Tooling Optimization- Milling:

One cannot but emphasize the need to focus on optimizing Cutting data, to reduce costs without compromising Productivity.

To do this one needs to understand a few basics in Milling as there are more than one cutting edge in contact. In turning you have just one edge in contact. Milling is an inherently a cyclical and an intermittent process.

- Cutting Speed Vc: Meters/Min
- RPM N:
- Diameter of Cutter: Dc
- Feed
  - ✓ Per Cutting edge(tooth) Fz = mm per Tooth
  - ✓ MM per Minute Vf= mm per minute

$$N = \frac{v_c \times 1000}{D_c \times ®}$$

- Percentage arc of engagement Ae mm
- Depth of Cut Ap mm
- Work piece material.

Optimization of the Milling Process:
The milling process has many factors which naturally influence each other.
These factors as an overview are:

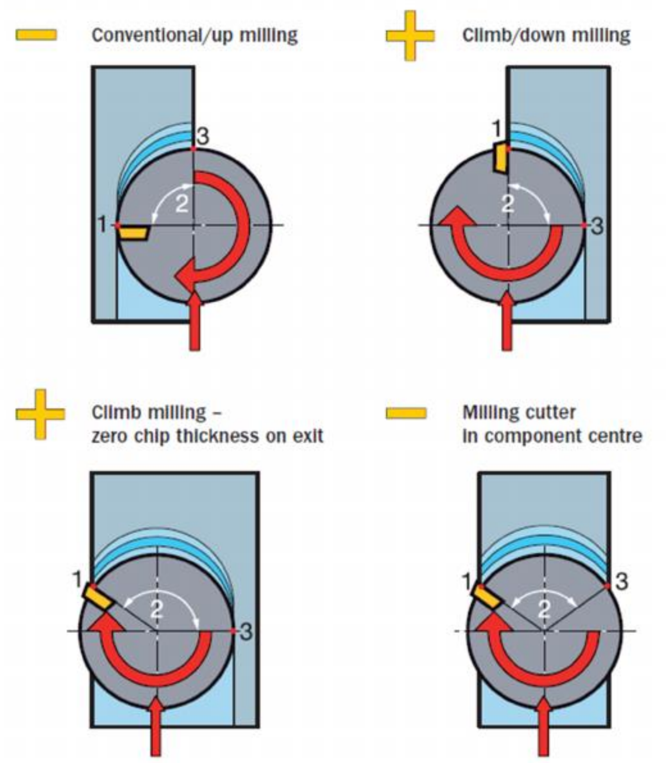
- Calculate the feed per tooth calculated on maximum chip thickness.
- Optimized Cutter Diameter best suited to the machine and component features to be machined.
- Optimized insert shape and low entry angle will allow higher feed rate capability.
- Optimized insert size – a smaller insert if suitable for the operation will allow more teeth in the cutter which will increase the table feed.
- Optimum method and programming strategy depending upon material, component and machining centre.
- Cutting speed to suit the grade and material. Cutting speed will directly affect the tool life and should be respected.
- Number of teeth in the cutter. Consider power, Torque, Machine and Setup stability.
- Radial and axial cutting depth eg Profiling:
  - ✓ High Ap, Low Ae, high Fz;
  - ✓ Face milling- End milling: Low Ap & high Ae (70%)

Let’s now look at the most important of the factors in detail, so that we can understand how they influence the optimization of the Milling process.

1. Up Milling and Down Milling and its relationship with Chip Thickness:

Milling is also a cyclic process with the cutting edge entering and exiting the work piece. The thickness of the chip being generated is constantly changing when feeding the cutter in a radial direction;

This depends on the positioning of the cutter with respect to the width of the surface being milled and the direction of the feed of the cutter.



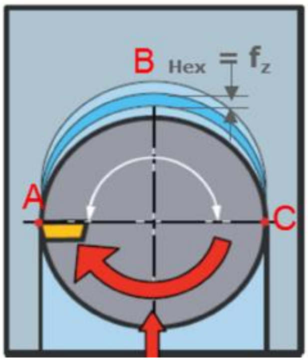
Top LH shows Conventional Milling (Up Milling) – where the Cutter enters to generate a thin chip at the Entry 1, but a thicker chip at the exit3…. This creates a heavier load on the cutting edge; same is the case shown at Bottom RH, where chip thickness reduces at the exit 3.

Top RH shows the cutter entering to generate a thicker chip at start of cut 1 and a thin chip at the Exit 3- this creates a much lower chip load on the cutting edge; same is the case for Bottom LH, where the chip is thicker at the start 1 and thinner at Exit 3.

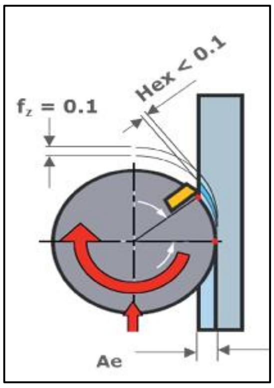
2. Cutter Engagement, Feed per Tooth and Chip Thickness

In full slotting cutter engagement is 100% the maximum chip thickness is at the center; As the cutter engagement Ae is reduced, the chip thickness at the exit is reduced, thus reducing the load on the cutting edge and enabling the use of a higher Feed per Tooth, resulting in higher productivity without any loss in the process security.

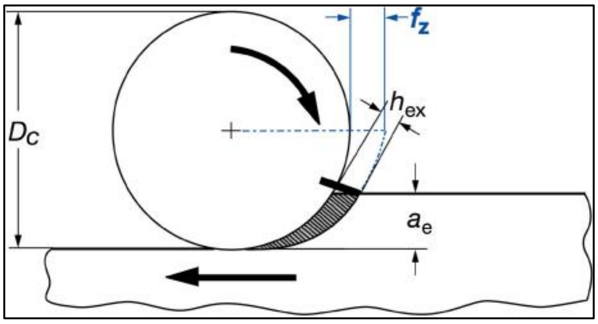
Full Slotting



Cutter Engagement Ae

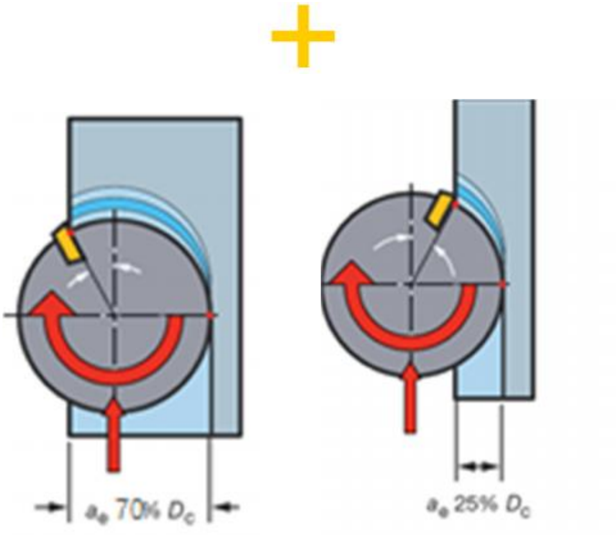


Feed per Tooth and Chip Thickness

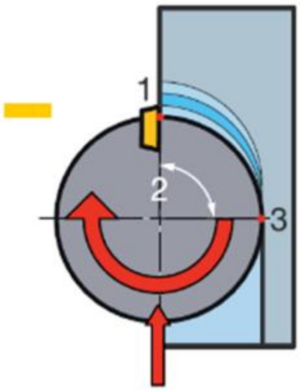


The approach to Cutter Engagements:

Ae=70% and 25%



b) Ae= 50%



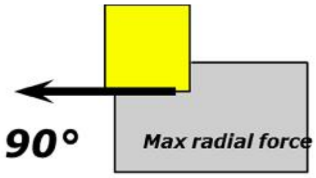
We can see in the above figures the impact of cutter Engagements on chip thickness at entry and Exit; most Milling applications are done with Ae= 70 % to take advantage of a good entry and exit condition.

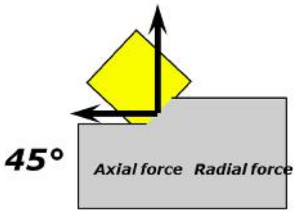
For Milling in Steel and Cast Iron materials; Ae= 70% works best for Productivity and economics. Ae= 50% , when the cutter center line is at the work piece edge when the entry condition is the harshest and inserts tend to chip off and the economics are not so good.

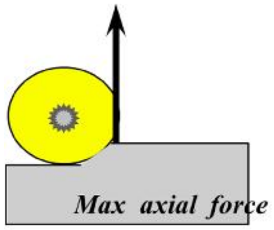
For more difficult to mill materials like Stainless steels, Duplex Stainless steel, Titanium etc – lower engagements are preferred to reduce cutting forces, thereby the temperature at the cutting edge and thereby reduce work piece work hardening tendencies.

Lower engagements allow higher feeds to be used.

3. Effect of Approach Angle of the Cutting edge on Fz and Hex in Milling:





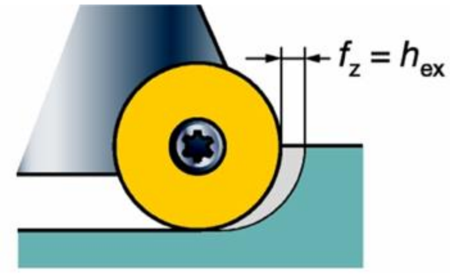


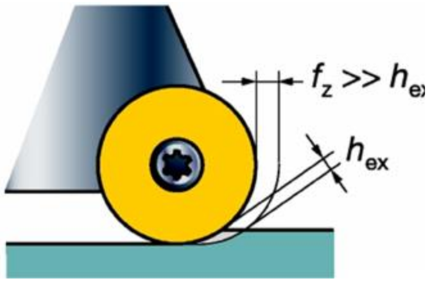
The work piece material and its geometry will influence the selection of the approach angle. For the same Fz, the chip thickness will vary as per the approach angle;

Milling in materials like Materials like Steel and Cast Iron that have good machinability do not need much optimization and the parameters recommended by the Tool manufacturers could be directly used.

Eg Hex = Fz for 90 degrees, for 45 degrees Hex= @ 0.6 Fz ;

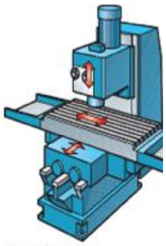
For a Round insert the approach angle itself would vary as per depth of cut and the chip thickness reduces as the depth of cut reduces , thereby enabling use of higher feeds.

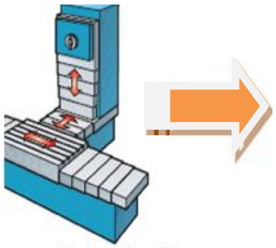


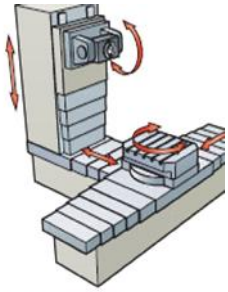


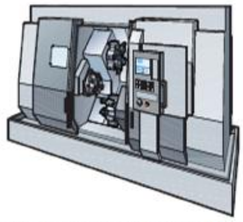
4. Trends of the Machines in Milling:

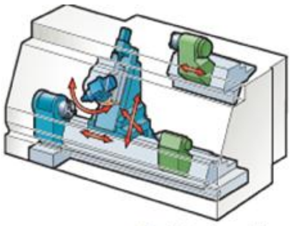
Earlier machines could be split into four categories – horizontal and vertical and turning or milling. Today machines are developing in all directions, turning centres now have milling capability through driven tools and machining centres have turning capability - turn mill or mill turn?


Vertical machine.


Horizontal machine.


Five axes machine.

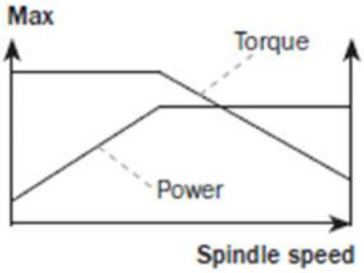

Turning centre with milling capability.


Multi-task machine.

Further development of CAM techniques mean that five axes machines are increasing. The result of these trends:

- Increased flexibility
- Fewer machines/set ups to complete a component
- Reduced stability
- Longer tool lengths
- Lower depth of cuts

Spindle type and size; Power and Torque:



ISO 30, 40, 50 have are the natural spindle interfaces. As spindle rpms increase and demands on accuracies increase, spindle interfaces evolved into taper face contact type and we had HSK 50, 63,100 interfaces evolving. The majority of modern machining centres have direct drive spindles. With ever increasing spindle speed capabilities the result is:

- Lower torque at higher rpms
- Lower power at lower rpms

All the more reason we need to understand the effects of Cutter Engagements, Chip thinning, smaller cutters etc to optimize the milling process.