CHAPTER 23

Machining Processes Used to Produce Various Shapes
Homework Assignment
Due Wednesday 28/4/2010

1. Show that the distance $l_c$ in slab milling is approximately equal to $\sqrt{Dd}$ for situations where $D>>d$. (see Figure 23.3c)

2. Estimate the time required to face mill a 10-in long, 1.0-in wide brass block with a 6-in diameter cutter with 10 HSS inserts.

3. A 12-in long, 1-in thick plate is being cut on a hand saw at 150 ft/min. The saw has 12 teeth per in. If the feed per tooth is 0.003-in, how long will it take to saw the plate along its length?

4. A slab milling operation will take place on a part 300mm long and 40mm wide. A helical cutter 75mm in diameter with 10 teeth will be used. If the feed per tooth is 0.2mm/tooth and the cutting speed is 0.75m/s, find the machining time and metal removal rate for removing 6mm from the surface of the part.

5. In describing the broaching operations and the design of broaches, we have not given equations regarding feeds, speeds, and metal removal rates, as we have done in turning and milling operations. Review Figure 23.21 and develop such equations.
The IUG Machining Center, which does job shop machining, has received an order to make 40 duplicate pieces, made of AISI 4140 steel, which will require 1.0 hour per piece of actual cutting if an ordinary HSS milling cutter is used. Mohammad, a new machinist, says the cutting time could be reduced to not over 25 minutes per piece if the company would purchase a suitable tungsten carbide milling cutter.

Hassan, the foreman for the milling area, says he does not believe that Mohammad’s estimate is realistic, and he is not going to spend $450 of the company’s money on a carbide cutter that probably would not be used again. The machine-hour rate, including labor, is $40 per hour. Mohammad and Hassan have come to you, the supervisor of the shop, for a decision on whether or not to buy the cutter, which is readily available from a local supplier.

What factors should you consider in this situation? Who do you think is right, Mohammad or Hassan?
Typical Parts Produced Using the Machining Processes in the Chapter

(a) 
(b) 
(c) 
(d) 
(e) 

Stepped cavity 

Drilled and tapped holes
Milling and Milling Machines

Milling operations

- Milling: a process in which a rotating multi-tooth cutter removes material while traveling along various axes with respect to the wp.
- Figure 23.2: basic types of milling cutters & milling operations

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Milling and Milling Machines

Milling operations: Slab milling

- Axis of cutter is parallel to wp surface
- Conventional Milling (Up Milling)
  - Max chip thickness is at the end of the cut
Milling and Milling Machines

Milling operations: Slab milling

- Conventional Milling (Up Milling)
  - Advantage: tooth engagement is not a function of wp surface char, and contamination or scale on the surface does not affect tool life
  - Cutting process is smooth
  - Tendency for the tool to chatter
  - The wp has a tendency to be pulled upward, necessitating proper clamping.
Milling and Milling Machines

Milling operations: Slab milling

Climb Milling

- Cutting starts at the surface of the wp, where the chip is at its thickest
- Downward comp of cutting forces hold wp in place
- Because of the resulting high impact forces when the teeth engage the wp, this operation must have a rigid setup, and backlash must be eliminated in the table feed mechanism
- Not suitable for machining wp having surface scale
Milling and Milling Machines

Milling operations: Slab milling

Milling Parameters - TABLE 23.1

- **N** = Rotational speed of the milling cutter, rpm
- **f** = Feed per tooth, mm/tooth (in/tooth) = \( \frac{v}{N \times n} \)
- **D** = Cutter diameter, mm (in)
- **n** = Number of teeth on cutter
- **v** = Linear speed of the workpiece or feed rate, mm/min (in/min)
- **V** = Surface speed of cutter, m/min (ft/min) = \( \pi D \times N \)
- **l** = Length of cut, mm (in)
- **t** = Cutting time, s or min = \( \frac{l + l_c}{v} \)
- **l_c** = extent of the cutter’s first contact with workpiece
- **MRR** = mm³/min or in³/min = \( w \times d \times v \), where \( w \) is the width of cut
- **Torque** = N-m (lb-ft) = \( (F_c) \times (D/2) \)
- **Power** = kW (hp) = (Torque) \( \times \omega \), where \( \omega = 2\pi N \) radians/min
Milling and Milling Machines

Milling operations: Face Milling

- The cutter is mounted on a spindle whose axis of rotation is perpendicular to wp surface
- Face climb milling: fig 23.5b
- Conventional milling: figure 23.5c
Milling and Milling Machines

Milling operations: Face Milling

- Figure 23.7 Schematic illustration of the effect of insert shape on feed marks on a face-milled surface:
  a) small corner radius
  b) corner flat on insert
  c) wiper, consisting of a small radius followed by a large radius which leaves smoother feed marks
  d) Feed marks due to various insert shapes.

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Milling operations: Face Milling Terminology

- End cutting edge angle
- Corner angle
- Peripheral relief (radial relief)
- Radial rake
- Axial rake
- End relief (axial relief)
Milling and Milling Machines

Milling operations: Face Milling - Effect of Lead Angle

- Lead angle of insert has a direct influence on undeformed chip thickness.
- As the lead angle increases, undeformed chip thickness decreases, length of contact increases.
- Range of lead angles = 0°-45°.
- X-sectional area of undeformed chip remains constant.
- As lead angle decreases, there is a smaller vertical force comp (axial force).
- Ratio of cutter diameter, D, to width of cut should be no less than 3:2.

(a) (b)
Milling and Milling Machines

Milling operations: Face Cutter and Insert Position

- The same insert engages wp at diff angles, depending on relative positions of the cutter and wp:
  - a) Tip of the insert makes the 1st contact, so there is a possibility for the cutting edge to chip off
  - b) 1st contacts (at entry, reentry, and the two exists) are at an angle and are away from tip of insert. So less tendency for insert to fail because forces on insert vary more slowly

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Milling operations: End Milling

- The cutter usually rotates on an axis perpendicular to wp.
- It can be tilted to machine tapered surfaces.
Milling and Milling Machines
Other Milling Operations And Cutters

(a) Straddle milling
(b) Form milling
(c) Slotting
(d) Slitting
Milling and Milling Machines
Other Milling Operations And Cutters

(a)

First cut (slotting)

Second cut

T-slot

Workpiece

(b)
Shank with taper

Spacers

Milling cutter

Arbor bearing surface for outboard support

Drive key

Arbor nut
Milling and Milling Machine
Milling Process Capabilities

- Table 23.2: typical capacities and max wp dimensions for some machine tools
- Table 23.3: approximate cost of selected tools for machining
- Table 23.4: general recommendations for milling operations
- Table 23.5: General Troubleshooting Guide for Milling Operations
Milling and Milling Machine Design And Operating Guidelines

- Use standard milling cutters as much as possible
- Chamfers should be used instead of radii
- Avoid internal cavities and pockets with sharp corners
- WP should be sufficiently rigid to minimize any deflections resulting from clamping and cutting forces
- Table 23.5: General troubleshooting guide for milling operations
Milling and Milling Machine
Surface Features and Corner Defects

(a) Milled surface

Back striking

No back striking

Direction of workpiece travel

(b) Milled surface

Cutter (top view)

Chatter

(c) Cutter

Insert

Burr

(d) Large breakout

Small breakout

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Milling and Milling Machine

Milling Machines

- Figure 23.15: a horizontal spindle column-and-knee type milling machine.
Milling and Milling Machine

Milling Machines

- Figure 23.16: a vertical-spindle column-and-knee type milling machine (also called a knee miller)
Milling and Milling Machine

Milling Machines – Bed Type

- Cross-rail
- Spindle carrier
- Spindle carrier
- Workpiece
- Table
- Bed

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Milling and Milling Machine

Milling Machines

- Figure 23.18 A CNC vertical-spindle milling machine
Milling and Milling Machine

Milling Machines

- Figure 23.19: 5-axis profile milling machine
Planning and Shaping

Planning

- Planning is a Cutting operation by which flat surfaces, grooves, notches are produced along the length of wp.
- Usually done on large wp (up to 25mx15m)
- The wp is mounted on a table that travels along straight path
- Because of the reciprocating motion of wp, elapsed time in the return non-cutting stroke is significant.
- Hence, these operations are suitable only for low quantity production
Planning and Shaping

Planning

- Efficiency can be improved by equipping planners with tool holders and tools that cut in both directions of table travel.
- To prevent chipping of tool cutting edges on the return stroke due to rubbing along wp, tools either tilted or lifted mechanically.
- Cutting speeds: up to 120 m/min, power up to 110 kW
- For cast and irons and steels: speed 3-6 m/min
- For Al and Mg: speeds up to 90 m/min
- Feed: 0.5 to 3 mm/stroke
- Tool material: HSS (M2 or M3) and C2 and C6
Planning and Shaping

Planning

Block diagram showing the basic components of a double-housing planer.

(a)

Block diagram of an open-side planer.

(b)
Planning and Shaping

Planning

- Figure 23.20 Typical parts that can be made on a planer.
Planning and Shaping

Shaping

- Parts are smaller
- In horizontal shapers, the tool travels along a straight path, while the wp is stationary
- In most machines, cutting is done during the forward movement of the ram (push cut)
- Vertical shapers are used to machine notches, keyways, ...
Broaching and Broaching Machines

- A broach: is a long multi-tooth cutter
- Total depth of material removed in one stroke is the sum of the depths of cut of each tooth of the broach
- A large broach can remove material up to 38mm in one stroke
- Rake angle depends on the material cut (0 to 20°)
- Clearance angle: 1 – 4°
Broaching and Broaching Machines

- Finishing teeth have smaller angles
- Too small a clearance angle causes rubbing of the teeth.
- Pitch depends on length of wp, tooth strength, and size and shape of chips
- At least 2 teeth should be in contact with the wp at all times
- $k = 1.76$ when $l$ is in mm, and $0.35$ when $l$ is in inch.
- Average pitch range for small broaches: 3.2-6.4mm
- Average pitch range for large broaches: 12.7-25mm
- The cut per tooth depends on wp material and desired surface finish
- Cut per tooth for medium size broaches: 0.025-0.075m
- Cut per tooth for large size broaches: 0.25mm or larger
Broaching and Broaching Machines

a) Typical parts made by internal broaching

b) Parts made by surface broaching. Heavy
Broaching and Broaching Machines
broaching machines

- Either pull or push, horizontal or vertical
- Push broaches are usually shorter, 150-350mm
- Pull broaches tend to straighten the hole, where pushing permits the broach to follow any irregularity of the leader hole
- Force required to pull or push the broach depends on:
  1. strength of the wp
  2. total depth and width of cut
  3. cutting speed
- Pulling force capacities: up to 0.9MN.
Broaching and Broaching Machines
broaching machines
Broaching and Broaching Machines
Terminology for a pull-type internal broach used for enlarging long holes

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Broaching and Broaching Machines

Broaching Process Parameters

- Cutting speed: from 1.5m/min for high strength alloys to 15m/min for Al and Mg alloys
- Broach materials: HSS (M2 and M7), and carbide inserts, or coated with titanium nitride

Design consideration for broaching

- Part design should allow Secure clamping
- Avoid blind holes, dovetail splines, and large flat surfaces
- Chamfer round corners
Sawing

- Cutting process in which the cutting tool is a blade having a series of small teeth, each tooth removing small amount of material.
- Near net shape process
- Little waste material
- See fig 23.28 for typical saw configuration
- Alt least 2 or 3 teeth should engage with wp
- The thinner the stock, the finer the saw tooth should be
- Cutting speeds: up to 90m/min
Sawing - Sawing Operations

(a) Sawing

(b) Internal cuts

(c) Angular cuts

(d) Contour cutting

(e) Stack cutting

(f) Wafer being sliced

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Sawing - Types of Saw Teeth

- At least 2 or 3 teeth should engage with wp
- The thinner the stock, the finer the saw tooth should be
- Cutting speeds: up to 90m/min

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Sawing - Saw Teeth

- M-2 HSS 64-66 HRC
- Electron-beam weld
- Flexible alloy steel backing

- Carbide insert
- Tungsten-carbide tip
Sawing - Types of Saws

Hacksaws
- Straight blades and reciprocating motions
- Power hacksaws: 1.2-2.5mm thick and up to 610mm long
- Strokes per min: 30-180

Circular saws
- High prod rate sawing

Band saws
- Continuous long flexible blades
- Continuous cutting action
- Vertical band saws
- Horizontal band saws
Sawing - Friction Sawing

- A process in which a mild steel blade or disk rubs against the wp at speeds up to 7600m/min
- The frictional energy is converted into heat, which rapidly softens a narrow zone in the wp
- The action of the blade pulls and ejects the softened metal from the cutting zone
- This process is suitable for hard ferrous metals and reinforced plastics, but not for non-ferrous metals