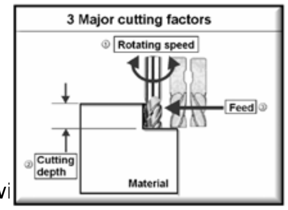
Cutting Tools
Geometry & Milling Processes

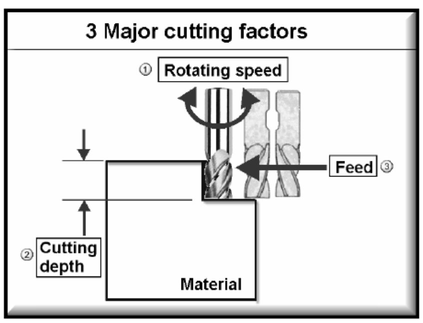
Introduction of Cutting Tools

- There are three factors that make up the cutting conditions:
  - cutting speed
  - depth of cut
  - feed rate



- All three of these wi lessons

Introduction of Cutting Tools



Introduction of Cutting Tools

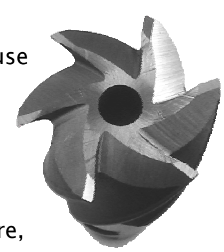
- What is a cutting tool?
  - Just as it is described – a tool that cuts
- Specific names
- Different Materials
- Common Cutting Shape Features
- Different Uses

Introduction of Cutting Tools

- Criteria for the ideal cutting tool
  - Should be:
    - Sturdy enough to support and maintain its cutting edge
    - Tough enough so the cutting edge won't erode quickly
    - Tough so the cutting edge won't chip easily
    - Large enough to carry away the heat generated during the cut
- Most important part is the cutting edge

Introduction of Cutting Tools

- A tool with more cutting edges will last longer because there are more edges to share the load



- More cutting edges there are, smaller the chips become
  - Result is a smoother surface

Introduction of Cutting Tools

- What is a cutting tool?
  - Just as it is described – a tool that cuts
- **Specific names**
- Common Cutting Shape Features
- Different Uses

Introduction to Cutting Tools

- **Specific Names**
  - Face Mill
  - End Mill
  - Ball Nose End Mill
  - Countersink
  - Counterbore
  - Drill
    - Spot Drill
    - Center Drill
  - Tap
  - Reamer

Photos Courtesy of Iscar LTD., Metalworking Tools

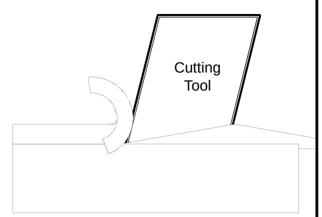
Introduction of Cutting Tools

- What is a cutting tool?
  - Just as it is described – a tool that cuts
- Specific names
- **Common Cutting Shape Features**
- Different Uses

Introduction to Cutting Tools

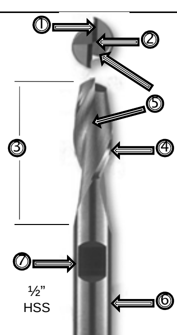
Common Cutting Shape Features

- Rake Angle
- Clearance Angle
- Lead Angle
- Corner Radius



Introduction of Cutting Tools

- 1. Cutting Lip/ Edge
- 2. Dead Center
- 3. Flute Length
- 4. Margin
- 5. Flute
- 6. Shank
- 7. Descriptor



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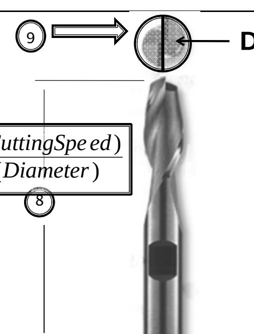
Introduction of Cutting Tools

- 1. Cutting Lip/ Edge
- 2. Dead Center
- 3. Flute Length
- 4. Margin
- 5. Flute
- 6. Shank
- 7. Descriptor
- 8. Overall Length
- 9. Diameter

$$RPM = \frac{12(CuttingSpeed)}{\pi(Diameter)}$$



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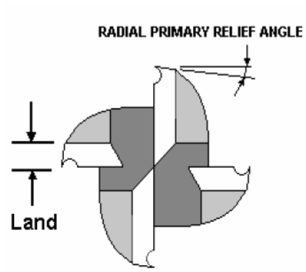
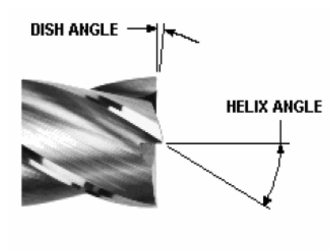
Introduction of Cutting Tools



Introduction of Cutting Tools



Introduction of Cutting Tools

- **Two Fluted End Mill** vs. **Four (or more) Fluted End Mill**

•Slots
•Grooves
•Plunge Cutting

•Surface milling
•Profile milling

Feed Rate and Material Removal Rate
(Feed per tooth)

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Introduction of Cutting Tools

- Two Fluted End Mill
  - Flute extends to the center

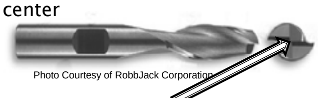
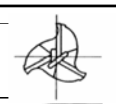


Photo Courtesy of RobbJack Corporation

- Results
  - Good results in roughing and in slot milling
  - Also used for plunge milling in aluminum alloys and materials with long chips
  - Allows for maximum chip volume and is used for plunge milling, roughing of slots or peripheral milling

Introduction of Cutting Tools



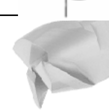


Photo Courtesy of Iscar Tooling

- Three Fluted End Mill
  - One end flute extends to the center
- Results
  - Excellent choice for slot milling and "ramping" in ferrous materials and heat resistant alloys.
  - Less vibration and a straighter plunge cut than 2-flutes.
  - It has more chip room than a 4-flute and allows higher material removal rates.
  - It is more rigid and less likely to "walk" in the cut.
  - 3-flutes provides for reduced deflection also improves tool life and work piece finish.
  - Recommended for aluminum.

Introduction of Cutting Tools

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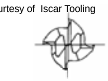


- Four Fluted End Mill
  - Sometimes this end mill is center cutting and non-center cutting
- Results
  - Universal geometry, used for side and face milling and peripheral milling.
  - High tool rigidity due to the larger web diameter.
  - 4-flute end mills are stronger than either the 2- or 3-flute designs.
  - Limited chip volume area restricts stock removal rates and deep plunge

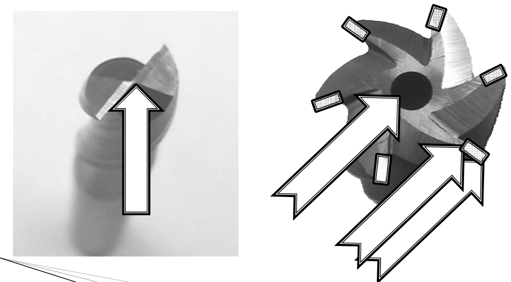
Introduction of Cutting Tools

- Four or more Fluted End Mill
  - The internal chamfer on the center hole is cleared and allows plunge milling to the depth of the chamfer only.
  - The end teeth are long to accommodate a large corner radius or chamfer when required
- Results
  - Used mainly for finishing – good surface finish.
  - Allows a higher feed rate.
  - Smoother cut because there is always a tooth in contact with the work piece material.

Photo Courtesy of Iscar Tooling

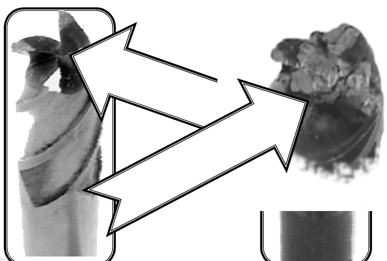
Introduction of Cutting Tools

- Center Cutting vs Non-Center Cutting



Introduction of Cutting Tools

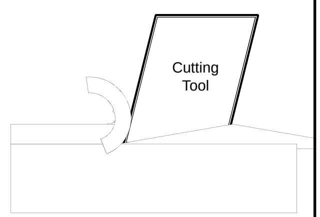
- Center Cutting vs Non-Center Cutting



Introduction to Cutting Tools

Common Cutting Shape Features

- Rake Angle
- Clearance Angle
- Lead Angle
- Corner Radius



Introduction to Cutting Tools

Common Cutting Shape Features

- <u>Rake Angle</u>
- Clearance Angle
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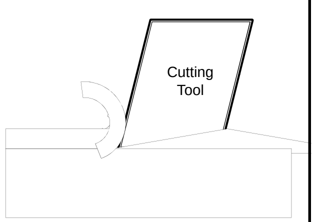
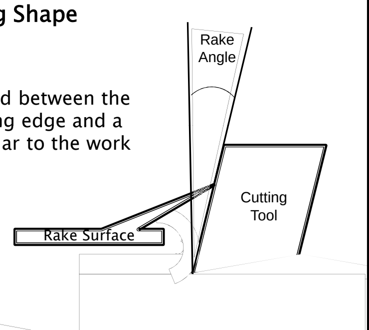


Introduction to Cutting Tools

Common Cutting Shape Features

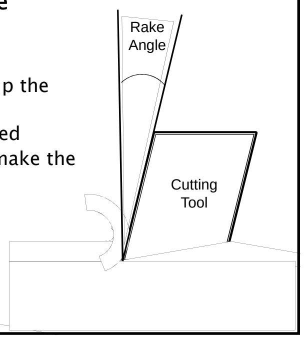
- <u>Rake Angle</u>
  - the angle formed between the top of the cutting edge and a line perpendicular to the work surface
  - Two types
    - **Positive**
    - **Negative**



Introduction to Cutting Tools

Common Cutting Shape Features

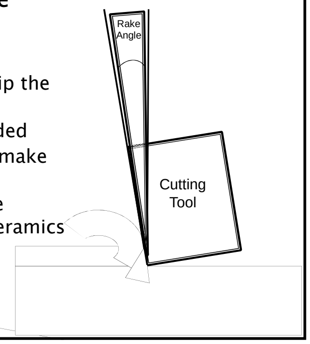
- Positive Rake
  - Bends (deforms) the chip the least
  - Less cutting force needed
  - Less power needed to make the cut



Introduction to Cutting Tools

Common Cutting Shape Features

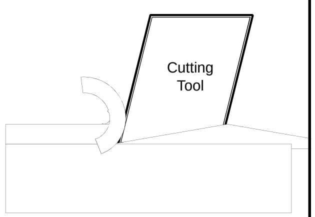
- Negative Rake
  - Bends (deforms) the chip the most
  - More cutting force needed
  - More power needed to make the cut
  - Suitable for hard-brittle cutting materials like ceramics



Introduction to Cutting Tools

Common Cutting Shape Features

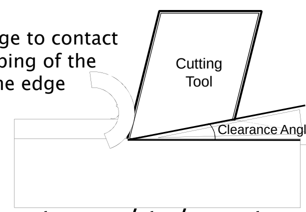
- Rake Angle
- **Clearance Angle**
- Lead Angle
- Corner Radius



Introduction to Cutting Tools

Common Cutting Shape Features

- Clearance Angle
  - Allows the cutting edge to contact the work with no rubbing of the cutting tool behind the edge

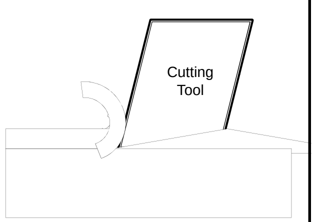


Too much clearance creates a weak tool prone to heat build-up and breakage

Introduction to Cutting Tools

Common Cutting Shape Features

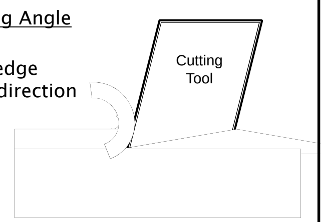
- Rake Angle
- Clearance Angle
- **Lead Angle**
- Corner Radius



Introduction to Cutting Tools

Common Cutting Shape Features

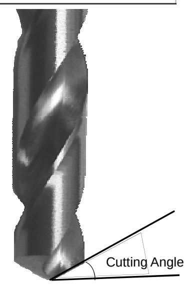
- Lead Angle
  - Also called the Cutting Angle
  - Angle of the cutting edge compared to the cut direction



Introduction to Cutting Tools

Common Cutting Shape Features

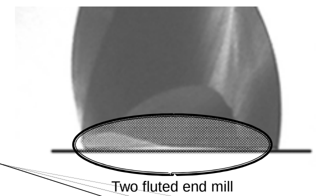
- Lead Angle
  - Also called the Cutting Angle
  - Angle of the cutting edge compared to the cut direction
  - Too much Lead can cause chatter (vibration)
  - Too little and the cut is not effective

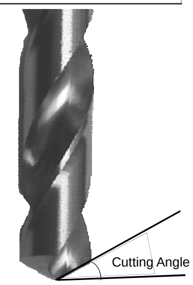


Introduction to Cutting Tools

Common Cutting Shape Features

- Lead Angle
  - Also called the Cutting Angle





Introduction to Cutting Tools

Common Cutting Shape Features

- Rake Angle
- Clearance Angle
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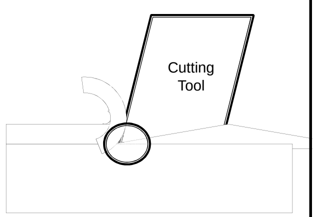
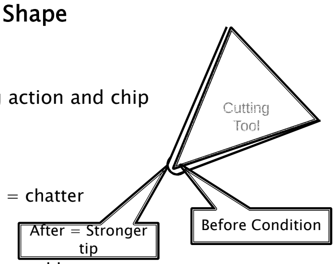


Introduction to Cutting Tools

Common Cutting Shape Features

- Corner Radius
  - Smoother cutting action and chip distribution
  - Better finish
    - Too much radius = chatter
  - Stronger tool
    - The tip is stronger and less prone to breakage



Cutting Tools – Keys to Remember

- There are three factors that make up the cutting conditions:
  - cutting speed
  - depth of cut
  - feed rate
- Center cutting tools can plunge cut, non-center cutting tools can not.

Cutting Tools – Keys to Remember

- The ideal cutting tool should be:
  - Sturdy enough to support and maintain its cutting edge
  - Tough enough so the cutting edge won't erode quickly
  - Tough so the cutting edge won't chip easily
  - Large enough to carry away the heat generated during the cut
- Remember, the most important part is the cutting edge

Cutting Tools – Keys to Remember

- Particular attention should be taken when considering the common cutting shape features
  - Rake Angle
  - Clearance Angle
  - Lead Angle
  - Corner Radius

Introduction of Cutting Tools

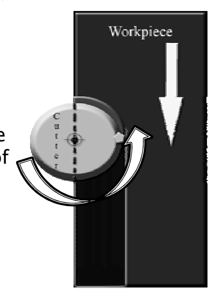
Conventional Milling vs. Climb Milling

Introduction of Cutting Tools

- The direction of the end mill rotation relative to cutting direction is described either as:
  - **conventional cutting** (up milling) or
  - **climb cutting** (down milling)

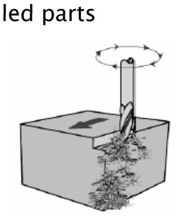
Introduction of Cutting Tools

- Conventional (up milling)
  - The revolution of the end mill is opposite to the direction of the work piece feed direction
  - The cutting edge meets the work piece at the bottom of the cut
    - the width of the chip starts at zero and
    - increases to a maximum thickness at the end of the cut



Introduction of Cutting Tools

- Advantages of Conventional (up) Milling
- Rigidity is not as critical because the cutter is opposed by the feed of the work.
- Good for machining thin walled parts

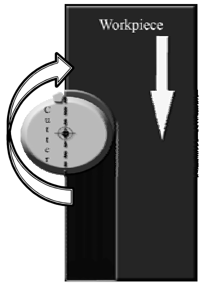


Introduction of Cutting Tools

- Disadvantages of Conventional (up) Milling
- Tends to cause more tool chatter.
- Surface finish not as smooth as climb milling.
- Work piece or part can move up.

Introduction of Cutting Tools

- Climb (down milling)
  - The revolution of the end mill is the same direction of the work piece feed direction
  - The cutting edge meets the work piece at the top of the cut
    - the width of the chip starts at maximum thickness and
    - decreases to a zero at the end of the cut



Introduction of Cutting Tools

- Rules of Thumb
- When cutting metals, you should climb cut whenever possible

  <u>Reason</u>:
  - The inserts or flutes enter the cut at full feed per tooth, and exit as the chip thins to zero
  - In this situation, less heat is generated and work hardening of the surface of the work piece is minimized
  - Inserts can easily take the forces generated. Properly designed freecutting positive geometries are easier on the machine and won't shake the machine excessively

Introduction of Cutting Tools

- Rules of Thumb
  - *However, if you are machining thin walls, the setup is not very rigid, or the machine is overly worn, use conventional cutting.*

Introduction of Cutting Tools

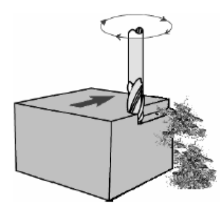
- Advantages of Climb Milling
  - <u>Increased tool life</u>
    - The chips pile up behind the cutter rather than in front and can increase the tool life by 50 percent.
  - <u>Less costly fixture devices</u>
    - Climb milling exerts a downward force making it easier to hold.
  - <u>Improved surface finishes</u>
    - Chips are less likely to be carried by the tooth, reducing marring of the machined surface.

Introduction of Cutting Tools

- Advantages of Climb Milling
  - <u>Easier chip removal</u>
    - Chips are tossed behind the cutter, resulting in faster and easier chip removal
  - <u>Decreased power requirements</u>
    - A higher rake angle can be used on the cutting tool, resulting in lower power consumption. This is particularly applicable in smaller milling machines.
  - <u>Low temperature (long tool life)</u>
  - <u>Smoother surface finish</u>

Introduction of Cutting Tools

- Disadvantages of Climb Milling
  - Rigid setup is required because the cutter pulls the work piece along.
  - In routing, the material can be pulled out of your hands or the fixture if not handled carefully.



Introduction of Cutting Tools

- Cutting Tool Milling Processes
- Peripheral and plunge milling are the most frequently used milling processes for cutting 3D parts.
  - In peripheral milling, the tool cuts a surface that is parallel to the end mill axis.
  - Side and face milling are examples in the next picture.
  - In plunge milling, the tool sinks directly into the work piece and moves directly through the work piece along the center line.

Introduction of Cutting Tools

- Cutting Tool Milling Processes
  - Side Milling
    - Milling with a side-milling cutter to machine one vertical surface

Side milling

Introduction of Cutting Tools

- Cutting Tool Milling Processes
  - Face Milling
    - Milling flat surfaces perpendicular to the rotational axis of the cutting tool.

Face milling

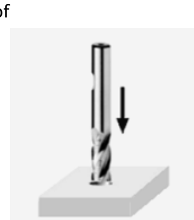
Introduction of Cutting Tools

- Cutting Tool Milling Processes
  - Shoulder Milling
    - Milling a flat surface and a vertical surface at the same time on the work piece

Side and Face (Shoulder) milling

Introduction of Cutting Tools

- Cutting Tool Milling Processes
  - Plunge Milling
    - Milling perpendicular to the axis of the spindle into the work piece. This method is very similar to drilling.



Plunging

Introduction of Cutting Tools

- Cutting Tool Milling Processes
  - Diagonal Plunge Milling
    - Milling that occurs and utilizes two axes for movement. Direction of the cutting tool is diagonal as it plunges into the work piece.

Diagonal plunging

Introduction of Cutting Tools

- Cutting Tool Milling Processes
  - Pocket Milling
    - Milling that utilizes plunging and produces an interior recess that is cut into the surface of a work piece.

      Pockets may be round or rectangular in shape.

Pocketing

Introduction of Cutting Tools

- Cutting Tool Milling Processes
  - Helical Interpolation
    - Milling where the cutting tool begins a plunge into the work piece while also moving in a spiral interpolation.

Helical interpolation

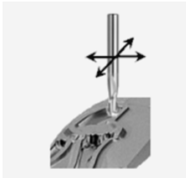
Introduction of Cutting Tools

- Cutting Tool Milling Processes
  - Slot Milling
    - Milling that utilizes a combination of plunge, side and shoulder milling to create a slot through the work piece as it removes material.

Slot milling

Introduction of Cutting Tools

- Cutting Tool Milling Processes
  - Contour Milling
    - Milling that creates movement along an irregular surface to create geometry.



3D contouring

Cutting Tools – Keys to Remember

- Conventional (up) milling
  - Thickest portion of the chip is at the end of the cut
  - Good for thin walled parts
  - Causes more tool chatter
  - Surface finish is not as smooth
- Climb (down) milling
  - Thickest portion of the chip is at the beginning of the cut
  - Increased tool life
  - Less costly fixture devices
  - Improved surface finishes
  - A more rigid workpiece setup and work-holding are required