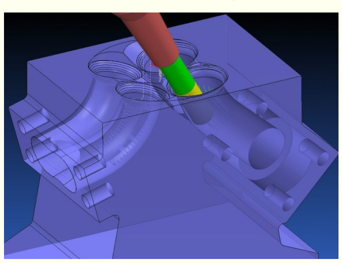
Advantages of 5-Axis Machining

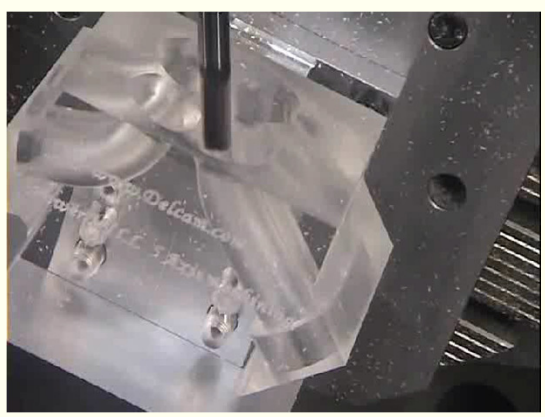
- Minimal setup



Advantages of 5-Axis Machining

- Machining of difficult areas





Advantages of 5-Axis Machining

- Polar machining