Cutting Tool Design

Training Objective

After watching the program and reviewing this printed material, the viewer will understand the basics of cutting tool design.

- Primary types of cutting tools are shown
- The concept of a “tool signature” is explained
- Cutting tool geometries are detailed
- Basic machining operations are explored

Cutting Tool Design Concepts

Workpiece shaping occurs as the edges of the cutting tool, driven by the power of the machine tool into the workpiece, force grains of the metal to move away from the advancing cutting edge. This displacement causes the metal to fail. A chip forms along this line of failed metal, which separates from the work material. How such material failure takes place is determined by the following factors:

- Cutting tool design & geometry
- Cutting tool material
- Workpiece material
- Machine forces on the workpiece
- Various process conditions

Cutting tool design requires an understanding of the application difficulties that can be encountered during the machining process, including:

Setup rigidity – critical to dimensional accuracy and finish quality of the part.

Cutting tool strength – must be sufficient to prevent breakage and/or deformation due to anticipated machining forces.

Weak links – consisting of wear and breakaway members included in the tool design, which limit damage to toolholders and other machine components.

Machine speed and feed - these parameters along with tool adapter capacity and working clearances all establish restrictions on tool design and production rates.

Total cutting force usually resolves into three mutually perpendicular components:

- Feed force
- Radial force
- Tangential force, which is the most significant, acts upon the top of the cutting tool, tangent to the rotary direction of the part or tool

Chip disposal – single-point cutting tools usually have a pressed-in, chip-breaker design to curl and break the material removed into manageable chips. Milling cutters must include ample chip space to hold the chip until it can be thrown or washed out between successive cut passes.

Chatter – results from the momentary separation of the cutting tool and the workpiece. It can cause tool breakage as well as impair surface finish, and can be prevented by eliminating uneven motions and loose fits.

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Single-Point Cutting Tool Design

Most turning operations use single-point cutting tools. The nomenclature for a single-point tool is a sequence of alpha and numeric characters, also referred to as the "tool signature". This signature represents the following tool aspects:

- Various angles such as the back rake, side rake, end relief, side relief, end cutting and lead angles
- Significant dimensions
- Special features
- Nose radius size

This method of tool identification has been standardized by ANSI (American National Standards Institute), for carbide and high-speed-steel tools. However, the ANSI classification does not characterize all tool aspects such as the variety of chip-breaker geometries.

The cutting tool's nose radius connects the side and end cutting edges. By function, it must be equal to or less than the smallest radius on the finished part. Other factors influencing tool nose radius selection include:

- Surface finish requirements
- Tool strength, with the largest tool nose radius permissible giving the highest strength

While a larger nose radius can absorb more of the generated heat and produce a smoother cut, it can also generate greater radial cutting forces and increase the chance of chatter. In general, the quality of the finished surface results from the proper combination of nose radius and feed per revolution.

Chip-breaking Geometries

Chip-breaking geometries are designed to provide chip control and force reductions at specified feed rates and depth of cut. These geometries can be ground into the cutting surface of the tool or pressed-in using mechanical pressing.

Single-Point Cutting Toolholders

Insert-type toolholders consist of a shank, head, pocket and clamping device. They may be left or right handed or neutral. Commonly, much of the required geometry is built into the toolholder rather than the cutting-tool insert itself.

Multipoint Cutting Tools

Multipoint cutting tools are comprised of a series of single-point cutting tools mounted in or integral with a holder or body. They are operated in such a manner that all the teeth or cutting edges follow essentially the same path across the workpiece. Most multipoint tools create discontinuous chips that must be carried for some distance over the work before they can be ejected. The design of such tools must include sufficient chip space without compromising tool rigidity.

Cutting edges may be straight or contoured and may be designed for either linear or rotary travel. The most common, among many types of multipoint cutting tools, are the broach, the twist drill, and the face mill.

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The Broach

The broach is the most common multipoint, linear-travel cutting tool. Both external and internal surfaces can be produced in various profiles. Broach teeth (the cutting edges) can be of several angles and geometries. In operation, each tooth on the broach is generally higher than the one before. Thus the depth of cut or chip load progressively increases. Tooth shape and chip space depend on workpiece length, chip thickness per tooth and type of chip made. Broach teeth are typically grouped into three distinct regions:

- Roughing teeth, which make the first and generally heavier cuts in a broaching operation
- Semi-finishing teeth, which take smaller, semi-finishing cuts
- Finishing teeth, which are arranged at a constant size for finishing

The Twist Drill

The twist drill is the most common axially fed rotary tool used in holemaking operations. Either the drill itself may be rotated or it can be held stationary while being fed into a rotating workpiece. The three essential parts of the twist drill are:

The shank, which is the means by which the drill is held and driven. Shanks are either straight or tapered.

The flutes, which let coolant into and carry chips out of the hole being produced. Flutes may be of various helix angles depending on the material being drilled.

The drill point, which does the work of metal cutting. The drill point is formed by two cutting lips and a chisel edge. The standard drill-point angle is 118°, and has a clearance angle typically between 10° and 20°.

The Face Mill

Face mill cutters generate flat surfaces. The cutter body has multiple pockets to accept a variety of indexable insert cutting tools. At least one of the cutter teeth is always in contact with the work, thus keeping the milling cutter and the work under constant load. This avoids vibration and shock and enhances the finish surface of each cut. The designs of all face mills incorporate certain variables such as:

Effective diameter, which is measured between the highest cutter insert points directly opposite each other.

Cutter hand, which is determined by examining the cutter's face while running on a machine tool. A right-hand cutter rotates counterclockwise, while a left-hand cutter rotates clockwise.

Cutter geometry, which describes various radial and axial rake angles.

Lead angle, which influences cutting forces and chip thickness generated by the cutting tool.

Insert pocket design, which can be either fixed or modular. The modular types accept a variety of interchangeable insert cartridges that hold various insert designs and seat the inserts at different angles.

Cutter pitch, which determines the number of inserts relative to the cutter diameter and can be defined as the distance from a point on one edge to the corresponding point on the next edge.

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Review Questions

1. Most critical to dimensional accuracy with respect to the machining process is:
   a. Part tolerances
   b. Setup rigidity
   c. Tool strength
   d. Feed & speed settings

2. Tangential forces result from the:
   a. Rotary direction of the part or tool
   b. Workpiece hardness
   c. Feed direction of the cutting tool
   d. Cutter shape

3. Momentary separation of the tool and the workpiece often results in:
   a. Discontinuous chips
   b. Chatter
   c. Thermal cracking
   d. Coolant flow disruption

4. Turning operations most commonly employ:
   a. Face mill cutters
   b. Multipoint cutting tools
   c. Single-point tools
   d. Neutral toolholders

5. A tool's nose radius is required to be:
   a. Equal or less than the smallest radius on the finished part
   b. Equal or smaller than the largest radius on the part
   c. As large as possible for strength
   d. As small as possible for a fine part finish

6. Critical to multipoint cutting tools is:
   a. Overall diameter
   b. Plunge depth capability
   c. Sufficient chip space
   d. Maximum feed speeds

7. The standard drill point angle is:
   a. 122^{o}
   b. 128^{o}
   c. 118^{o}
   d. 120^{o}

8. Face mills are used primarily to generate:
   a. Contours
   b. Pockets
   c. Grooves
   d. Flat surfaces

9. "Cutter hand" relates to a cutter's:
   a. Rotational direction
   b. Feed
   c. Speed
   d. Pitch

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Answer Key

1. b
2. a
3. b
4. c
5. a
6. c
7. c
8. d
9. a