ME-101/EE-101:
Basic Engineering Skills

Manufacturing at a Glance

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Outline

- Preambles
- Introduction (space & energy; Manufacturing; Heat, Pressure & time; HED; Motion systems; Fits & tolerances)
- Various Processes (Machining; Non-traditional manufacturing; Casting; Froming; Welding; Additive Manufacturing)
- Conclusions

Preambles

Preamble-1

Learn (Pull); not taught (Push)

Buddha needed a Bodhi tree but the entire sky can be our bodhi tree! Because knowledge is transmitted by all objects, animate as well as inanimate. You need to just tune your antenna to receive.

Preamble-1

Learn (Pull); not taught (Push)

- There is a song by Vairamuthu “ek do teen lallalla ..” in the Tamil movie “Nizhalgal”. The lines I want to quote are:

<table>
<tr><td>Vaanam enakkoru bhodhi maram</td><td rowspan="2">Buddha required a Bodhi tree to attain realization. Vairanuthu says that the entire sky is his Bodhi tree and it teaches him every moment.

Knowledge & wisdom are transmitted by every living & non-living thing. We should be receptive for them.</td></tr>
<tr><td>Naalum enakkadhu saedhi tharum</td></tr>
<tr><td>Oru naal ulagam needhi perum</td><td></td></tr>
<tr><td>Thirunaal nigazhum thaedhi varum</td><td></td></tr>
<tr><td>Kelvigalaal vaelvigalai naan seivaen</td><td>Learn through questioning;
Questioning is worship or penance.</td></tr>
</table>

Preamble-1

Path to creativity

- Knowledge is transmitted by all. Just keep your antenna tuned!
- Learn to unlearn!
- Don’t fall in love with your ideas!
- Respect others’ ideas!
- Iterations lead to evolved solutions.

Preamble-2

Iceberg! Hanumans!! Gold coin!!!

- This course will cover your entire curriculum. So, we will only give you an appreciation – only the tip of the iceberg! In-depth coverage will happen in the other courses. In fact, most of the learning happens outside the class rooms, through your own initiatives & interactions with peers, seniors & professor...
- We are Jambhavans (bears) and you are Hanumans (monkeys)! We shall only instill the confidence in you. We inspire; you perspire!
- You are gold coins, which have value but no use. The goldsmith will convert into beautiful ornaments by heating & hitting. Obviously he does not seek the permission of the gold coins to heat & hit!

Introduction

Introduction

Space, Energy & Time

- There are only two things in the universe:

1. Space (Emptiness)
2. Energy

- Space is infinitely vast & empty by itself. Some of the attempts to measure space are [x, y, z], [r, θ, z] and [r, θ, ϕ].

- Energy is inside space. It is in two forms:

1. Energy in its various forms:
   Heat (ultimate), force, electric, magnetic …
2. Matter in at least 4 states
   1. solid, 2. liquid, 3. gas & 4. plasma

- Time t is another measurement reference like [x, y, z]. More details of time is beyond the scope of this course.

Introduction

Manufacturing

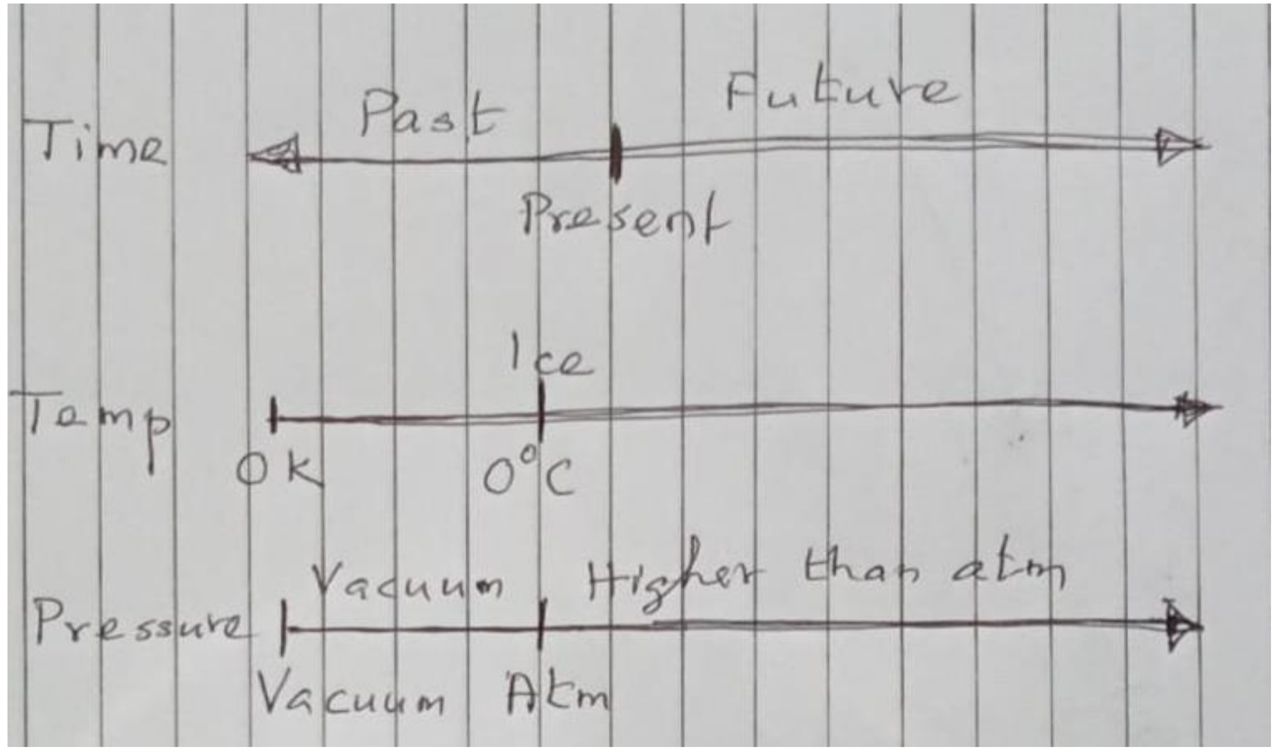
- Manufacturing is physical realization. Its various types are mechanical/ discrete/ solid manufacturing (car, ship, plane …), chemical/ fluids manufacturing (Food, medicine, chemicals, gases, …), electrical manufacturing (PCB, IC chip, …), civil manufacturing (Buildings, roads, bridges, dams, …) etc.
- We will discuss here only mechanical/discrete/solid manufacturing It is shape realization. That means our focus is limited to solids.
- Our aim is to achieve the geometry (external – shape/form, size, color) & matrix (internal – composition, porosity etc.) of the solid. We have reasonable success in geometry but not so in matrix.
- The following two most popular energy forms for manufacturing:

1. Heat
2. Force or pressure

Introduction

Ranges of heat, pressure & time

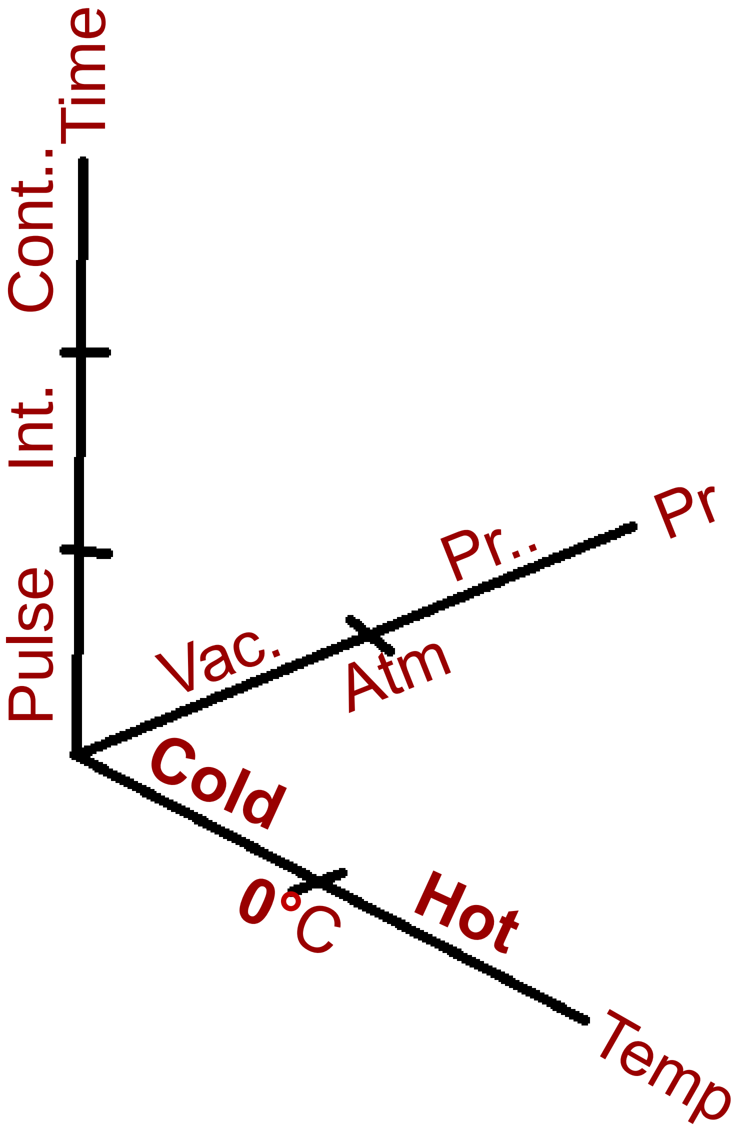
- Time has no lower bound. All three, heat, pressure & time, have no upper bound.
- Heat has a reference w.r.t. water and pressure has a reference w.r.t. atmosphere.



- Heat & pressure each can act on a point, surface or volume. Furthermore, their applications can have temporal variations as continuous, intermittent, spike.

Introduction

3D nim of [Temp, Pr & Time]



- For the purpose of classifying the processes, we can think of a discrete 4D plot of the following variations

  Temperature (cold & hot)
  Pressure (vacuum & pressure)
  Temporal (pulse, int & continuous)
  Spatial (point, area & volume))):

- Left side 3D graph is obtained by ignoring spatial variations. So, there will be 3 of them to account it..
- Some tables are also attempts.

Introduction

Usage of heat / pressure

		Point	Surface	Volume
Pr.	>atm	Jet: Air/gas/water jets with/without abrasives particles	Forming: Blow Moulding	Pressure chamber: Cold Isostatic Pressing (CIP)
	<atm	Suction nozzle: Vacuum cups	Forming: Vacuum Forming	Vacuum chamber: Electron Beam Welding (EBW)
Heat	>0°C	Beam: Gas flame, Electric arc, Laser, Electron Beam etc	Hot/cold plate: Solder Bath	Hot chamber: Furnace etc
	<0°C	Chilling jet: Cryogenic Turning/ Drilling	Machining: Cryogenic facing	Cold chamber: Freezer, refrigerator etc.

Introduction

Usage of heat & pressure

		Point	Surface	Volume
Both	>atm >0°C	Hot jet: Flame cutting .	Forging: Hot Stamping	Bulk Pressurization: Hot Isostatic Pressing (HIP), High-Pressure Die Casting (HPDC)
	>atm <0°C	Cold Spraying: High Pressure Cold Spraying AM	Sub-zero Multi-Point Cutting : Cryogenic Machining (Milling)	Subzero Bulk Pressurization: Cold Isostatic Pressing (CIP)
	<atm >0°C	Vacuum Processing: EB	Surface Grinding	Vacuum Sintering
	<atm <0°C	Sub-zero (<0°C) Single Point Cutting (High Force >atm): Cryogenic Machining	Vacuum Processing: Vacuum Surface Freeze Drying	Vacuum Processing: Vacuum Bulk Freeze Drying

Introduction

Usage of heat & pressure & time (Point based)

Time	Pressure	Temperature	Example
Continuous	>atm	>0°C	High-Pressure Water Jet Cutting
	>atm	<0°C	High-Pressure Cold Spray
	<atm	>0°C	Traditional CNC Machining
	<atm	<0°C	Cryogenic Machining
Intermittent	>atm	>0°C	Water Jet Peening
	>atm	<0°C	Cold Spray AM
	<atm	>0°C	EDM
	<atm	<0°C	Freeze Drilling

Introduction

Usage of heat & pressure & time (Surface based)

Time	Pressure	Temperature	Example
Continuous	>atm	>0°C	High-Pressure Die Casting (HPDC)*
	>atm	<0°C	Cryogenic Machining
	<atm	>0°C	Sanding
	<atm	<0°C	Cryogenic Deburring
Intermittent	>atm	>0°C	Forging
	>atm	<0°C	Cryogenic Shot Peening*
	<atm	>0°C	Surface Grinding
	<atm	<0°C	Cryogenic Polishing

Introduction

Usage of heat & pressure & time (Volume based)

Time	Pressure	Temperature	Example
Continuous	>atm	>0°C	High-Pressure Die Casting (HPDC)
	>atm	<0°C	High-Pressure Cryogenic Forming
	<atm	>0°C	Vacuum Sintering
	<atm	<0°C	Freeze Granulation (Vol. Freeze Drying)
Intermittent	>atm	>0°C	Powder Metallurgy
	>atm	<0°C	Cold Isostatic Pressing (CIP)*
	<atm	>0°C	Injection Moulding
	<atm	<0°C	Freeze Forming (Food Processing)

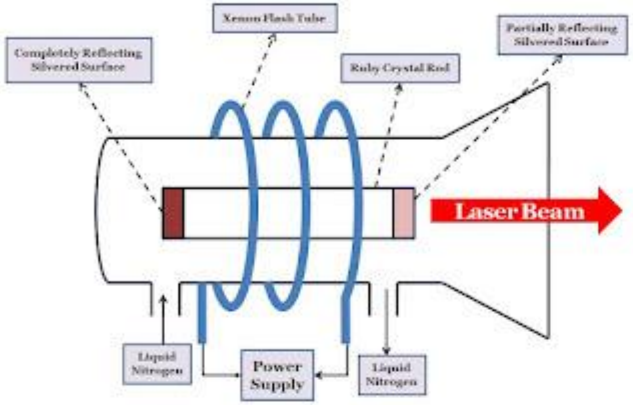
Introduction

High Energy Density (HED) Beams/Jets

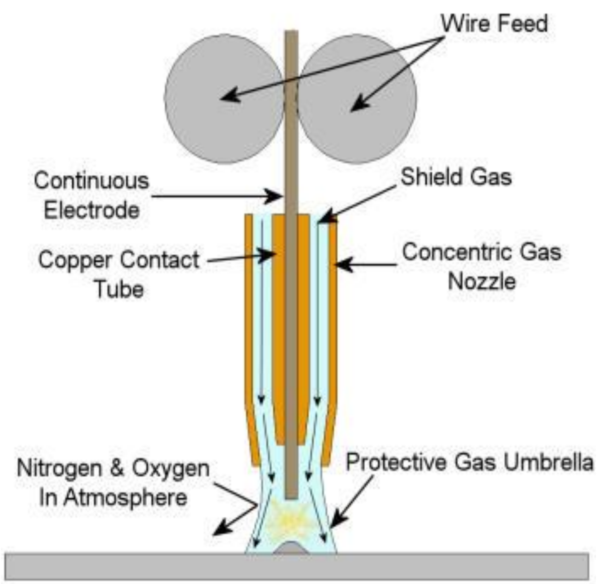
Beams	Jets
• Oxy-acetylene flame • Plasma (Arc as MIG/TIG/PAW) • Lasers • Electron Beam (EB)	• Air/gas/water jet with/without abrasives (Typically for cutting) • Binder jet (typically multi-jet for AM) • Polymer jet (typically multi-jet for AM)

Introduction

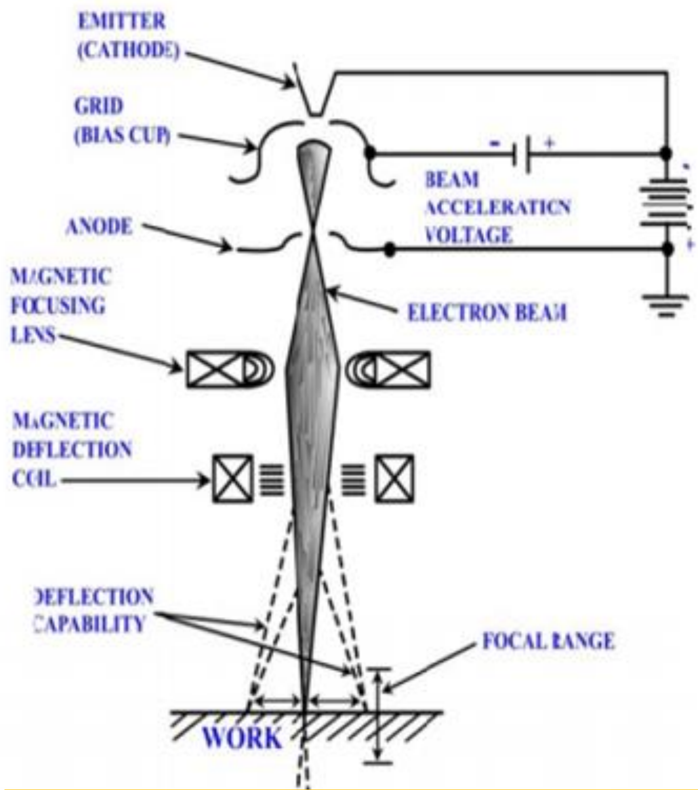
HED Beams: Arc, Lasers, Electron Beam (EB)

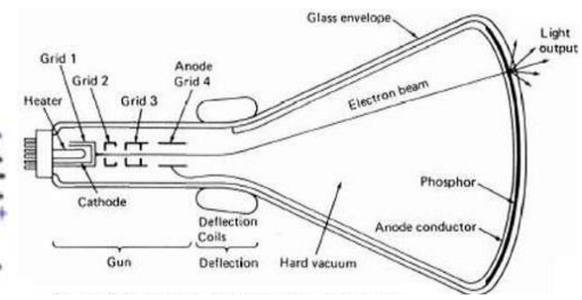


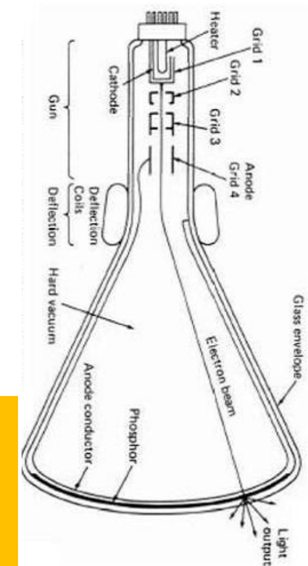
LASER



Arc (MIG)







EB machine (EBW, SEM etc.) is nothing but Cathode Ray Tube (CRT) of olden day TV turned 90º.

Electron Beam (EB)

Introduction

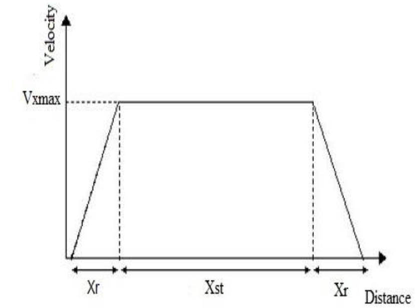
High Energy Density (HED) Beams: Comparison

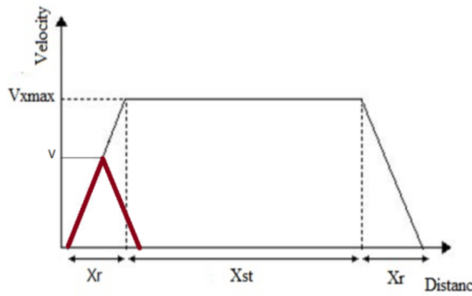
Feature	Lasers (Plural?)	EB (singular?)
Particle/EMW	EMW. Photons.	Particle. Electrons.
Charge	Neutral	Negative
Freq (c/λ)	Multiple wavelengths/ colors. Different materials absorb differently.	No notion of wavelength yet. 60-70% of c.
Freq (pulsing)	Very popular (DC, to 10^{12})	Not yet; but possible in future.
Manipulation	Cannot be bent easily. So, mirrors are used to deflect. Mirrors' weight limits speed & acceleration.	Can be bent easily using an electric/ magnetic field. So, coils are used. Unlimited speed & acceleration.
Versatility	Versatile operations: Cutting, Curing (polymerization), melting, joining … Unsuitable for highly conductive (thermally & electrically) & reflective materials	More versatile operations: Cutting, Curing (polymerization), melting, joining, pre-/post-heating, online radiography … Versatile for all metals (few exceptions of Sn, Zn and Cd!)
Efficiency	Low (15-20%)	High (95%)

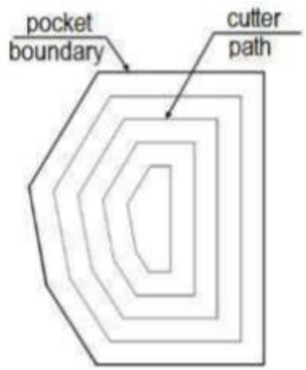
Introduction

Motion systems

- Manufacturing typically involves 2 entities, viz., tool & workpiece. Two motions are (a) power motion & (b) shaping/ relative motion
- Each have 6 DoFs. These 6+6=12 DoFs are constrained to obtain their desired relative motions t realize the geometry. Power motion is not a DoF.
- The relative motion is such that the tool & workpiece are typically in higher pair contact.
- The acceleration of the motion system is often more important than the velocity because:
  - It is not only a kinematic parameter but mechanistic too [F = ma]
  - The max. velocity cannot be reached in short motions with low acceleration.

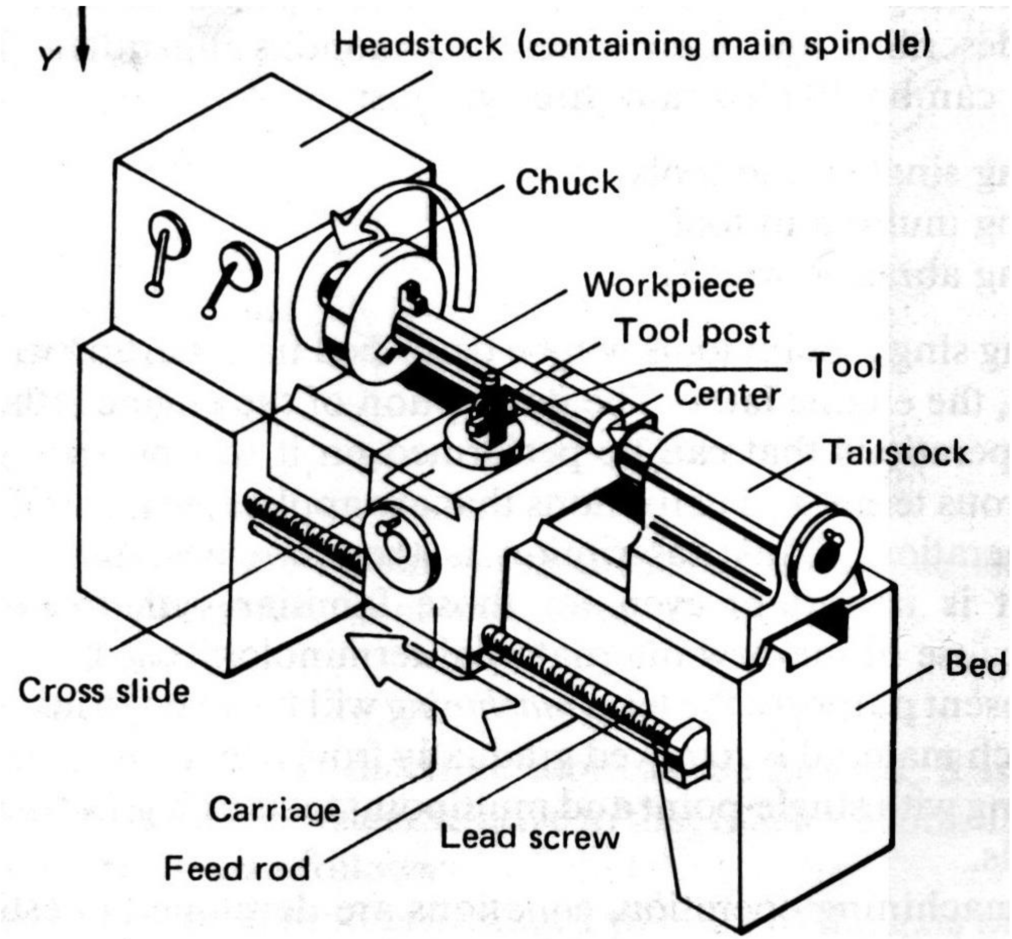






Introduction

Motion systems: Power motions types

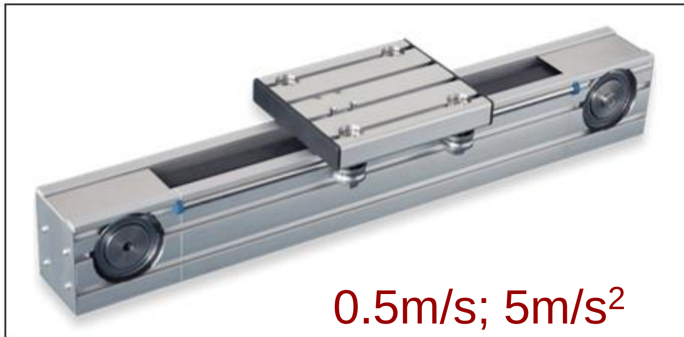


By work piece rotation

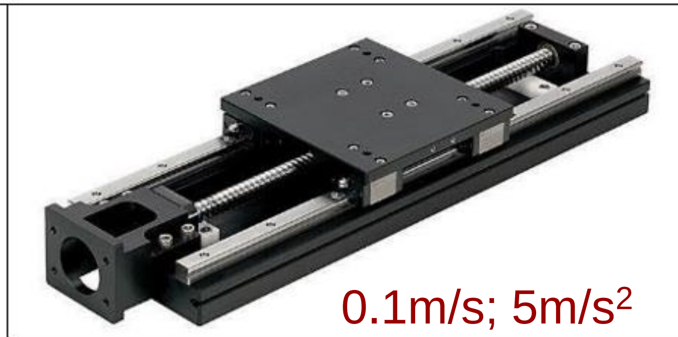
By cutter rotation

Introduction

Motion systems: Types



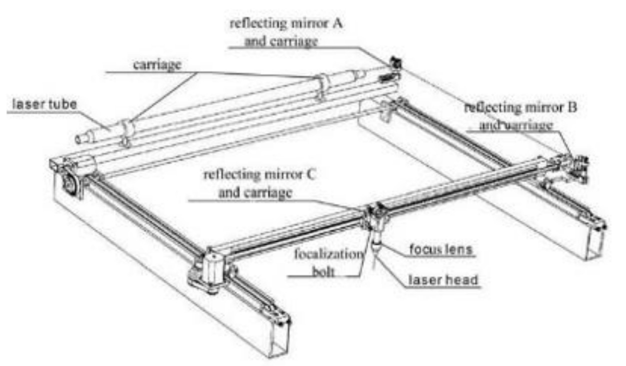
(a) Belt driven



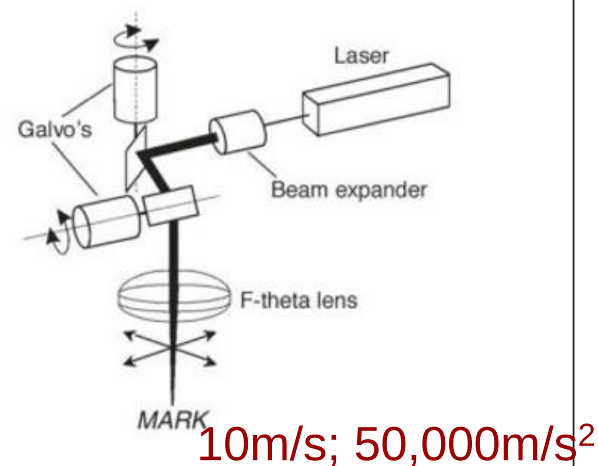
(b) Screw driven

Rotary motor system

(c) Linear motor system

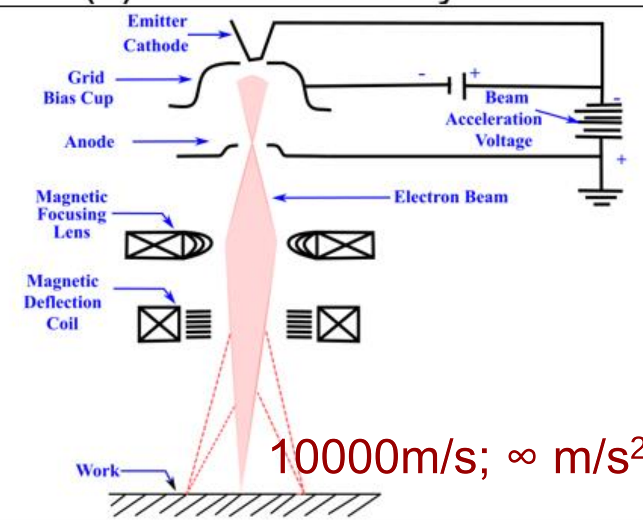


(e) Flying optics



(f) Galvanometer

Motion controls specific to lasers



(g) Deflection coils

Motion control specific to EB

Introduction

Motion systems: 2 Velocities of the tool

We observe 2 velocities/frequencies in most tools.

Tool/ Process	Velocity/ Frequency	
	1 (to enable process)	2 (to achieve geometry)
Machining	Rotation of tool/workpiece	Feed motions
Welding	Wire feed speed	Torch speed
Extrusion	Extrusion speed	Head speed
Laser	ff = c/λ [Laser type and material it affects depend on this. >8µm for non-metals; <1µm] for metals.	Shutter frequency
EB	f < c	Continuous now. Soon, shutter will be introduced.

Introduction

Fits & Tolerances

- No dimension can be exactly produced or measured. So, we define a range within which they can be realized. This is known as tolerance. Related term for the machine/process is process capability. Eg.: Reaming is limited to H5.

- Two types of tolerances are:

  1. Dimensional tolerances (length, angle etc.)
  2. Geometric tolerances (perpendicularity, concentricity, parallelism etc.)

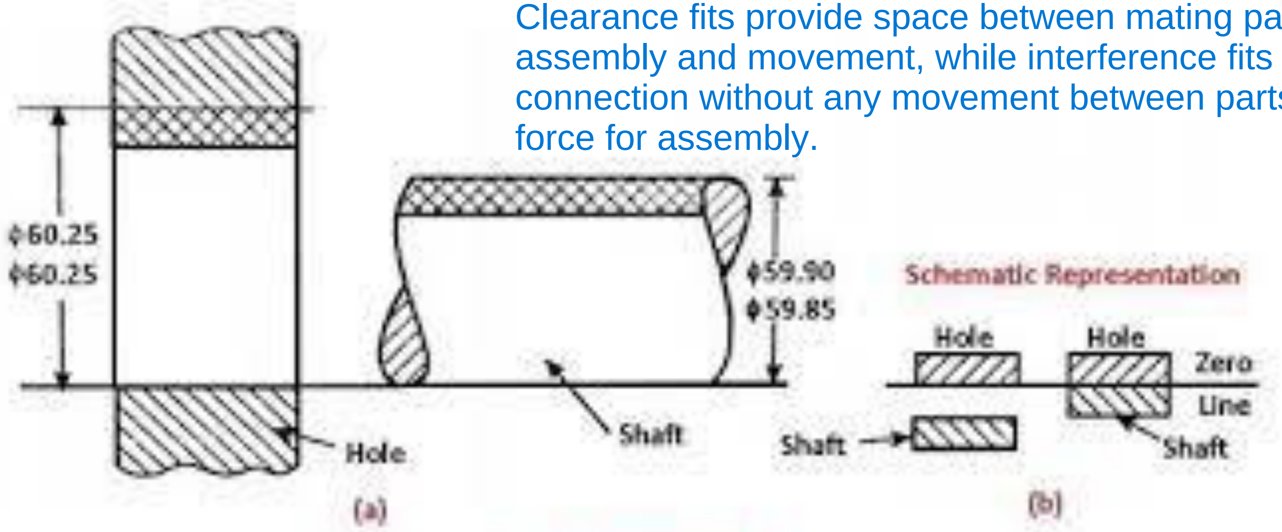
- Capital letter is used for holes and small for shafts. Eg.:10H7 = 10.000 to 10.015; 10r6 = 10.019 to 10.028).

- Fit is assembly tolerance. (clearance & interference). 10H7r6 is an interference fit of 0.004 (largest hole & smallest shaft) to 0.028 (smallest hole& largest shaft). Transition fit is in-between them. Eg.: Chained watch, strapped watch & ear stud. Process related terms are: Drive fit, shrink fit, sliding fit etc.

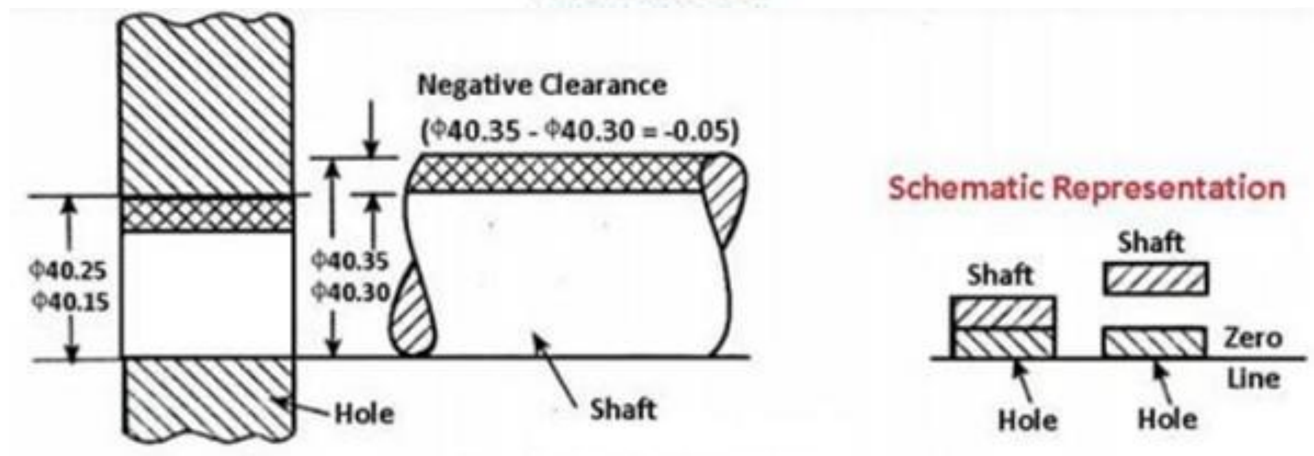
Introduction

Fits & Tolerances

Clearance fits provide space between mating parts for ease of assembly and movement, while interference fits create a tight connection without any movement between parts but require force for assembly.



Clearance Fit



Interferance Fit

Introduction

Groups of Manufacturing Processes

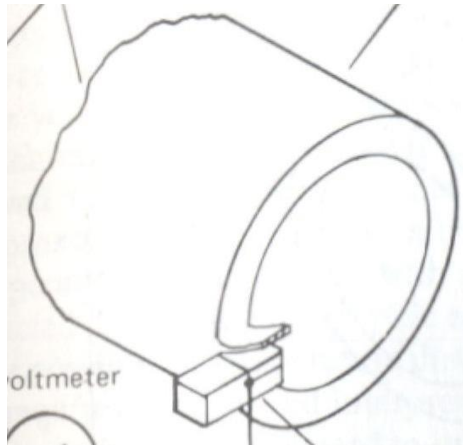
1.	Processes for discrete parts manufacturing	- Machining - Casting - Forming (bulk, sheet, pipe) - Grinding - Non-Traditional Manufacturing - Additive Manufacturing (AM)	- Internal conditioning (Heat/pr treatment,) - Surface conditioning (Painting, plating, …) - Quality Control
2.	Processes for assembly of the discrete parts	- Welding - Brazing - Soldering - Bonding	- Riveting - Fastening - Assembly - …
3.	Manufacturing automation	- Hard (automat, copying machine, …) - Soft (CNC, Robotics, AS&RS, AGV, …)	- Assembly automation
4.	Manufacturing management	- Inventory Control - Production Planning & Control	- Plant Layout - Human Resource Management - …

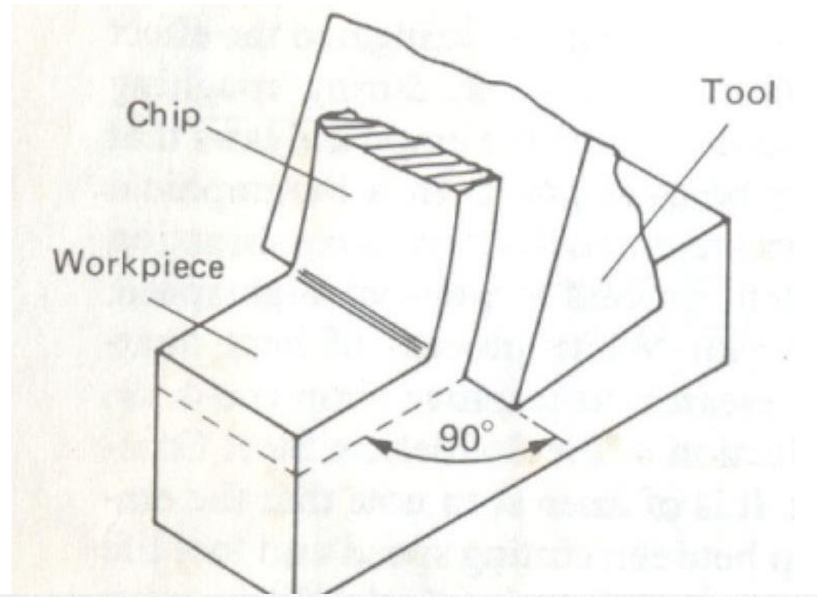
Machining

Machining

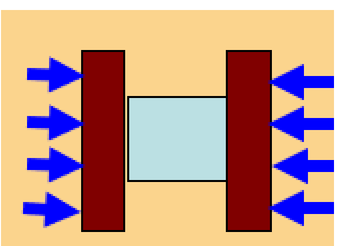
Principle

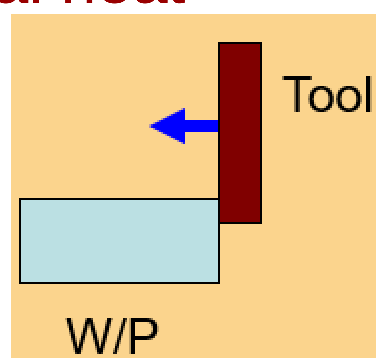
A hard tool interferes with the relatively soft work piece at adequate speed to cause material separation in the form of chips. It is shear failure in extreme compression.

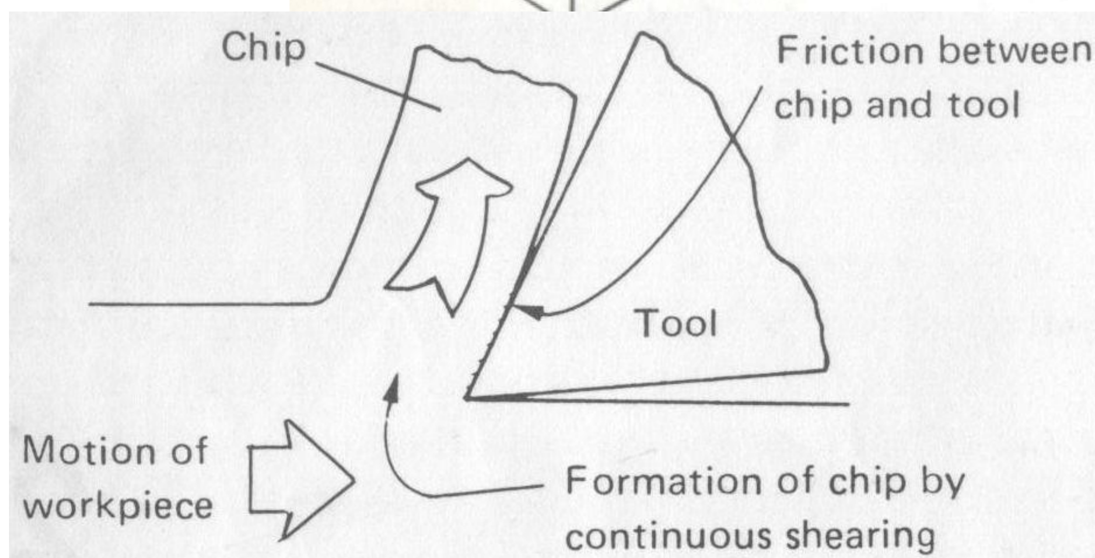




Normally external heat is not used.





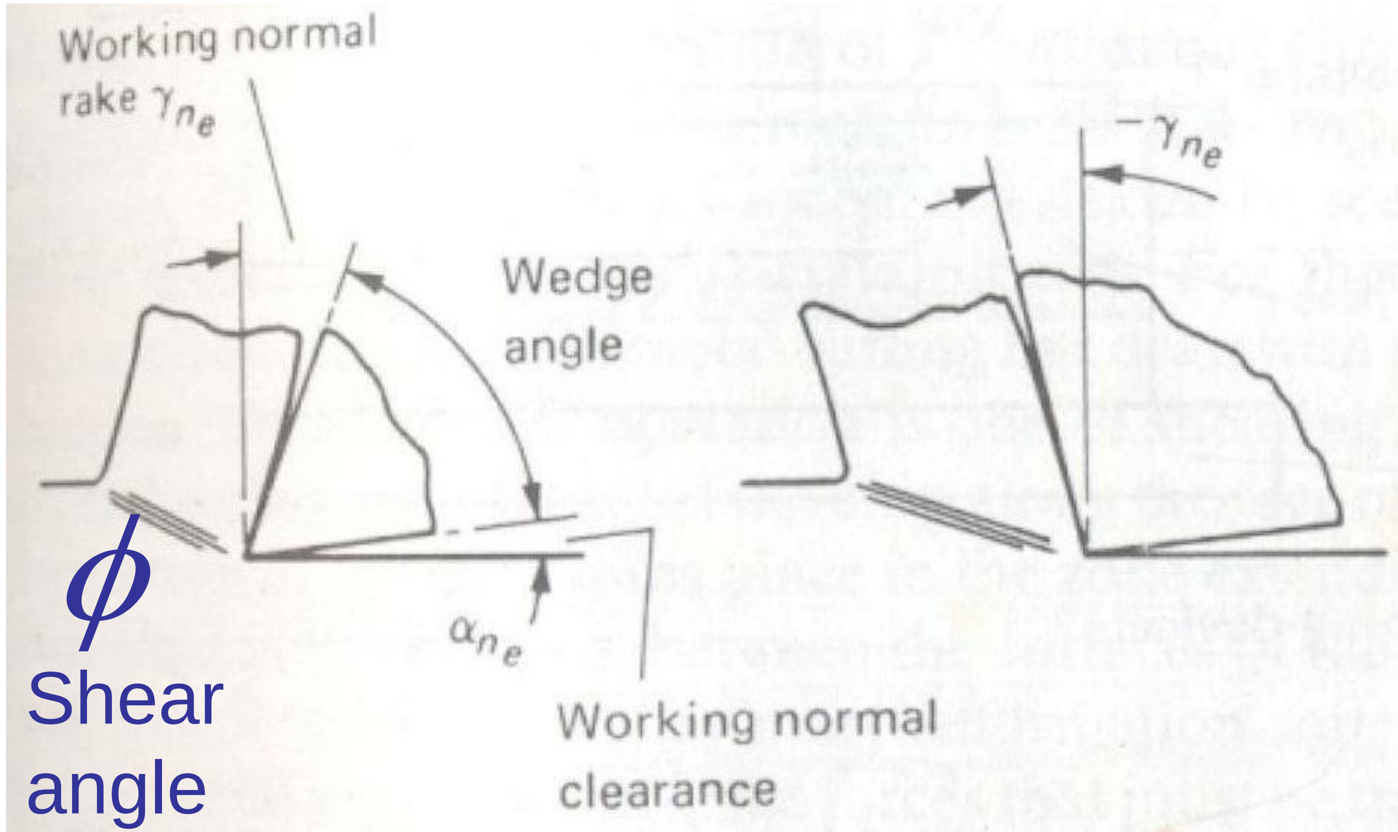


Machining
Principle

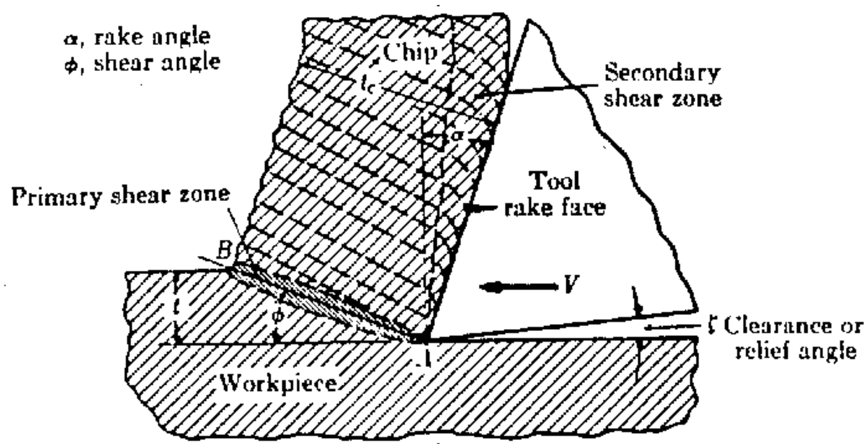
Chip formation is by shear and not by tear. So, the rake angle can be negative too.

The mechanical energy gets fully converted into heat. So, cooling is required.

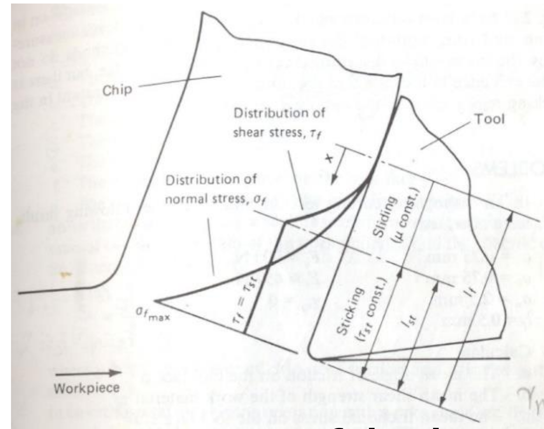
Friction is high at tool-chip interface. So, cooling too is required. ..



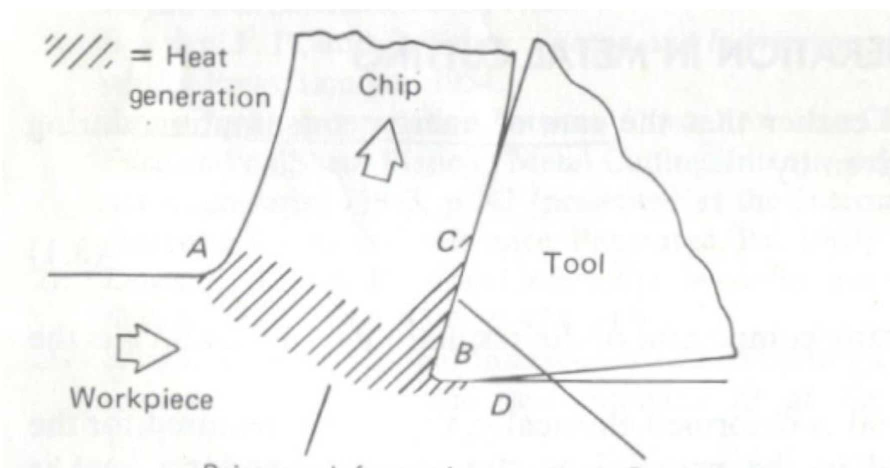
Machining
Principle



Intermittent cutting - Chatter



Extreme friction



Heat generation & distribution

Cutting fluid (liquid, mist & graphite/glass) serves as

(a) coolant

(b) lubricant

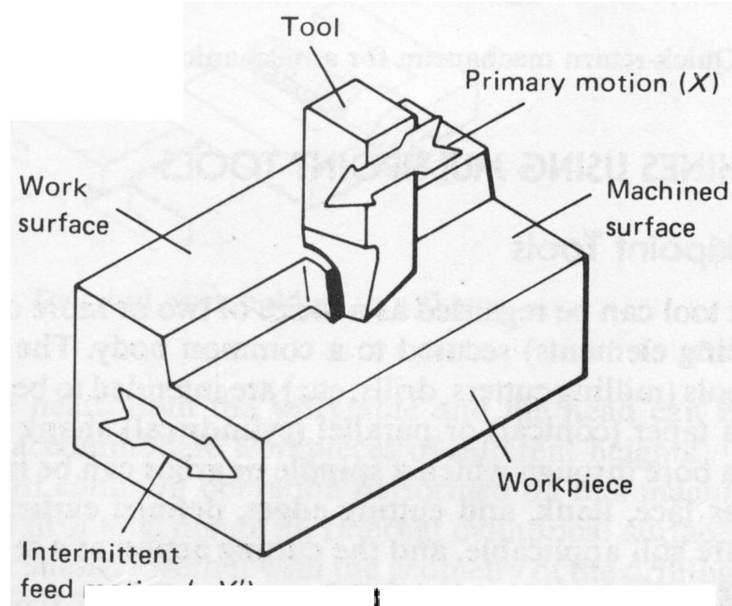
Machining

Types: Single-point & Multi-point cutting

1. Single-point cutting

Continuous chip as the cutting egde of the tool is in contact with the work piece throughout the stroke

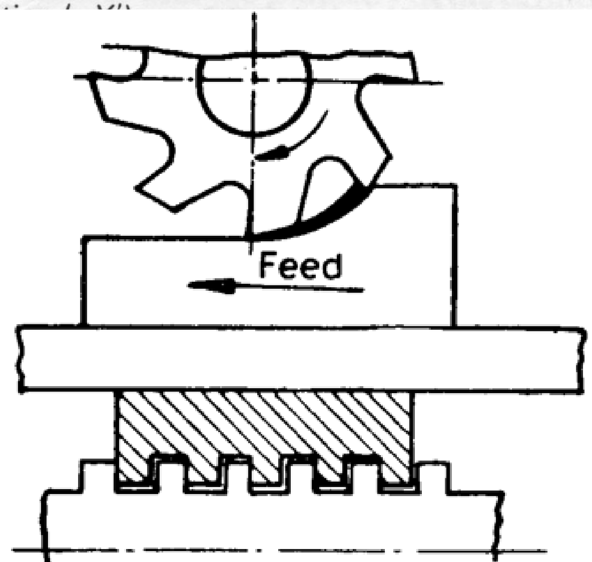
Examples: Turning, shaping, planning, drilling.



2. Multi-point cutting

Broken chips as the cutting egde of the tool is in intermittent contact with the work piece throughout the stroke

Examples: Milling, broaching



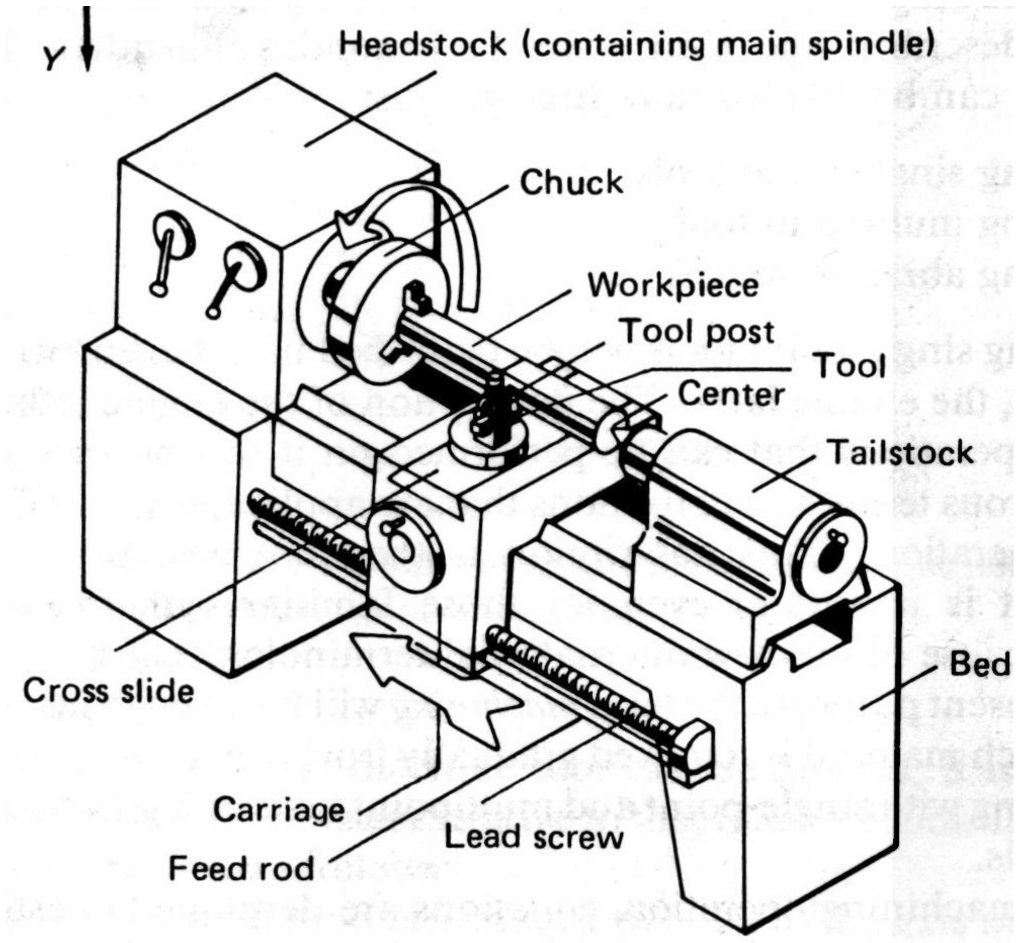
Machining

Machine tools: Lathe

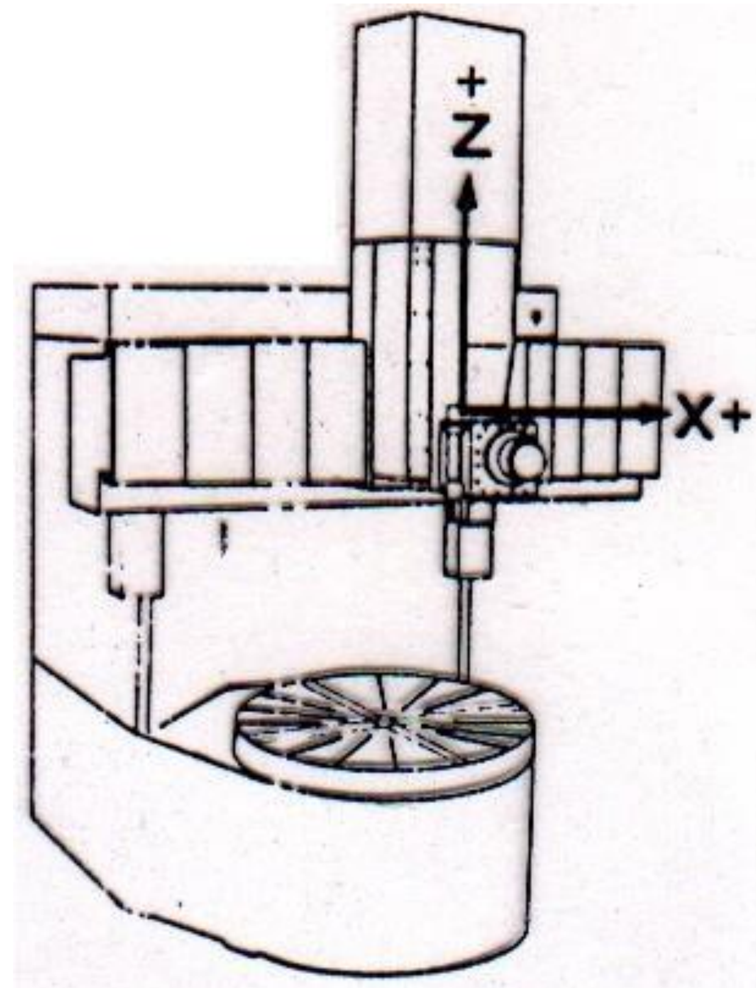
- The most ancient & versatile & cheapest machine tool.
- Job rotates and tool traverses axially & radially. Operation is called Turning
- It can produce axi-symmetric features & flat surfaces orthogonal to the axis. Any convex polyhedral object can be made.
- Single point cutting is the most popular.
- It can hold tools like drilli & reamer in the tail stock for making axial holes. Other tools like turning & boring are held in the tool post.
- Lathe can be used for flow forming too.

Machining

Machine tools: Lathe



Engine lathe



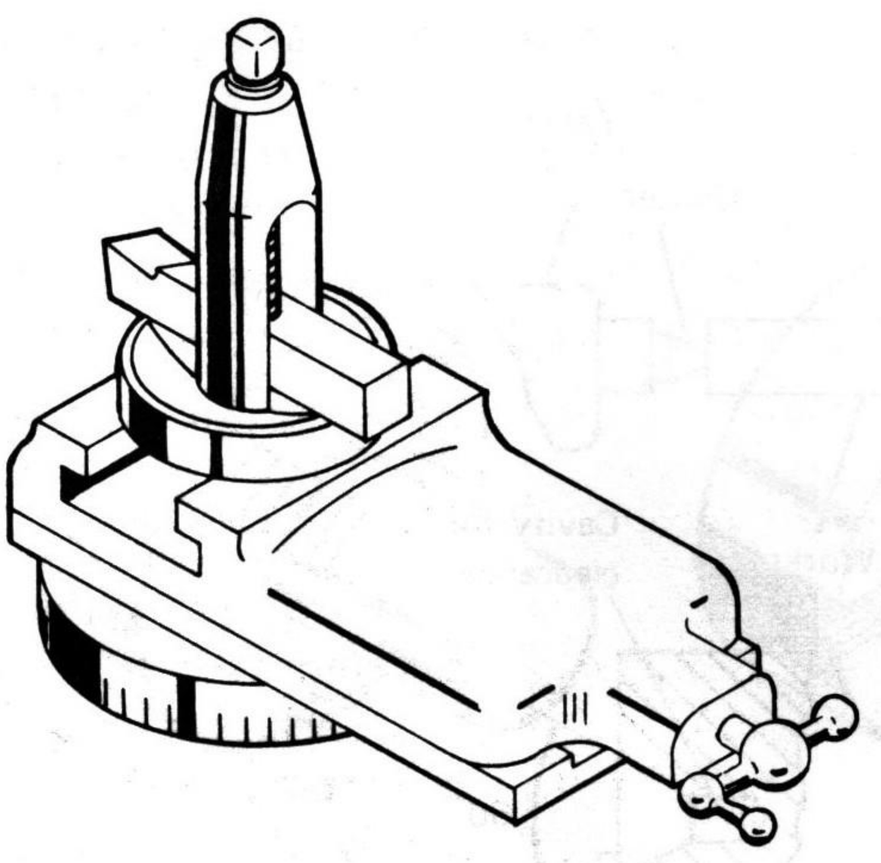
Vertical lathe

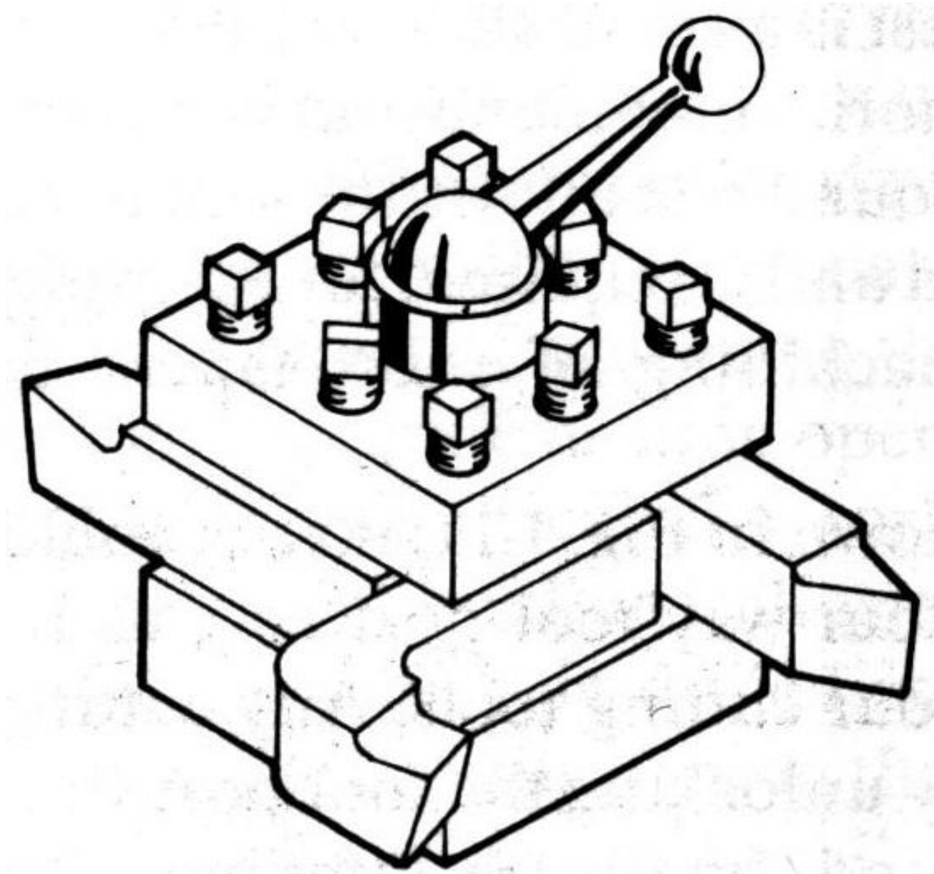
Machining

Machine tools: Lathe: Tool holding

Tool post will be on compound rest.

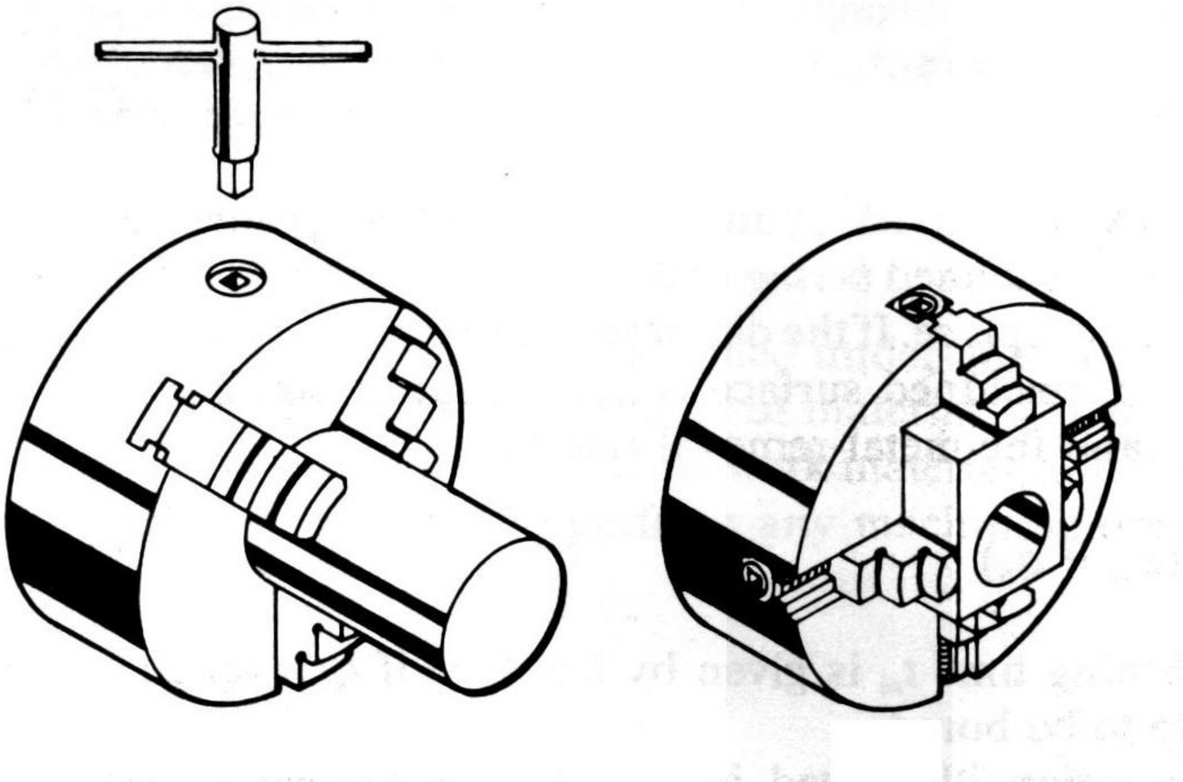
Iu can be a single tool. An indexable 4 tool post is very common.





Machining

Machine tools: Lathe: Work holding



(a) Three-jaw chuck (b) independent four-jaw chuck

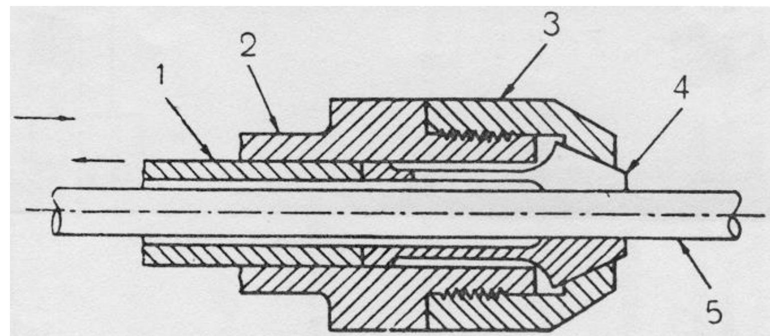


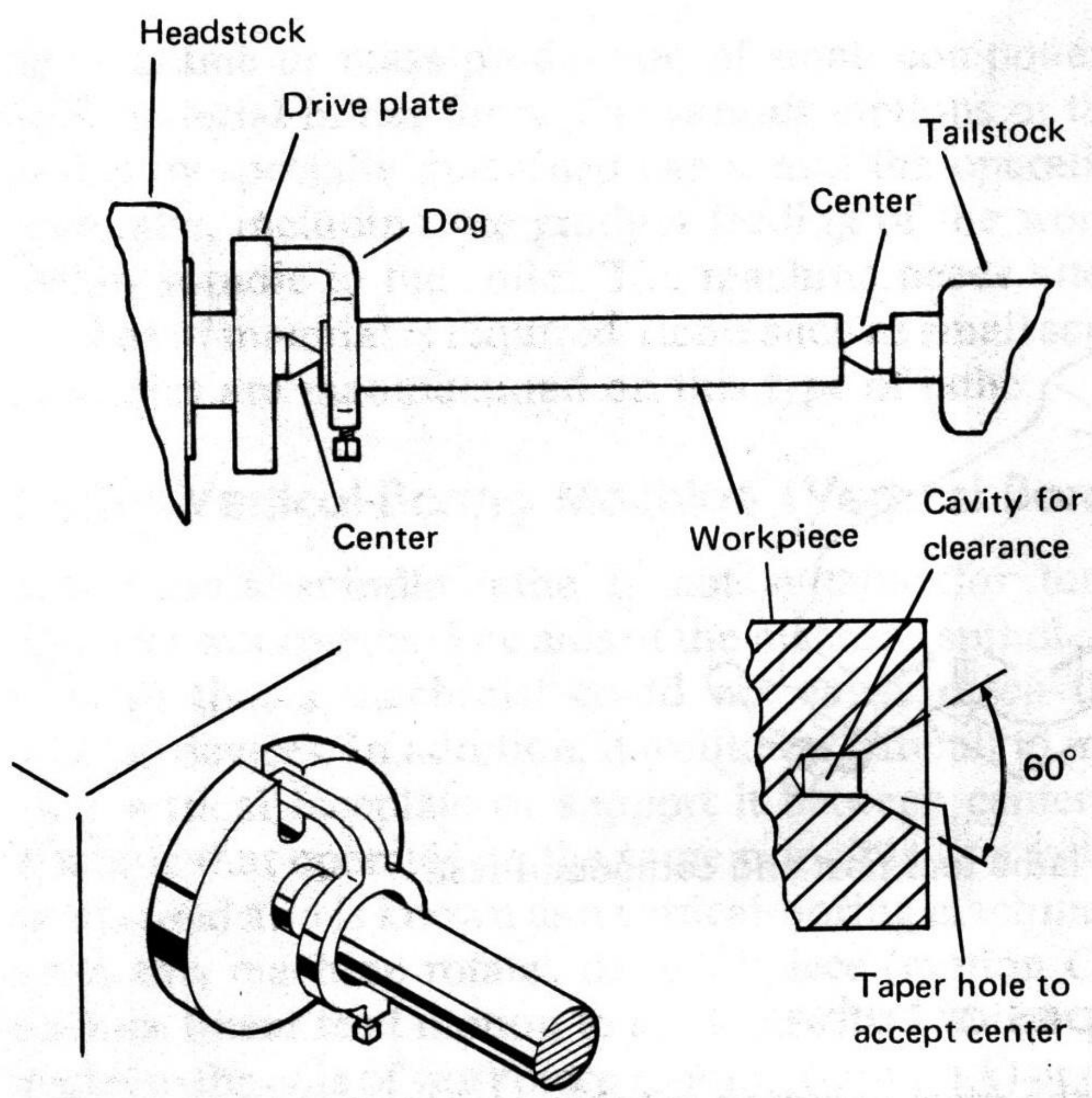
Fig. 4.7 Push out type collet chuck
1. *Push tube*, 2. *Headstock spindle*, 3. *Hood*, 4. *Collet*, 5. *Bar*.

3 & 4 jaw chucks

Colletchuck

Machining

Machine tools: Lathe: Work holding of long jobs



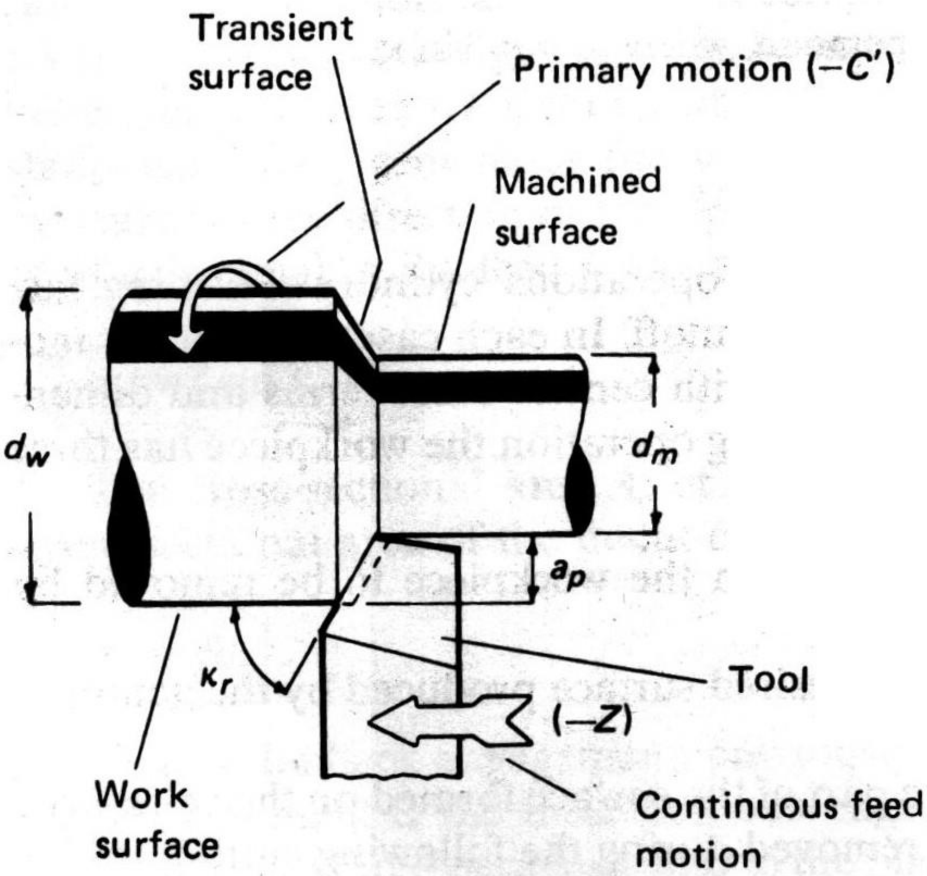
Tail srock will have a centre which could be (a) dead or (b) live.

Drive plate and dog will give positive transmission.

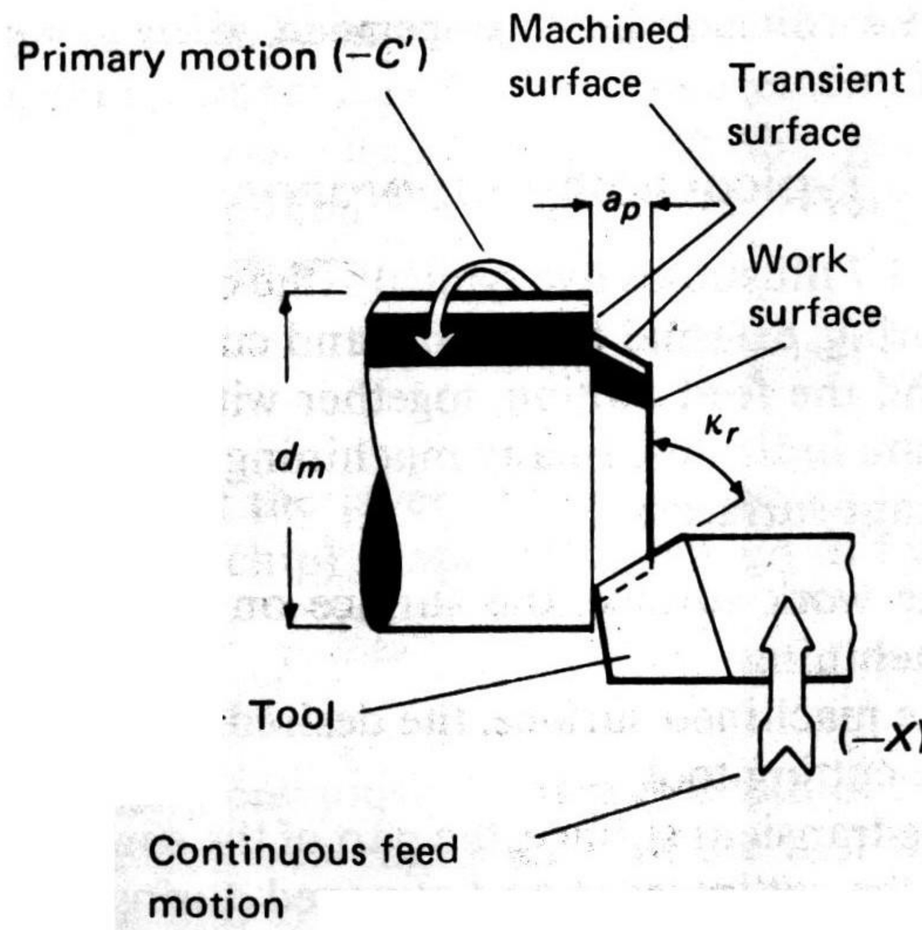
Sometimes, a moving rest will also be used.

Machining

Machine tools: Lathe: Operations



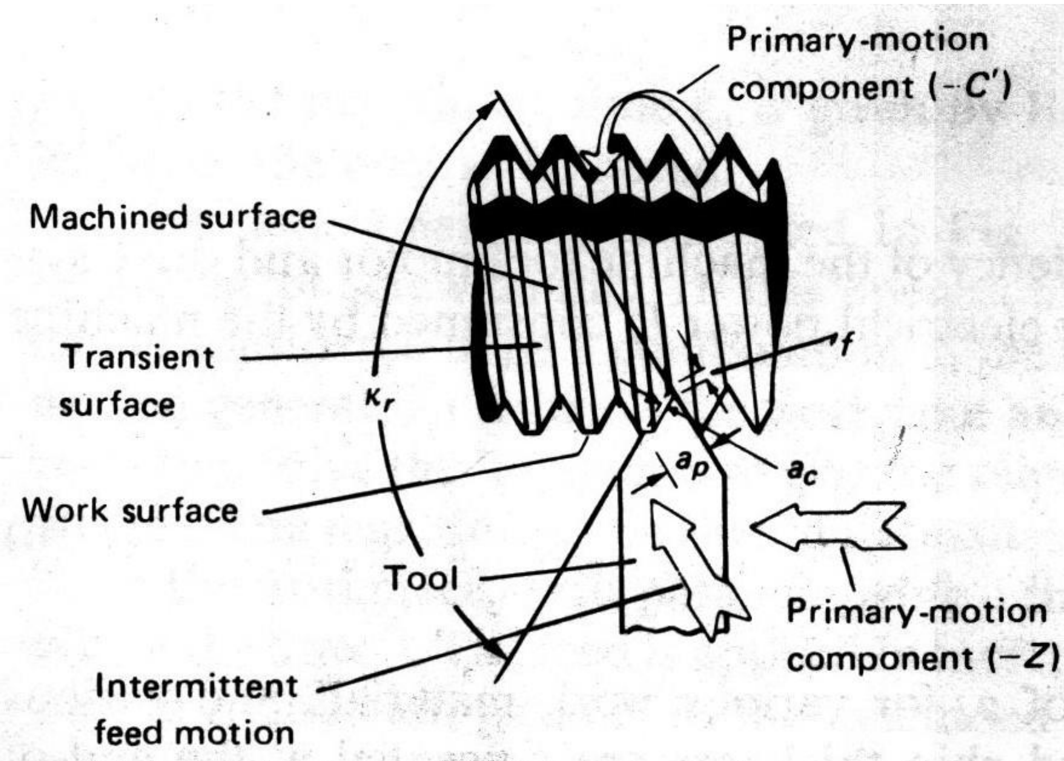
Cyl. turning



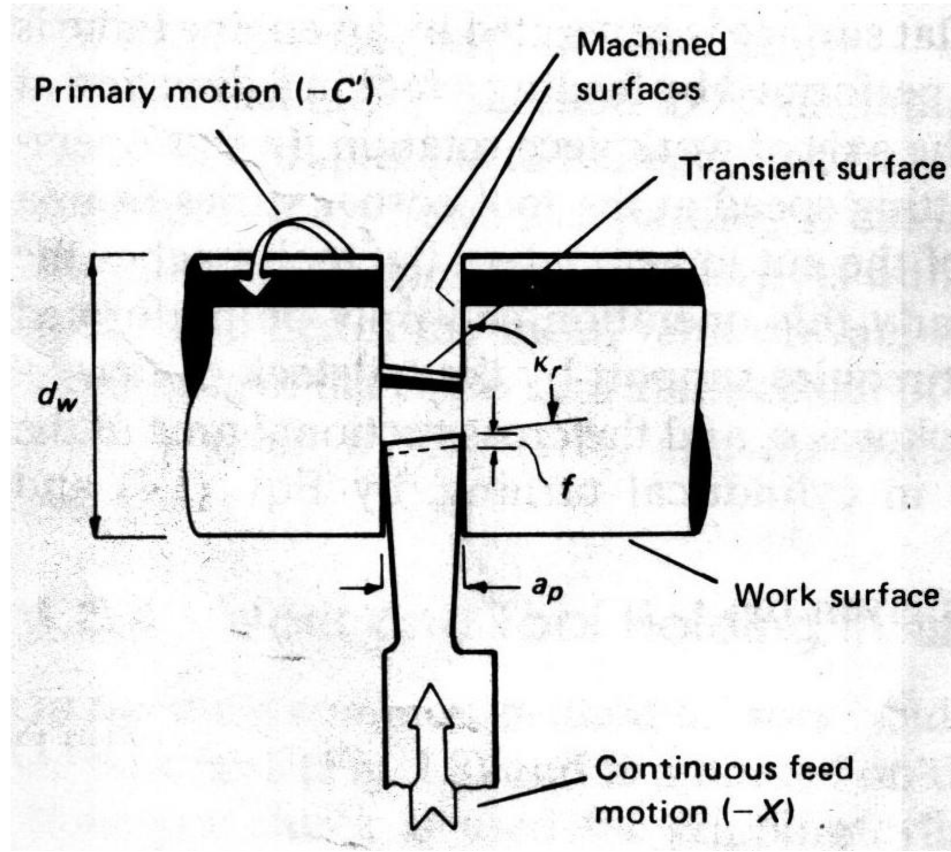
Facing

Machining

Machine tools: Lathe: Operations



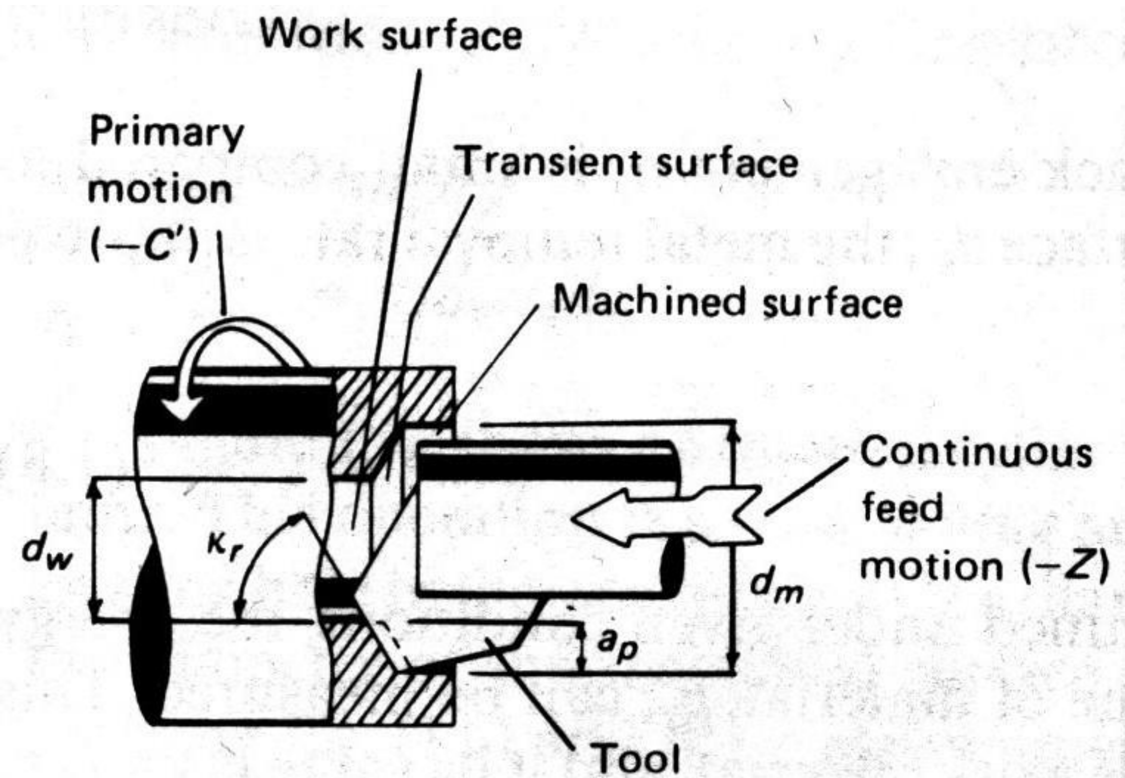
Thread cutting



Parting off/ grooving

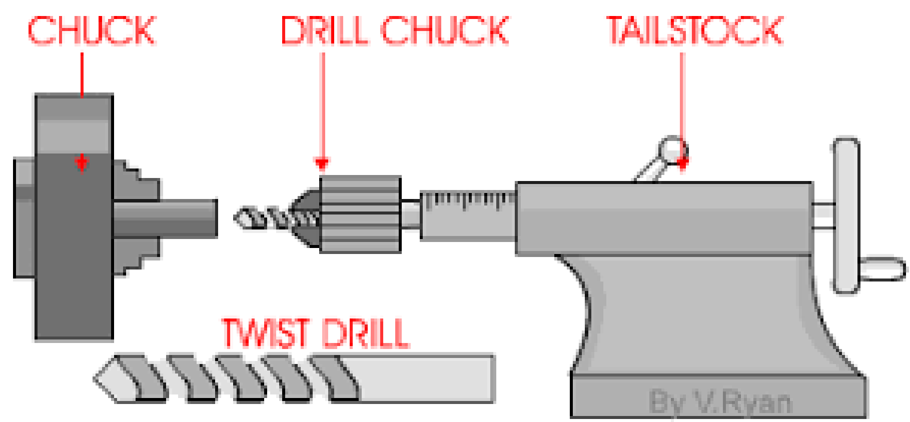
Machining

Machine tools: Lathe: Operations



Boring

(Tool will be in the tool post & not tail stock)

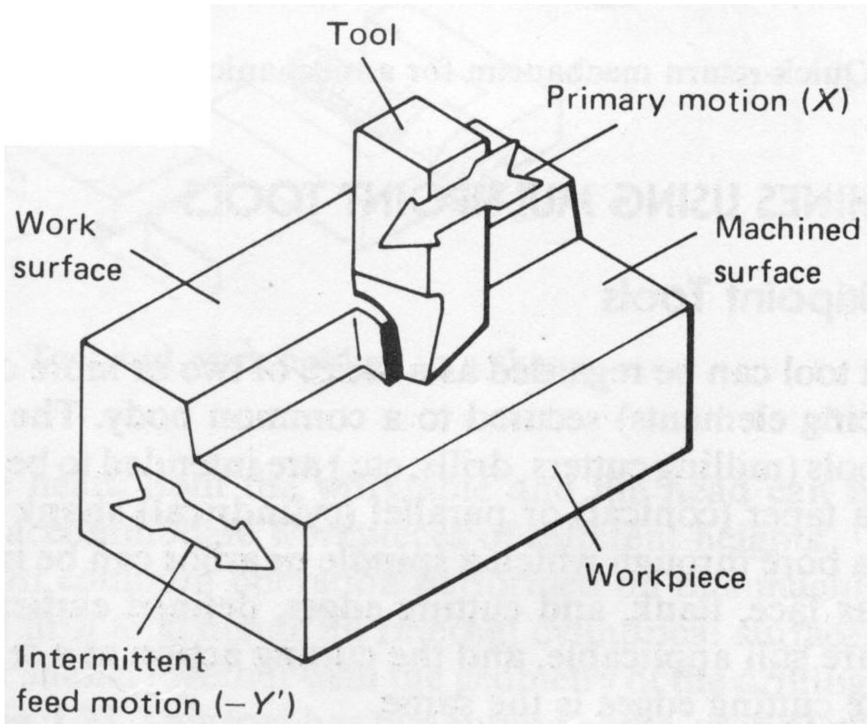


Drilling using tailstock

Machining

Machine tools: Shaper & Planer

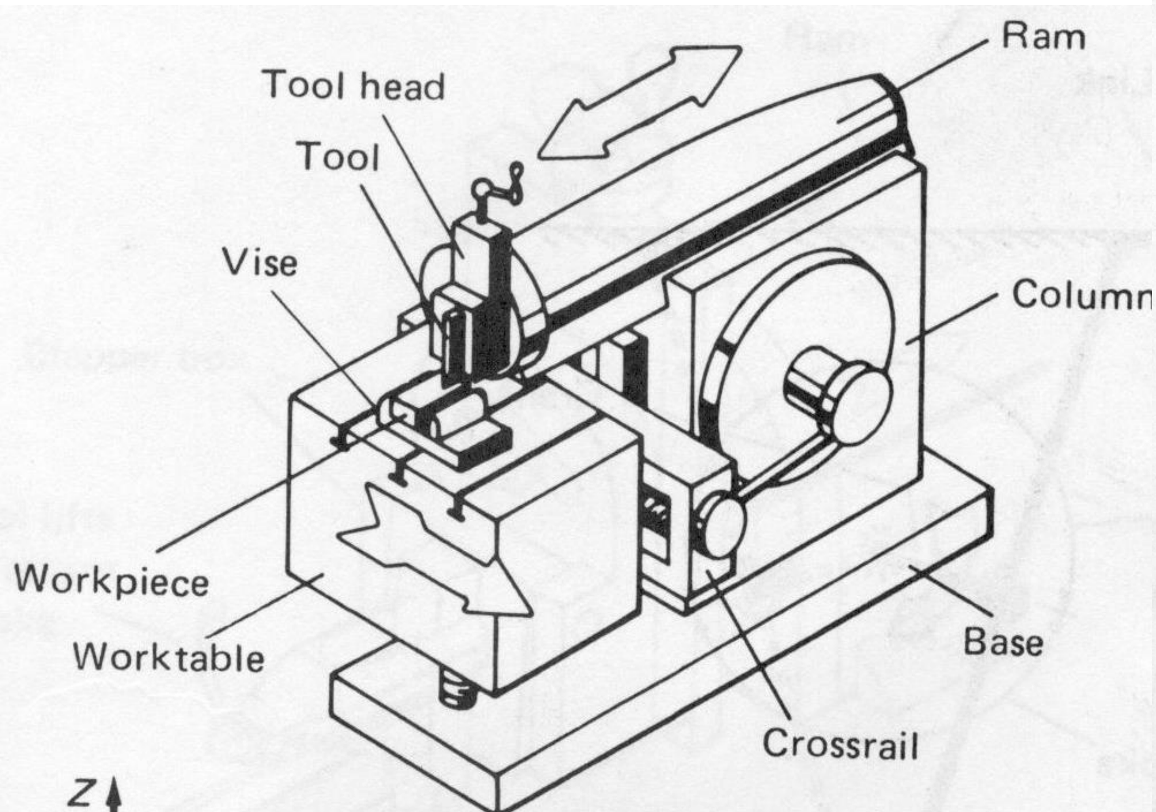
- Shaper & planar are cheaper machines for producing planar surfaces.
- They uses reciprocatory motion between tool & work piece; The tool steps over after each pass.
- Quick return is used for efficiency..
- Single point cutting is used.
- Keyways, splines, dovetail slots can be made.



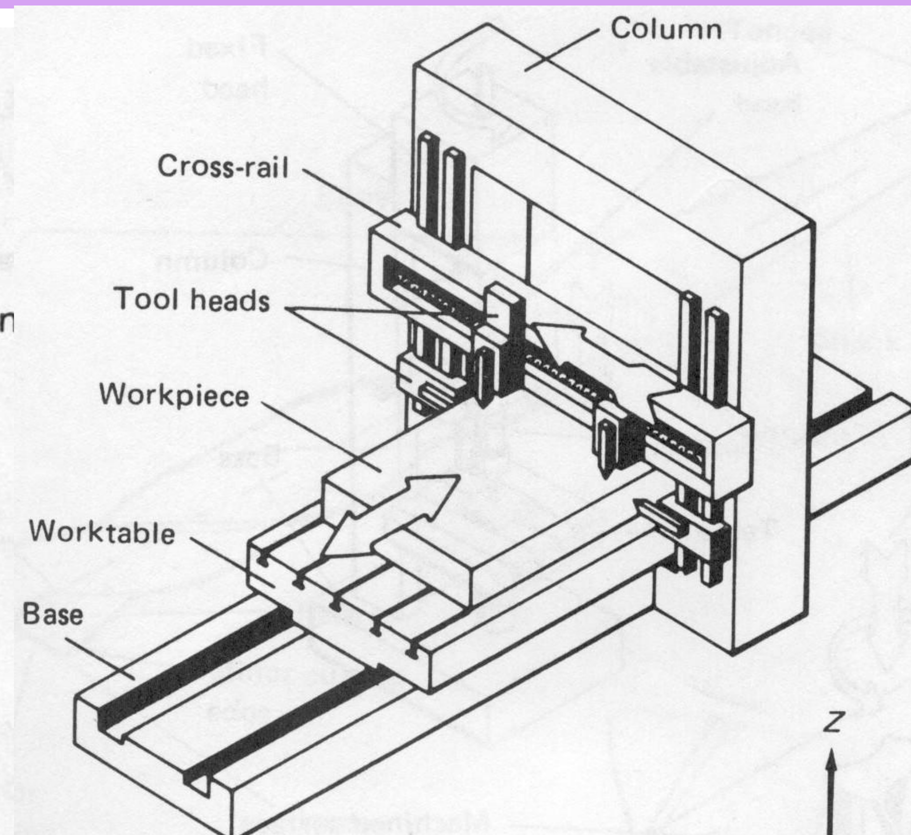
- Vertical gear shapers are popular for generative manufacturing of spur & helical & herringbone gears.

Machining

Machine tools: Shaper & Planer



Shaper

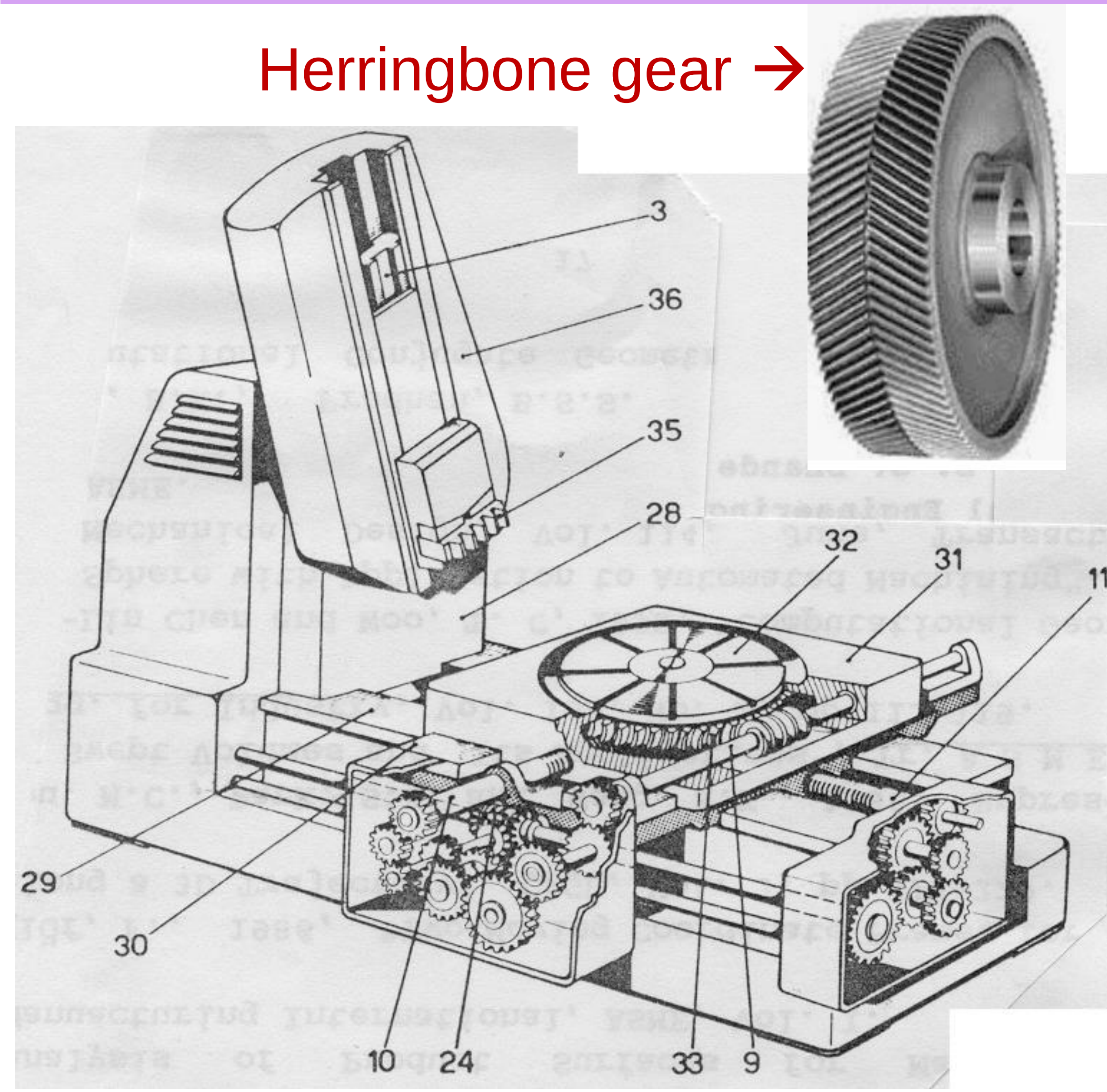


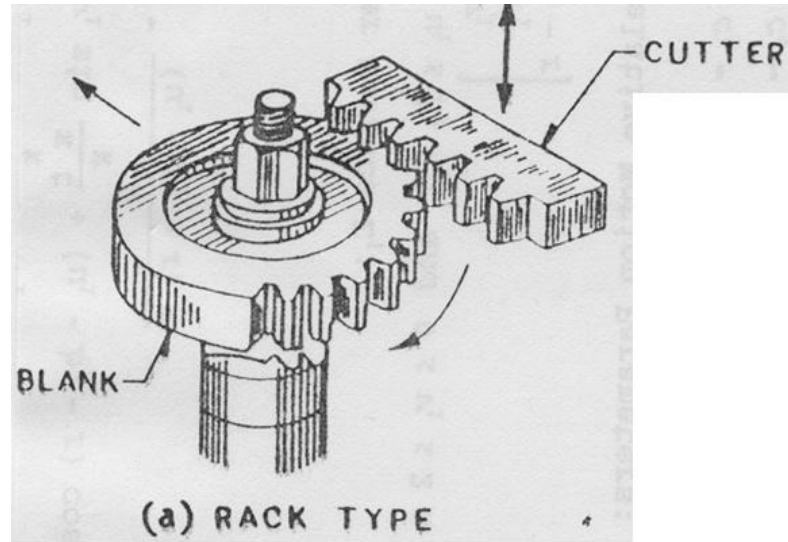
- Planers are much larger than shapers and hence only horizontal. Job moves in planar. Typically belt drive is used.

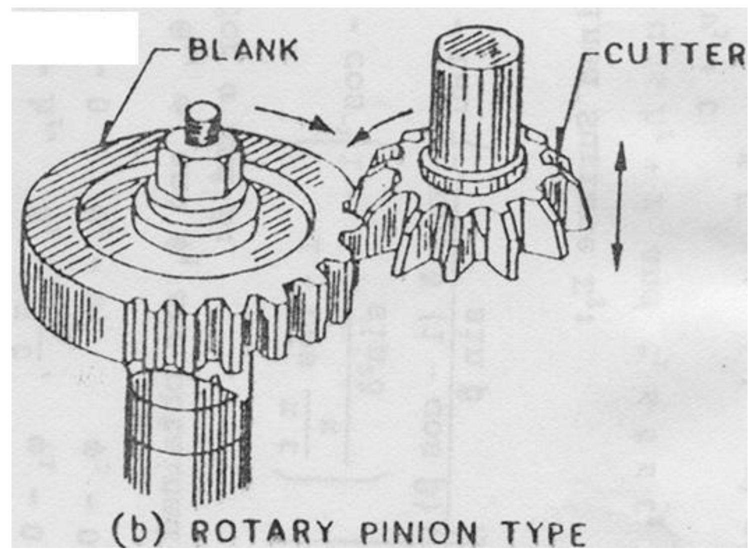
Machining

Machine tools: Shaper & Planer – Gear shaper

Herringbone gear →

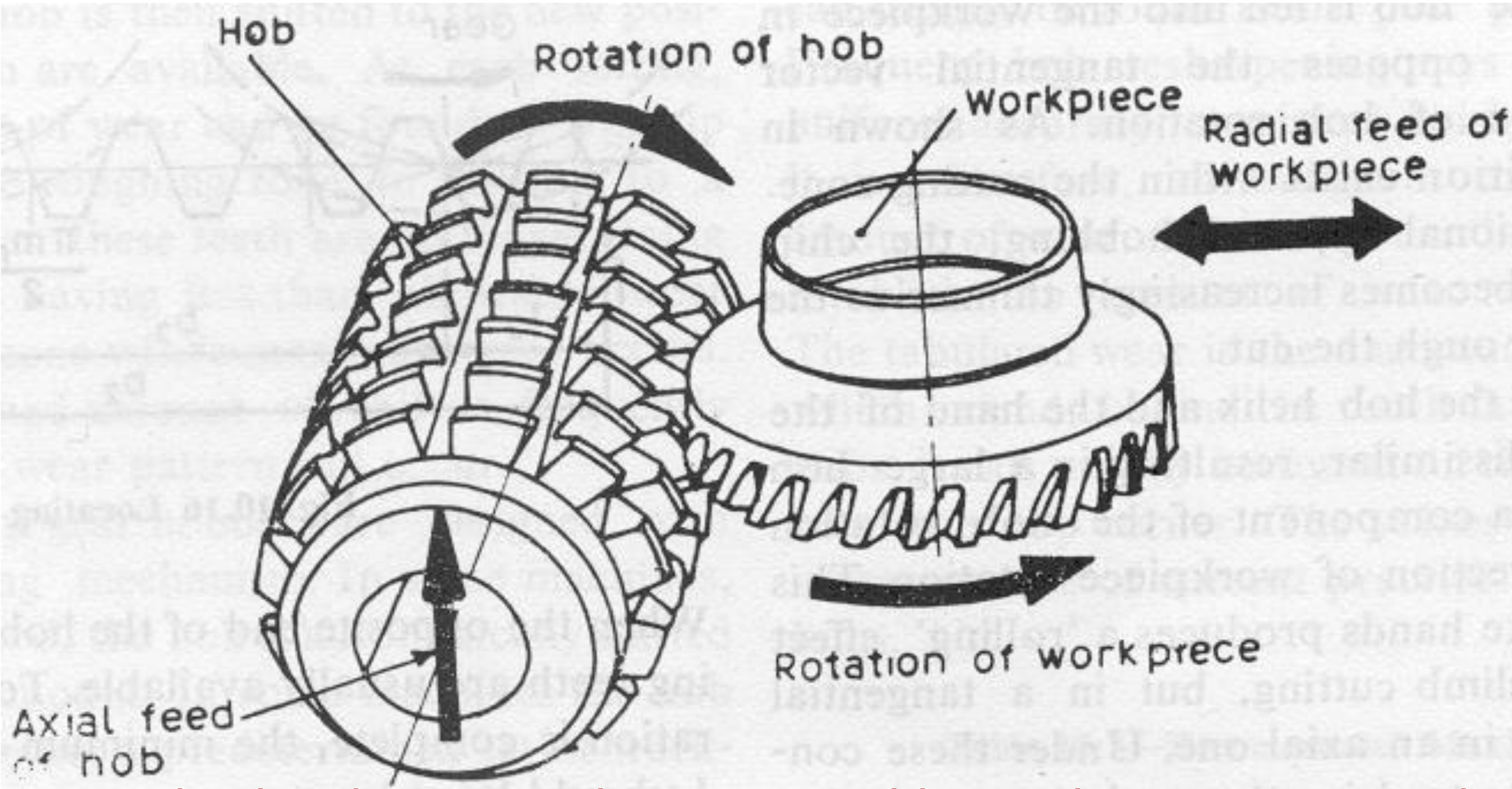






Machining

Machine tools: Shaper & Planer – Gear hobbing



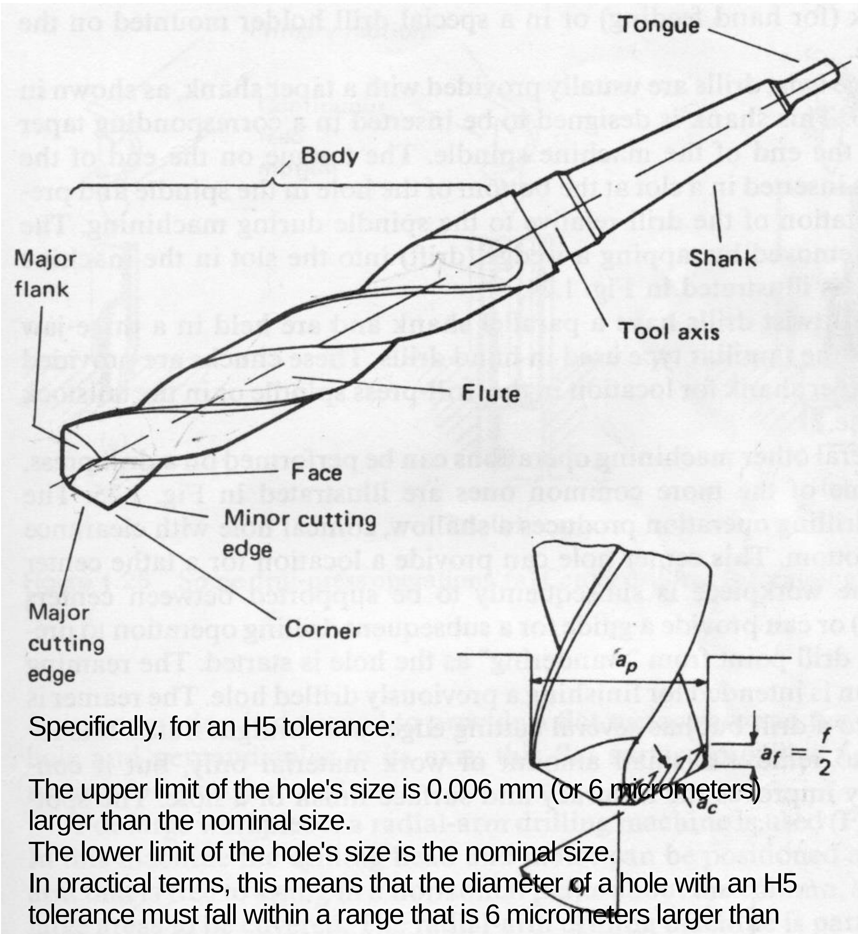
More productive than gear shapers. But this requires overruns on both sides. So, this is not suitable for herringbone or compound gears.

Machining

Machine tools: Drilling

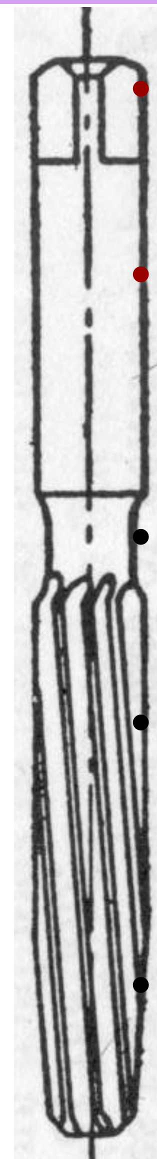
Machining

Machine tools: Drill, Reamer



Specifically, for an H5 tolerance:

The upper limit of the hole's size is 0.006 mm (or 6 micrometers) larger than the nominal size.
The lower limit of the hole's size is the nominal size.
In practical terms, this means that the diameter of a hole with an H5 tolerance must fall within a range that is 6 micrometers larger than the nominal diameter. This level of tolerance ensures a high degree of precision and accuracy in the machined hole.



- The most popular drills have 2 flutes.
- In terms of chip formation, they come under single-point cutting.
- Centre drill helps in (x, y} control.
- Reamer finishes the drilled hole. can give upto H5 tolerance.
- Boring & honing can correct axis in addition high finish.

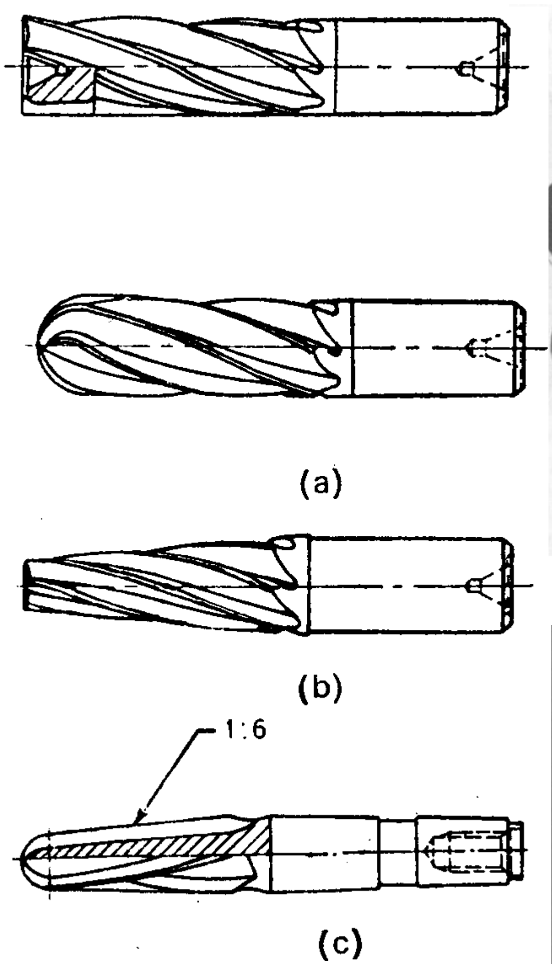
Machining

Machine tools: Milling

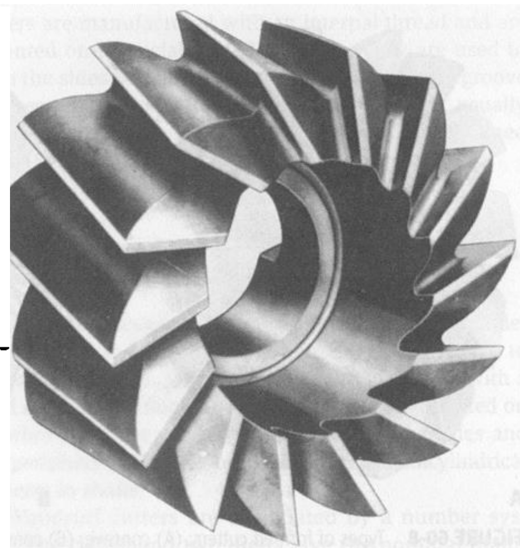
- Milling cutters are invariably multi-point cutters It rotates to produce the cutting velocity.
- Milling can produce virtually any surface using various cutter geometries in multiple passes.
- The relative motion ensures realization of geometry on the work piece.
- Milling cutters are very expensive.
- Monolithic, brazed as well as insert cutters are popular.
- Cutting tool materials are: Hidh Speed Steel (HSS), Tunstan Carbide, Alumina, Cubic Boron Nitride (CBN). Multi-layer coating also is very common.

Machining

Machine tools: Milling cutters

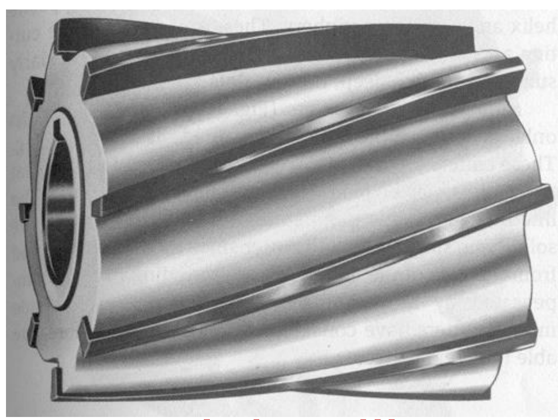


End mill (flat, ball, andle etc.)

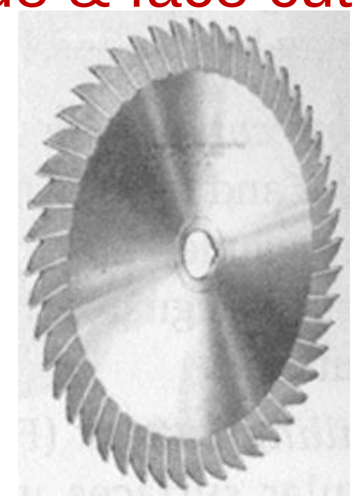


Face mill

Side & face cutter



Slab mill



Slitting saw

Insert end mill

Machining

Machine tools: Milling

Vertical milling machine

Horizontal milling machine

Machining

Machine tools: Milling

1987: 3-spindle 5-axis profiler: India’s largest even now

Machining

Advantages

- Simple and versatile.
- Wide variety of options are available in terms of tooling, operations, speed, level of automation etc. Therefore, using a series of appropriate machining processes
  - any desired accuracy can be achieved.
  - it can be economically feasible for any volume of production.
- Since the operation is visible and observable, online control is possible.
- No thermal ill effects.
- There are more machining operations. Therefore, more employment for machinists.

Machining

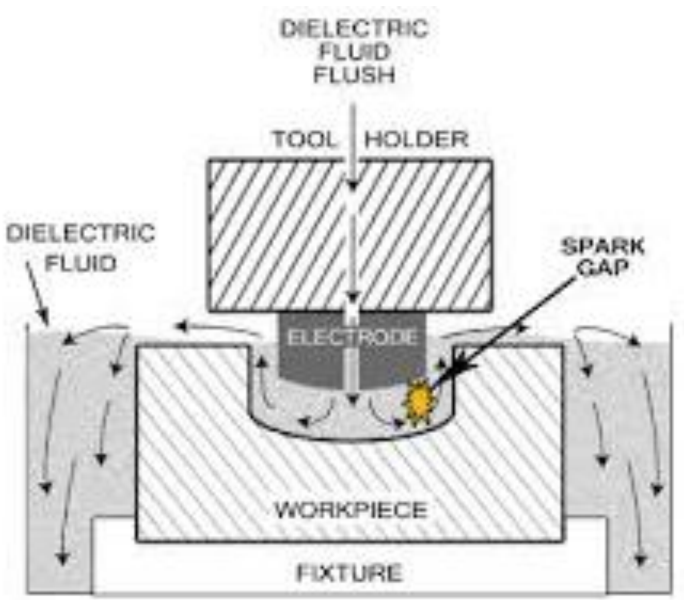
Limitations

- Several passes, set up's, cutting tools, holding tools (jigs/ fixtures) and a few machine tools may be required to machine one component.
- Hard materials and materials with strain hardening tendency are difficult to machine. Sometimes even soft materials like thermocole prove to be difficult for machining.
- Some features are not achievable due to inaccessibility, inherent tool geometry and process mechanics & kinematics. Eg.: deep features, sharp concave corners.
- Slow process.
- Poor fatigue life as machining passes may interrupt the grain flow.
- Wastage of material in the form of chips. About 60% of material is wasted in tooling and as much as 90% material is chipped off in aerospace components.

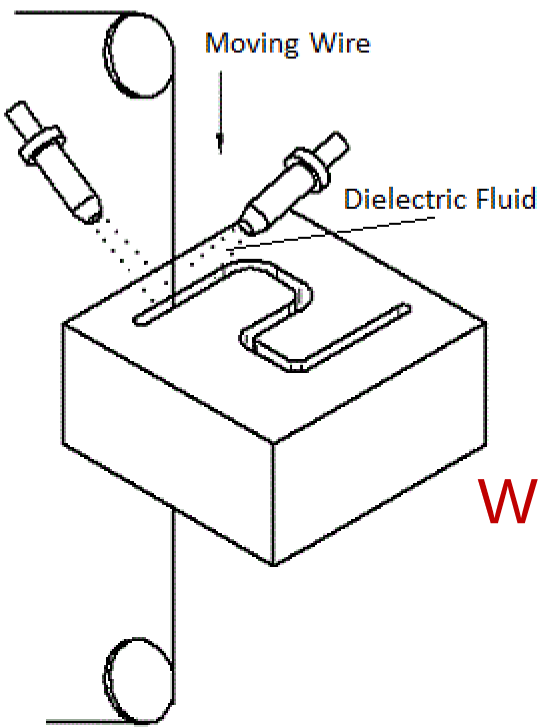
Non-Traditional Manufacturing

Non-Traditional Manufacturing
EDM Process

Material removal is effected by other forms of energy than heat and force. Some of the energy sources are kinetic energy of beams (laser, electron beam, plasma) and jets (water-jet, abrasive jet etc.),, electro-thermal energy, chemical energy, electro-chemical energy, ultrasonic vibrations etc.



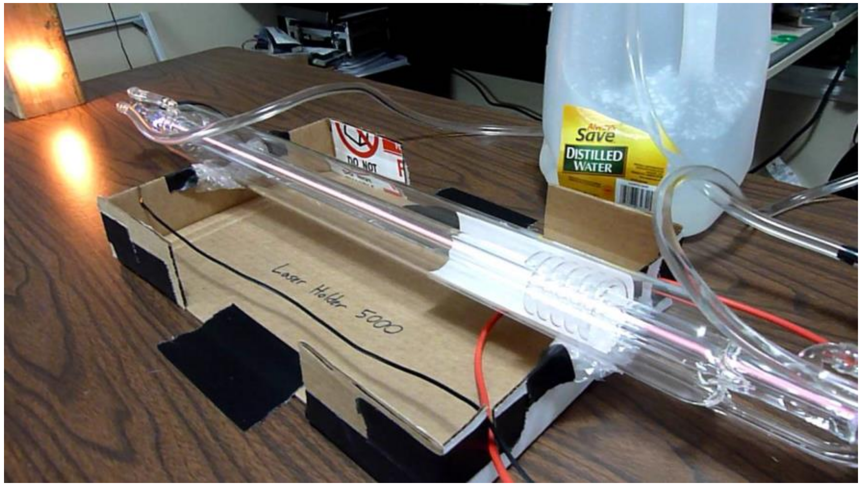
Electro-Discharge Machining (EDM)



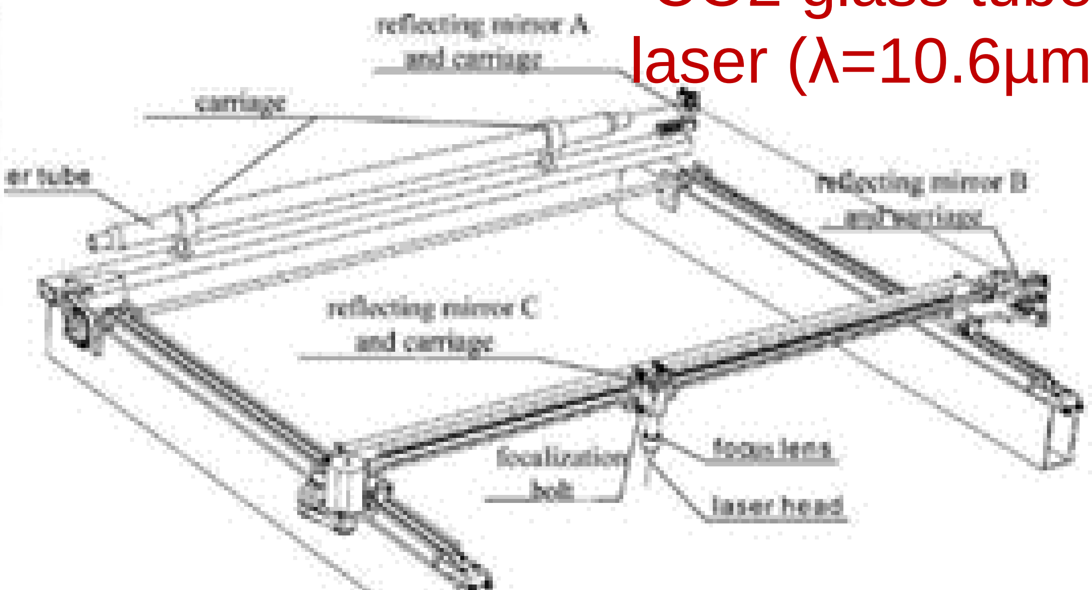
Wire EDM

Non-Traditional Manufacturing
Laser cutting

Laser is a versatile tool. Ir can do cutting, sintering, curing or polymerization etc.



CO2 glass tube laser (λ=10.6μm)



Non-Traditional Manufacturing

Advantages

- Tool need not be harder than work piece.
- Tool need not rotate or push through the material, i.e., no force. Therefore, more complicated shapes and sharp corners are possible.
- Surface integrity is excellent
- Accuracy is better
- Miniature features can be made.
- Improves performance of conventional machining. Eg.: Electro-chemical grinding.

Non-Traditional Manufacturing

Limitations

- Specific energy is higher than machining
- Slowest manufacturing processes.
- Often toxic fumes are created.

Casting

Casting

- Second most ancient → right from Bronze Age. First was machining right from Stone Age.

- Casting is obtained by pouring and solidifying the molten metal into a container or cavity called mold or die. It is negative of the part.

- The cavity in sand casting is used once only but the pattern (wood) is reused. Die casting uses reusable metallic mold. In Investment Casting, both the pattern (wax) and mold are used once only.

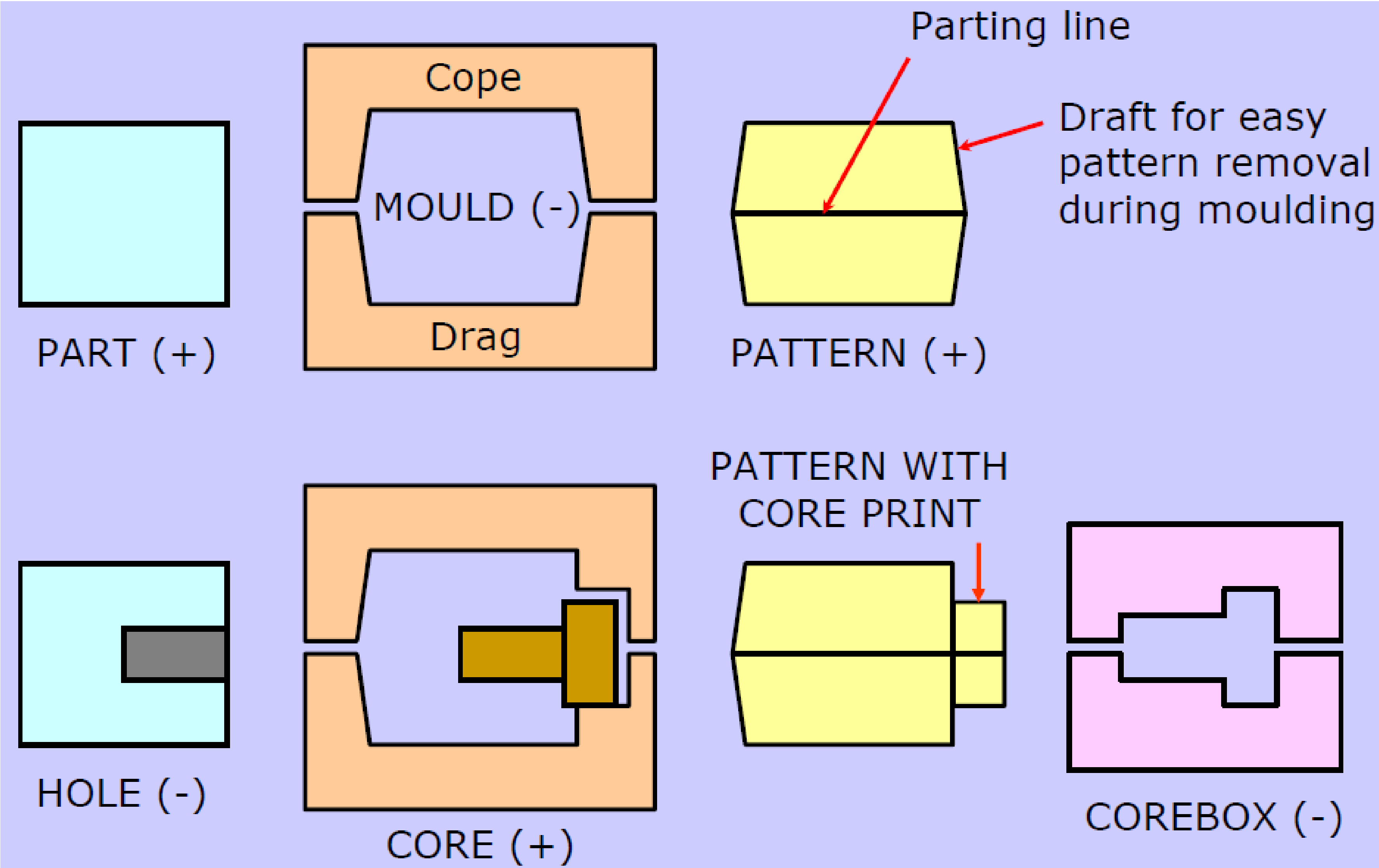
- Casting involves

  (a) mold making (b) melting, pouring and solidification.

  These are preceded by mold design to determine orientation, parting line & surface, gating system etc. These are followed by frettling, straightening, HT, machining etc.

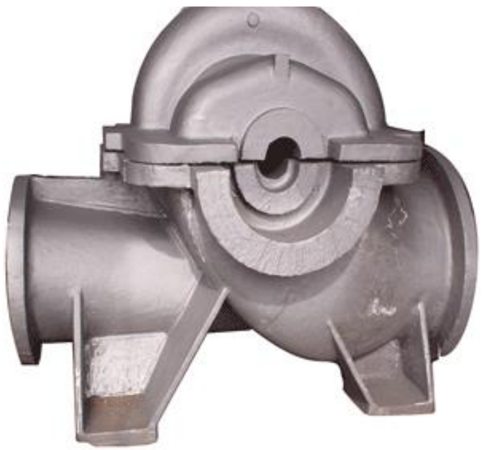
Casting

Sand Casting



Casting

Sand Casting - Examples



Casting

Die Casting (& Injection Molding)

- While one sand mold can produce one casting only, mold iin die casting s made of hard steel. Hence, it can produce multiple castings.
- Equivalent of die casting for plastics is called Injection molding.

Casting

Investment Casting

Wax pattern injection

Pattern tree assembly

First coat of ceramic slurry

Metal pouring in hold shell

A/C Drying of shells

Stuccoing with sand

Casting

Investment Casting - Examples

Casting

Advantages

- Several features can be realized simultaneously.
- Certain features which are impossible by machining can be obtained. Eg.: Deep internal features (bores, conformal ducts and undercuts).
- Very huge parts are generally cast. Same with expensive materials too.
- Scrap material can be recycled.

Casting

Limitations

- Very high specific energy
- Inhomogeneous micro-structure
- Poor accuracy. Machining invariably follows.
- Online monitoring is not possible.
- Slow process.
- Pattern/ mold making is expensive. Therefore, suitable for mass production or huge objects only.

Forming

Forming

Primary forming processes → Conversion of the ingots into billets, coins, foils, bars, channels, wires etc. using cold/ hot rolling, extrusion, drawing etc.

Secondary forming processes → Forging, secondary extrusion, rolling, sheet metal forming (bending, drawing …) etc.

Forming: Forging (Bulk Frming)

Process

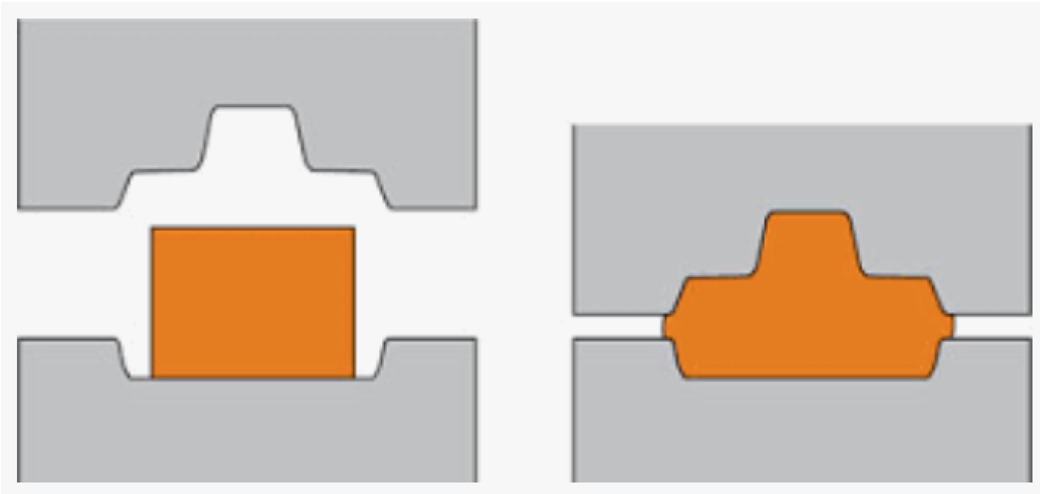
Measured quantity of material is heated to above its recrystallization temp, kept between open die halves and subjected to heavy impact force to shape it.

Both heat and force are used.

Multiple progressive die sets are often required. Multiple stroke are some times required.

Undercuts are not possinle.

Extremely high fatigue life.



Forming: Forging (Bulk Frming)
Advantages

- Several features can be realized simultaneously.
- Fast process.
- Better grain orientation, hence Good fatigue life.

Forming: Forging (Bulk Frming)

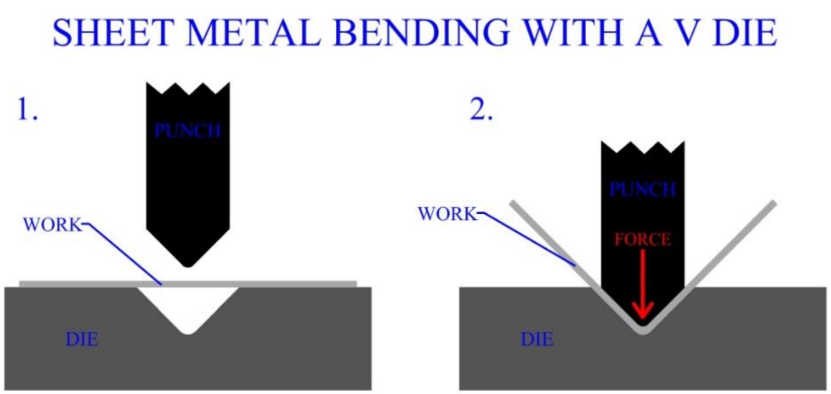
Limitations

- Undercuts are simply not possible.
- Very high specific energy but less than casting
- Poor accuracy. Machining invariably follows.
- Online monitoring is not possible.
- Forging dies are expensive. Therefore, this is suitable for mass production only.
- Low die life. So die shop is part of the company.

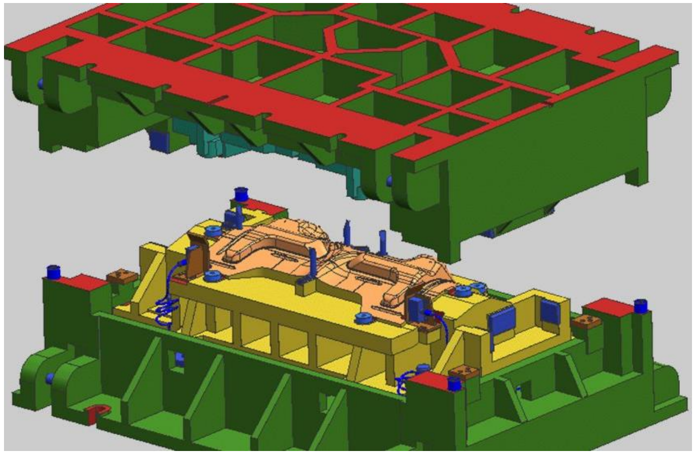
Forming: Sheet Metal Forming
Process

Slow application of force is used to form the required features on a sheet material by keeping it between the die and punch. Sometimes, either of them is enough (Eg.: Vacuum forming – only die is required; stretch forming – only punch is required). Progressing forming requires multiple die sets.

Heat is generally not used; however, inter-stage solution treatment may be required.



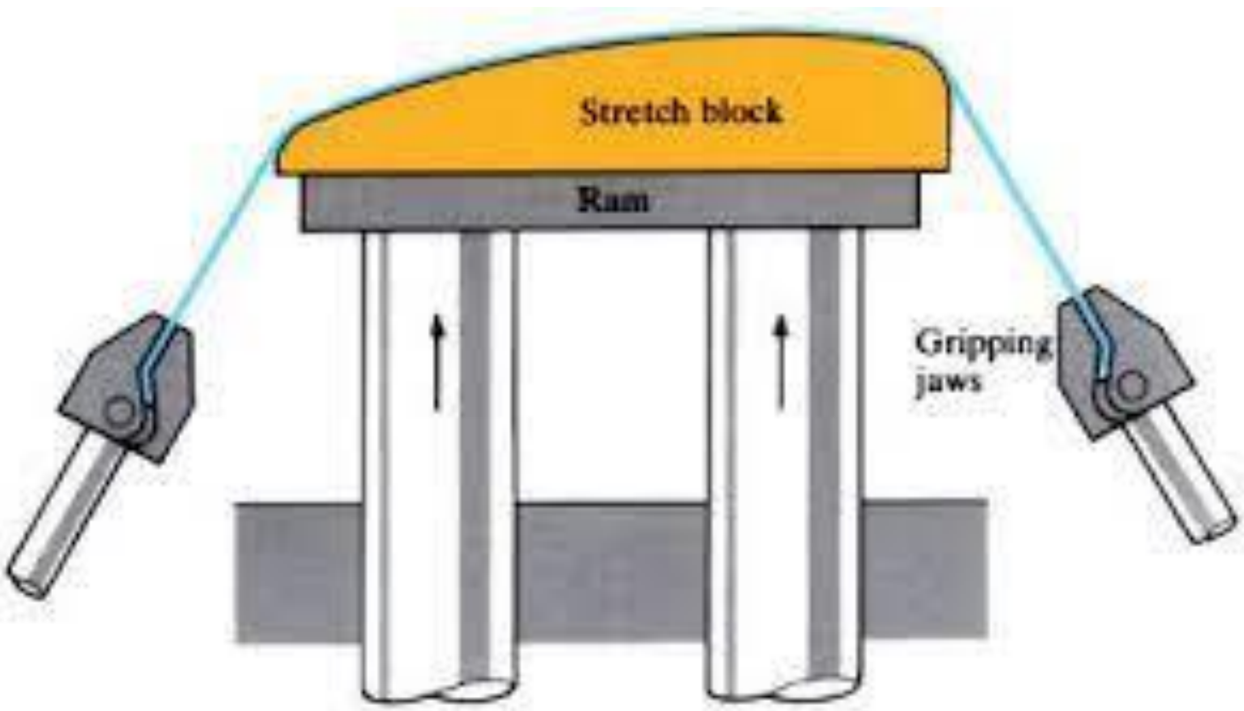
Bending die



Stamping die

Forming: Sheet Metal Forming
Single Die Process: Stretch Forming

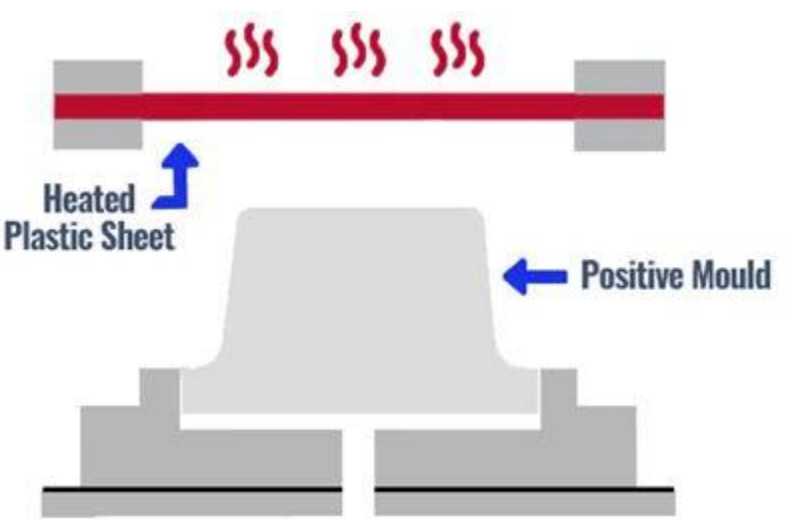
- Die will be a protrusion.
- The sheet is stretched on top of it to absorb its shape.
- Sheet may be metal as well as polymer.

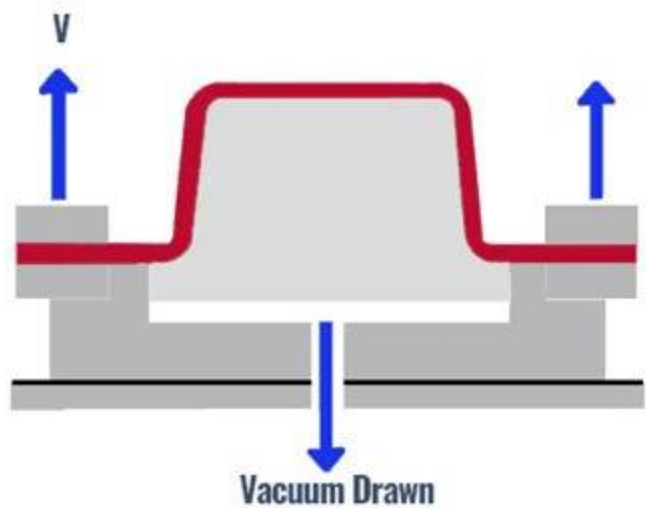


Forming: Sheet Metal Forming
Single Die Process: Vacuum Forming

- Die will be a cavity with vacuum ports.
- The sheet is sucked into it to absorb its shape.
- Sheet may be metal as well as polymer.

Plastic inner liner of refrigerator

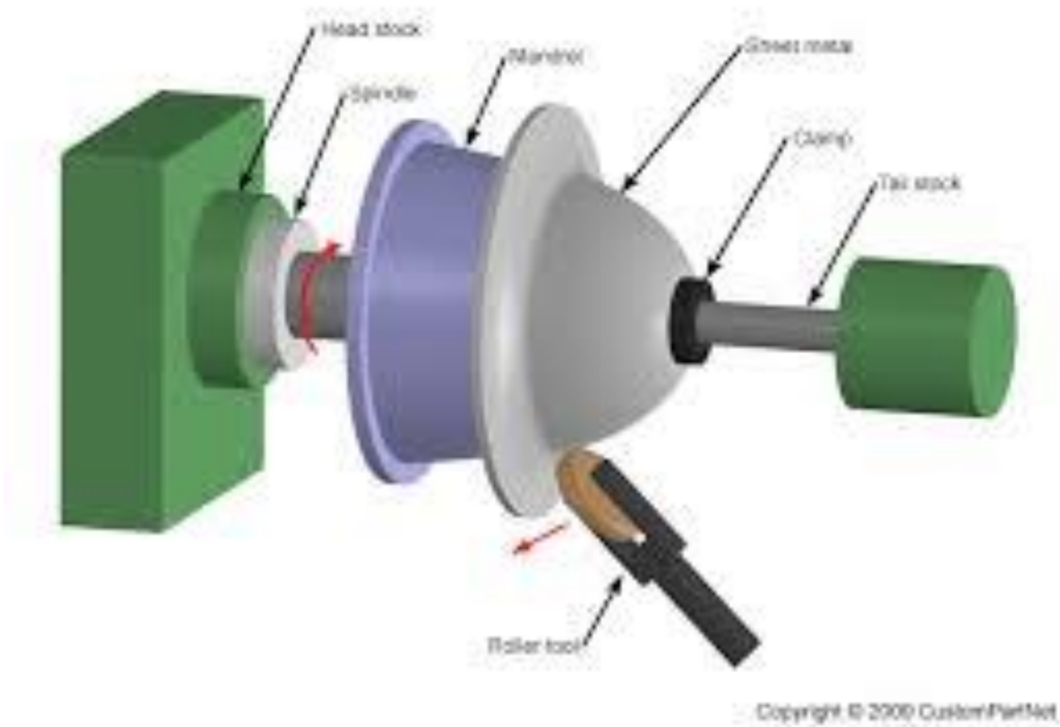




Forming: Sheet Metal Forming

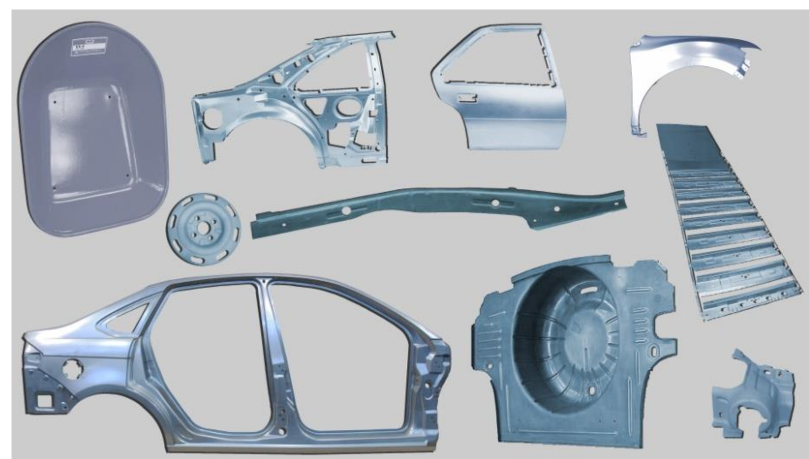
Single Die Process: Flow Forming

- Die will be a rotating axi-symmetric protrusion.
- The sheet clamped & rotating with the die is pressed against the die by a blunt tool with axial & radial movement similar to the lathe.



Forming: Sheet Metal Forming
Advantages

- Specific energy required is the least.
- More features can be realized simultaneously.
- Good fatigue life.
- Fast operation.
- Cheaper tooling.
- Product will be light.
- Since forces are less, soft tools made of delron or wood or epoxy can be used for low volume.



Forming: Sheet Metal Forming

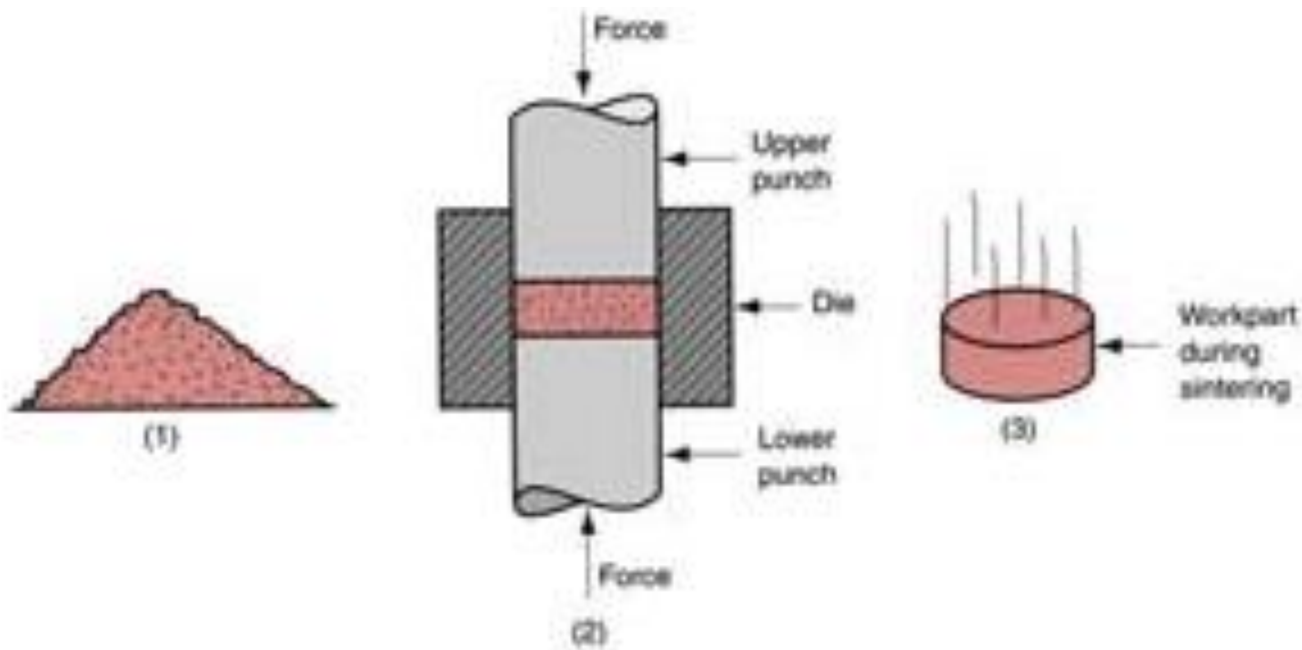
Limitations

- Number of parts are more in the product. Assembly also will require jigs. Some parts may need multiple stages of forming. So the tools are large in number and size. So storage and tracking is a major problem.
- Poor accuracy due to spring back.
- Low natural frequencies lead to noisy operations and resonance (canning effect).
- Spring back requires some iterations in tool design and in manufacture too at times.
- There is an increasing trend to replace sheet metal assemblies by castings or machined parts or composites or plastic parts. Eg.: Dashboard of cars, bumpers, aircraft wings, household appliances.

Forming: Powder Metallurgy
Process

Powder is compacted in a die at very high pressure. The resulting green part is sintered in a furnace.

Pressure first (in the dies) and then heat. CIP/HIP also may be used.



Forming: Powder Metallurgy

Advantages

- Unique compositions and structures possible as there is no melting e.g. introduction of specific particles to give special properties such as silica and graphite in brake pads, and porosity in bearings for oil retention.

- Non-equilibrium compositions possible e.g. copper-chromium alloys, WC-Co tools etc.
- Gradient objects (FGM) can be produced.
- No wastage of material as chips or gating system.

- Homogeneous structure resulting in strong parts with good fatigue life.
- Few or no secondary processes

Forming: Powder Metallurgy

Limitations

- High cost (powder preparation is the major component).
- Limitations on the shapes and features which can be generated. e.g. the process cannot produce re-entrant angles by fixed die pressing or radial holes in vertically pressed cylinders.
- The size will always change during sintering. This can usually be predicted as it depends on a number of factors including ‘as-pressed’ density which can be controlled.

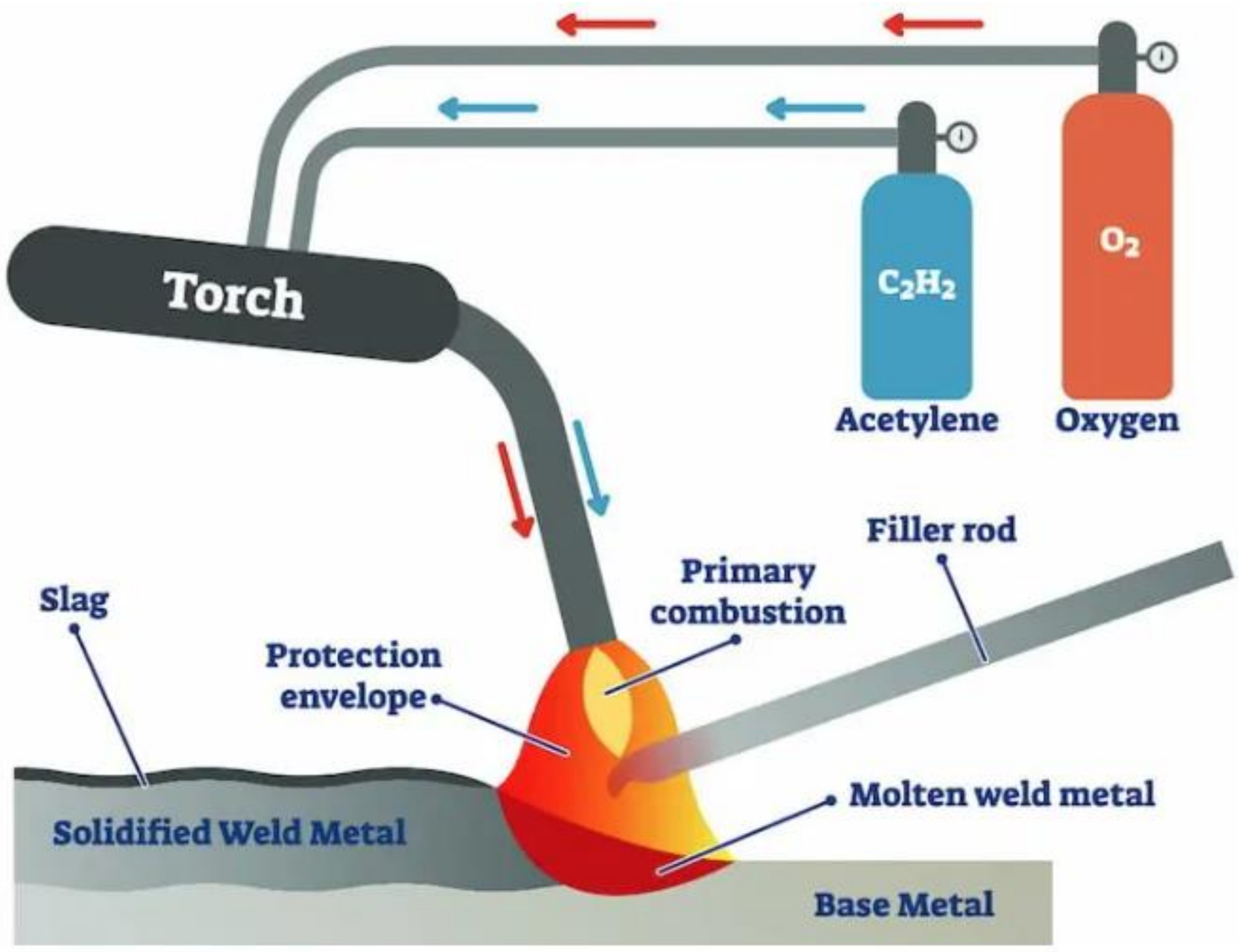
Welding

Welding

- Welding is fixed permanent joining of parts.
- We shall discuss only of similar metal welding. There are processes like Friction Stir Welding (FSW), laser welding, Electron Beam welding, Hot Isostatic Pressing (HIP) can join dissimilar metals too.
- Welding happens in inert environment (inert gas such as Argon, Helium, CO_2, or vacuum).
- Most welding processes can be used for cutting too. Cutting, distinctly happens in an oxidizing environment using an oxygen jet to speed up metal oxidation and blow them away.
- Types of welding: Gas welding, arc welding, laser welding, Electron Beam welding, Resistance welding, Ultrasonic welding etc. We shall study a few.

Welding

Gas/Flame welding

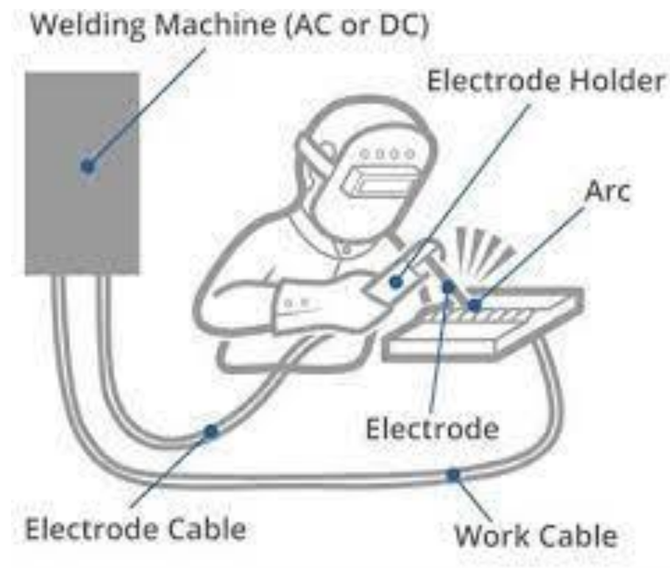


- Oxy-acetylene is the popular mixture. Sometimes, people use cooking gas too!

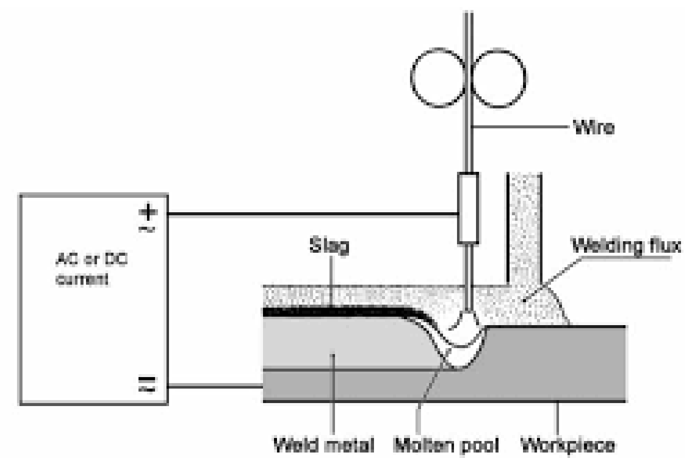
Welding

Arc welding – stick electrode type

- Electric arc is the heat source.
- Typically low voltage (40-150V) and high current (50-500A).
- Since voltage is low, a gas environment is used to create a low breakdown potential. So, the welding gas has two purposes:
  - (a) Gas that has low breakdown potential.
  - (b) Inert gas to prevent oxidation.

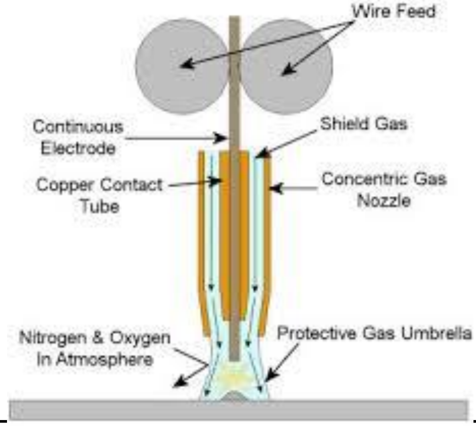
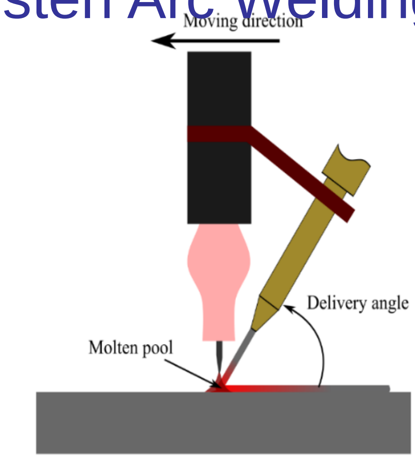


- Inert gas can be used from cylinders. They can also be generated through flux as coating (as in stick electrode) or powder (as in Submerged Arc Welding).



Welding

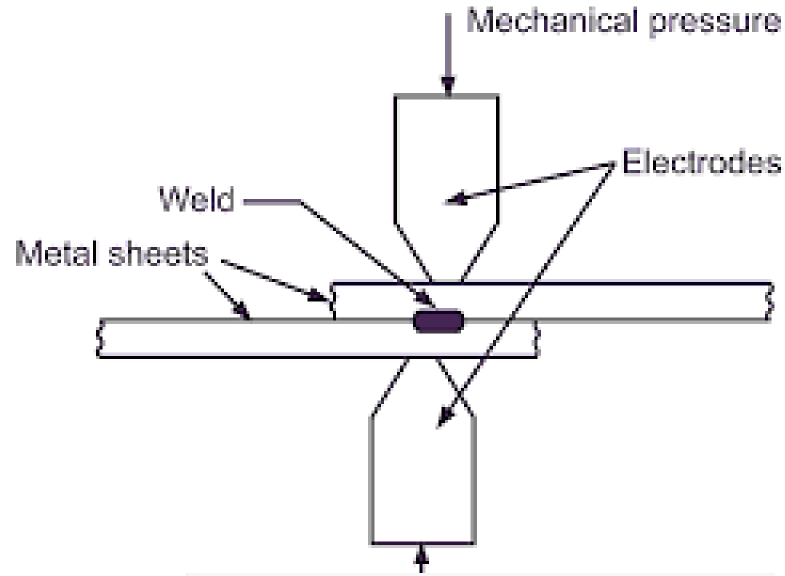
Resistance welding (Spot & Seam welding)

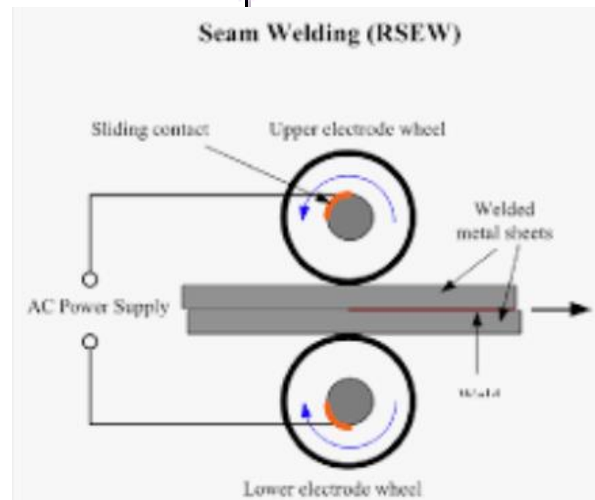
Metal Inert Gas (MIG) welding Gas Metal Arc Welding (GMAW)	Tungsten Inert Gas (TIG) welding Gas Tunsten Arc Welding (GTAW)
	
Filler wire is also the electrode.	Fixed tungsten tip is the electrode. Filler is fed from the side..
Inherent omni-directionality	No omni-directionality
Fast (>2kg/min)	Slow (<60g/min)
Poor quality as mass and energy cannot be independently controlled	Good precision as mass and energy can be independently controlled

Welding

Resistance welding (Spot & Seam welding)

- Resistance heating is the heat source.
- Extremely high & brief current (>20,000A) for few ms.
- Melting inside called nugget is unique. So, good surface finish.
- Types: Spot welding & seam welding.
- Welding of cells to form batteries is a very important application. Although laser is being tried, laser will melt the sheet fully.
- Car body and utenlsils use both spot & seam welding.





Additive Manufacturing

Additive Manufacturing

Principle-1: Divide & conquer,i.e., slicing

AM is ancient - all buildings followed this. Only its automation is new.

- Rapid Manufacturing: Original term when it was launched in 1987.
- Stereo-Lithography: Name of the first machine by 3D System..
- Additive Manufacturing: For domain experts; 3D Printing: For users.

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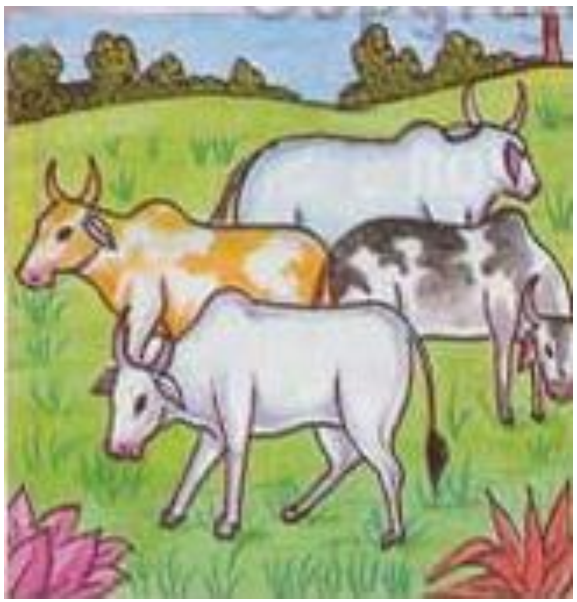
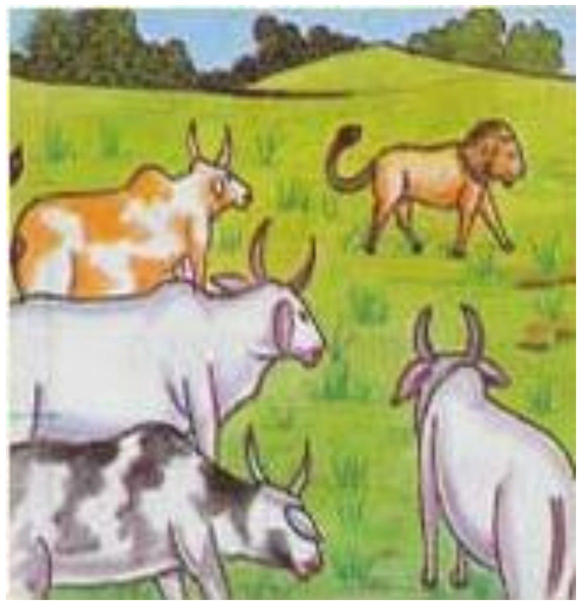
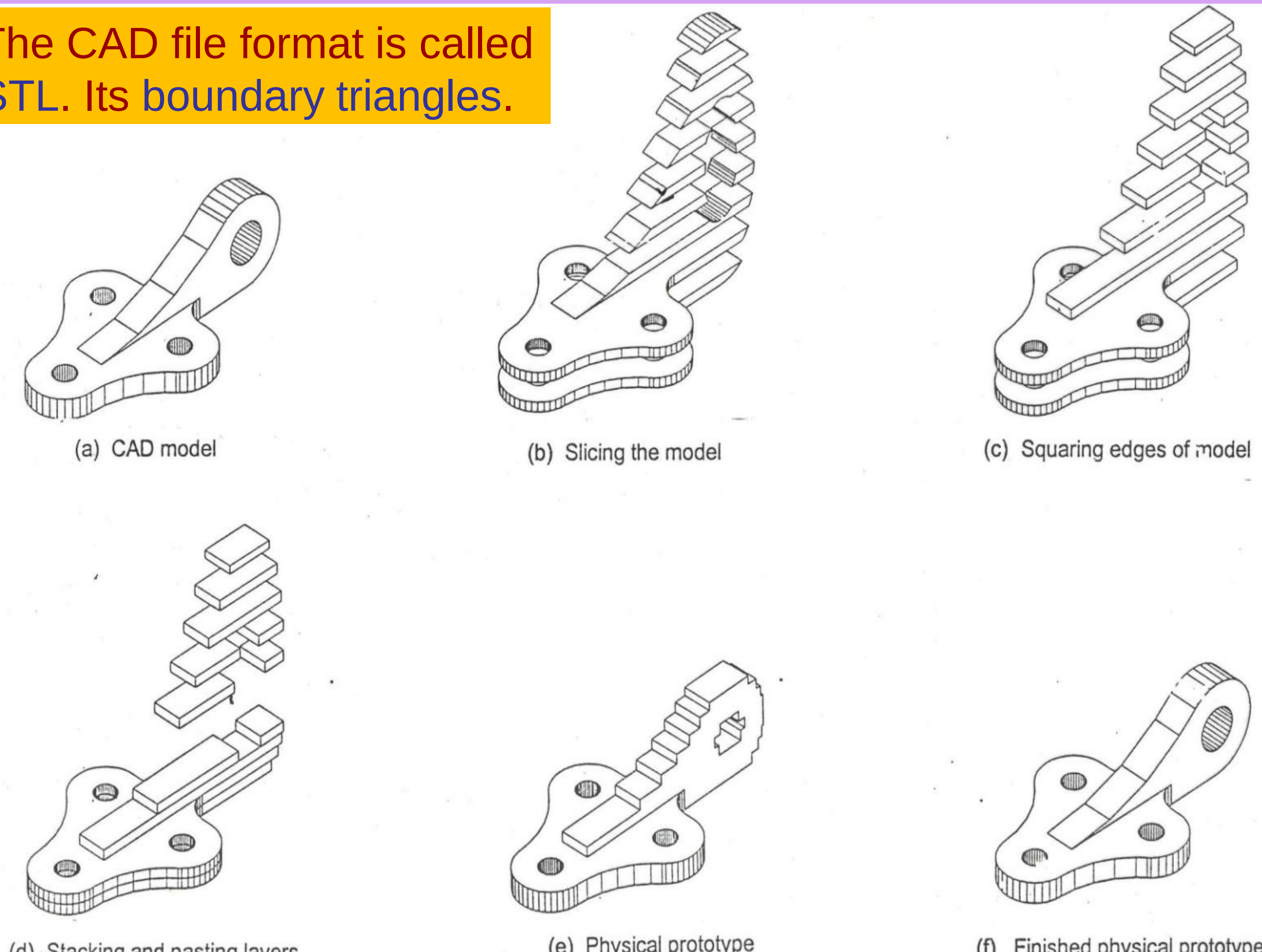




Moral: 1. Stay together (for cows);
Moral 2. Divide and Conquer (for lion)

Additive Manufacturing
Principle-1: Divide & conquer,i.e., slicing

The CAD file format is called STL. Its boundary triangles.

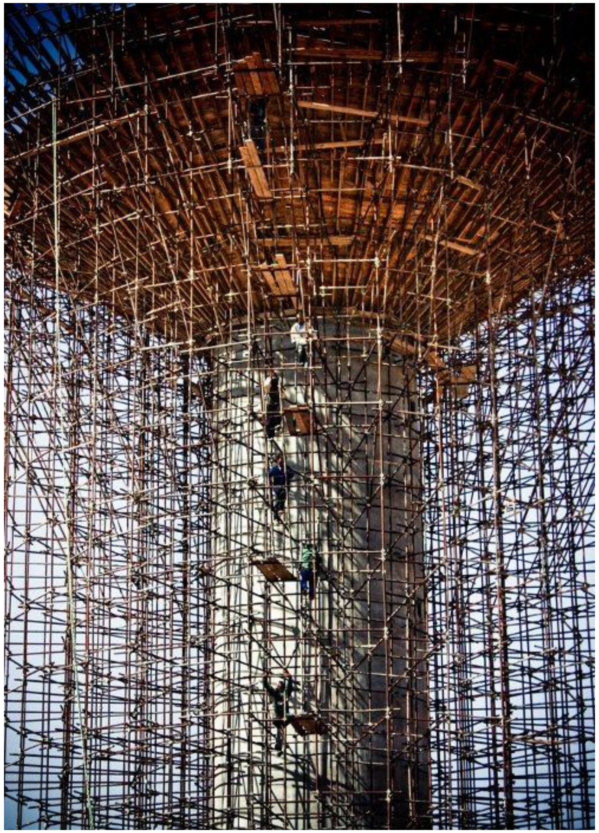


The associated defect is stair-step error.

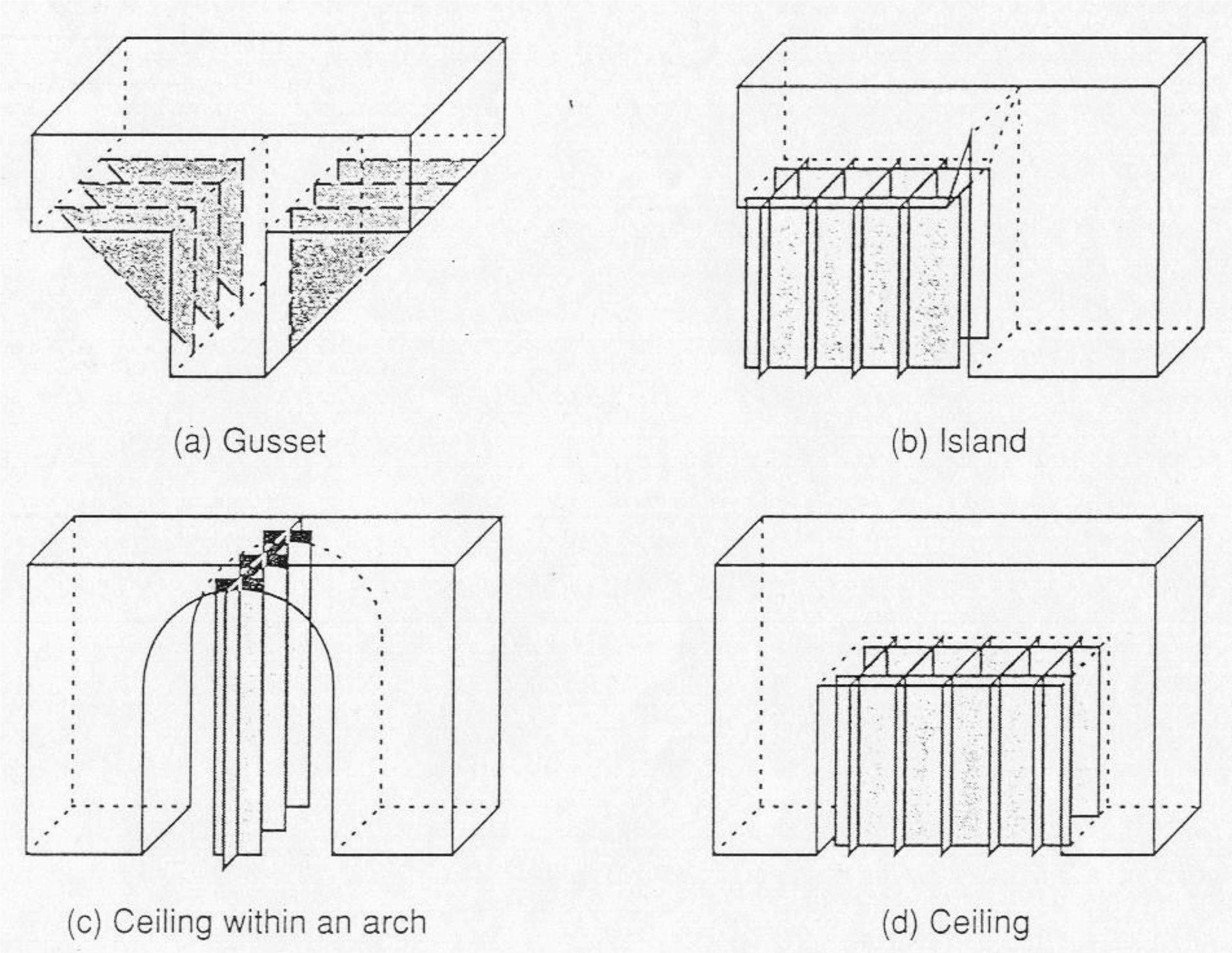
This can be minimized by
- lowering the layer thickness or
- post-processing (polishing or filling)

Additive Manufacturing

Principle 2. Need for support mechanism



Scaffolding for a water tank



The associated defect is poor finish at supported surface. Judicious build orientation can minimize this.

Additive Manufacturing

Popular AM technologies

- Laminated Object Manufacturing (LOM)
- Stereo-Lithography Apparatus (SLA)
- Fused Deposition Modeling (FDM) → Metallic version is Wire Arc AM (WAAM) & Wire AM (WAM)
- Powder-Bed Fusion (PBF)
  - Selective Laser Sintering (SLS)
  - Electron Beam Melting (EBM)
- Powder-Bed Bonding (PBB) known as 3D Printing
- Photo Masking or Solid Ground Curing (SGC)

Solid form (powder, wire, sheet & granules) are very important. Powder form is the most popular as it can alleviate the need for supports.

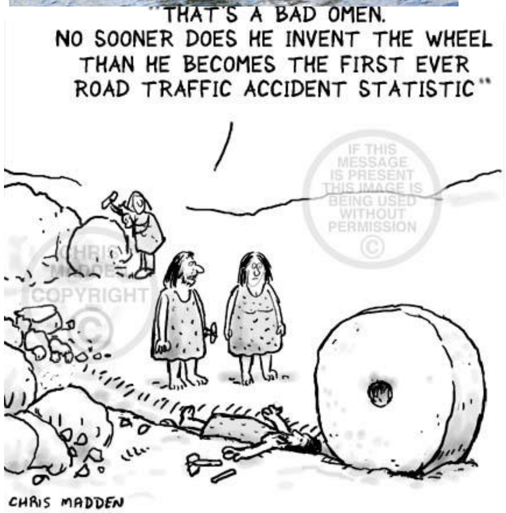
Additive Manufacturing

AM Takes Us Closer to the Nature!

Characteristics of Nature - Rotation:

Nothing rotates in nature (except at the extremes of celestial and atomic scales!)

Is wheel really the greatest invention of mankind? Could have been something else? Our imaginations are blocked by the symmetry of wheel!

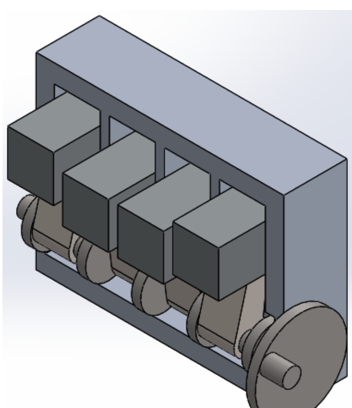


Additive Manufacturing

AM Takes Us Closer to the Nature!

Characteristics of Nature - Rotation:

Mathematically simpler horizontal flat surface “z=0” is more expensive to produce than a cylindrical surface which is mathematically more complex “$x^2 + y^2 – r^2 = 0$”

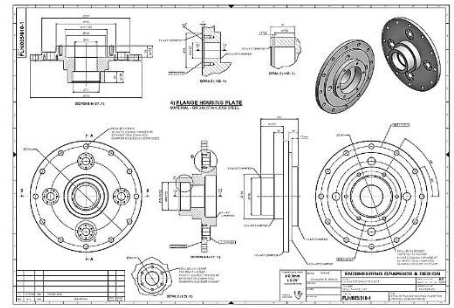


The cheapest machine is lathe, then shaper, milling machine etc.

AM can handle all geometries (cyl. or planar or freeform) with the same ease.

Additive Manufacturing
AM Takes Us Closer to the Nature!

Nothing in nature is flat (2D) or symmetric; all are 3D, organic and asymmetric.



Engineering graphics – Effort to capture 3D on 2D!

Is writing – expressing the sense of sound through symbols, the simplest form of sense of vision, another worst invention of mankind? It has been a major source of human conflict!

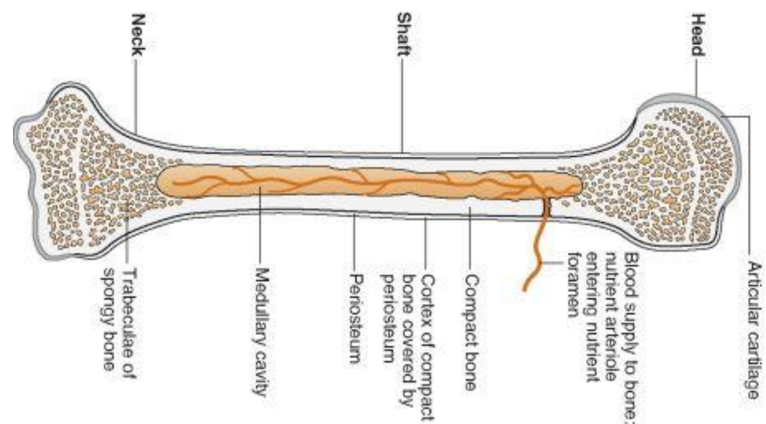
Additive Manufacturing

AM Takes Us Closer to the Nature!

Nothing in nature is homogeneous.

Apart from the desired external geometry, the possibility of manufacturing smooth or abrupt variation of (a) densities/porosities and/or (b) composition is emerging today. This known as Functionally Gradient Matrix (FGM).

Design & analytic tools are actually the bottlenecks today.



Additive Manufacturing

AM Takes Us Closer to the Nature!

Assembly is natural & built-in. But we make in individual parts and assemble later.

Additive Manufacturing

AM Takes Us Closer to the Nature!

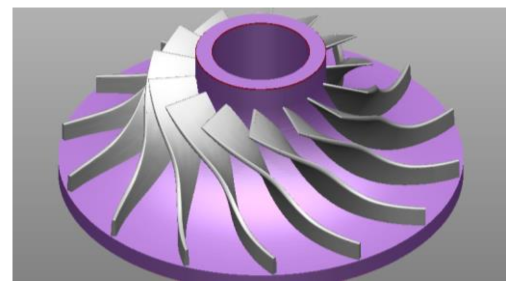
- Nature's manufacturing has minimum wastage!

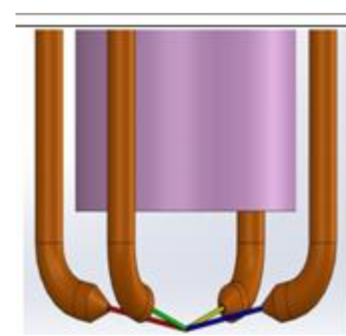
Additive Manufacturing
AM Takes Us Closer to the Nature!

- All these characteristics are because, Nature rarely does subtractive manufacturing!
- Subtraction means destruction!!
- Nature mostly does Additive Manufacturing!!!
- Since 3D printing also uses Additive Manufacturing, it takes us closer to the Nature. So, it can realize
  - Direct assemblies
  - Non-linear ducts
  - Custom geometries
  - gradient matrix
  - …

Today's AM still has a more few things to minic:

- Horizontal planar layers
- Multiple materials





Additive Manufacturing

A Disruptive Technology of This Era

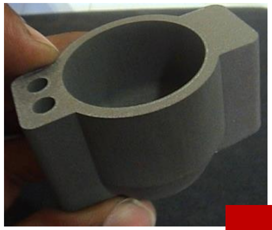
Total automation is the foremost advantage of 3D printing.

Objects of any kind of geometric (direct assemblies, non-linear ducts, custom, difficult, opti-light/lattice structures) or material (any variety – poly/ metal/ ceramic, non-equilibrium, gradient – mono/ composite/ gradient, porous/lattice, soft/hard) complexity can be produced.

DFM (compromise) vs DFAM (design freedom makes it disruptive).

Geometric (boundary)

Material (interior)



Anything that can be modelled, can be printed!

Additive Manufacturing
Advantages & Limitations

Advantages

- Total automation → time-compression for product launch.
- Ability to realize a variety of geometric and matrix complexities difficult through other routes.

Limitations

- Poor in surface finish arising out of its two principles. So, poor in fatigue strength. So, some fine features like threads cannot be realized.
- Each AM technology is limited to a narrow family of materials.
- The raw material is proprietary and hence unfairly priced as in 2DP. They have limited shelf life too.
- AM is limited to a few pieces only. For mass production, it lacks in QCD – Quality, Cost & Delivery (QCD). But they can become masters or tooling in mass production.

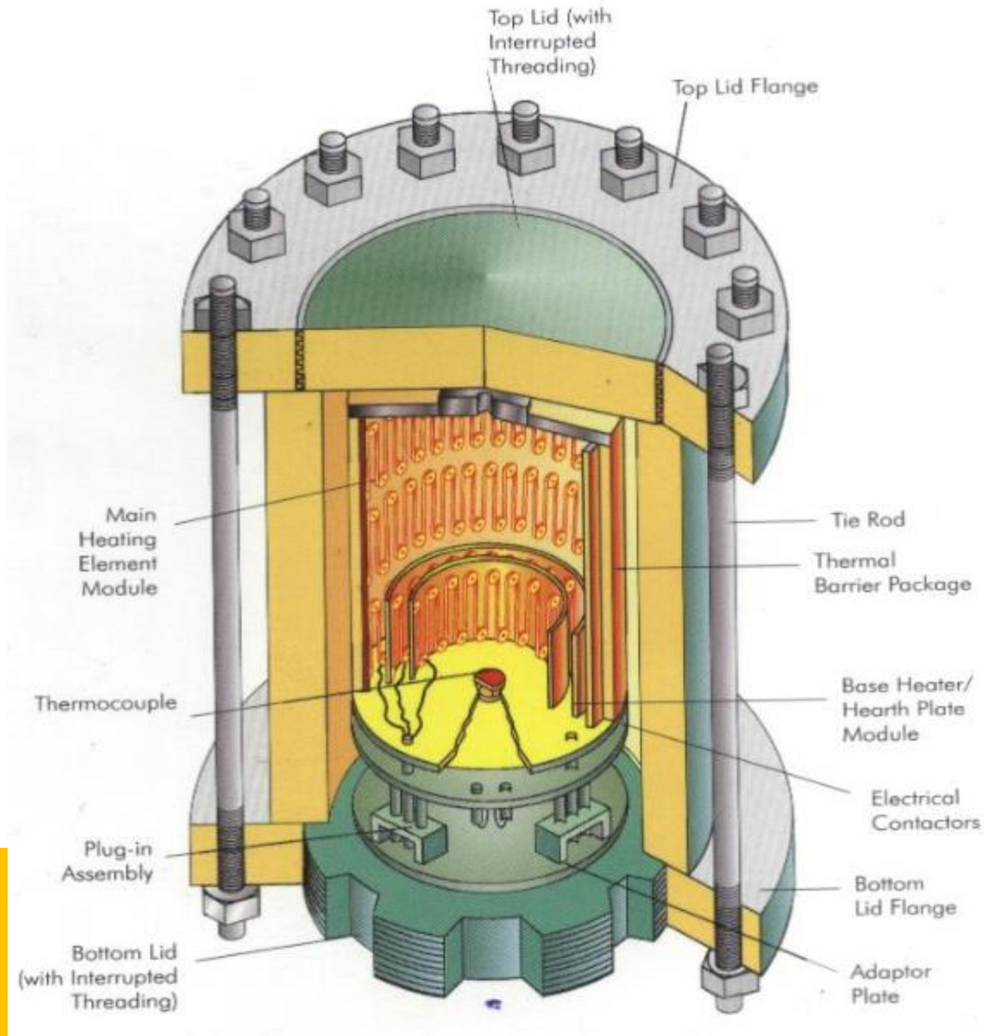
Conditioning (External & Internal)

Internal Conditioning

Post-processing - Hot Iso-static Pressing (HIP)

Powder-based RP (laser/EB sintering or bonding) is not strictly PM as compacting is missing. Powder-based metallic AM processes invariably have some micro-porosities which reduce their fatigue life required in aerospace. HIP makes them as strong as machined or forged components.

HIP combines the geometric complexity of Casting with the matrix quality of Forging!



Cutaway view of a Tie Rod PCS Hot Isostatic Press

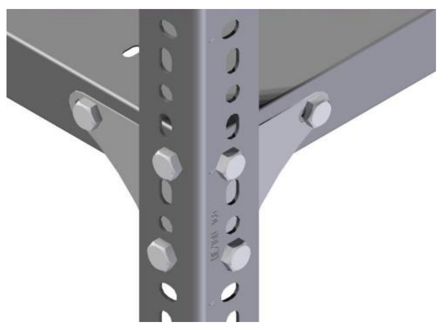
Assembly

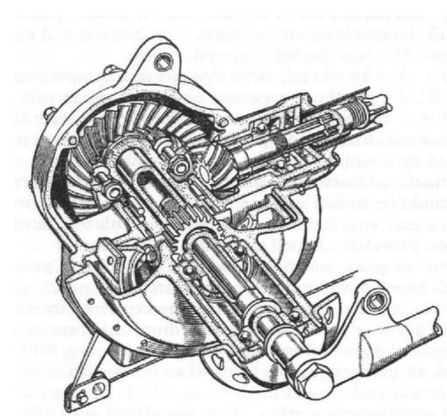
Assembly slides are only for the completion of the subject. No questions will asked from this for the mid-semester examination.

Assembly

Types

- Assembly
  - Fixed
    - Permanent
    - Detachable
  - Movable
    - Permanent
    - Detachable





Assembly

Types based on interchangeability

1. Fully Interchangeable Assembly

2. Partially Interchangeable Assembly

3. Selective Assembly (two types: (i) matched parts assembly and (ii) Group interchangeable assembly)

4. Adjusted Parts Assembly

5. Fitted Parts Assembly

6. Compensated Assembly

7. Hybrid Assembly

1 is ideal and 2 is practical. 3-6 are for achieving tight fit of the assembly from mating components made to wide tolerances. This is achieved with some compromise on

- interchangeability or
- reusability or
- need for high skill requirement or
- need for additional resource (cost &time) for inspection/ sorting.

Assembly

1. Fully Interchangeable Assembly

Definition:

Any two elements picked at random shall match lucidly.

Eg.: nuts and bolts, tires

Advantages:

+ Enables mass production, division of labor, automation etc.
+ Simplifies spares supply

Limitations:

- Tolerances have to be strictly adhered.
- 100% inspection is required to avoid problems in automatic assembly.
- 100% interchangeability can be only approached but never can be reached. It can be ascertained only through rejection/ rework of non-conforming parts.

Assembly

2. Partially Interchangeable Assembly

Definition:

Most practicable version of fully interchangeable assembly.

Advantages:

+ Enables mass production, division of labor, automation etc.
+ Simplifies spares supply

Limitations:

- Tolerances have to be strictly adhered.
- Penalty for misfit in terms of rework and delays.

Assembly

3. Selective Assembly

Definition:

Most practicable for extremely tight tolerances that go beyond the process capability. Produce both matching parts in large number. Measure each and fit.

Eg.: Ball bearings, slip gauges

Advantages:

+ Cheap to manufacture individual parts.

Limitations:

- More time spent on inspection/sorting
- No interchangeability. Hence, both mating parts shall be replaced.
- If the process of the individual components are not under control, one may land up accumulating more unused components.

Assembly

4. Adjusted Parts Assembly

Definition:

The components are manufactured to wide tolerances and randomly used. The desired fit is achieved during assembly using certain adjustment features. The adjusting element may be set screws, washers, spacers, wedges, shims, putty etc.

Eg.: Where designer is unable to decide the required fit with confidence. Rail joints with gap for weather changes - clock, carburetor, leveling of machine tools, Alignment of machine tool bed, elimination of backlash using preloading, cycle wheel assembly, gear mountings in watches or clocks, …

Advantages:

+ Simple way of obtaining fine fit. Cheap as tolerances are wide.
+ High performance of the assembly due to exacting fit.
+ Interchangeability of components is maintained.

Limitations:

- Requires skilled labor. Not suitable for automatic assembly.
- Increased number of components and weight.
- non-standard process.

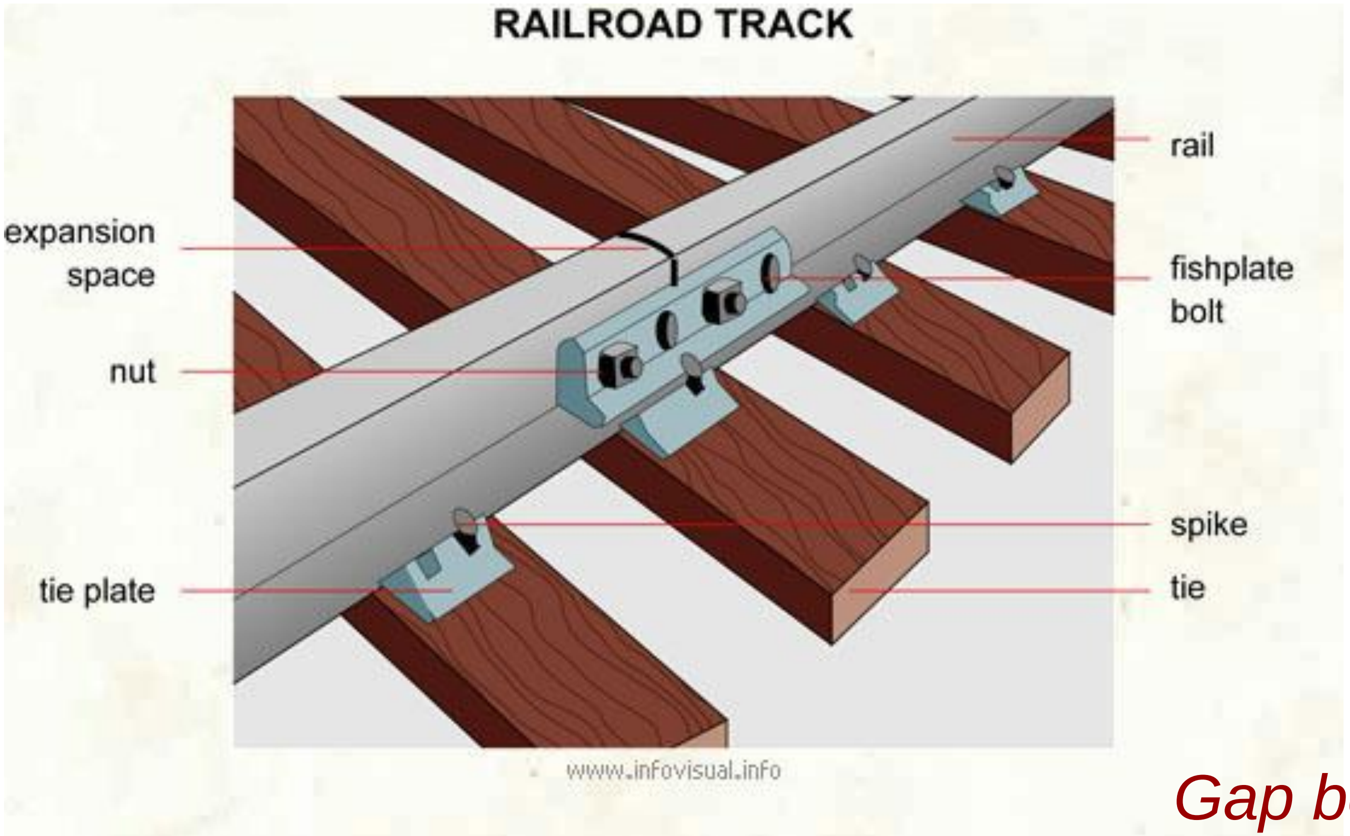
Assembly

4. Adjusted Parts Assembly …

Carburetor:
Not because of manufacturing difficulties but to adopt to varying needs.

Assembly

4. Adjusted Parts Assembly …



Gap between rails:

Not because of manufacturing difficulties but to adopt to varying needs.

Assembly

4. Adjusted Parts Assembly …

cycle wheel spoke adjustment

Assembly

5. Fitted Parts Assembly

Definition:

The components are manufactured to wide tolerances for tight fit. The desired fit is achieved during assembly by adjusting one of the matching dimensions by filing, cutting, chiseling, scrapping, lapping etc.

Eg.: Machine bed manufacture, implants, …

Advantages:

+ Simple way of obtaining tight fit. Cheap as tolerances are wide.

Limitations:

- Requires skilled labor. Not suitable for automatic assembly.
- Slow.
- non-standard process.
- You may not be able to repeat again in case of disassembly.

Assembly

6. Compensated Parts Assembly

Definition:

The components are manufactured to wide clearance fits. The desired tight fit is achieved during assembly by filling the clearance with some material. It could be welding with washer, filler, brazing, soldering, bonding etc.

Eg.: Machine tool grouting, molding of cable ends with the connector, use of washers/shims/wedges …

Advantages:

+ Simple way of obtaining tight fit. Cheap as tolerances are wide.
+ Suitable for automatic assembly.

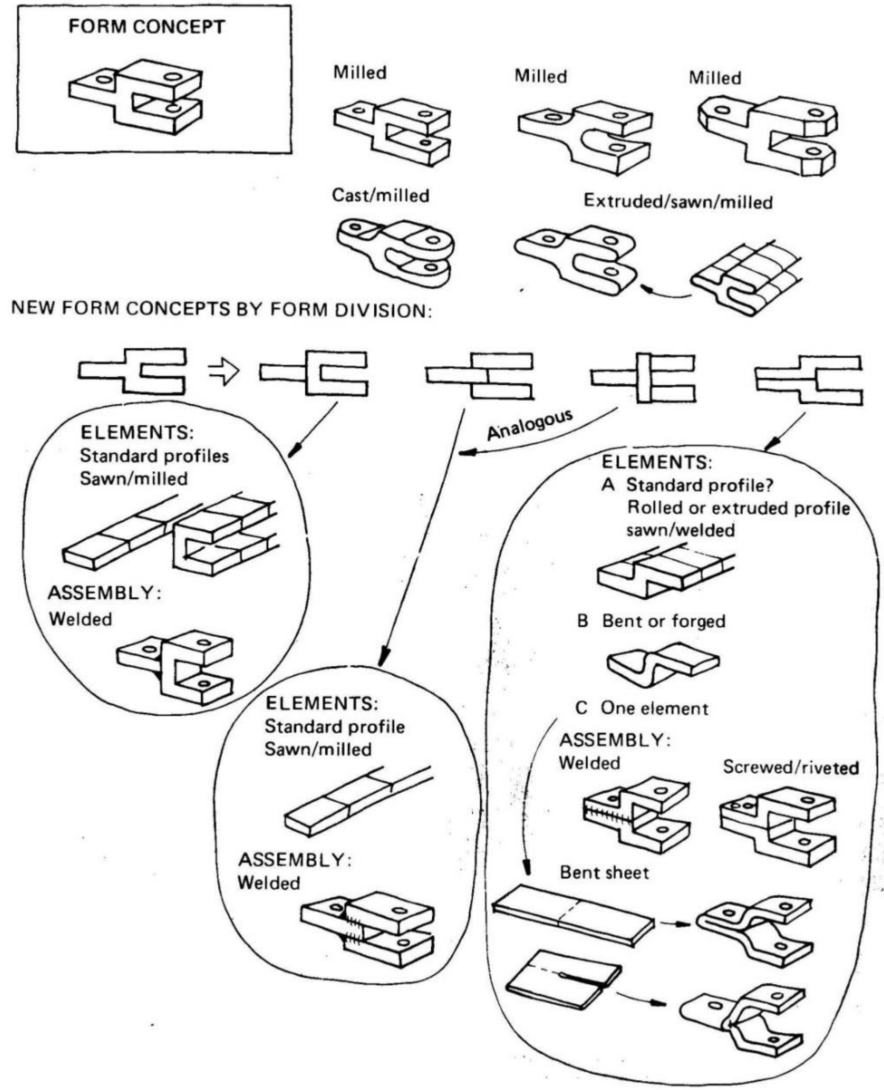
Limitations:

- Shims are not a preferred method for critical assemblies.

Assembly

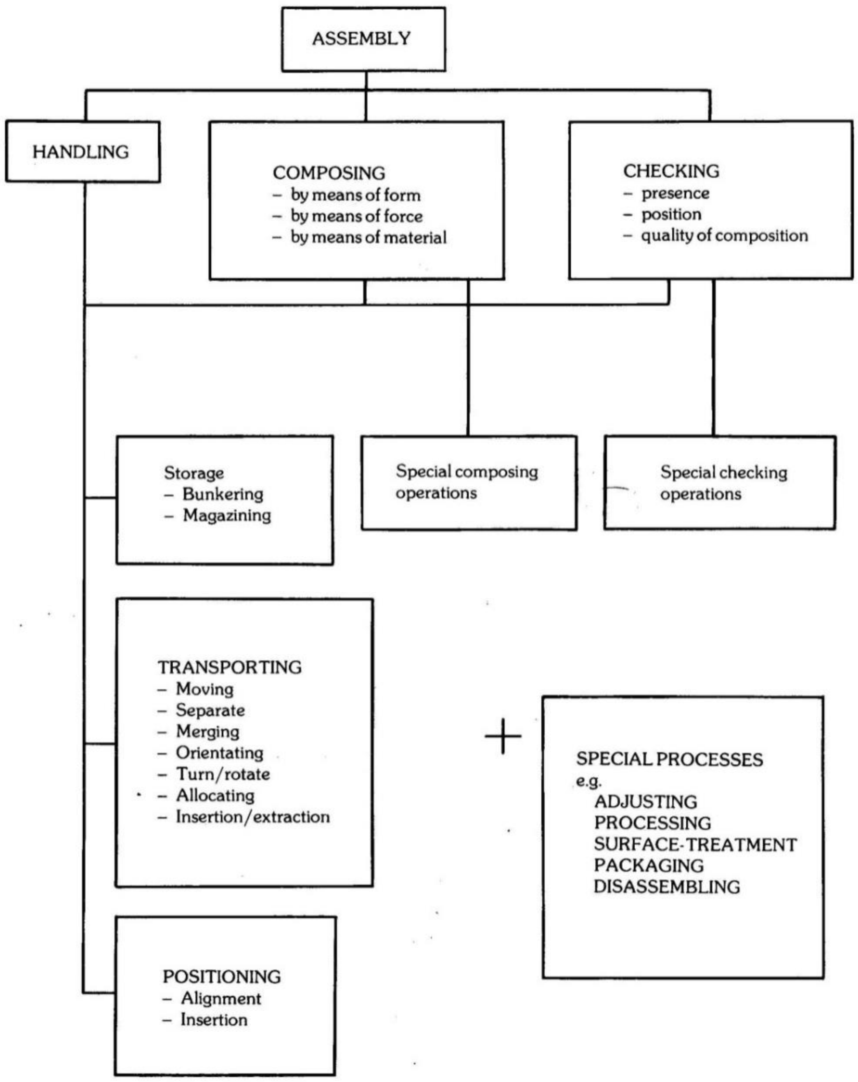
Example of a fork

Various possibilities of producing a fork →



The ultimate aim of an assembly engineer is to eliminate assembly itself.

Assembly
Various operations



By form:

- Tabs
- Rivets
- Threaded joints

By force:

- Friction (interference fit, friction welding etc.)
- Magnetic force
- Electrostatic force
- Atmospheric pressure

By material:

- All compensated assemblies (welding with filler, brazing, soldering, bonding etc.)

Assembly

Various operations

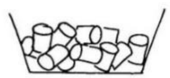
Handling

Storage

The time-oriented process by which components are stored before or after handling, composing and checking.

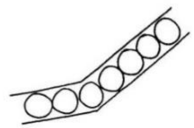
Hopper Storage

Time-oriented storage of components as yet unoriented.



Magazining

Time-oriented storage of oriented components.



Positioning

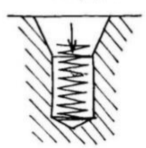
The process with the aim of orientating one component in relation to another.

Alignment

Positioning of component in one or more axial directions in relation to the base component.

Insertion

Relocation of component in relation to base component resulting in the terminal position.

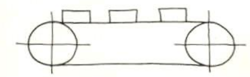


Transporting

Process with the aim of moving and orientating components according to the demands of the composition and checking processes.

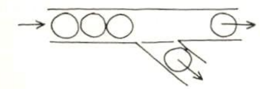
Moving

Constant or indexing relocation within the assembly system.
If this operation is carried out by an operator or robot there will be three phases: recognition, gripping and moving.



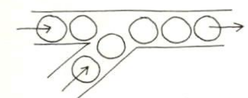
Separating

Division of a single stream of components into many streams.



Merge

Merging of two or more streams of components.

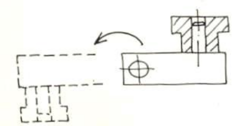


Orientation

Orientation of stream of components in relation to the system.

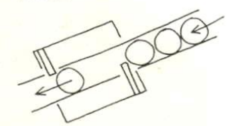
Turning/rotating

Orientation of components within stream in relation to system.



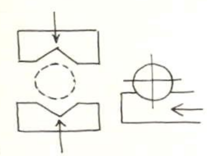
Allocating

Release of a given number of components from stream, to the system.



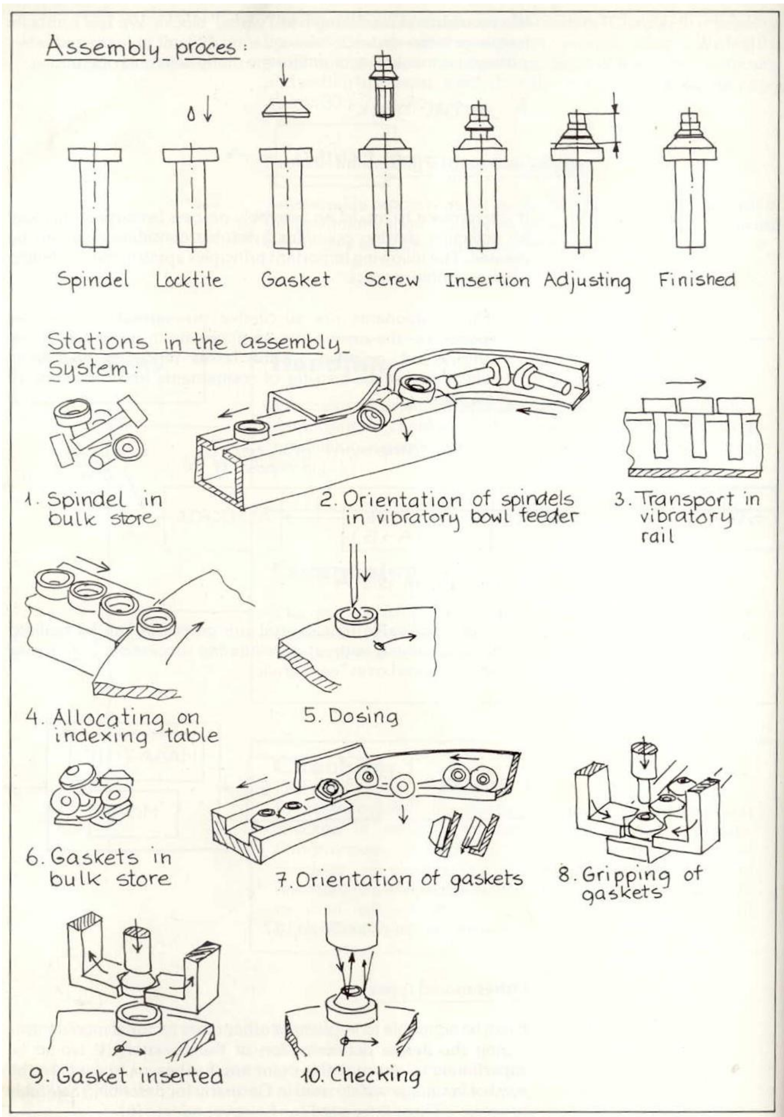
Insertion/Extraction

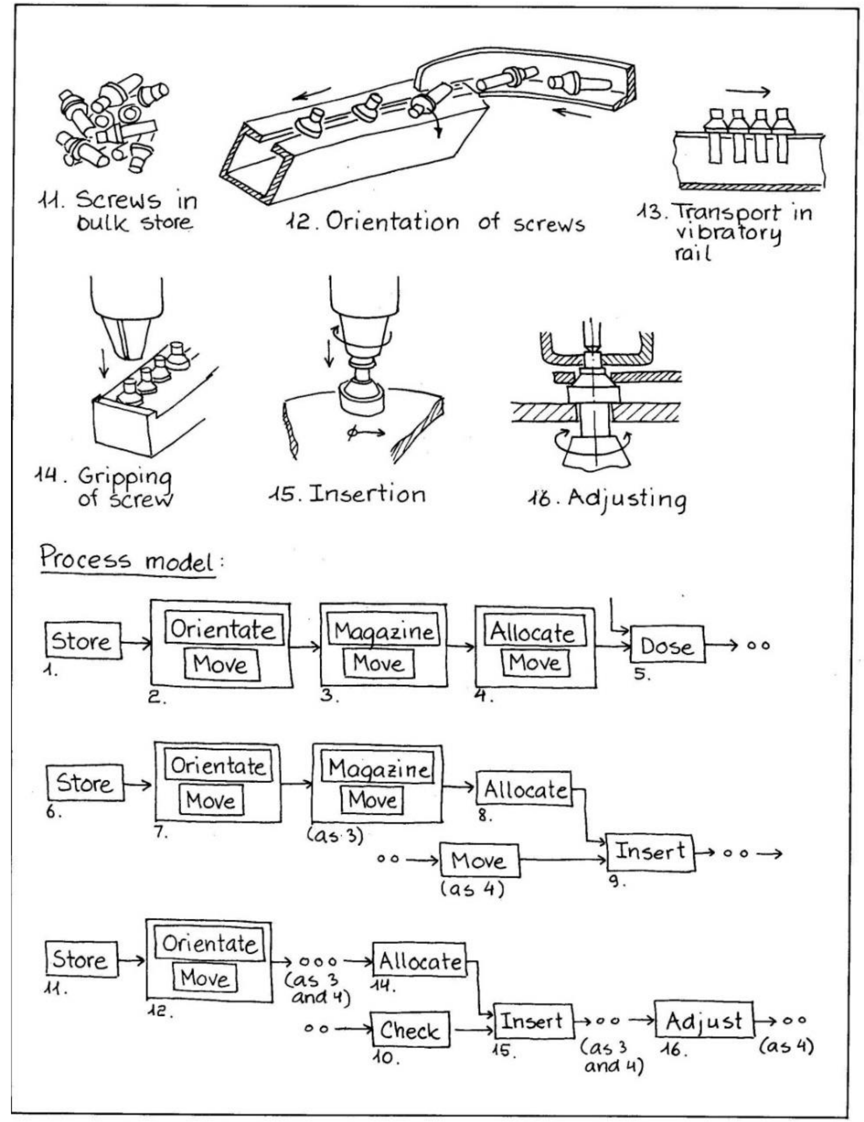
Positioning of component in the tool, removal of component.



Assembly

Various operations …





Conclusions

Conclusions

- Manufacturing requires all the processes we discussed so far. Each has its domain of applications.
- The purpose of giving their comparison is not to argue in favor of one another but to enable the selection of the correct combination for the given situation.

Conclusions

Comparison of the Processes

Process	Force	Heat	Addressing Locally/ Fully	Rate
Casting	Nil	Very high	Fully (Vol.)	Slow
Forging	High impact	High	Fully (Vol.)	Fast
Sheet metal forming	Moderate	Nil	Locally	Slow
Machining	Very high strain & strain rate	Nil	Locally	Very fast but one feature at a time.
Non-trad.	Nil	Nil	Locally	Very slow
AM	Nil	In some	Locally	Fastest for prototypes

Conclusions

Comparison of the Dies

Process	Material formed	Life in shots Before repair	Material of dies/molds	Remarks
Inj. Molds	Non-metals (Eg. Plastics, wax)	As much as 5,00,000	Tool steel of as much as 50HRC (Eg. P20, H13 …)	Rarely repaired.
Die Casting dies	Soft metals (Eg. Al)	As much as 1,00,000	Tool steel of as much as 50HRC (Eg. P20, H13 …)	Rarely repaired.
Sheet metal forming	Metallic sheets	As much as 5,00,000	High carbon steel (<40HRC)	Rarely repaired.
Forging dies	Bulk metal	3,000-5,000	Tool steel of as much as 50HRC (Eg. P20, H13 …)	Frequent repair, i.e., within one or two shifts. So, an in-house die shop is must.

Conclusions

Criteria for the Selection of the Process

- Quantity of production over its life time
- Batch quantity (demand pattern over its life time)
- Accuracy requirement
- Cost and quality of available labor
- Govt. regulations (subsidies on power tariff and tax, pollution laws etc.)
- Value of raw material
- …

Thank You!

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