Training Objective

After watching the program and reviewing this printed material, the viewer will gain knowledge and understanding of basic milling theories and procedures. In addition, the viewer will become aware of the use of CNC technology and the features and functions of machining centers.

- the basic vertical knee mill machine is examined
- the parameters for successful metal removal are defined
- the application of CNC technology to milling is explained
- machining center features and functions are highlighted
- various cutting tools, workholding, and work-changing devices are detailed

The Milling Process

Milling is the most versatile of machining processes. Metal removal is accomplished through the relative motions of a rotating, multi-edge cutter and multi-axis movement of the workpiece. Milling is a form of interrupted cutting where repeated cycles of entry and exit motions of the cutting tool accomplish the actual metal removal and discontinuous chip generation. Milling has more variations in machine types, tooling, and workpiece movement than any other machining method.

All milling machines, from compact tabletop models to the standard vertical knee mill and the massive CNC machining centers, operate on the same principles and operating parameters. The most important of these operating parameters are:

- cutting speed, which is the speed at which the tool engages the work
- feed rate, which is the distance the tool edge travels in one cutter revolution
- the axial depth of cut, which is the distance the tool is set below an unmachined surface
- the radial depth of cut, which is the amount of work surface engaged by the tool

The capabilities of the milling machine are measured by motor horsepower, maximum spindle speeds and spindle taper size.

Milling Machine Basics

The most basic milling machine is the vertical spindle, ram-type “knee” mill. Though not well adapted to production milling, it is ideal for toolmaking and prototype machining. Knee mills are primarily used for manual operations, but their capabilities can be expanded.

The knee travels vertically, up and down the column, and supports the saddle and table. The saddle moves in and out from the column, while the table moves side to side of the column. Additionally, the ram, at the top of the column, supports the milling head which contains the motor, toolhead, speed and feed controls, quill and spindle. The non-rotating quill holds the rotating spindle. The ram can be moved both in and out from the column and can be tilted for angular milling and drilling.

Cutting tools are secured in collets or drill chucks held in the spindle. Work is usually secured to the table using bolts and clamps, or by using vises or fixtures bolted to the table. The work table contains longitudinal “T” slots to facilitate the attachment of these devices.

The knee mill’s capabilities are expanded by the use of digital readout displays and CNC technology. CNC technology provides three-axis capability to the mill.
Milling & Machining Centers

CNC Machining Centers

Manual mills require that the operator/machinist set all the required parameters, change tools, and manually direct all table movement. However, with CNC capability, work is performed much faster, with exceptional repeatability. In addition, CNC computer programs can be verified and completed graphically before actual metalcutting begins.

A machining center is a machine for both milling and holemaking on a variety of non-round or prismatic shapes. The primary types of machining centers are either vertical or horizontal. The vertical type is often preferred when work is done on a single face. With the use of rotary tables, more than one side of a workpiece, or several workpieces, can be machined without operator intervention. Vertical machining centers using a rotary table have four axes of motion. Three are lineal motions of the table while the fourth is the table’s rotary axis.

Horizontal centers with their horizontal spindles are better suited to larger, boxy workpieces. With a horizontal spindle, a wider variety of workpiece shapes are easier to mount and chips fall out of the way better. Like vertical machining centers, horizontal centers have multiple-axis table movements. Typically, the horizontal center’s table rotates to present all four sides of a workpiece to the tooling.

Toolchangers & Cutting Tools

The unique feature of the machining center is the tool changer. The tool-changer system moves tools from storage to spindle and back again in rapid sequence. While most machining centers will store and handle 20 to 40 individual tools, some will have inventories of over 200.

In general, a milling cutter is a rotary tool with one or more cutting edges, each of which removes a small amount of material as it contacts the workpiece. The variety of cutter types is almost limitless. One of the more basic is the face mill cutter used for milling flat surfaces. Used at high speeds, face mill cutters range from a few centimeters to over a half-meter in diameter. Some face mills will simultaneously mill a shoulder that is square to the surface.

Work that requires edge preparation, shoulders, and grooves, is accomplished with other milling cutters. An end mill cutter is a tool with cutting edges on its end as well as on its periphery. End mills are used for short, shallow slots and some edge finishing. Circular grooving or slotting cutters are more adapted to the making of longer and deeper slots. This is because end mills are susceptible to deflection during heavier cuts. Chamfers and contour milling are performed with specially shaped end mills.

Cutting tools are chosen not only for their geometries; they are also chosen for their material properties. More than ever, tougher cutter materials are available that extend tool life and allow faster cutting of tougher, harder workpiece materials. Standard or coated carbide tools work well in most cutting situations. However, cubic boron nitride, or “CBN”, tool inserts may be needed for cutting hardened materials. Additionally, tools with polycrystalline diamond, or “PCD”, surfaces may be needed for cutting difficult-to-machine nonferrous alloys, such as nickel superalloys. The higher costs of these cutting tools must be weighed against their improvements in speed and tool life.
Milling & Machining Centers

Workholding & Workchanging

In all kinds of milling, a critical component is the workholding device and the ability to be changed over quickly to present new work or work surfaces to the tooling. Machining centers can utilize long machine beds, pallet changers and multi-sided “tombstone” fixtures to enable new work to be set up and positioned while previously setup workpieces are being milled.

Machining Center Accessories & Programming

Machining centers can incorporate two very useful accessories. One is the touch-trigger probe which, with its computer software, will dimensionally check workpiece measurements before removal from the machining center. The probe is stored with other tooling for quick application. The second accessory is the tool presetting machine, which allows the technician to assemble the tooling according to the programmed part requirements before placing tools in the machining center’s tool storage.

The choice of toolholder itself can be critical. Chucks, collets and other mechanical-interference toolholders use applied clamping pressure to set tools for common milling situations. In recent years, shrink-fit toolholders have become more popular, especially for high-speed machining operations. Here, the toolholder develops uniform clamping pressure as it contracts around the tool shank, after first being heated and expanded. Shrink-fit systems require extra equipment, but the cost may be justified by the higher cutting speeds and feeds that they allow.

The programming and control software for “CNC” machining centers has become increasingly sophisticated and easier to use. Programming has also made milling more accurate, allowing higher productivity and better surface quality on parts. Software can allow a machine tool to learn how to correct for process variations in its actual tool path, in comparison with its desired programmed path. Other programs suppress machining vibrations, improving the surface finish of parts.

Simulation programs also can be used to optimize a process by predicting what the cycle time of a programmed tool path will be before milling begins.
Milling & Machining Centers

Review Questions

1. In milling, stock removal is accomplished by:
   a. repeated cycles of entry and exit motions of the cutting tool
   b. continuous chip generation
   c. the combination of speed and tool contact pressure
   d. continuous cutting tool contact with the work

2. Feed rate is described as:
   a. the down pressure by the spindle
   b. the travel speed of the work past the cutter
   c. the distance the tool edge travels in one cutter revolution
   d. the rotational speed of the spindle and cutting tool

3. The vertical spindle, ram-type knee mill is usually:
   a. manually operated
   b. capable of horizontal conversion
   c. CNC controlled
   d. used for high production

4. The singularly unique feature found on a machining center is the:
   a. spindle arrangement
   b. table movement
   c. number of possible axes
   d. the tool-changer

5. Horizontal machining centers are useful for work that is:
   a. small and round
   b. long and thin
   c. short and thick
   d. large and boxy

6. Face mill cutting tools can have diameters ranging from:
   a. 3 centimeters to 12 centimeters
   b. a few centimeters to over one meter
   c. 10 centimeters to 30 centimeters
   d. a few centimeters to over a half-meter

7. End mills do not produce accurate slots in heavier cuts due to:
   a. problems with lubrication
   b. tool chipping
   c. deflection
   d. limited feed rates

8. A machining center accessory used for checking part dimensions is called:
   a. a tool presetting machine
   b. a digital readout
   c. a touch-trigger probe
   d. a dial indicator
Answer Key

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