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Geometries At Work

Optimize edge and insert placement in facemill and endmill cutters.

Milling cutters are critical—and common—multipoint metalcutting tools. Their performance is dependent largely on the cutter's milling geometry, or the positioning of its cutting edges and inserts.

Optimal milling geometries can reduce cutting forces, prolong tool life, improve surface finish and facilitate chip removal. This is particularly true for cutters such as facemills and endmills that accept inserts. This article reviews the basics of facemill and endmill geometries, and what to keep in mind for optimal tool selection and machining.

Geometry, Angles

Every type of cutting tool has its own unique geometry. With single-point tools for turning, for example, the cutting edge usually is in constant contact with the workpiece. Multipoint tools, however, cut intermittently, as their cutting edges repeatedly enter and exit the workpiece.

During most milling operations, cutting takes place on two edges of the insert. A facemill cuts mainly with its end, creating a new surface after the peripheral edge has removed most of the metal ahead of the face.

An endmill, meanwhile, cuts with its periphery. Both the end and periphery of the insert remove metal as the insert enters the workpiece.

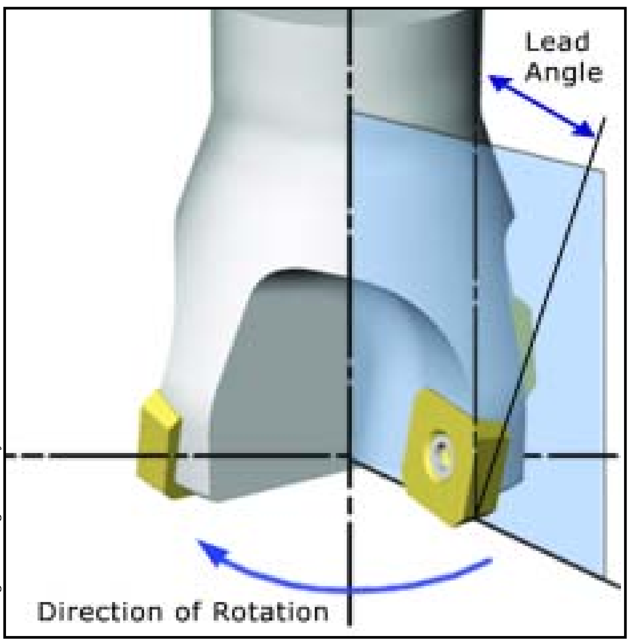
Generally, at least two teeth should contact the workplace at any given time. Manufacturers must carefully determine the feed and speed of a milling operation to ensure that cutting forces are balanced effectively among the teeth, or cutting points, that are engaged. The goal is to find the optimal chip thickness.

Flutes can be either straight or helical. Inserts are essentially replaceable teeth held in place by wedge or screw clamps. The distance between teeth is generally referred to as the "pitch." A coarse-pitch cutter offers fewer teeth than a fine-pitch cutter.

During metalcutting, a chip is formed at the two cutting edges. From there, it slides up the tooth face and into the flute, then strikes the "fillet," or round corner of the flute.

A key component of milling geometry is the "lead angle," formed by the peripheral edge of the solid tool or insert and the cutter's center axis. This angle describes how far the top of the insert is leaning away from being parallel with the cutter's axis (Figure 1). For general cutting, most lead angles range from 0°, for creating square shoulders, to 45° degrees, for finishing operations. For general milling, lead angles of 15° to 45° are recommended. The 15° lead angle allows for a deeper cut.

As the lead angle increases, the chip becomes thinner and longer for a cut of the same depth (Figure 2); the load is spread over a longer length, resulting in smoother cutting. Wide lead angles allow for fast feeds, but shallow cuts. However, since cutting with a wide lead angle reduces load, it also reduces vibration.



All images: Tooling University

Figure 1: The lead angle indicates how far the top of the insert is from being parallel to the cutter's axis.

The information in this article was supplied by Tooling University, a developer of online classes for training shop employees (www.toolingu.com). Sandvik Coromant Co., Fair Lawn, N.J., collaborated on the article (www.coromant.sandvik.com).

The axial rake angle formed by the peripheral cutting edge and the tool's center axis at the cutting point is best viewed in a plane perpendicular to the cutting plane (Figure 3).

The angle describes how many degrees the insert surface is from the center axis of the cutter, leaning forward or backward. The angle generally applies to facemilling.

A cutting edge with a positive axial rake angle scoops metal off the part's surface. In contrast, a negative axial rake directs chips back down onto the cutting surface like a knife spreading butter.

The radial rake angle, anywhere from -20° to 20°, is formed by the radius of the cutter and the tooth face at the cutting point and describes how many degrees the tooth is off the radius. It is best viewed from below the cutter, in a plane parallel to the cutting surface, and generally applies to face and peripheral milling.

Cutter performance depends upon whether the angle is positive or negative. Positive axial rake angles decrease the strength of the cutting edge, but allow for faster metal removal and reduce power requirements. In contrast, negative axial rake angles can take a deeper cut but require more power to do so.

The center axis of the cutter and the cutting edge of the periphery form the helical rake, or helix angle. Helical rake describes how the flutes twist around the tool. Ranging from 0° for straight flutes to 60°, most helix angles are between 20° and 40°. The helical rake angle is best viewed from the side of a milling cutter. On solid cutters, the helix looks like a ribbon wrapped around a cylinder. A larger helix angle creates greater forces along the axis of the cutter. For endmilling, the direction of rotation should be the same as the helix rotation. For peripheral cutting, the direction should be opposite.

Insert Geometries

The two most important angles in a milling insert's geometry are the axial and radial rake angles. Three combinations of these angles define milling geometry for indexable cutters. A positive axial rake angle and radial rake angle comprise the double-positive

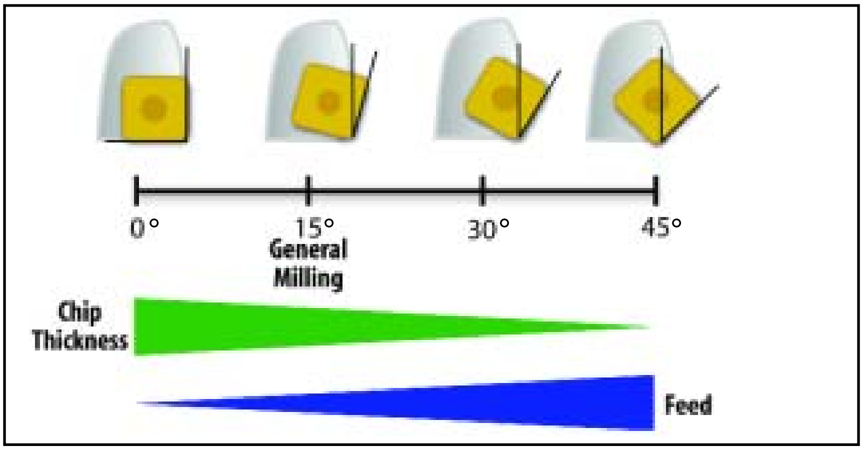


Figure 2: As the lead angle widens, chips become thinner and longer. Generally, wide angles permit fast feeds but limit the depth of cut.

geometry for milling (Figure 4). The insert leans back, away from the work, both axially and radially.

A tool with double-positive geometry uses single-sided, positive inserts held in positive pockets. The outer edge of the cutting point is the first part of the insert to move into the workpiece. Spiraling chips are scooped up and in toward the center.

Double-positive milling results in a small contact surface, offering the advantages of thin chips, low cutting forces and low power requirements. Free cutting and reduced likelihood of chatter are perhaps the greatest benefits of the double-positive geometry.

The tool's major disadvantage is a weak cutting edge, since the weakest part of the insert contacts the workpiece first. For this reason, though, the geometry is useful when dealing with fragile workpieces or unstable machines. In fact, double-positive milling may be the only option for materials that tend to form a built-up edge.

A positive axial rake angle and negative radial rake angle make up the positive-negative geometry for milling (Figure 5). In this configuration, the insert leans back away from the cut axially, but into the work radially.

A positive/negative geometry uses positive inserts held in negative pockets. The positive insert provides clearance during milling. The chips are scooped up from the workpiece and cleared out, away from the cutter.

A positive/negative geometry balances the best qualities of positive and negative rakes. Free cutting and effective chip formation and removal origi-

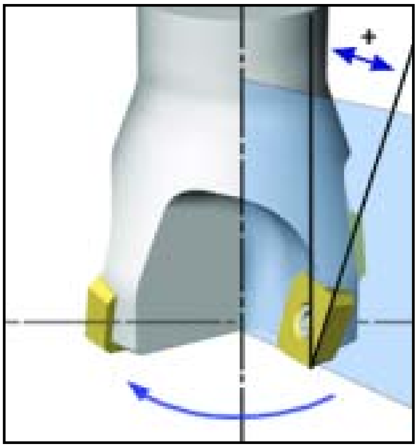


Figure 3: The axial rake angle, seen in a plane perpendicular to the cutting plane, shows how far the insert surface is from the cutter's center axis.

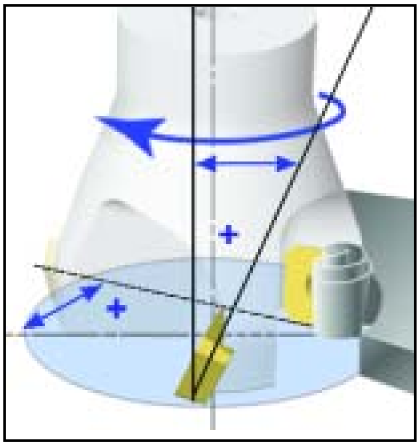


Figure 4: The double-positive geometry has both positive axial and radial rake angles. It lowers power requirements and is useful for milling fragile workpieces.

nate in the positive axial rake angle, while the negative radial rake angle's strength permits deeper cuts and higher feeds per tooth. The power requirements of a tool with positive/negative geometry are slightly higher than those for a double-positive tool.

A negative axial rake angle and negative radial rake angle define the double-negative geometry (Figure 6). The insert leans into the cut, both axially and radially. Double-negative mills accept only negative inserts held in negative pockets. Both sides of the insert may be applied, making it a practical and economical choice. The thick chips are forced down axially and out radially. The double-negative geometry provides the greatest cutting edge strength, making it good for roughing or severe interrupted cuts.

However, thin or lightly held workpieces will not respond well to double-negative tools. The large forces generated also require rigid machines. Double-negative cutters work well for short-chipping, hard steels and cast irons. They are a poor choice for soft, ductile, long-chipping materials, since the chips would just curl up in the chip pockets.

As mentioned before, the shape of the insert in indexable cutters accounts for some of the angles that affect milling. In addition, insert shape heavily influences the strength of the cutting edge and surface finish. An insert with a radius is best in roughing applications where surface finish is not critical. The radius, meanwhile, extends tool life, since heat generated during machining dissipates across a greater surface area.

The Impact of Lands

A "land" is a version of a chamfer at the cutting edge. A negative land is used to change the axial rake angle in a localized way at the cutting point. It also strengthens the cutting edge while increasing power requirements.

A parallel land is a straight edge on the insert, parallel to the plane of the cutter movement. It improves surface texture compared to an insert with just a radius. When the land width is greater than the advance per revolution, one insert forms the surface. Parallel-land inserts make good roughing and general-purpose inserts for positive/negative and double-positive cutters. The parallel land should be as large as possible without causing vibration.

When the surface texture produced by a parallel land is not smooth enough, a wiper insert offers increased accuracy in a finishing operation by reducing waviness and profile depth. Wiper lands fall about 0.002" below the parallel lands in the cutter and wipe, or sweep, the surface clean.

Because of axial height differences, wiper inserts wear faster than other inserts. Wipers are not always good for steel because of difficulties with chip flow and vibration. However, they work well with soft chipping and soft materials.

Relief vs. Clearance

Relief and clearance angles, two key concepts in milling geometry, are often confused. The relief angle is the small sliver of an angle that immediately trails the cutting edge. The clearance angle describes the next, larger section of space past the cutting edge, right after the relief surface. When there is no land, the clearance and relief angles are the same angle. Clearance, or the space left trailing the cutting edge, incorporates relief.

Both axial and radial relief and clearance angles, which can only be positive, account for each direction trailing the cutting edge. The axial angles can be viewed from the side of the insert, while the radial are best seen from the top. They range from 3° to 30°, with most being around 5° to 13°. It is best to apply the smallest angle possible. Larger angles weaken the cutting edges and may introduce chatter. Therefore, harder materials demand smaller angles.

Ultimately, the effectiveness of a milling cutter depends on how all these various angles work in harmony with other factors such as speed and feed rates, workpiece material and tool substrate. Understanding how the geometry of a milling cutter affects the cutting process helps you select the best tool for the job.

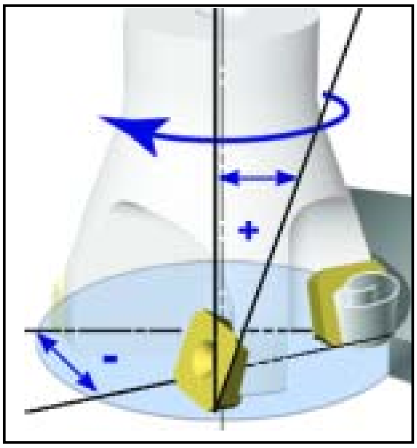


Figure 5: The positive-negative geometry features positive axial and negative radial rake angles. Positive-negative tools permit deeper cuts and higher feeds than double-positive tools.

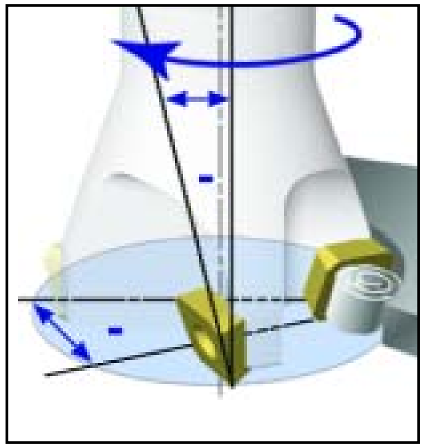


Figure 6: The double-negative geometry has both negative axial and radial rake angles. This allows for the strongest cutting edges, making it ideal for hard steels and cast irons.