Cutter concept

Modern milling is a very universal machining method. During the past few years hand in hand with machine tool developments, milling has evolved into a method that machines a very broad range of configurations. The choice of cutter concept is no longer straightforward – in addition to all the conventional applications, milling is a strong contender for producing holes, threads, cavities and surfaces that used to be turned, drilled, or tapped etc. (See hole making chapter). Tooling developments have also contributed to the new possibilities along with the gains in productivity, reliability and quality consistency that have been made in indexable and ceramic inserts.

The aim is to have a strategy suited to the machine tool and feature to be machined giving a maximum metal removal rate ($Q \text{ cm}^3/\text{min}$) that can be balanced with an economic tool life.

For milling there are many variables to consider:

- $D_c$ – cutter diameter
- $z_n$ – number of effective teeth
- $\kappa_r$ – entering angle
- $a_{p \text{ max}}$ – maximum cutting depth
- $a_{e \text{ max}}$ – maximum radial cut

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**Design types**

**Face mills**

<table>
<thead>
<tr>
<th>Round inserts</th>
<th>45°</th>
<th>90°</th>
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</thead>
<tbody>
<tr>
<td>CoroMill® 300</td>
<td>CoroMill® 245</td>
<td>CoroMill® 390</td>
</tr>
</tbody>
</table>

**End mills**

<table>
<thead>
<tr>
<th>Round inserts</th>
<th>90°</th>
<th>Solid carbide</th>
<th>Exchangeable head</th>
</tr>
</thead>
<tbody>
<tr>
<td>CoroMill® 300</td>
<td>CoroMill® 390</td>
<td>CoroMill® Plura</td>
<td>CoroMill® 316</td>
</tr>
</tbody>
</table>

**Ceramic insert cutter**

| S-R120R/CoroMill® 300C |

**Ball nose**

| CoroMill® Ball nose 216 |
The cutter diameter is more or less selected by the operation and the machine capability. The choice of ceramic insert, carbide inserts or solid carbide is determined by productivity calculations, surface requirements and process limitations (machine, fixturing etc). The \( \kappa_r \)/insert style (round, 45°, or 90°) and number of teeth selected will have a dramatic effect on the machining strategy and ultimately on the tool life and \( Q \). Therefore the feature type and machining strategy will influence which concept style should be selected.

### Milling process

#### Milling direction

During a milling operation, the workpiece is fed either with or against the direction of rotation and this affects the nature of the start and finish of cut.

- In up milling (also called conventional milling) – the chip thickness starts at zero and increases to the end of the cut. There are high cutting forces which tend to push the cutter and workpiece away from each other. The insert is forced into cut, creating a rubbing or burnishing effect work-hardening the surface.

- In down milling (also called climb milling) – the insert starts its cut with a large chip thickness. This avoids the burnishing effect with less heat and minimal work-hardening tendencies.

Always use down milling for machining of HRSA materials with carbide inserts.
Cutter diameter and position in face milling

The selection of milling cutter diameter is usually made on the basis of the workpiece width with the power availability of the machine also being taken into account. The position of the cutter in relation to the workpiece engagement and the number of teeth in contact are all vital factors for successful operation.

When machining in a single pass, a cutter diameter 20 to 30% larger than the workpiece width is recommended. The milling cutter should always be positioned off-centre producing the thinnest chip on exit. If several passes need to be taken, a radial cut ($a_e$) of 75% $D_c$ should be applied to ensure good chip formation and suitable cutting edge load.

Avoid positioning cutter on-centre.

Entry into and exit from the workpiece considerations

Each time one of the milling cutter inserts enters into cut, the cutting edge is subjected to a varying shock load. The right type of initial contact, and final contact, between edge and material is an important aspect of the milling process. Positioning the cutter right as regards entry and exit of the cutting edge is important – always avoid a thick chip on exit.
When profile milling the positioning of the cutter can be pre-defined, however for face milling where the position of the cutter is more flexible it can be prone to misapplication.

1) $a_e$ should not be greater than 75% of the cutter diameter, and not less than 30% – at least 2 teeth in contact (if $z_n > 2$).

2) The cutter should be off-centre giving as close to zero chip thickness as possible on exit from cut.

3) Entry into the workpiece should be programmed carefully until the cutter is in full cut by one of the following methods:

Roll on entry

Reduced feed on entry

Also when milling large workpiece surface areas, select tool path to keep the milling cutter in full contact rather than perform several parallel passes. When changing direction, include a radial tool path to keep cutter moving, avoiding dwell and chatter tendencies.

Below, worn inserts with the same cutting data and tool life in Waspalloy demonstrate the impact of keeping the cutter in contact with the workpiece.