

Refrigeration and Cryogenics

Janusz Skrzypacz, PhD

Integrated Production Systems

Choose yourself and new technologies

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Integrated Production Systems

Lecture 2, 3

Review of the manufacturing processes

Janusz Skrzypacz, PhD

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Types of Manufacturing

- Batch manufacturing —small lots & large variety.
- Mass production —large quantities & standard products.
- Continuous process industry —large volume of single (flow) product.

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Basic Manufacturing Processes

- Casting & molding
- Forming & shaping
- Machining (material removal)
- Joining & assembly
- Finishing (surface treatments)
- Heat treating

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Casting

Refractory mold → pour liquid metal → solidify, remove → finish

- VERSATILE: complex geometry, internal cavities, hollow sections
- VERSATILE: small (~10 grams) → very large parts (~1000 Kg)
- ECONOMICAL: little wastage (extra metal is re-used)
- ISOTROPIC: cast parts have same properties along all directions

Source: [http://www.ielm.ust.hk/dfaculty/ajay/courses/ieem215/lec3/1_mot\(prop\).ppt](http://www.ielm.ust.hk/dfaculty/ajay/courses/ieem215/lec3/1_mot(prop).ppt)

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Different Casting Processes

Process	Advantages	Disadvantages	Examples
Sand	many metals, sizes, shapes, cheap	poor finish & tolerance	engine blocks, cylinder heads
Shell mold	better accuracy, finish, higher production rate	limited part size	connecting rods, gear housings
Expendable pattern	Wide range of metals, sizes, shapes	patterns have low strength	cylinder heads, brake components
Plaster mold	complex shapes, good surface finish	non-ferrous metals, low production rate	prototypes of mechanical parts
Ceramic mold	complex shapes, high accuracy, good finish	small sizes	impellers, injection mold tooling
Permanent mold	good finish, low porosity, high production rate	Costly mold, simpler shapes only	gears, gear housings
Die	Excellent dimensional accuracy, high production rate	costly dies, small parts, non-ferrous metals	gears, camera bodies, car wheels
Centrifugal	Large cylindrical parts, good quality	Expensive, few shapes	pipes, boilers, flywheels

Source: [http://www.ielm.ust.hk/dfaculty/ajay/courses/ieem215/lec3/1_mot\(prop\).ppt](http://www.ielm.ust.hk/dfaculty/ajay/courses/ieem215/lec3/1_mot(prop).ppt)

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Sand Casting

Source: http://www.ielm.ust.hk/dfaculty/qjay/courses/ieem215/iecs/1_mot/prop.ppt

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Sand Casting

Source: www.youtube.com

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Sand Casting Considerations

Source: http://www.ielm.ust.hk/dfaculty/qjay/courses/ieem215/iecs/1_mot/prop.ppt

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Shell mold casting

(a) Pattern rotated and clamped to dump box

(b) Pattern and dump box rotated

(c) Pattern dump box in position for the investment

(d) Pattern and shell removed from dump box

Labels: Pattern, Coated sand, Dump box, Investment, Excess coated sand, MOLTEN METAL, CURED SHELL VALVES, CLAMP, BACKING MATERIAL, FLASK

Source: http://www.ielm.ust.hk/dfaculty/qjay/courses/ieem215/iecs/1_mot/prop.ppt

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Expendable Mold Casting

Labels: polystyrene pattern, support sand, pattern, molten metal, polystyrene burns; gas escapes

Source: http://www.ielm.ust.hk/dfaculty/qjay/courses/ieem215/iecs/1_mot/prop.ppt

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Lost wax casting

(a) Wax pattern (injection molding)

(b) Multiple patterns assembled to wax sprue

(c) Shell built → immerse into ceramic slurry → immerse into fine sand (few layers)

(d) dry ceramic melt out the wax fire ceramic (burn wax)

Source: http://www.ielm.ust.hk/dfaculty/qjay/courses/ieem215/iecs/1_mot/prop.ppt

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Lost wax casting

(e) Pour molten metal (gravity)
→ cool, solidify
[Hollow casting:
pouring excess metal before solidification]

(f) Break ceramic shell
(vibration or water blasting)

(g) Cut off parts
(high-speed friction saw)
→ finishing (polish)

Source: http://www.ielm.ust.hk/dfaculty/qjay/courses/ieem215/iecs/1_mot/prop.ppt

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Lost Wax Casting

Source: www.youtube.com

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Vacuum casting

Similar to investment casting, except: fill mold by reverse gravity

Easier to make hollow casting: early pour out

Source: http://www.ielm.ust.hk/dfaculty/qjay/courses/ieem215/iecs/1_mot/prop.ppt

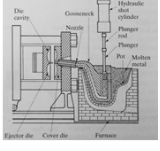
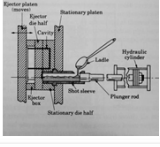
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Die Casting

HOT CHAMBER: (low mp e.g. Zn, Pb; non-alloying)
 (i) die is closed, gooseneck cylinder is filled with molten metal
 (ii) plunger pushes molten metal through gooseneck into cavity
 (iii) metal is held under pressure until it solidifies
 (iv) die opens, cores retracted; plunger returns
 (v) ejector pins push casting out of ejector die

COLD CHAMBER: (high mp e.g. Cu, Al)
 (i) die closed, molten metal is ladled into cylinder
 (ii) plunger pushes molten metal into die cavity
 (iii) metal is held under high pressure until it solidifies
 (iv) die opens, plunger pushes solidified slug from the cylinder
 (v) cores retracted
 (vi) ejector pins push casting off ejector die

Source: http://www.ielm.ust.hk/dfaculty/ajay/courses/ieem215/iecs/1_mot/prop.ppt

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Die Casting



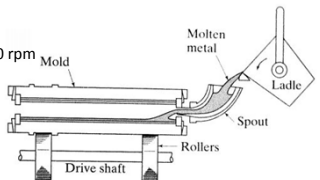
Source: www.youtube.com

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Centrifugal casting

- permanent mold
- rotated about its axis at 300 ~ 3000 rpm
- molten metal is poured



- Surface finish: better along outer diameter than inner,
- Impurities, inclusions, closer to the inner diameter (why?)

Source: http://www.ielm.ust.hk/dfaculty/ajay/courses/ieem215/iecs/1_mot/prop.ppt

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Casting Design: guidelines

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Forming

Any process that changes the shape of a raw stock without changing its phase

Example products:
Al/Steel frame of doors and windows, coins, springs,
Elevator doors, cables and wires, sheet-metal, sheet-metal parts...

Source: http://www.ielm.ust.hk/dfaculty/qjay/courses/ieem215/iecs/1_mot/prop.ppt

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Rolling

Hot-rolling

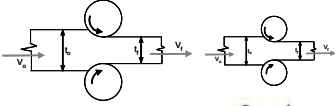
Cold-rolling

Source: http://www.ielm.ust.hk/dfaculty/qjay/courses/ieem215/iecs/1_mot/prop.ppt

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Rolling Basics



stationary die
thread rolling machine
rolling die
Reciprocating flat thread-rolling dies

Screw manufacturing:

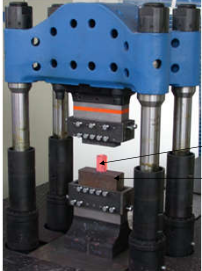


Source: http://www.ielm.ust.hk/dfaculty/qjay/courses/ieem215/iecs/1_mot/prop.ppt

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Forging



Heated metal is beaten with a heavy hammer to give it the required shape

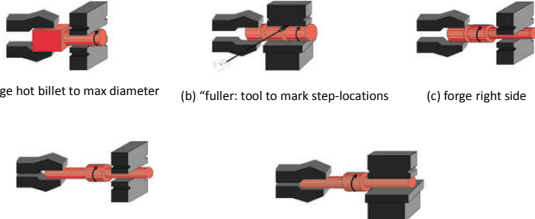
Hot forging,
open-die

Source: http://www.ielm.ust.hk/dfaculty/qjay/courses/ieem215/iecs/1_mot/prop.ppt

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Stages in Open-Die Forging



(a) forge hot billet to max diameter (b) "fuller" tool to mark step-locations (c) forge right side

(d) reverse part, forge left side (e) finish (dimension control)

Source: www.scotforge.com

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Stages in Closed-Die Forging

1. Blank (bar) 2. Edging 3. Blocking 4. Finishing 5. Trimming

Source: Schmid S. Kalpakjian S.: Manufacturing, Engineering & Technology (5th Edition), Prentice Hall, 2005

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Quality of forged parts

Surface finish/Dimensional control:
Better than casting (typically)

Stronger/tougher than
cast/machined parts of
same material

Original coarse grain structure
Plastic deformation (elongated grains)
Recrystallization (equiaxed grains)
Growth of new fine grains

Source: www.scotforge.com

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Extrusion: Schematic, Dies

chamber
stock
die
extruded shape

hydraulic piston

Direction of extrusion

Rubber
Backer
Die
Feeder

Source: http://www.ielm.ust.hk/dfaculty/ajay/courses/ieem215/iecs/1_motprop.ppt

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Extrusion

Metal forced/squeezed out through a hole (die)



Typical use: ductile metals (Cu, Steel, Al, Mg), Plastics, Rubbers

Common products:

Al frames of white-boards, doors, windows, ...



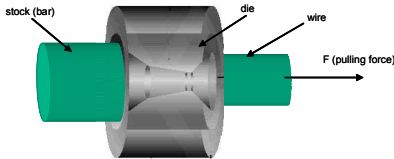
Source: www.magnode.com

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Drawing

Similar to extrusion, except: **pulling force** is applied



Commonly used to make wires from round bars

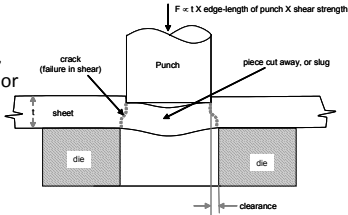
Source: http://www.ielm.ust.hk/dfaculty/qjay/courses/ieem215/iecs/1_mot/prop.ppt

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Punching

The cutting tool is a round/rectangular punch, that goes through a hole, or die of same shape



Source: http://www.ielm.ust.hk/dfaculty/qjay/courses/ieem215/iecs/1_mot/prop.ppt

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Punching





typical punched part

nesting of parts

Source: http://www.ielm.ust.hk/dfaculty/qjay/courses/ieem215/iecs/1_mot/prop.ppt

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Shearing

A large scissors action, cutting the sheet along a straight line



Main use: to cut large sheet into smaller sizes for making parts.

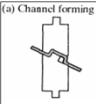
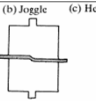
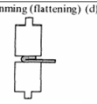
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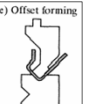
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Typical bending operations and shapes

(a) Channel forming (b) Joggle (c) Hemming (flattening) (d) Two-stage lock seam (e) Offset forming



(a)

(b)







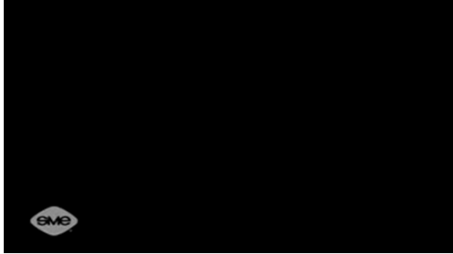
Straight flange Stretch flange Shrink flange Joggled flange Reverse flange

Source: Schmid S. Kalpakjian S.: Manufacturing, Engineering & Technology (5th Edition), Prentice Hall, 2005

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Shearing



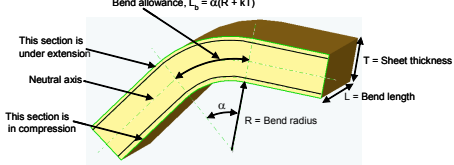
Source: www.youtube.com

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Bending mechanics

Bending Planning → what is the length of blank we must use?



Bend allowance, $L_b = \alpha(R + kT)$

This section is under extension

Neutral axis

This section is in compression

T = Sheet thickness

L = Bend length

R = Bend radius

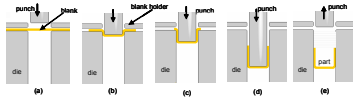
Ideal case: $k = 0.5$ Real cases: $k = 0.33$ when $(R < 2T)$ or $k = 0.5$ when $(R > 2T)$

Source: Schmid S. Kalpakjian S.: *Manufacturing, Engineering & Technology* (5th Edition), Prentice Hall, 2005

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Deep Drawing



Tooling: similar to punching operation, Mechanics: similar to bending operation



Examples of deep drawn parts

Common applications: cooking pots, containers, ...

Source: http://www.ielm.ust.hk/dfaculty/ajay/courses/ieem215/lec5/1_mot/prop.ppt

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Deep drawing

Ein Film der
Gut Metallumformung AG
CH-8712 Stäfa
www.metallumformung.ch

Source: www.youtube.com

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Material Removal Process

Mechanical Machining

- Turning
- Milling
- Drilling
- Grinding



Source: <http://www.gatewaycoalition.org/files/kinzel/machines/NVMachines.ppt>

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Machining DOF (Degrees of Freedom)

DOF- of independently controllable axes of motion-- excluding spindle rotation or tool translation responsible for cutting.

- 1 DOF**- Drill Press
- 2 DOF**- Lathe
- 3 DOF**- 3 independent axis motions between tool & table
Can use a ball end mill w/ 3 axis machine- for smoothest contour
Following a true 3-D contour requires a minimum of 3 DOF
- 2 1/2 DOF**- 3 independent axes, but can only move 2 at a time
- > 3 DOF**- Generally allows rotation of spindle wrist or table
Helps keep the tool normal to workpiece/ fewer separate fixtures
5 DOF- Minimum to follow any normal at any point

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Turning Operations

- Turning (Performed on lathe)
Part is moving and tool is stationary.
- Used to make parts of round cross section
Screws, shafts, pistons....
- A number of various lathe operations
Turning, facing, boring, drilling, parting, threading

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Operations Related to Turning

Source: Kalpakjian S.: Manufacturing Processes for Engineering Materials 2nd Ed, Addison-Wesley 1991.

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Work Holding

Source: Kalpakjian S.: Manufacturing Processes for Engineering Materials 2nd Ed, Addison-Wesley 1991.

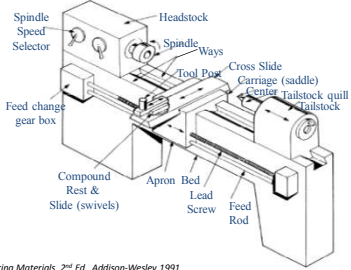
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Lathe

Machine Components (Main items)

- Bed: **Supports all other machine parts**
- Carriage: **Slides along the machine ways**
 - Head stock: **Power train of system (spindle included)**
 - Tail Stock: **Fixes piece at end opposite to the head stock**
 - Swing: **Maximum diameter of the machinable piece**
 - Lead screw: **controls the feed per revolution with a great deal of precision**



Source: Kalpakjian S.: *Manufacturing Processes for Engineering Materials* 2nd Ed, Addison-Wesley 1991.

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Lathe Tools

Lathe tools

- Left handed
- Right handed
- Threading
- Boring
- Groove
- Parting (Cut-Off)



Source: http://www.ielm.ust.hk/dfaculty/ajay/courses/ieem215/iecs/1_mot/prop.ppt

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Cutting Speeds

Typical Lathe Cutting Speeds

- Nominally 9 - 240 m/min
- Roughing cuts
 - Depth of cut greater then 0.5 mm
 - Feed speed of 0.02 - 2 mm/rev.
- Finishing Cuts
 - Lower than roughing cuts.

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Lathe



Source: www.youtube.com

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Milling

Types of Milling Machines

- Horizontal Milling Machine
- Vertical Milling Machine




Source: http://www.ielm.ust.hk/dfaculty/qjay/courses/ieem215/iecs/1_mot/prop.ppt

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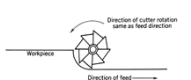
Mill Cutting Direction

Cutting direction- Depending on the orientation of the workpiece feed w.r.t. the rotation of the cutting tool.

- **Conventional (Up) Milling-** Maximum thickness of chip at end of cut



- **Climb (Down) Milling-** Maximum thickness of chip at start of cut.



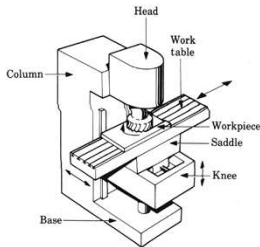
Source: Kibbe R. Machine Tool Practices 5th Ed, Prentice Hall, 1995.

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Vertical Knee Milling Machine

Base and Column- support structure
Knee- Connected to slide on column- can move up and down
Saddle- Engages slide on top of knee- can be moved in and out.
Table- Engages slide atop of saddle- moved lengthwise. Holds workpiece.
Ram- Engages swiveling slide atop column.
Toolhead- Attached to end of ram, contains motor and quill.
Quill- Non rotating, but contains rotating spindle. Can be moved up and down.

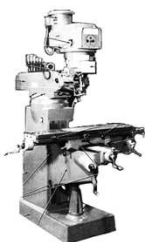


Source: Kalpakjian S.: Manufacturing Processes for Engineering Materials 2nd Ed, Addison-Wesley 1991.

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Vertical Milling Machine



- Flexible
- Versatile
- Newer machines – more DOF

Source: http://www.ielm.ust.hk/dfaculty/gjay/courses/ieem215/iecs/1_mot/prop.ppt

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Bed Mill

- Similar to vertical knee milling machines
- Less versatile than knee mill
- No knee - Bed does not move up and down
- Vertical motion possible in head only
- Controllable range of motion of head larger than in knee mill
- Bed mill is stiffer than knee mill



Source: http://www.americanmachinetools.com/bed_milling.htm

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Vertical Milling Applications

The diagram illustrates various vertical milling cutters: Collet chuck, Slot drill, End mill, Dovetail cutter, Reverse dovetail, Woodruff cutter, and Ball end cutter. A detailed view of an end mill setup shows the Spindle, Shank, End mill, and Collet.

Source: J. D. Booker K G Swift: Process Selection: From Design to Manufacture, 1997

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Horizontal Milling Machine

The diagram shows the components of a horizontal milling machine: Overarm, Arbor, Column, Workpiece, Base, Work table, Saddle, Knee, and Spindle.

COMPONENTS
 Base & Column
 Knee
 Saddle
 Table
 Spindle
 Overarm & Arbor Support

Source: Kalpakjian S. Manufacturing Processes for Engineering Materials 2nd Ed, Addison-Wesley 1991.

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Types Horizontal Milling Operations

The diagrams illustrate three types of horizontal milling operations: Slab, Side, and Face.

Slab- Axis of cutter // to workpiece surface

Side- Axis of cutter // to workpiece surface

Face- Axis of rotation $\perp$ to workpiece surface

Source: Kalpakjian S. Manufacturing Processes for Engineering Materials 2nd Ed, Addison-Wesley 1991.

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Milling

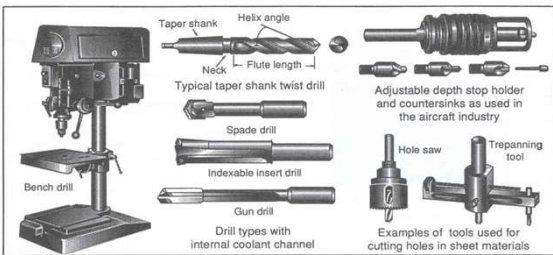


Source: www.youtube.com

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Drilling



Source: J. D. Booker, K. G. Swift: Process Selection: From Design to Manufacture, 1997

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Grinding and Abrasive Processes

Abrasive Processes- Generally slower (more expensive) than other traditional machining processes. Used on very hard materials, and can achieve HIGH (virtually unmatched) levels of precision and finish.

- Grinding
- Deburring
- Honing
- Polishing
- Lapping
- Superfinishing



Source: http://www.ielm.ust.hk/faculty/ajay/courses/ieem215/lec3/1_motprop.ppt

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Grinding Machines

Pedestal Grinder
Surface Grinder
 Type I- Horizontal spindle w/ reciprocating table
 Type II- Horizontal spindle w/ rotary table
 Type III- Vertical spindle, table either reciprocates or rotates (blanchard)
Cylindrical Grinder
 Center-type
 Roll-type- workpiece in bearings rather than on centers
 Centerless Grinder- workpiece supported on rest blade, grinding wheel on one side, regulating wheel on the other
 Internal Cylindrical Grinder
 Tool Cutting Grinders
Specialty Grinders
 Form Grinders and Generating Types

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Surface Grinders

Type I Type II Type III

Reciprocating Table Rotating Table

Source: Kibbe R.: Machine Tool Practices 5th Ed, Prentice Hall, 1995.

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Cylindrical Grinders

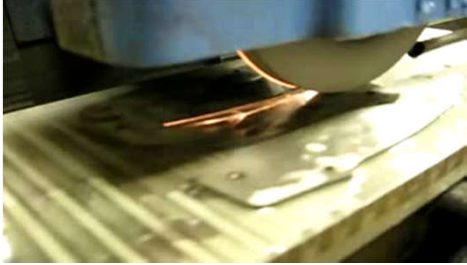
Center/Roll Type Centerless Type

Source: Kibbe R.: Machine Tool Practices 5th Ed, Prentice Hall, 1995.

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Grinding



Source: www.youtube.com

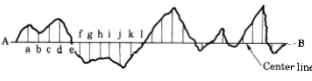
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Surface Roughness

Surface roughness is generally described with 1 of 2 methods

R_a- Arithmetic Mean Value- the average of the absolute values of the deviations from the center line of the surface

$$R_a = \frac{(|a| + |b| + |c| + |d| + \dots)}{n}$$


R_z Ten-point mean roughness(Rz) - the average of the five highest and the five deepest valleys within the sampling length, measured from a line parallel to the mean line.

$$R_z = \frac{1}{5} \left[\sum_{i=1}^5 |y_{pi}| + \sum_{i=1}^5 |y_{vi}| \right]$$

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Roughness Units

- 1 Micrometer = $1\mu\text{m} = 10^{-6}$ meters
- $1\mu\text{m} = 40 \text{ min}$
- Human hair $\sim 40 \mu\text{m}$

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