Manufacturing Systems

Made by Dr. István Németh

2019

Subject:

Machine Design and Production Technology

BMEGEGEMW01

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Introduction: Manufacturing Technologies

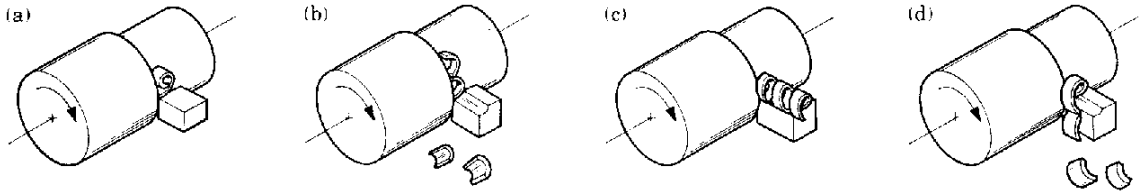
- Component production (Shape giving technologies):
  - Material removal, material separation
    - E.g. metal-cutting → metal-cutting machine tools (e.g. lathe, sawing machine, grinding machine)
  - Additive technologies
    - E.g. rapid prototyping, 3D printing
  - Forming and shaping
    - E.g. rolling, forging, extrusion, sheet forming
  - Casting
  - Material joining
    - E.g. welding, soldering, mechanical joining
  - Etc.
- Assembly

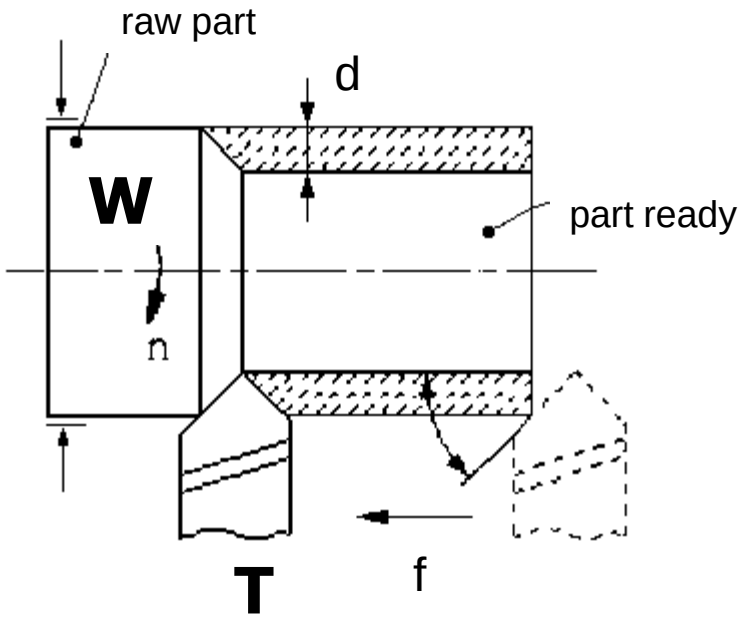
Topics of the Lecture

- Manufacturing automation
- Equipment and layouts of manufacturing systems
- Examples: mainly metal-cutting technology:
  - machine tool = metal-cutting machine tool
  - robot = industrial robot

Metal-Cutting Machining

- Machining by material removal (chips)
- Relative motion between the **T**ool(s) and the **W**orkpiece(s)
- Cutting force





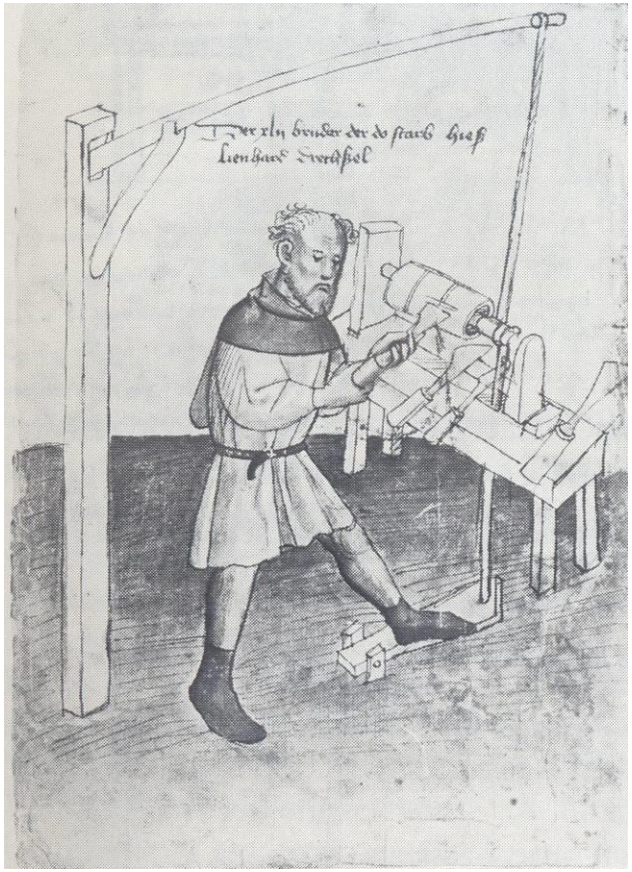
Primary motion (speed)

- n [1 /min]
- v [m/min, m/sec]

Secondary motion (feed)

- f [mm/rev, mm/min]
- d [mm]

The Beginning (1)

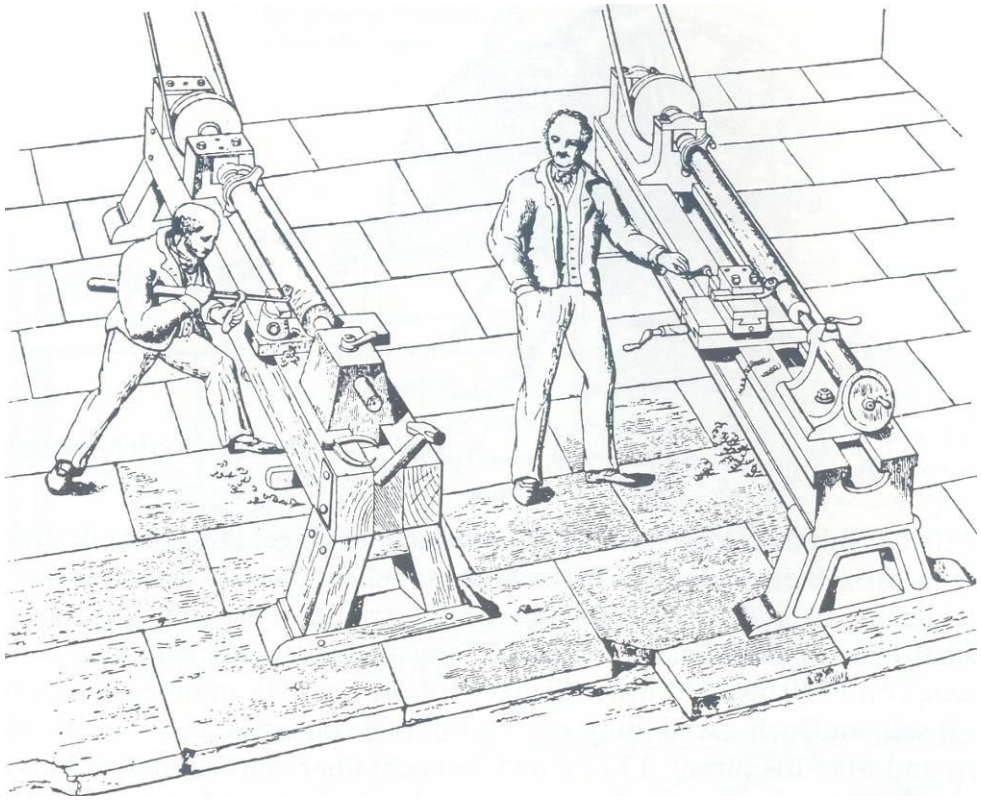


Fully manual wood lathe
(around 1425)

Primary motion (speed) and force
(= power): by foot

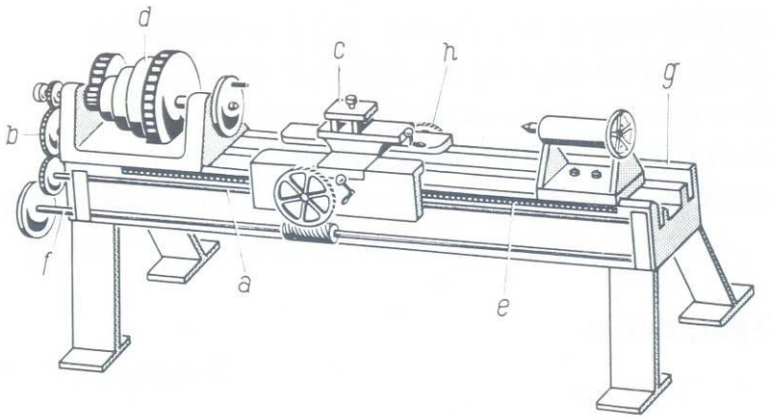
Secondary motion (feed) and force (= power and position): by hand

The Beginning (2)



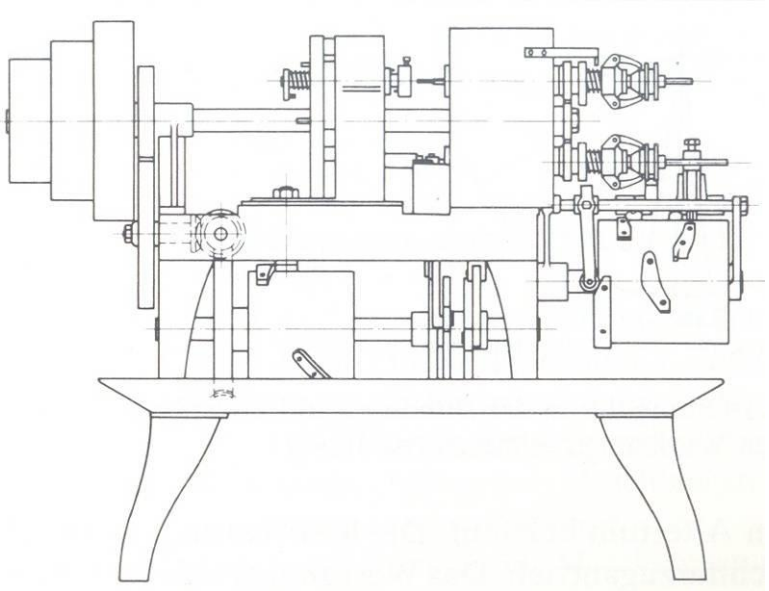
Further development steps: transmission (steam engine), automatic tool movement (Maudslay)

The Beginning (3)



Engine lathe (around 1840). Lead screw, interchangeable gears, stepped pulley (Maudslay, Roberts, Fox és Whitworth)

Multi-spindle automatic lathe (patent in 1894 in the USA)



Aims of Manufacturing Automation

- Improve productivity
  - more efficient material handling
  - machines are used more effectively → minimise cycle times and effort
  - production is organised more efficiently
- Reduce manufacturing costs
- Improve quality
- Reduce human involvement
  - boredom
  - possibility of human error
  - dangerous tasks
- Reduce workpiece damage
- Integrate manufacturing operations
- Raise the level of safety
- Economise on floor space
  - arranging machines, material movement, and auxiliary equipment more efficiently

[5]

History of Manufacturing Automation

1750s	Industrial revolution.
1800-1900	Turret lathe, universal milling machine.
1900-1920	Geared lathe, automatic screw machine.
1920	First use of the word 'robot'.
1920-1940	Transfer machines; mass production.
1940	First electronic computing machine.
1952	First prototype of NC machine tool.
1960s	Industrial robots. Just-in-time production systems.
1968	PLC.
1970	First integrated manufacturing system; spot welding of automobile bodies with robots.
1970s	Microprocessors; flexible manufacturing systems; group technology.
1980s	Artificial intelligence; intelligent robots; smart sensors; untended manufacturing cells.
1990s	Integrated manufacturing systems; intelligent and sensor based machines; global manufacturing networks.
2000s	Additive technologies; multi-task and hybrid machine tools; mass customisation; reconfigurable manufacturing systems.
2010s	Internet of things; smart factories; Web-, agent-, cloud-based manufacturing, Cyber-physical production systems ...

The 4th Industrial Revolution - „Industry 4.0"

The same history simplified and presented with fashionable words (introduced in Germany):

- **1st Industrial Revolution**

  1782 – Power generation → *Mechanical Automation*
  (water power, steam power, machine tools)

- **2nd Industrial Revolution**

  1913 – Industrialisation, mass production → *Electric Automation*
  (conveyor, assembly line, electric power)

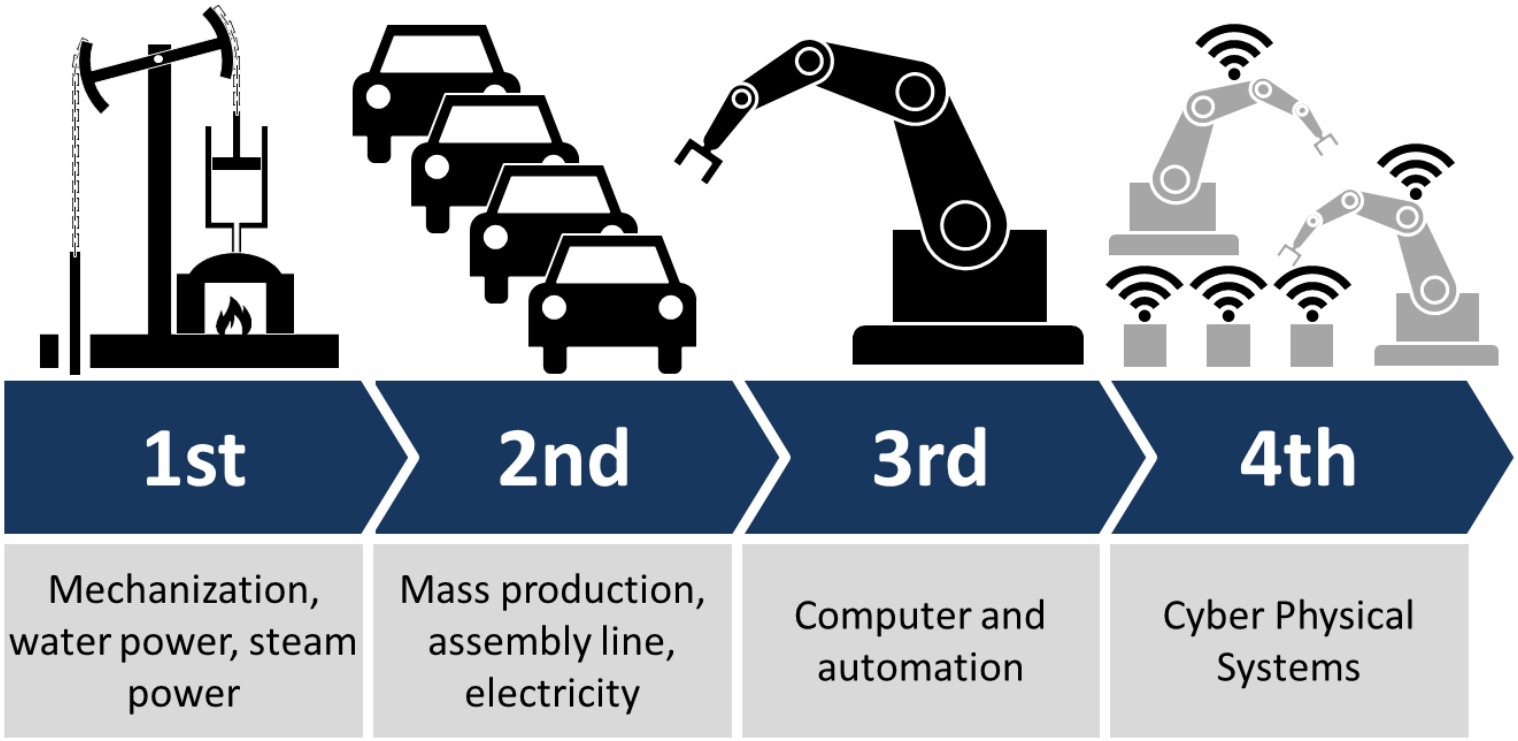
- **3rd Industrial Revolution**

  1954 – *Electronic Automation*
  (computer, NC, PLC)

- **4th Industrial Revolution – „Industry 4.0"**

  2015 – *Smart Automation*
  (sensors, internet of things, cloud computing, cyber physical systems)

Industrial Revolutions



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Types of Automation

- Hard Automation
  - very high number of products (e.g. engine blocks)
  - low flexibility (≈0)
- Soft Automation
  - (flexible or programmable automation)
  - medium-high number of products
  - high flexibility

Classification of Machine Tools (1)

- Machine tools for defined cutting edge (cutting)
  - Primary motion: Translation
    - Broaching machines
    - Band saw and Hacksaw
    - Planer
    - Shaper
  - Primary motion: Rotation
    - Turning machines, lathes
    - Milling machines
    - Drilling machines
    - Machining centres
    - Turning centres
    - Gear manufacturing machines
    - Transfer machines and systems

Classification of Machine Tools (2)

- Machine tools for undefined cutting edge (abrasive)
  - Grinding machines
    - Cylindrical grinder
    - Surface grinder
    - Centreless grinder
  - Honing machines
  - Lapping machines
- Non-conventional (erosion)
  - Electrodischarge machining
  - Electrobeam machining
  - Ultrasonic machining

Classification of Machine Tools (3)

- Multi-task machines
  - Turning + Milling
  - Milling + Grinding
  - Turning + Electrodischarge machining
- Hybrid machines
  - machining process + other manufacturing processes
    - machining + laser heat treatment
    - machining + rolling
    - subtractive technology + additive technology

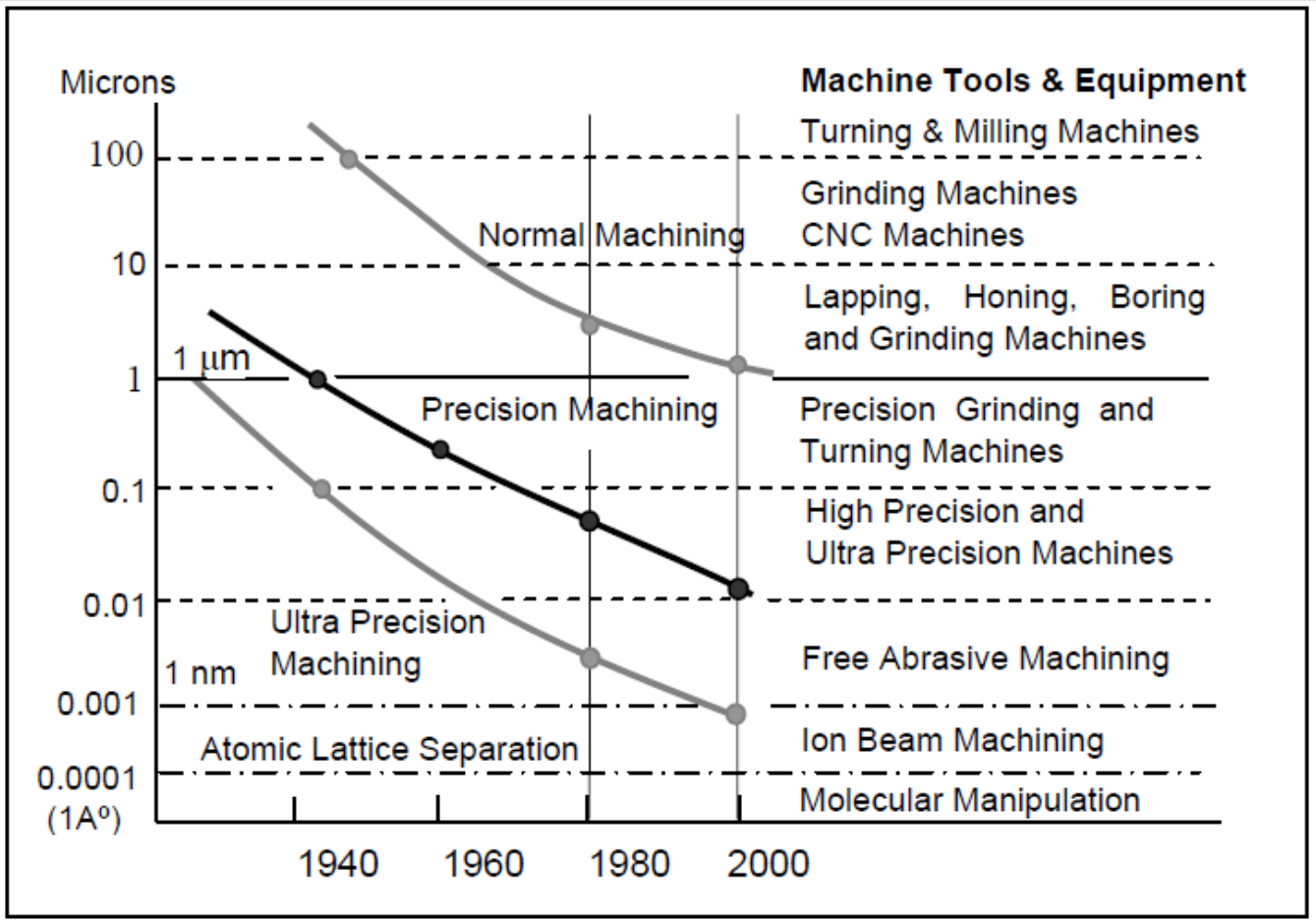
Selection of Machine Tools (1)

- Maximum part size
  - Machine workspace must be greater than the workpiece size
- Workpiece main geometry
  - global shape of the part
    - cylindrical → lathe
    - prismatic → milling machine
  - number of complexity of the details
    - complex geometry → complex machine tool
- Type of the manufacturing process, type and number of tools needed
- Material removal rate
  - productivity / production rate
- Precision
  - accuracy
  - repeatability

Selection of Machine Tools (2)

- Precision (cont.)

A comparison with the boring machine by J. Wilkinson in 1775 “which bores with a thickness error of one shilling in a fifty-seven inch diameter” (2 mm in 1500 mm),

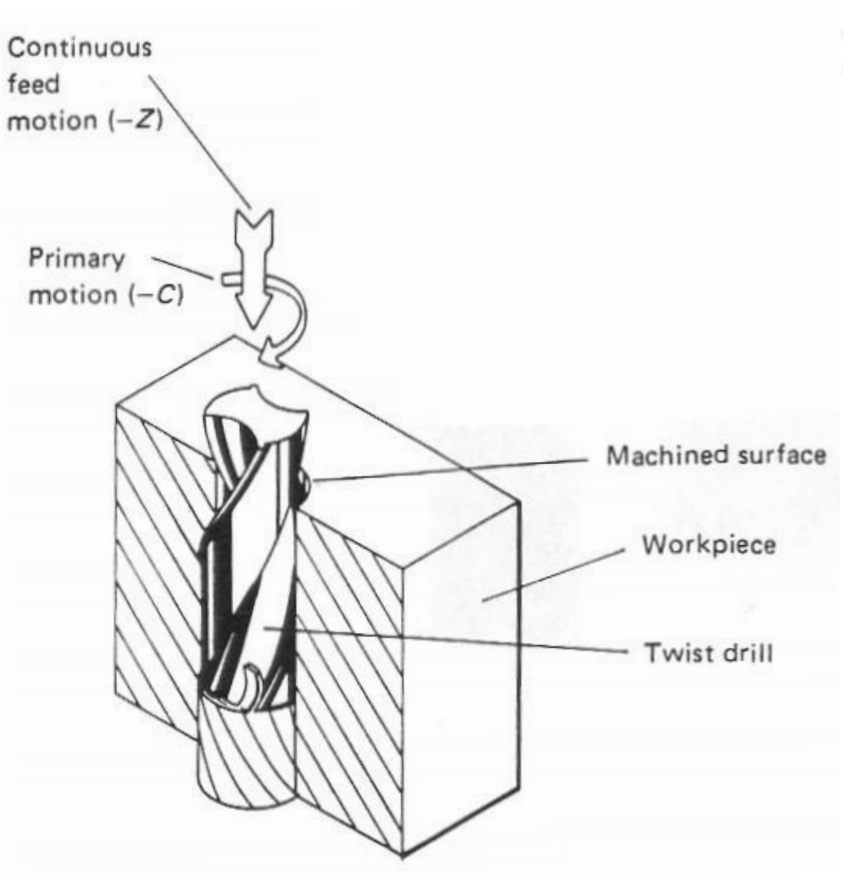


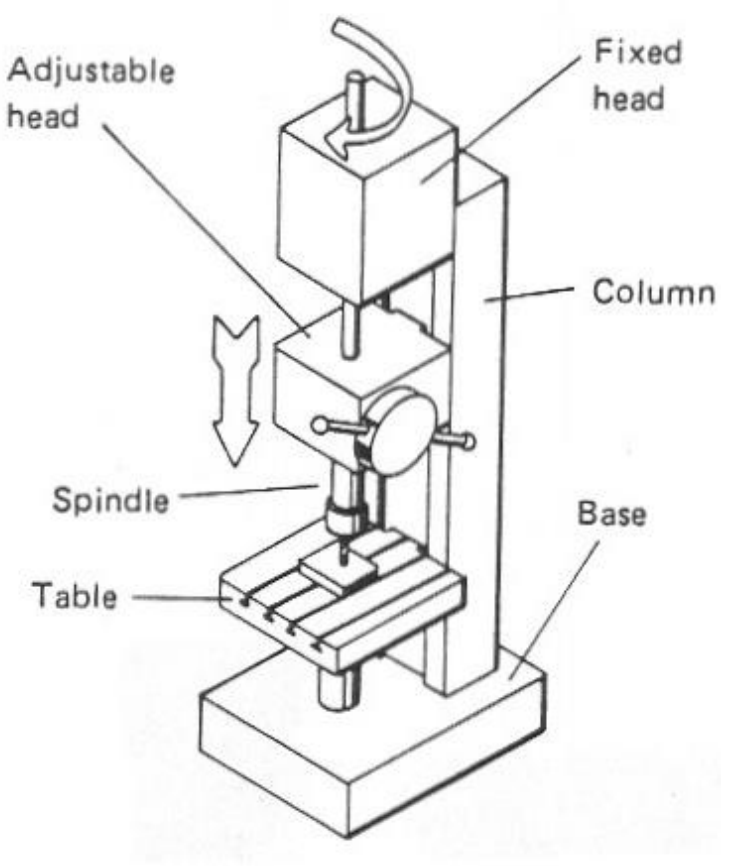
[1]

Selection of Machine Tools (3)

- Kinematic behaviour (i.e. speed and acceleration)
  - to calculate the work-in-progress and idle movements
- Batch size
  - determines the automation level of machine tools and the use of auxiliary devices (tool change, workpiece change, multi-machine system)
- Price → life cycle costing point of view
- Environmental impact
- Ergonomics
- Design
- Comply with existing standards
- Etc.

Drilling on a Drill Press

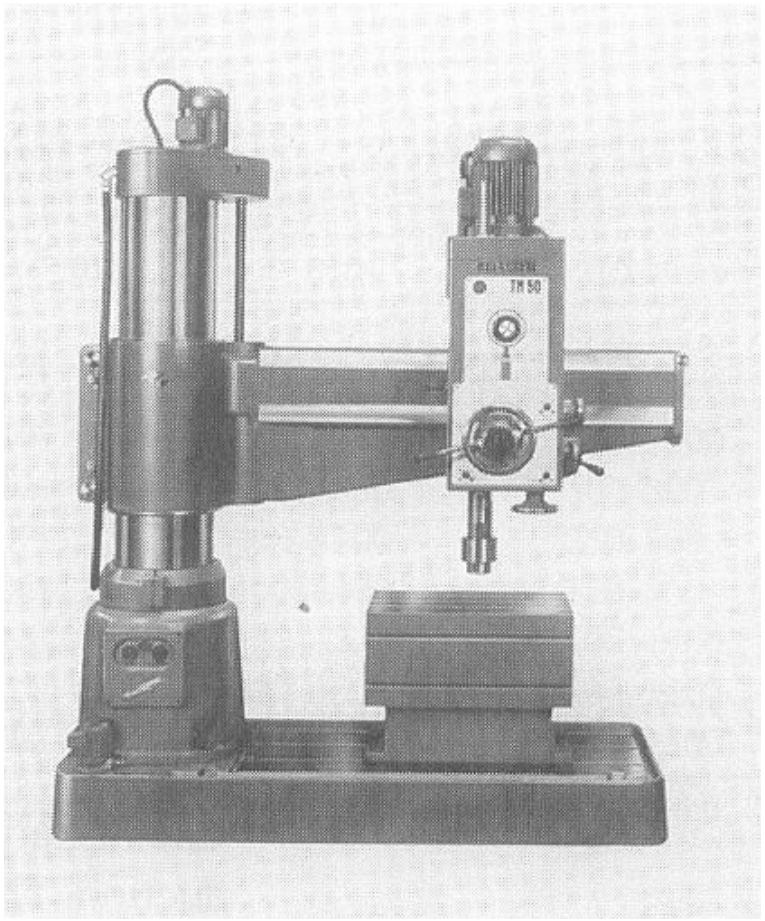




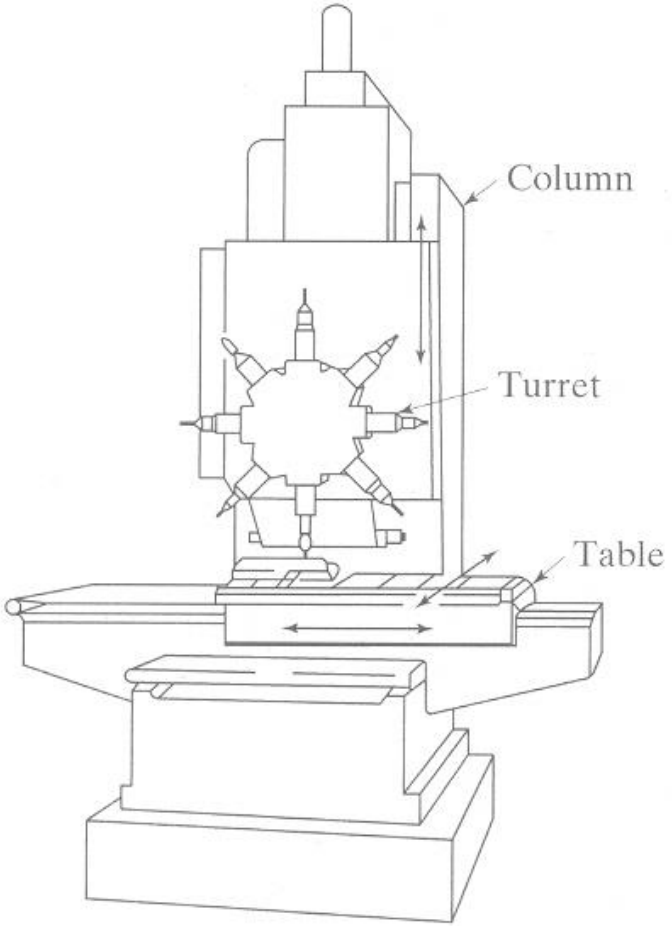
The drilling process

[3]

Drilling Machines



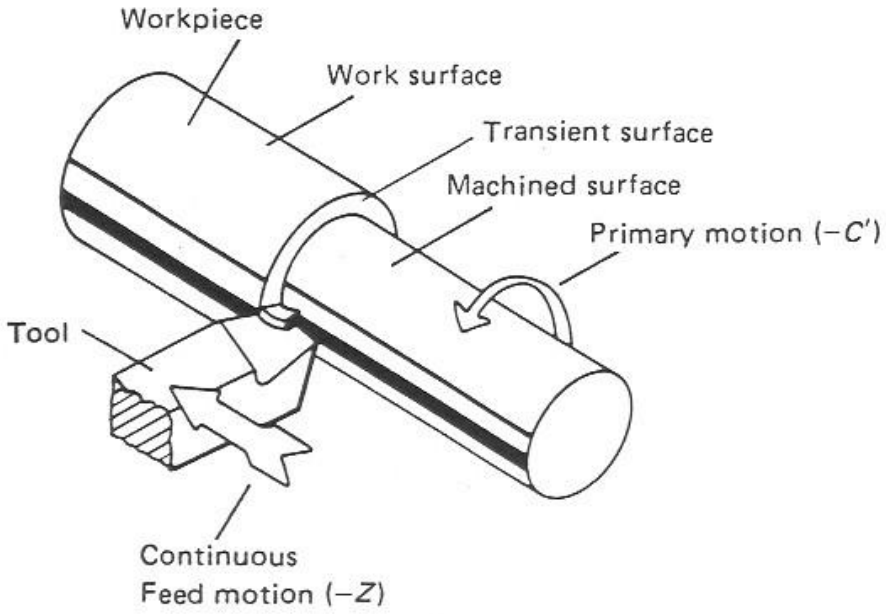
radial drilling machine



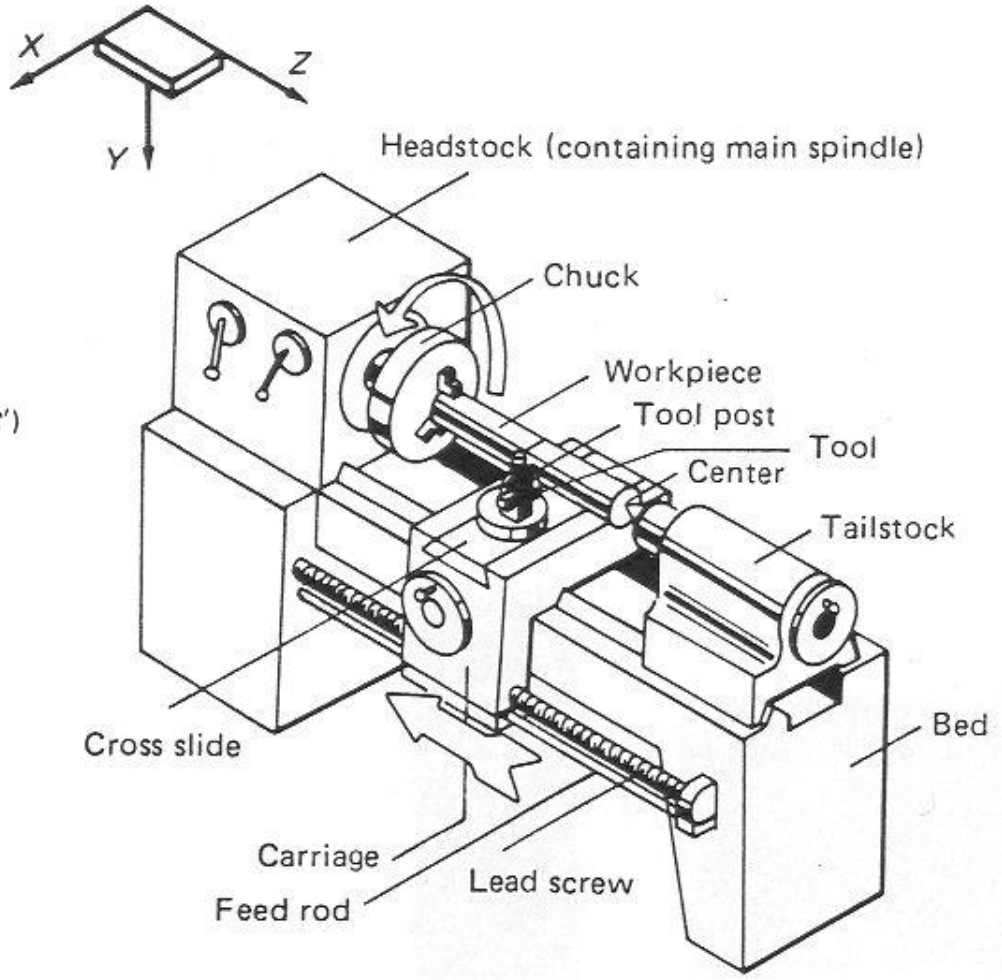
CNC drilling machine

[5]

Cylindrical Turning on an Engine Lathe

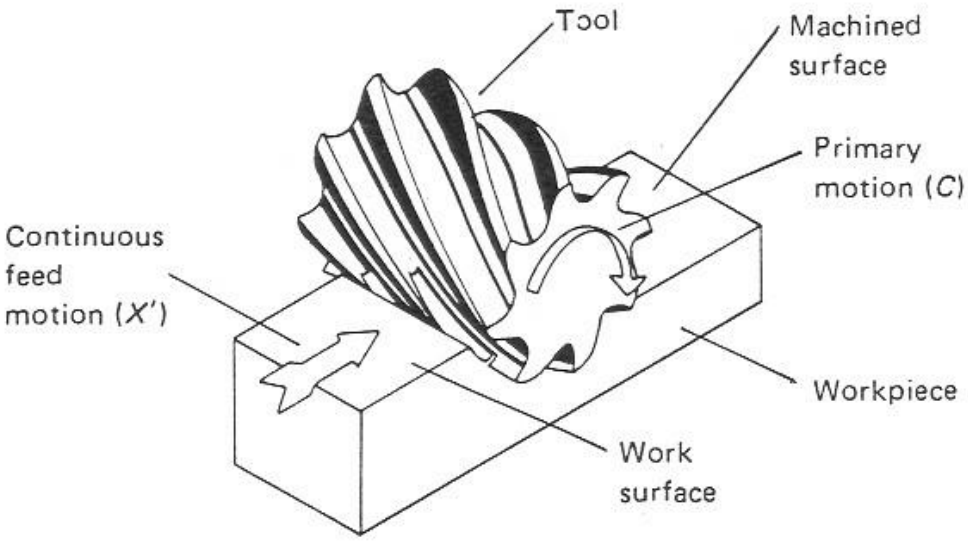


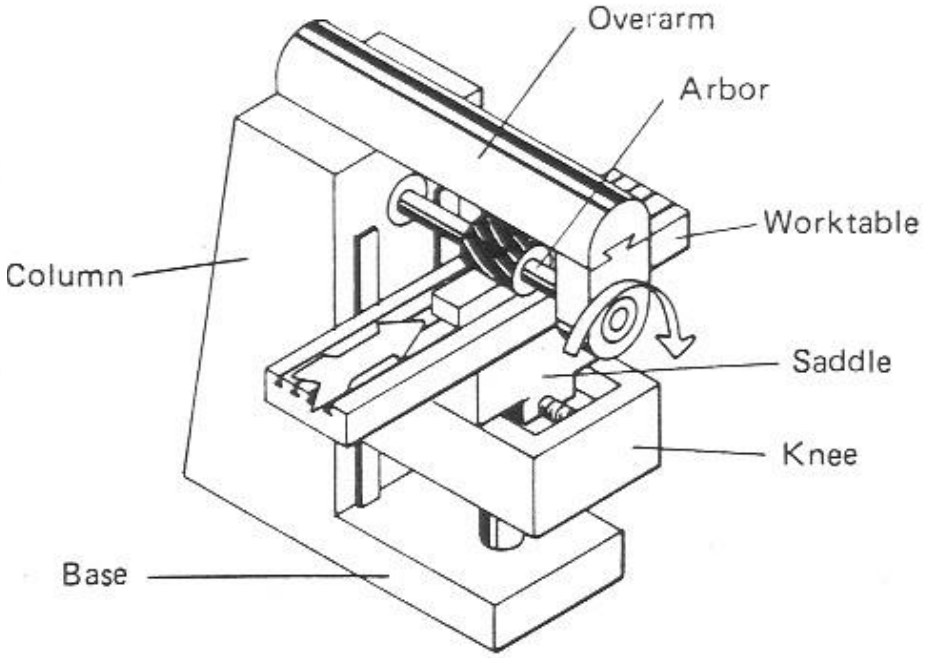
The turning process



[3]

Slab Milling on a Knee-type Horizontal Milling Machine

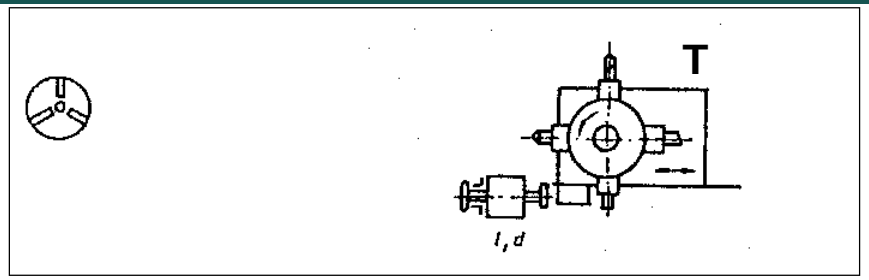




The milling process

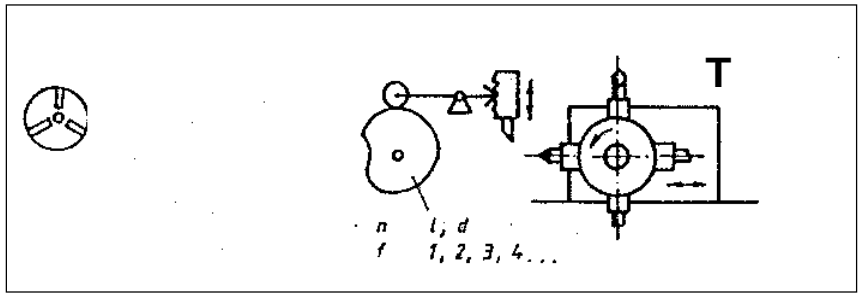
[3]

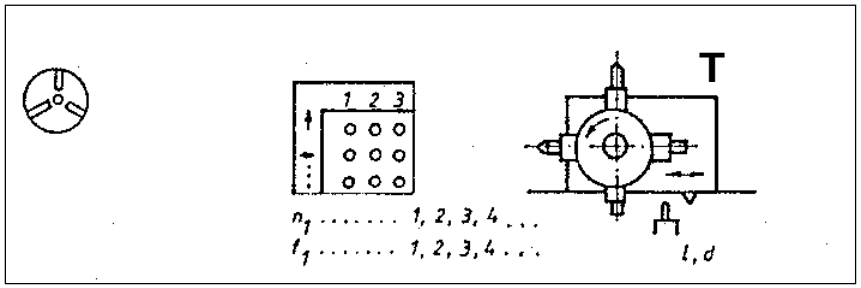
Lathes with Different Level of Automation (history of the automation of lathes)



Turret lathe

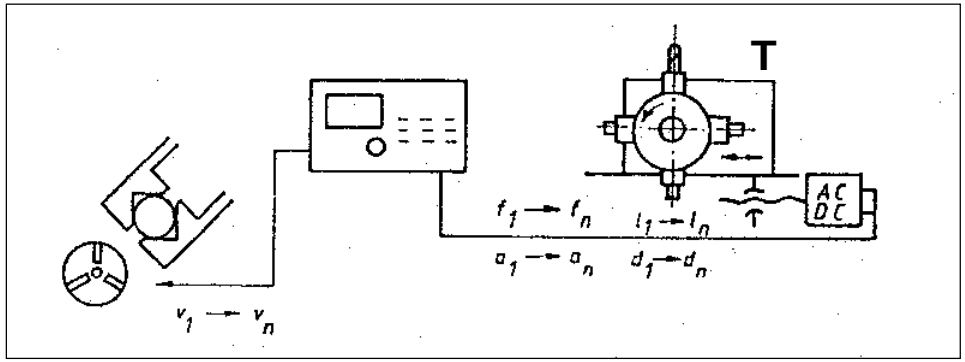
Cam controlled lathe





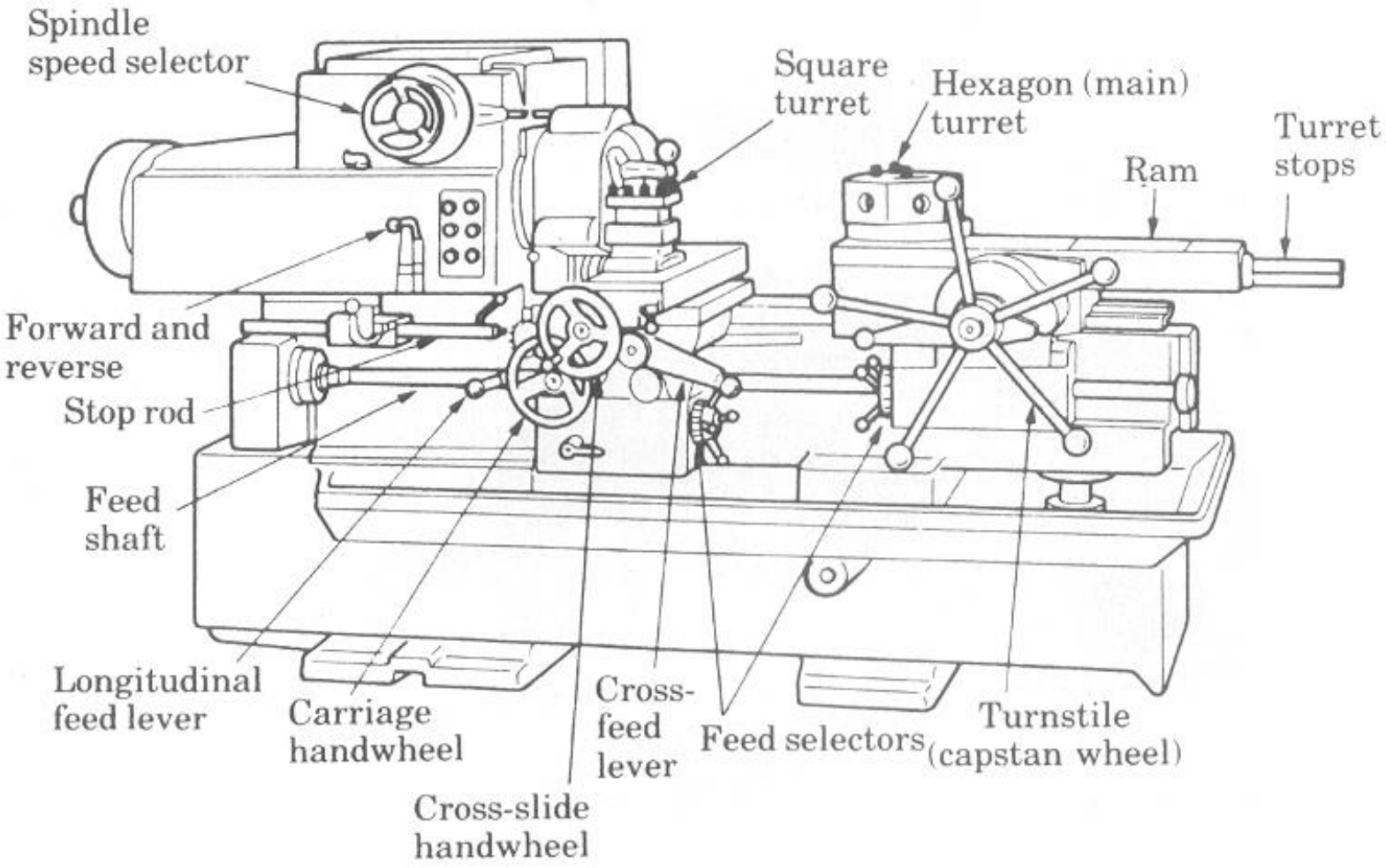
Plug/cycle controlled lathe

CNC controlled lathe



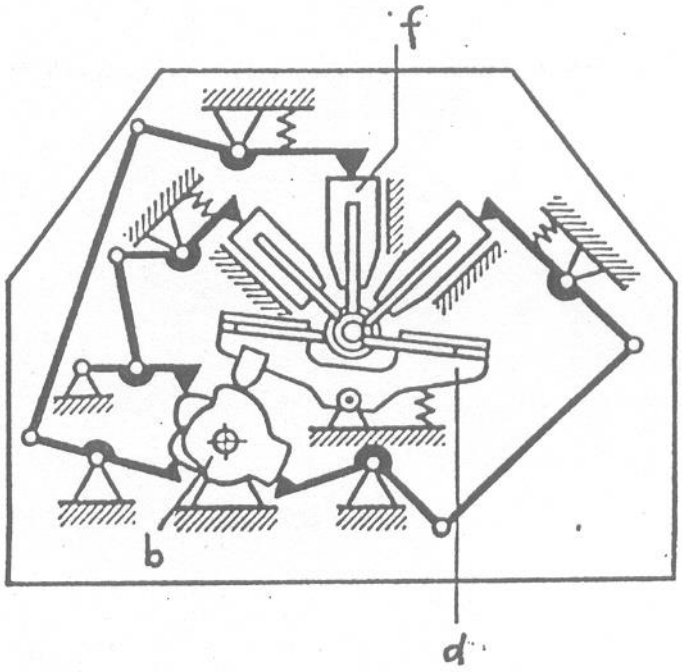
turning process

Turret Lathe



[5]

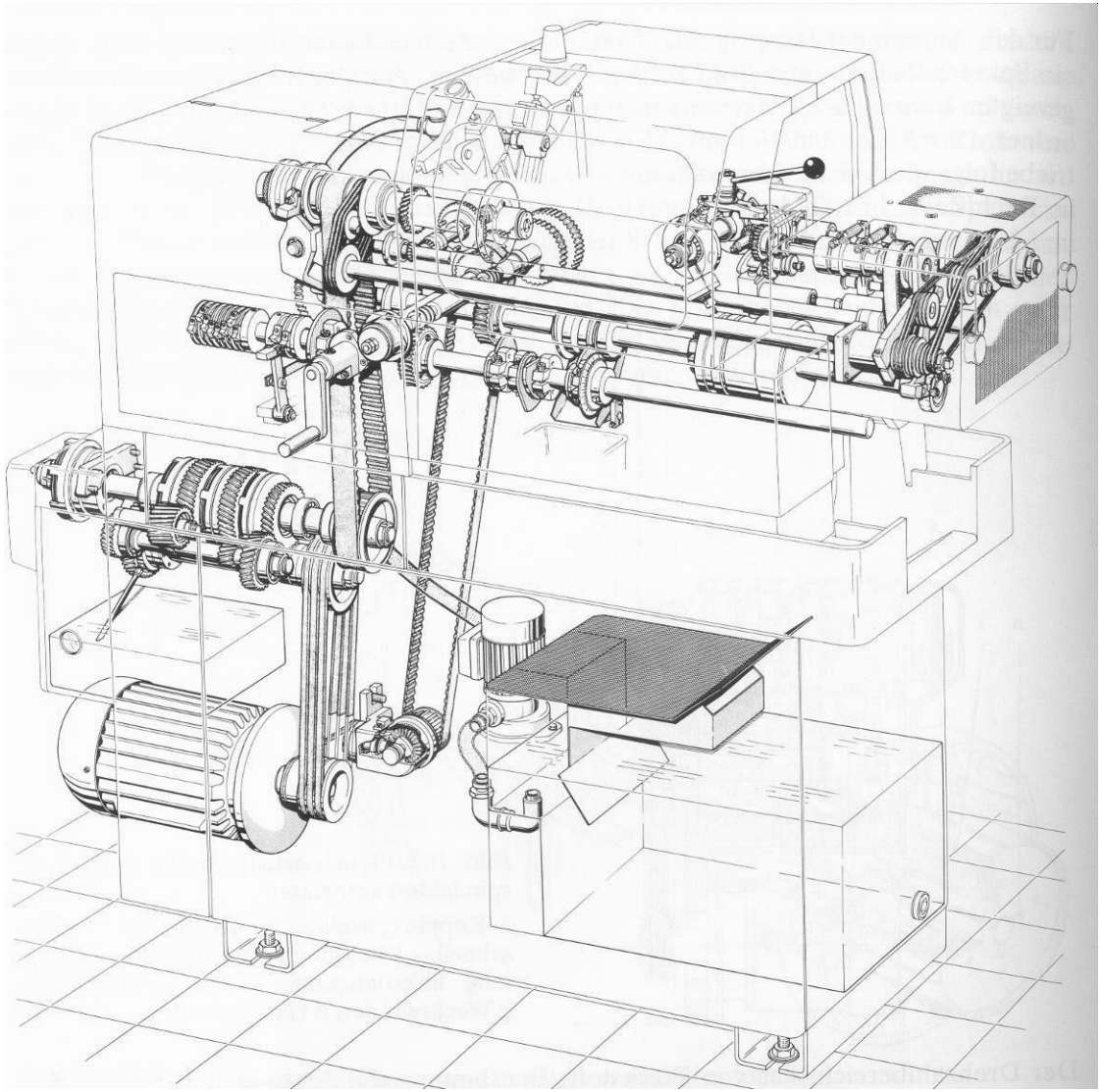
Automatic Bar Machine



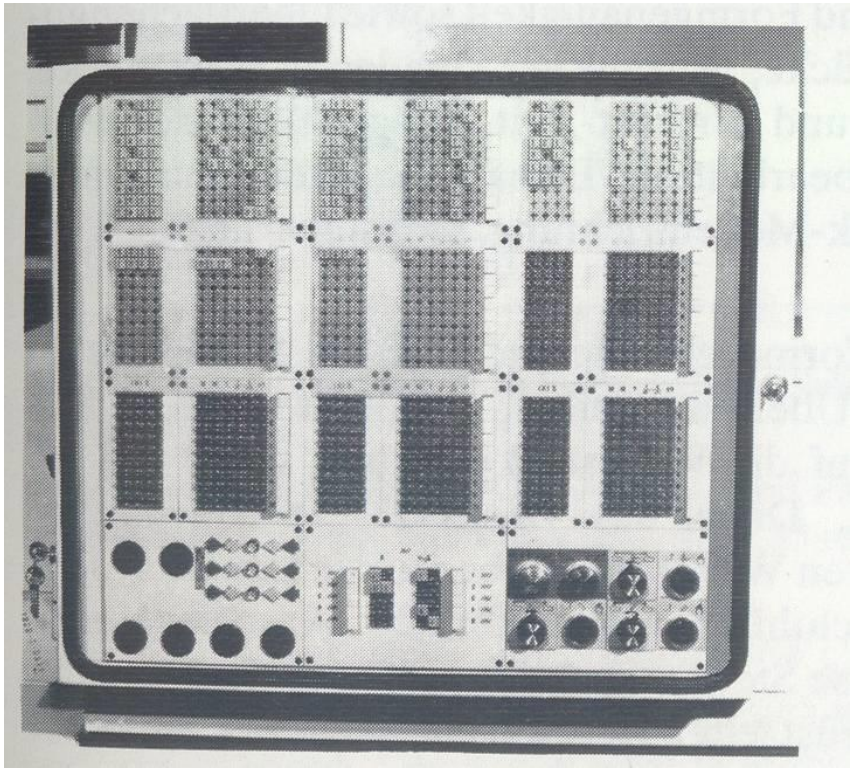
b: cam
d: rocker
f: vertical slide

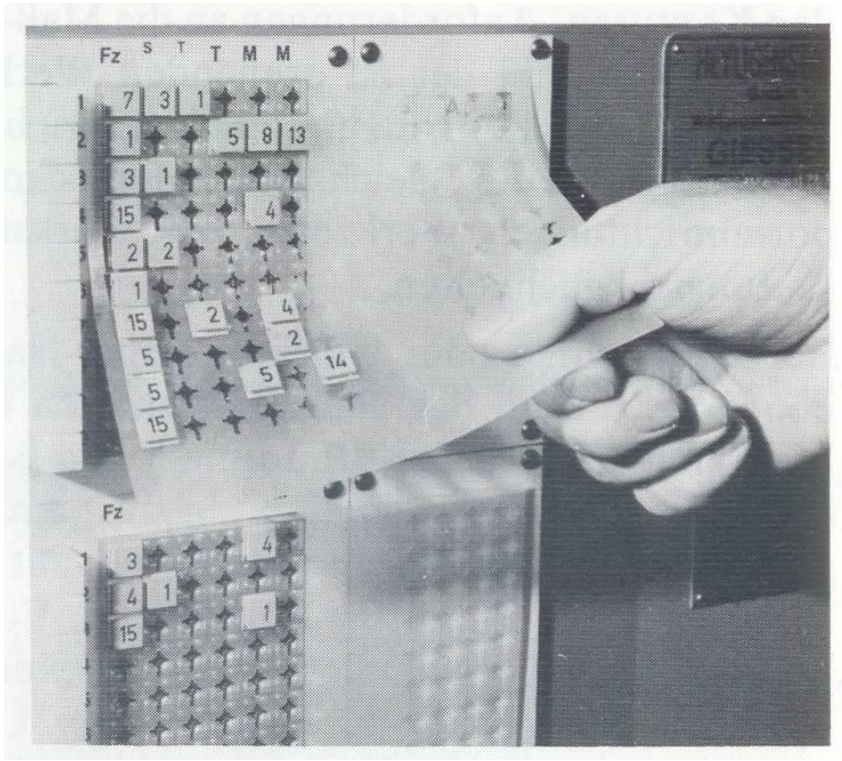
Other name: Swiss-type automatic screw machines
(single spindle)

Automatic Bar Machine (Index)



Plug/Cycle controlled lathe



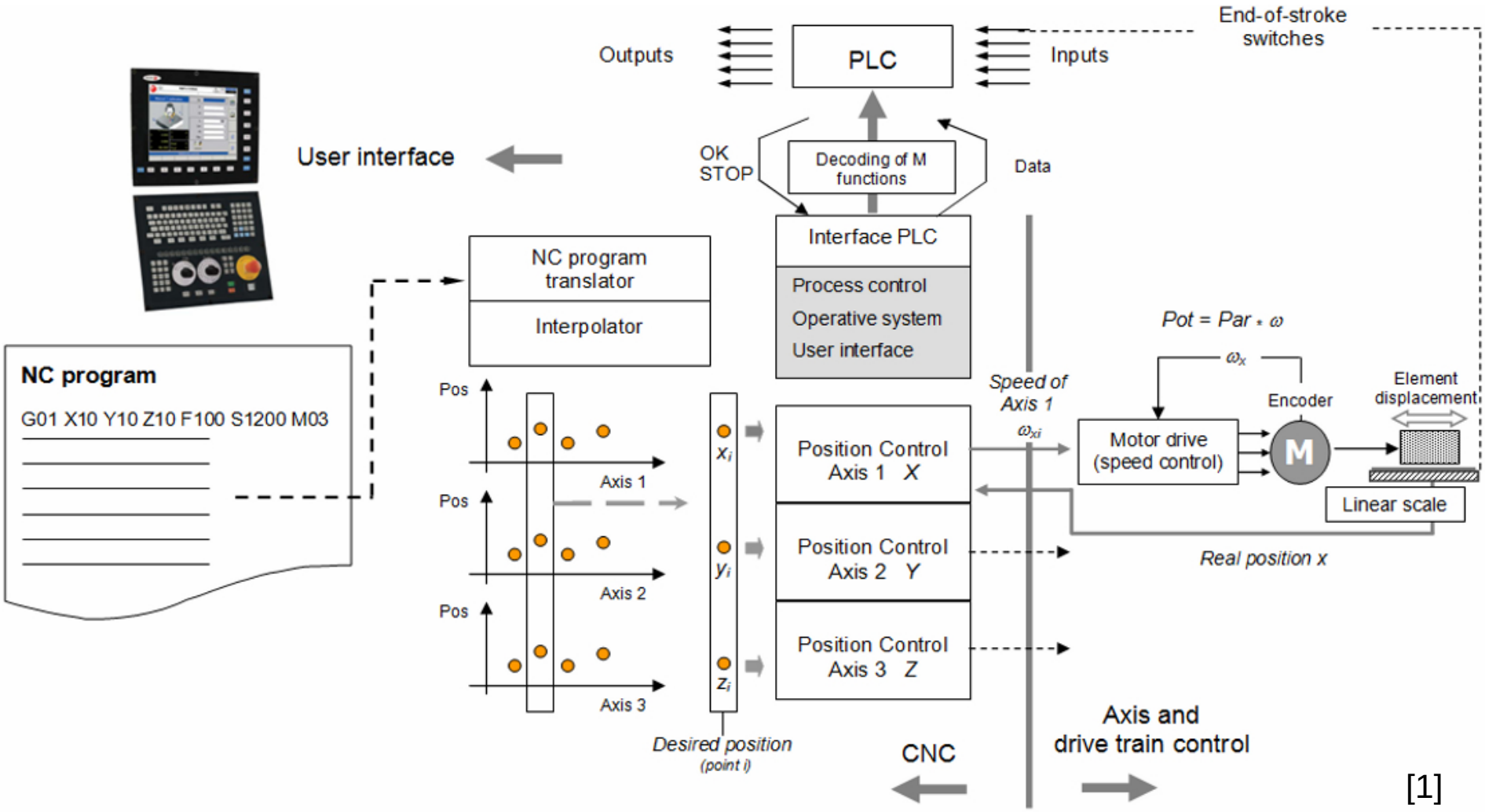


The plug/cycle controlled lathe was a transition between mechanically controlled and NC/CNC machine tools

NC, CNC

- NC – Numerical Control
- CNC – Computer Numerical Control

CNC Integration (1)



[1]

CNC Integration (2)

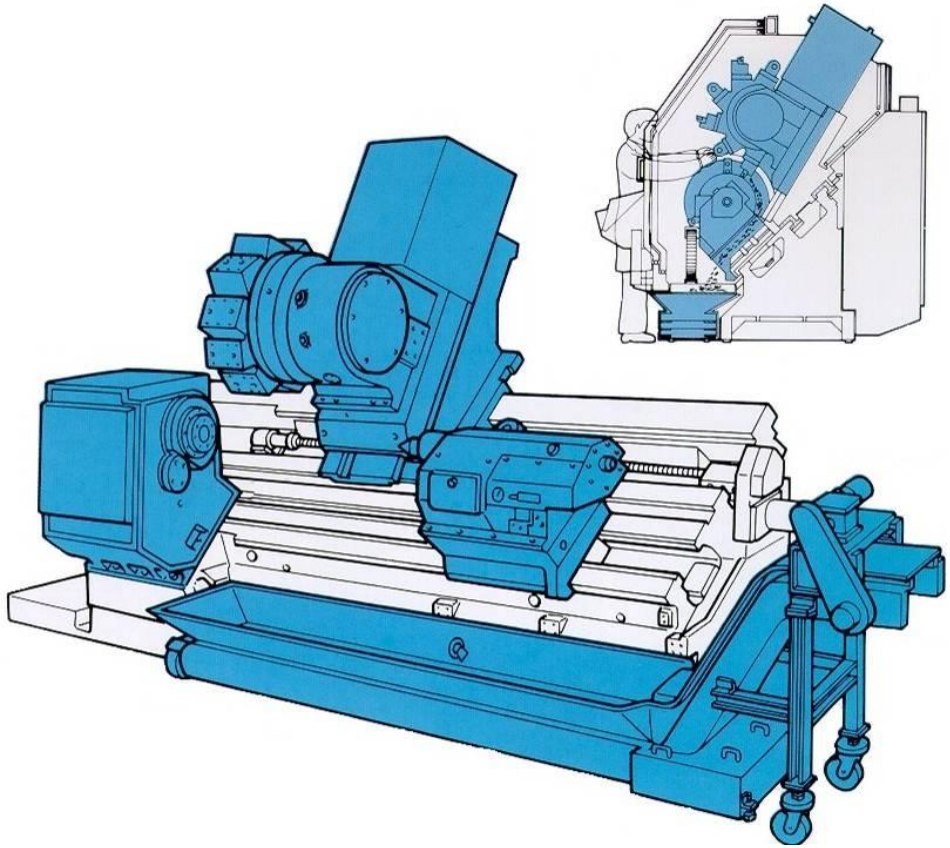
- User interface
- Basic operating system (PC based today)
- Program translator
  - ISO codes
    - G, M codes (e.g. G01 X100 Y200 Z300 F2000 S8000)
  - Special NC languages (per manufacturer)
  - STEP NC
- Interpolator
  - linear, circular, etc.
- Axes control
  - sensors (position sensors: rotary encoder or linear scale)
  - motors and their servoamplifiers, high voltage power amplifier unit
  - feed back control techniques (e.g. PID)
- PLC (Programmable Logic Controller)
  - to control the auxiliary machine functions (M functions in ISO) such as tool change, coolant on/off, etc.

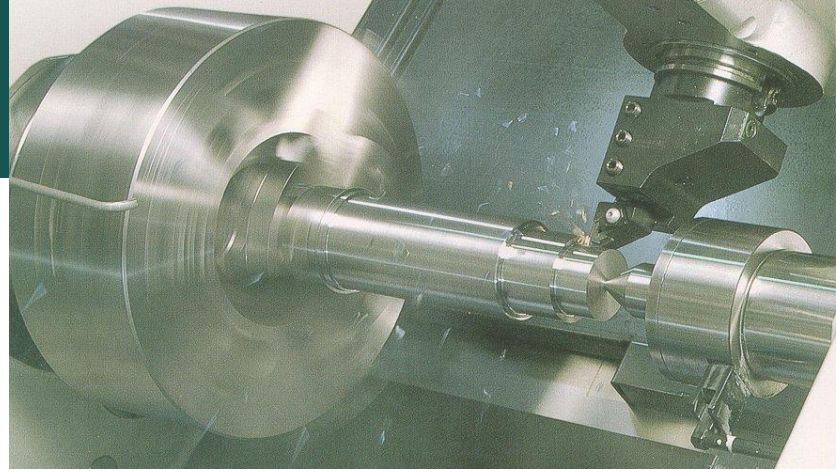
[1]

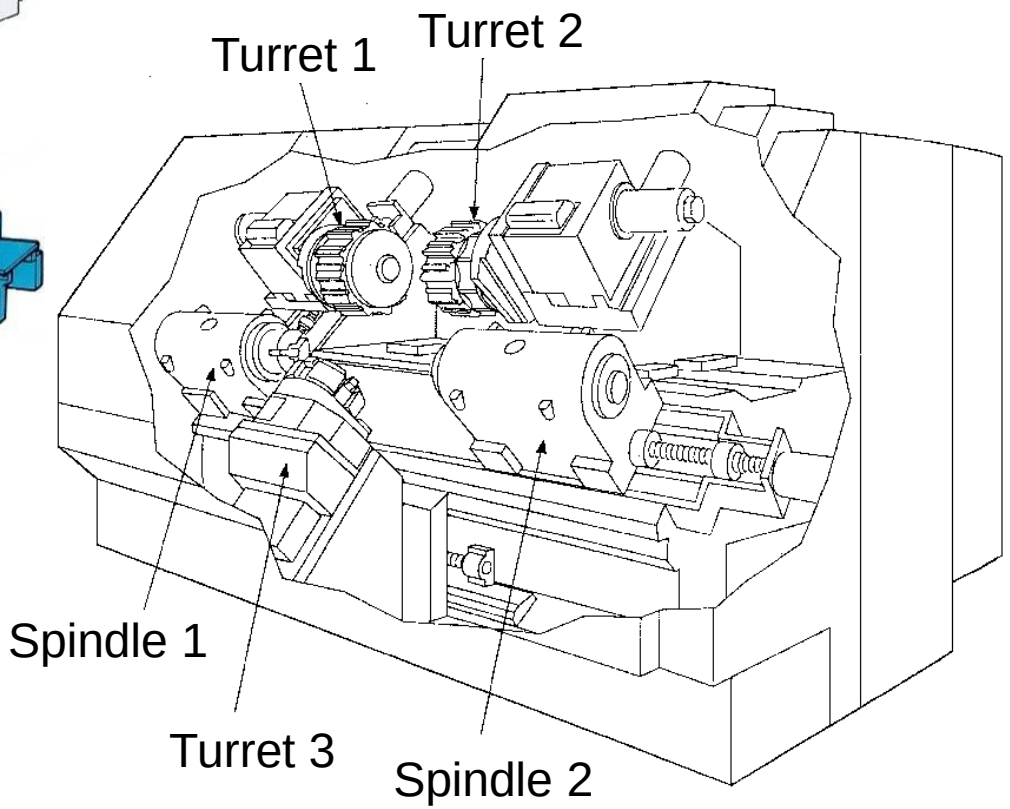
Advantages of Application of CNC Machine Tools

- Increased flexibility
  - easy to setup from one part to another
- Greater accuracy
  - computers have a higher sampling rate and faster operations
- More versatility
  - editing and debugging programs, reprogramming
- Higher productivity
- Integration into a system is easier

CNC Lathe





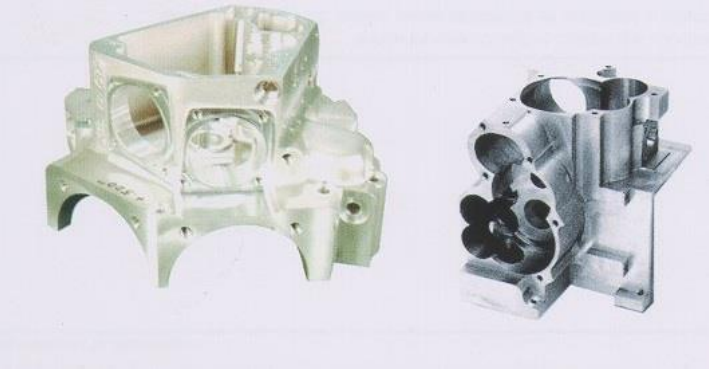


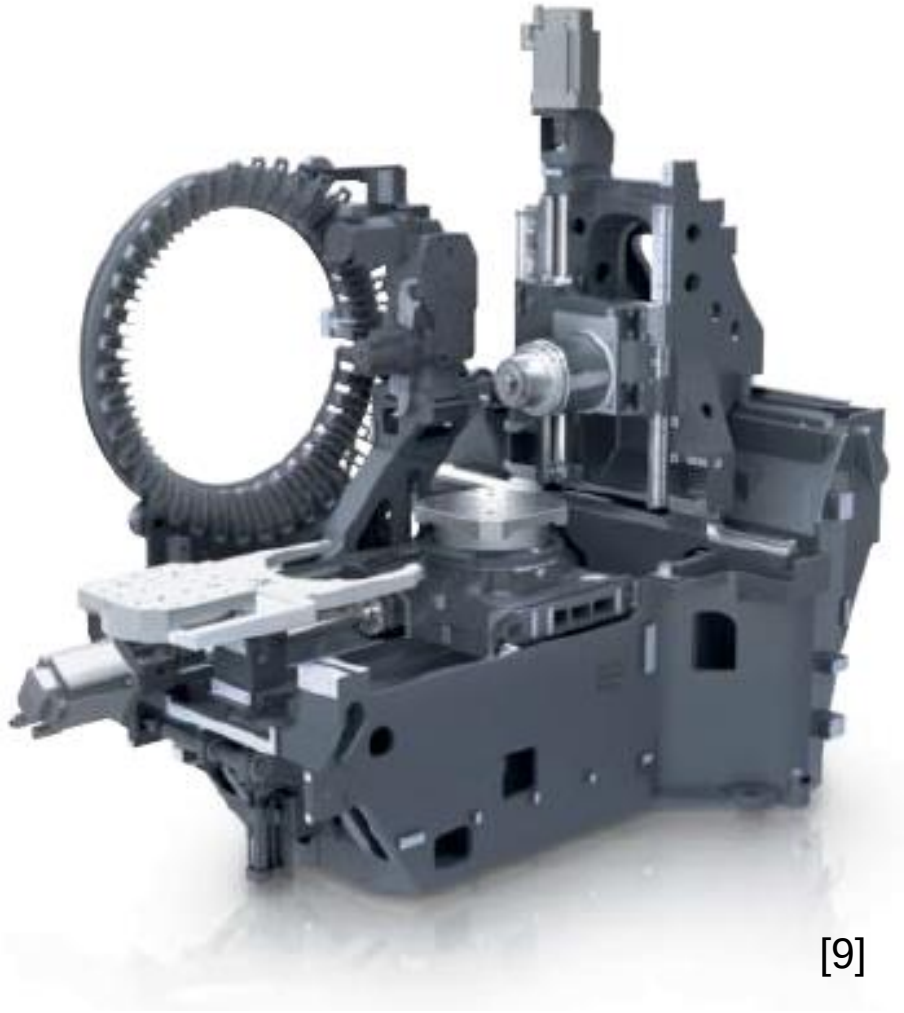
turning process

Machining Centres

- CNC machine tool with rotating tool
- Automatic tool change
  - increased productivity
  - increased accuracy (fewer error caused by part change)
  - fewer machines required

Typical workpieces:



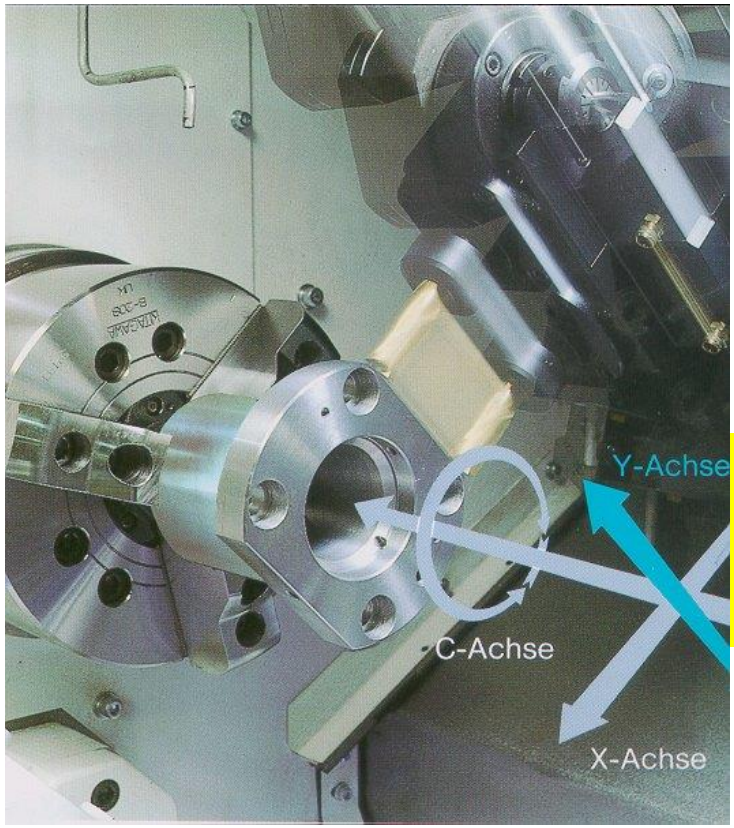


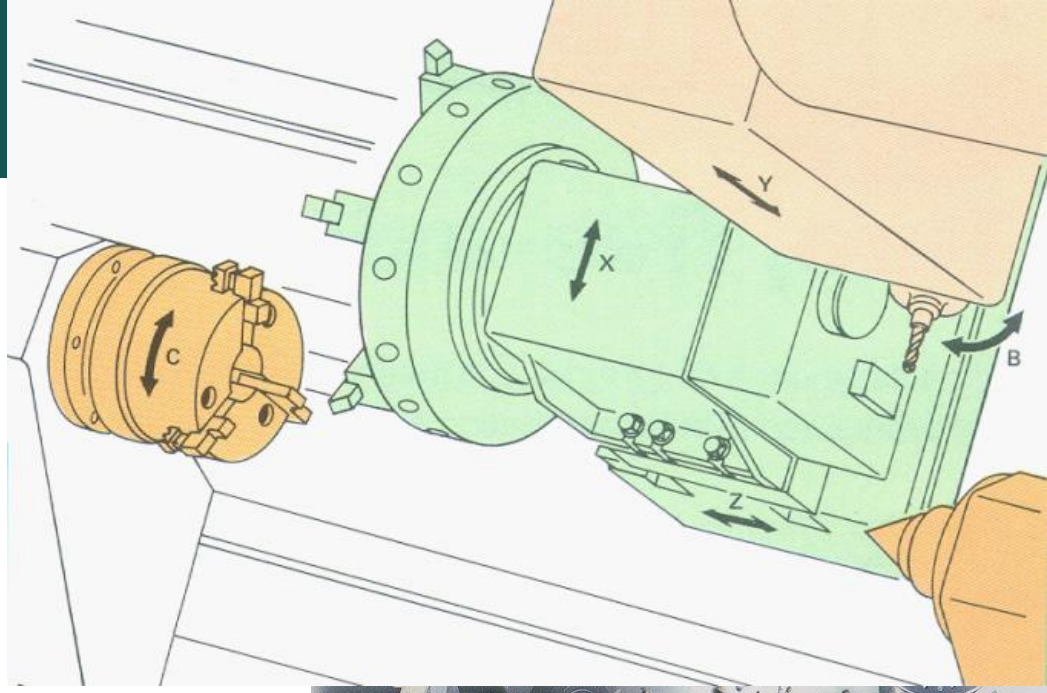
[9]

milling-drilling process

Turning Centres

C and Y axes machining

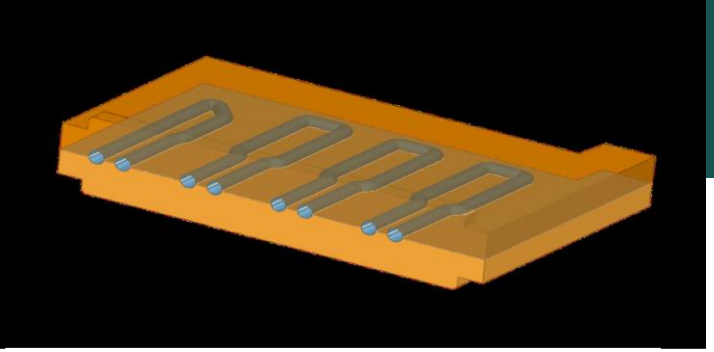


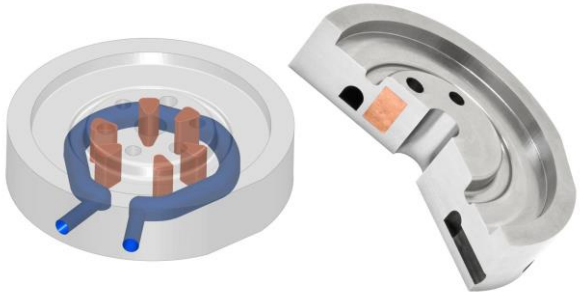


Turning + Milling-drilling processes

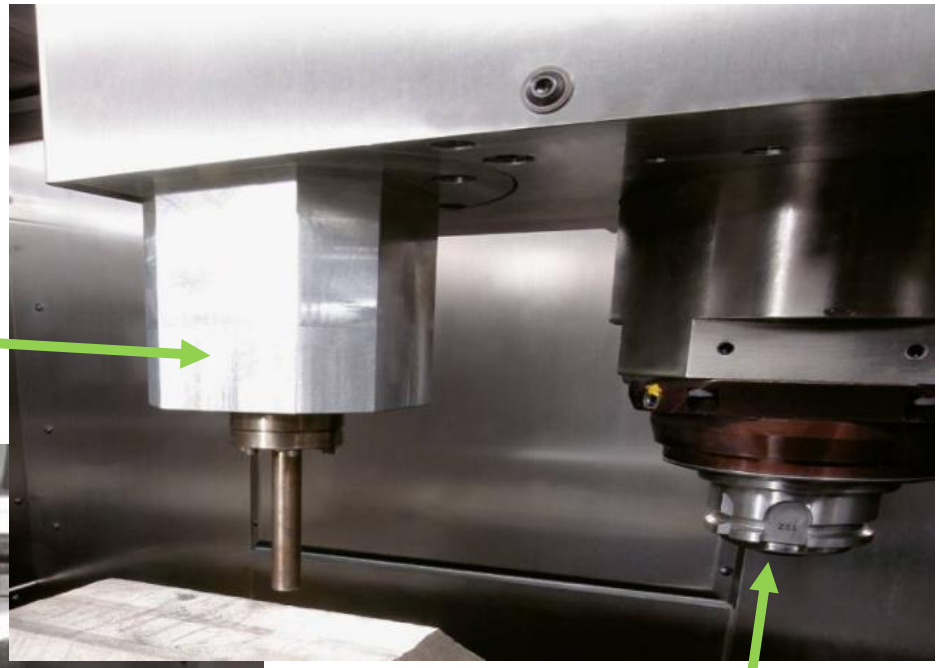
C, Y and B axes machining

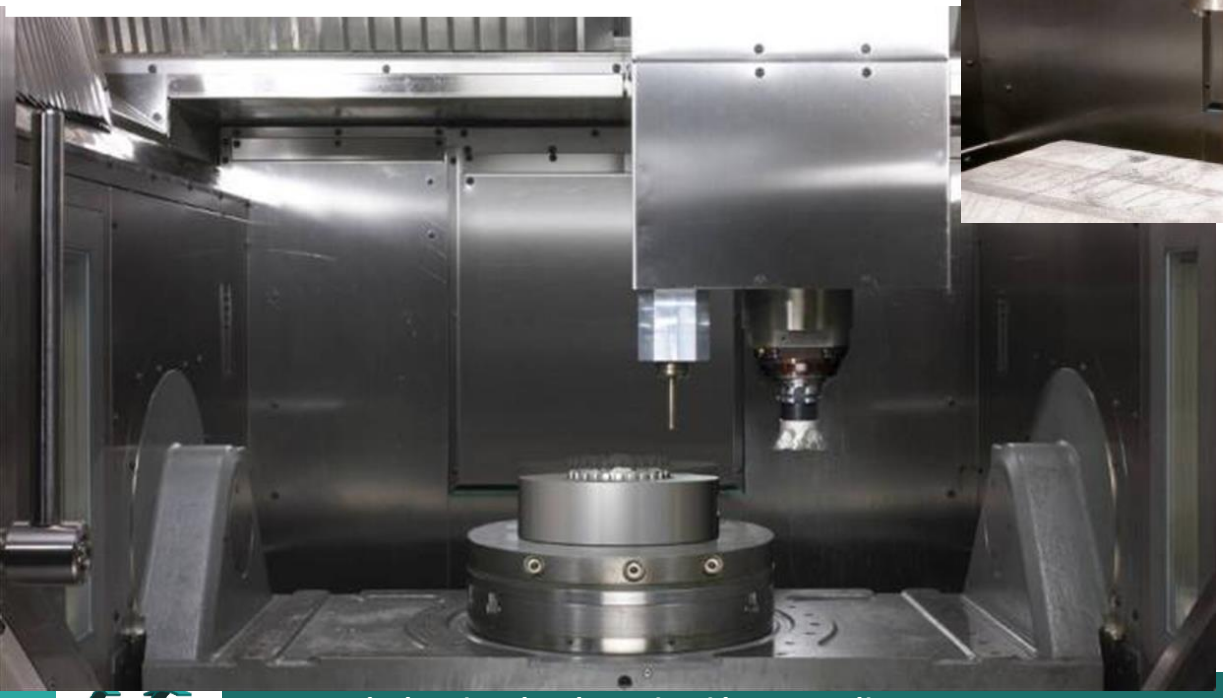
Hybrid Machine Tools





Additive technology (MPA)



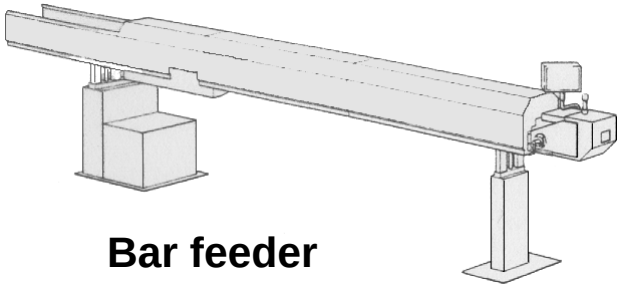


Cutting technology (subtractive)

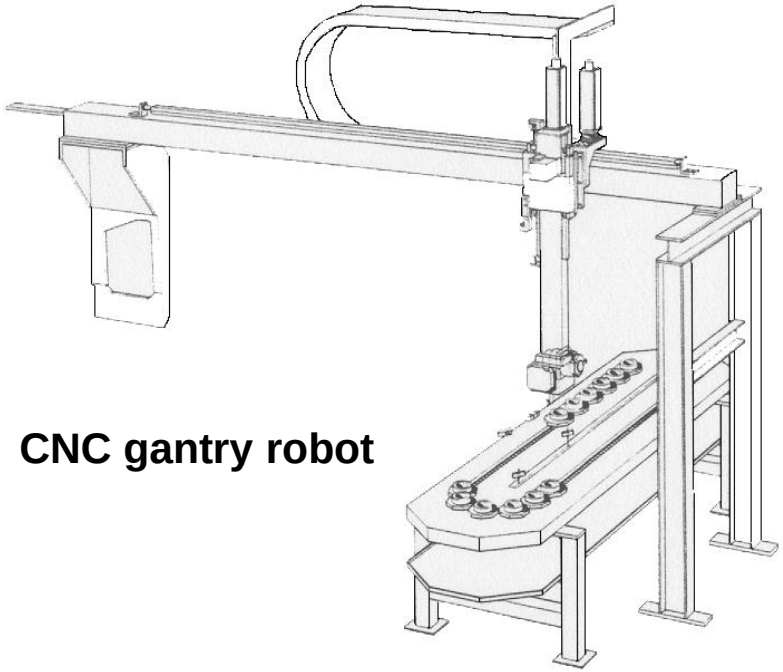
[22]

Workpiece Load/Feed/Unload on Machine Tools

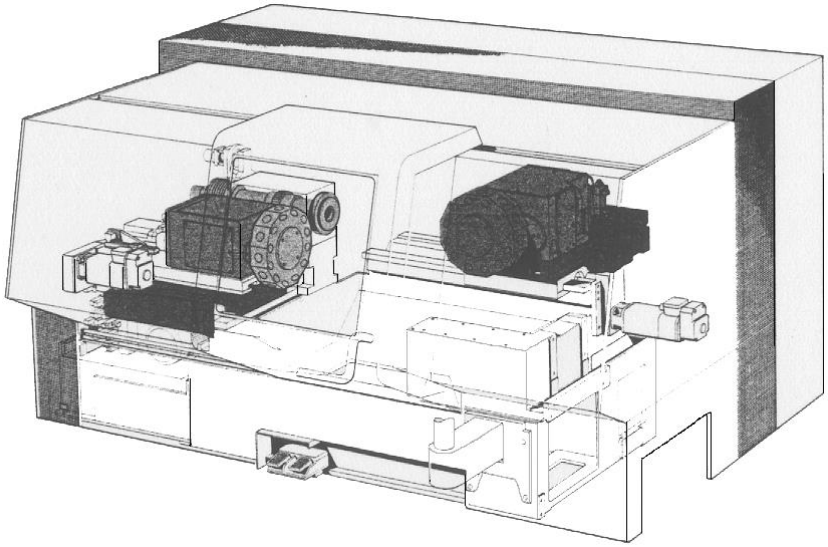
Workpiece Feeding of CNC Lathes

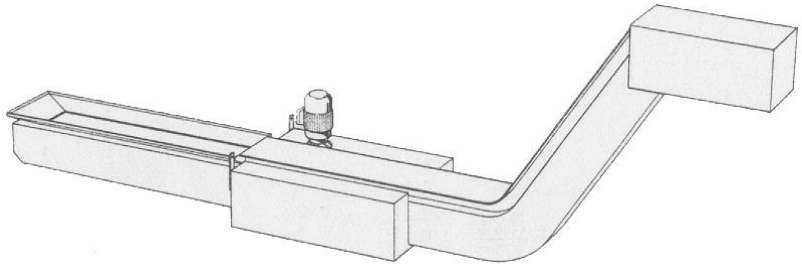


Bar feeder



CNC gantry robot

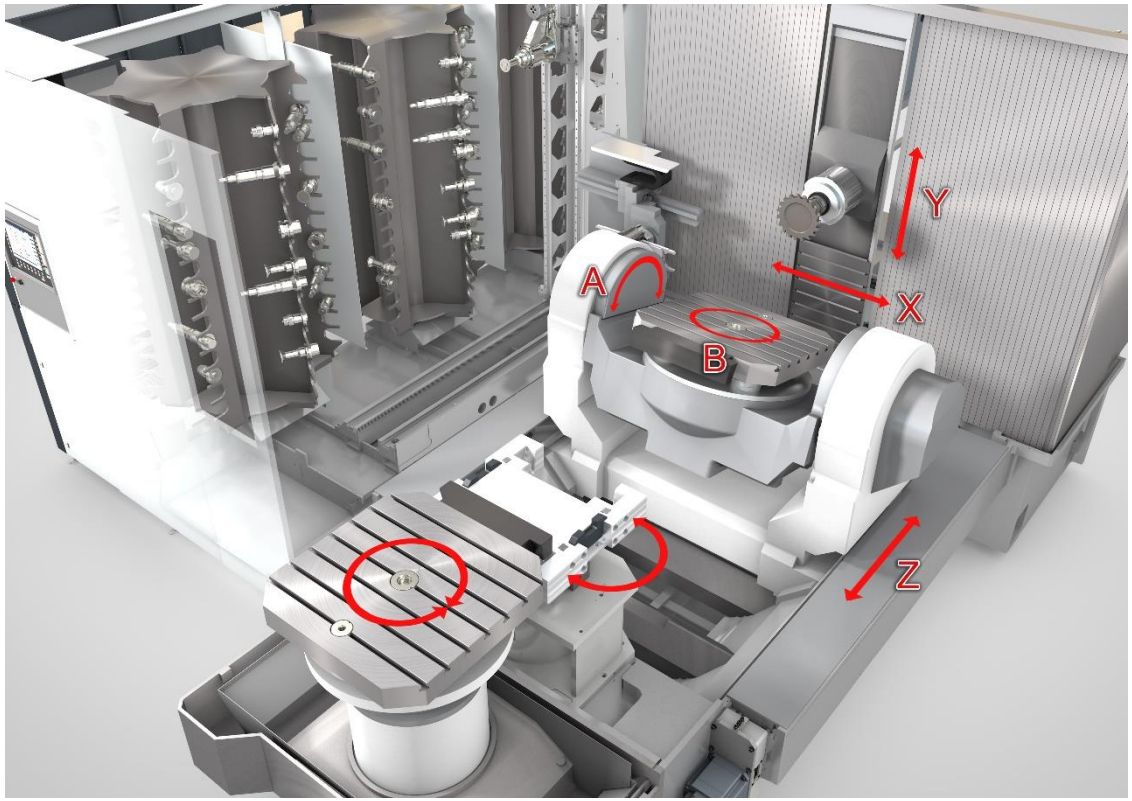




(Chip conveyor)

Automatic Pallet Change

5-axis machining centre with tower tool magazine + pallet changer



Starrag Heckert HEC X5 series

Material Handling Equipment

- Storage equipment
  - racks
  - stacking frames
  - shelves, bins and drawers
  - mezzanines
  - etc.
- Intermittent operation material handling machinery
  - cranes
  - industrial trucks (e.g. forklifts, automatic guided vehicles (AGVs))
  - robots
  - etc.
- Continuous operation material handling machinery
  - conveyors
    - power or free
    - overhead or floor: belt, roller, chain
  - elevators
  - etc.

Automated Guided Vehicles (AGVs)

- Several transporting solutions
  - load carrier, tractor, fork lift, etc.
- Several steering solutions
- Path control
  - Wire-guided
  - Light-guided
  - Free-ranging
  - Image processing

[15]


[16]


[17]

Industrial Robots

- Programmable multifunctional manipulator designed to move materials, parts, tools or other devices.
- Basic kinematics + end effector
- "Programmable":
  - playback robot
  - numerically controlled robot (similar to NC/CNC machine tools)
  - intelligent robot (sensory robots)

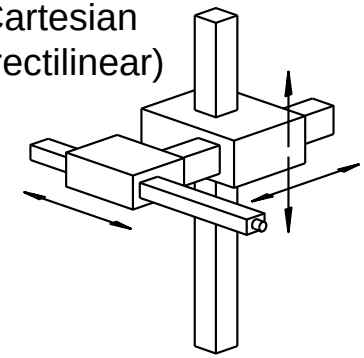
BMW's robotic welding line, in Spartanburg, S.C. [19]

[5]

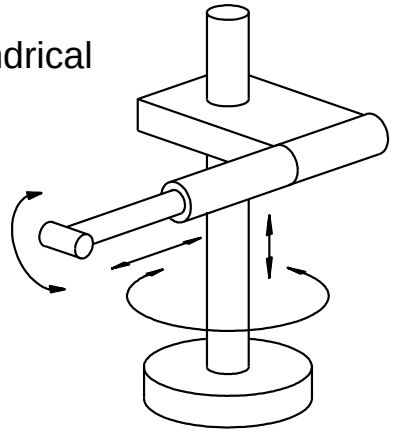
Basic Kinematics of Industrial Robots

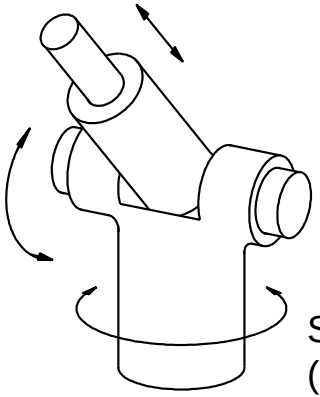
Serial kinematics

Cartesian
(rectilinear)



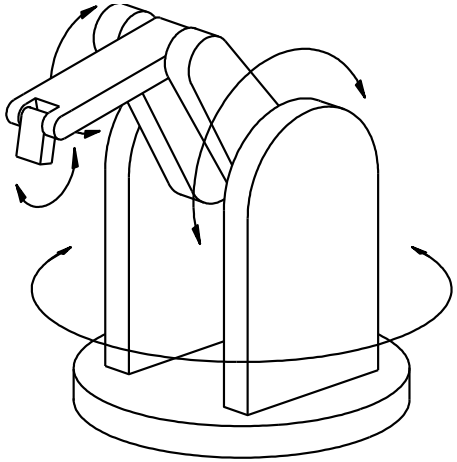
Cylindrical

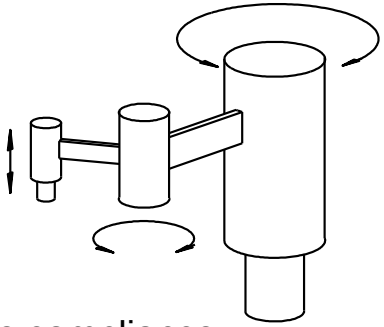




Spherical
(polar)

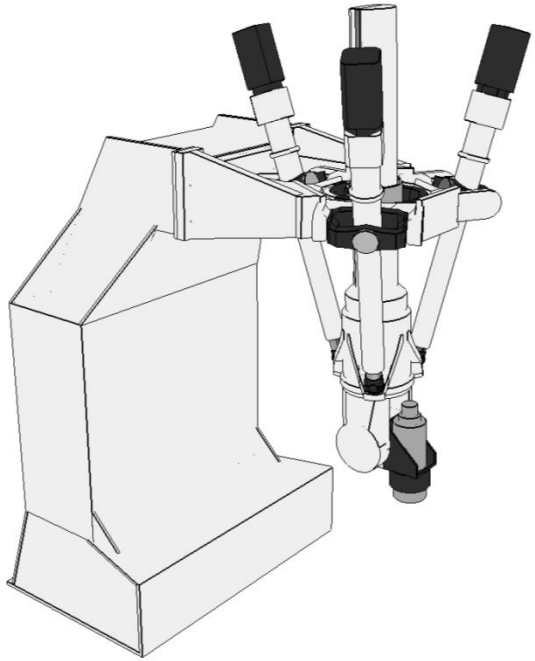
Anthropomorphic
(humanoid)





SCARA
(selective compliance
assembly robot arm)

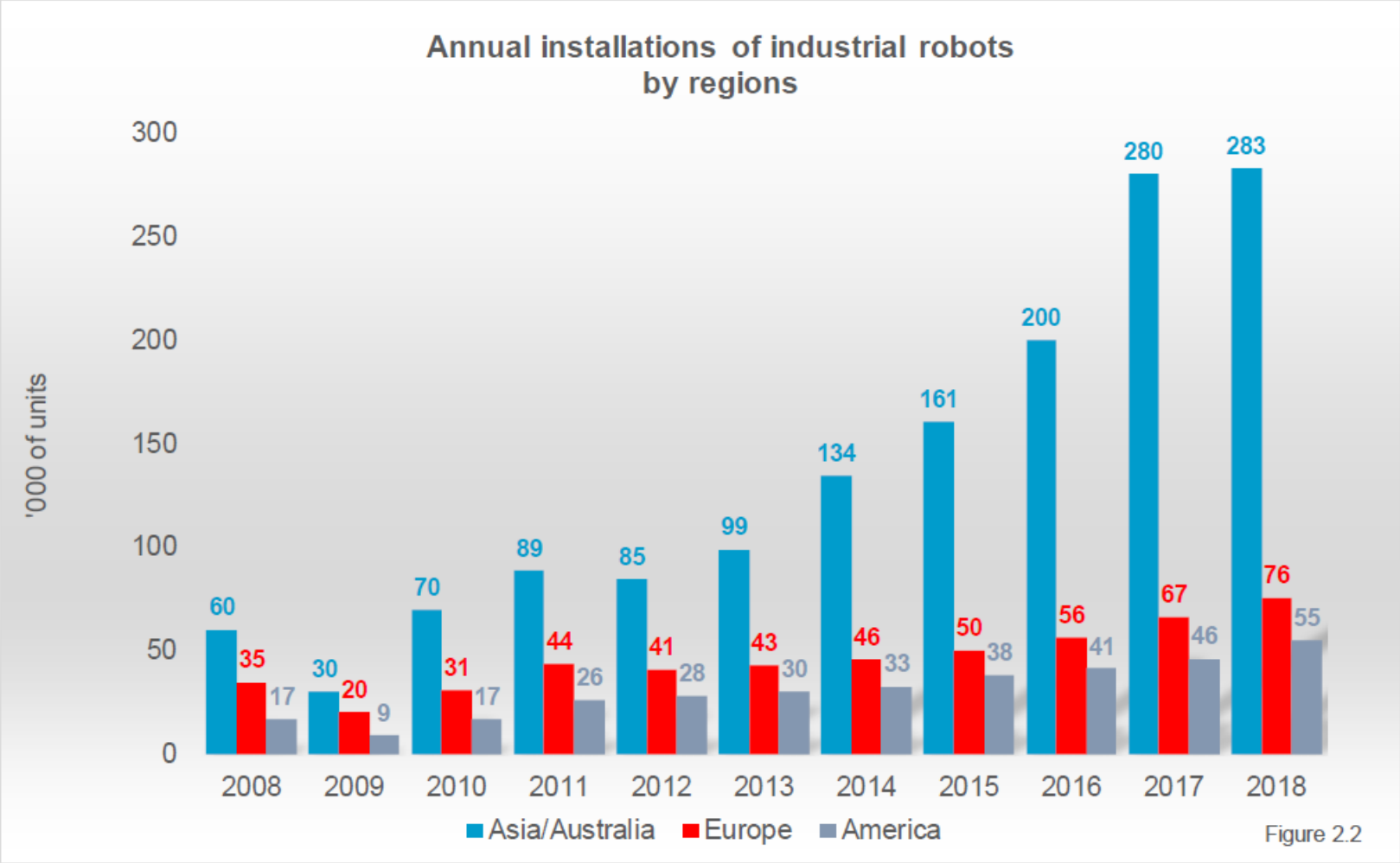
Parallel kinematics



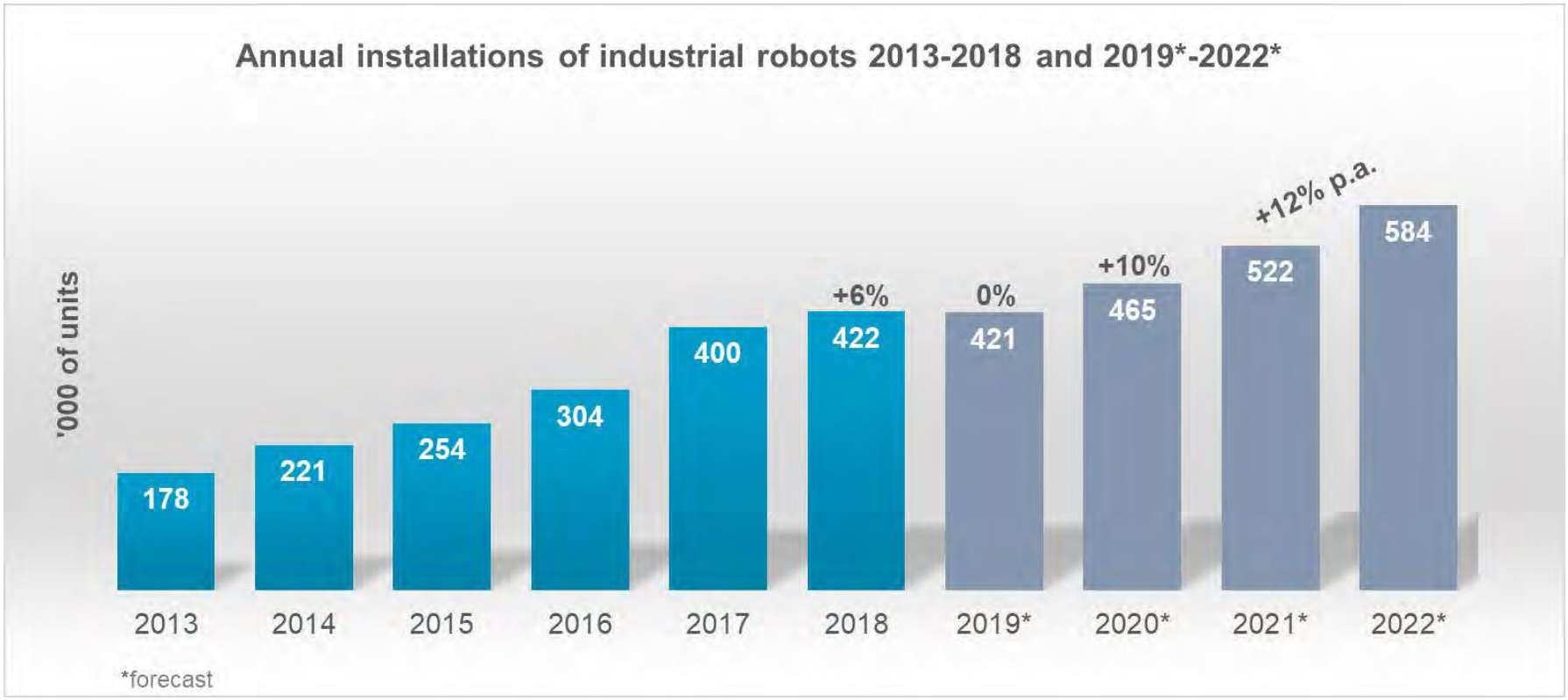
Source: Tricept model,
Visual Components Library

Application of Industrial Robots in Manufacturing

- Material handling: loading, unloading, transferring
- Spot welding, arc welding, arc cutting, riveting
- Deburring, grinding, polishing
- Applying adhesives and sealants
- Spray painting
- Assembly
- Inspection and gauging
- Machining (drilling, milling)
- Other (laser welding)


Annual installations of industrial robots by regions
'000 of units
300
250
200
150
100
50
0
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
60
35
17
30
20
9
70
31
17
89
44
26
85
41
28
99
43
30
134
46
33
161
50
38
200
56
41
280
67
46
283
76
55
Asia/Australia
Europe
America
Figure 2.2

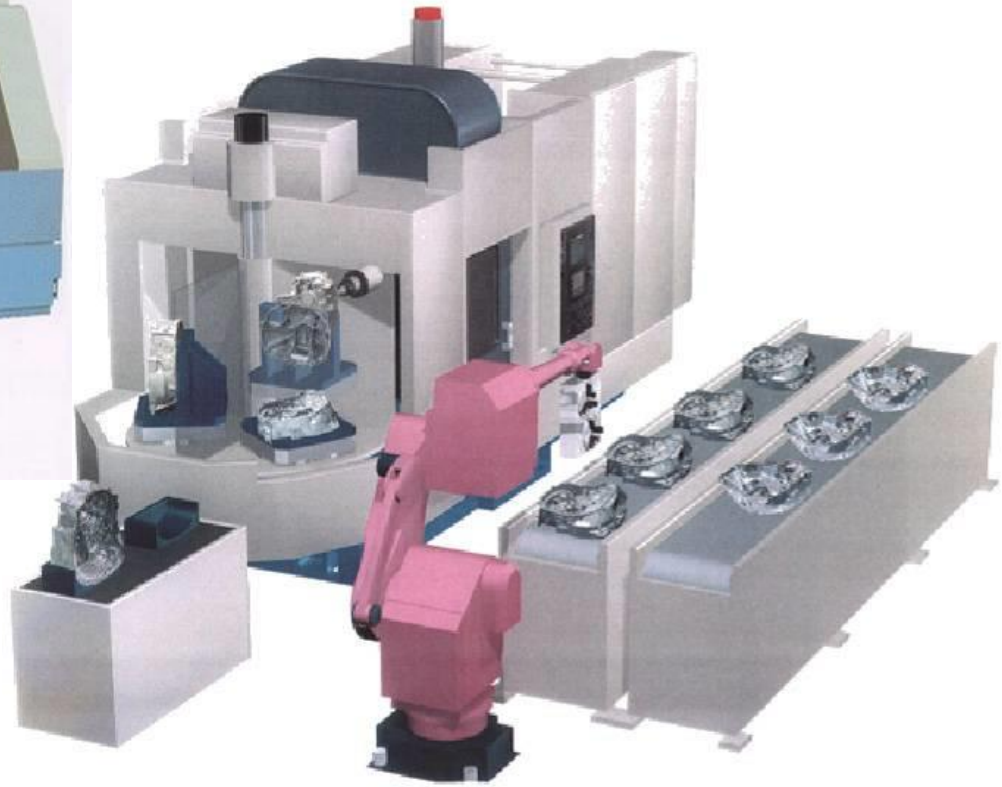
[19]


Annual installations of industrial robots 2013-2018 and 2019*-2022*
'000 of units
178
221
254
304
400
+6%
422
0%
421
+10%
465
+12% p.a.
522
584
2013
2014
2015
2016
2017
2018
2019*
2020*
2021*
2022*
*forecast

Robotic Loading of Machine Tools

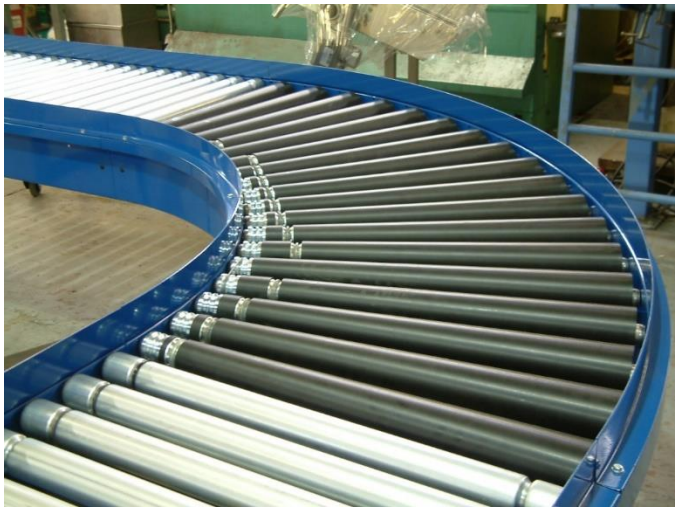
Turning cell

Milling cell

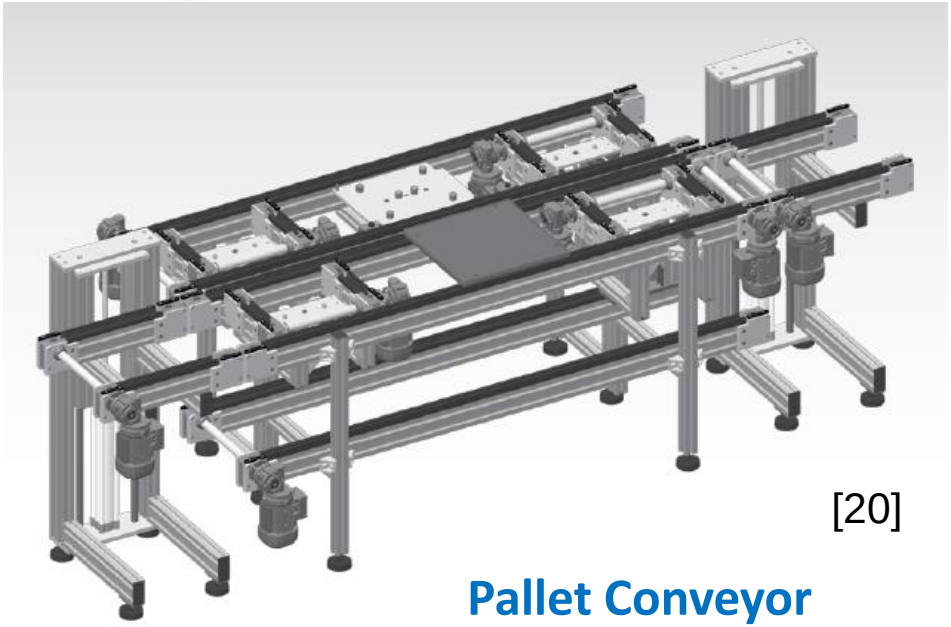


Conveyors (few examples of many types)

Belt conveyor



Roller conveyor [18]



[20]

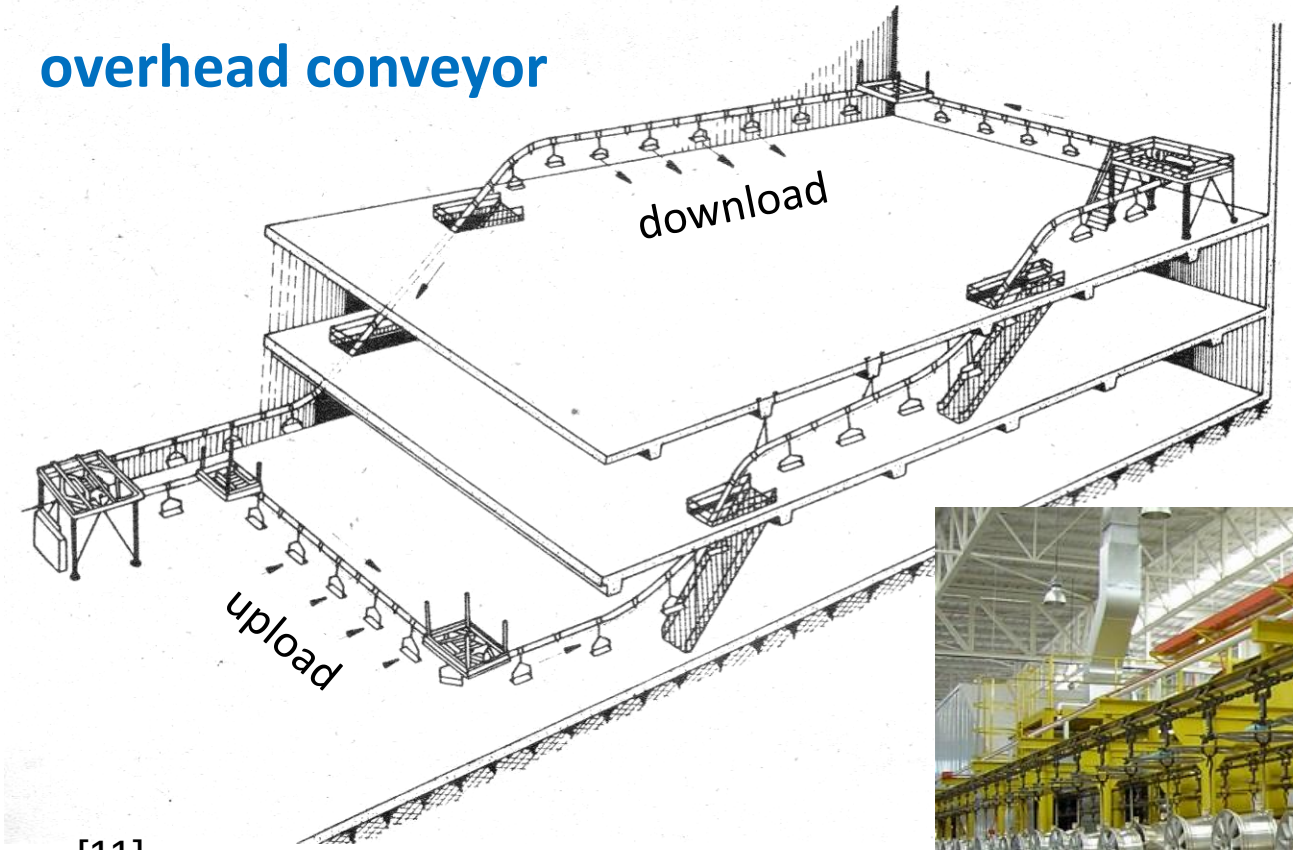
Pallet Conveyor

[18]

Flexible chain conveyor

Conveyors (few examples of many types)

overhead conveyor

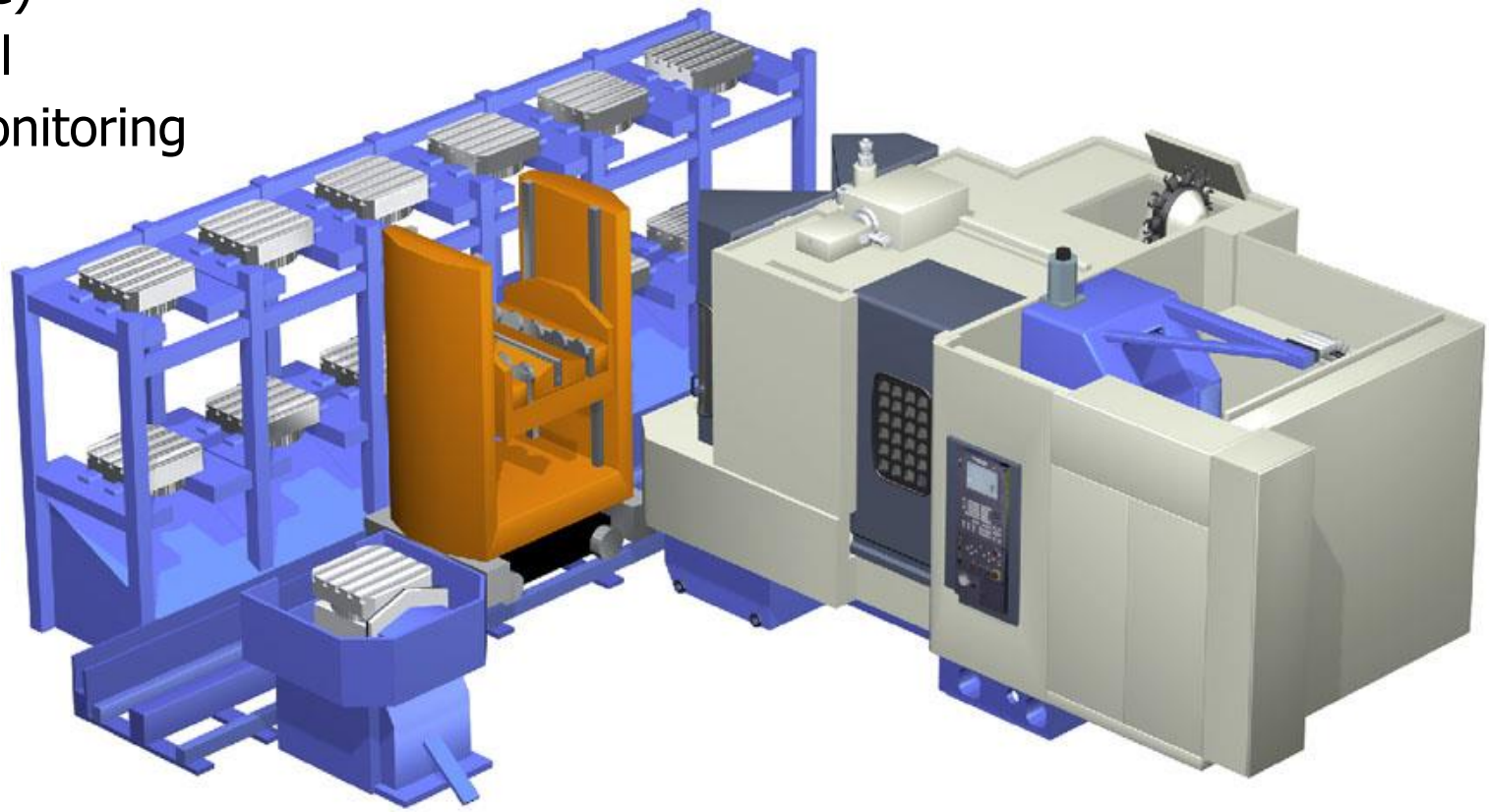


[11]

[18]

Machining (Milling) Cell

- Machining centre
- Automatic workpiece change (e.g. pallet changer)
- Automatic workpiece store (e.g. pallet store)
- Cell control
- System monitoring

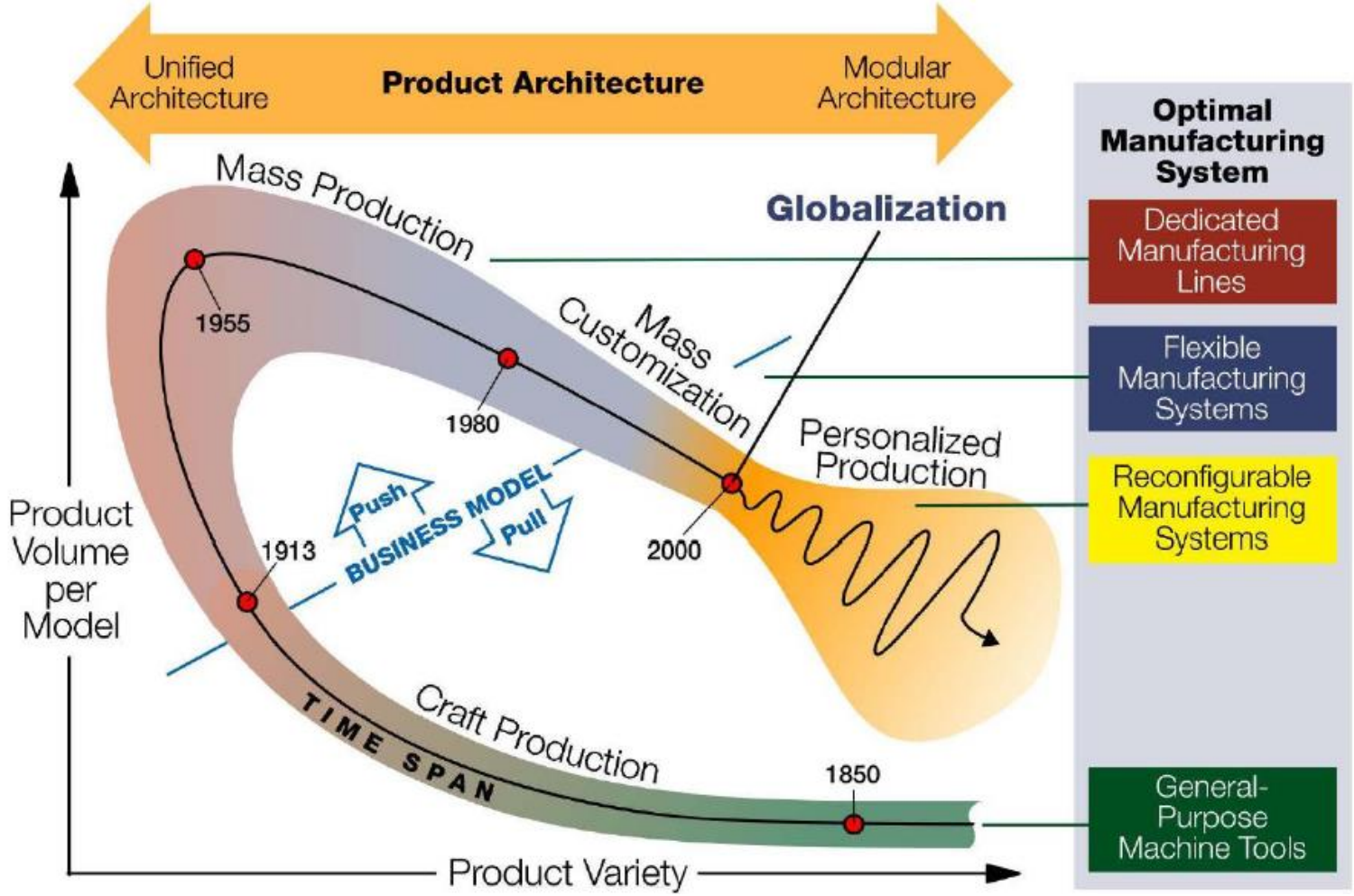


Manufacturing System (definition)

- "System"
  - Greek "systema" = to combine
  - Today "system" = An arrangement of physical entities, one characterised by its identifiable and quantifiable interacting parameters.
- Manufacturing System:
  A large number of interdependent activities consisting of distinct entities (such as materials, tools, machines, power, and human beings)

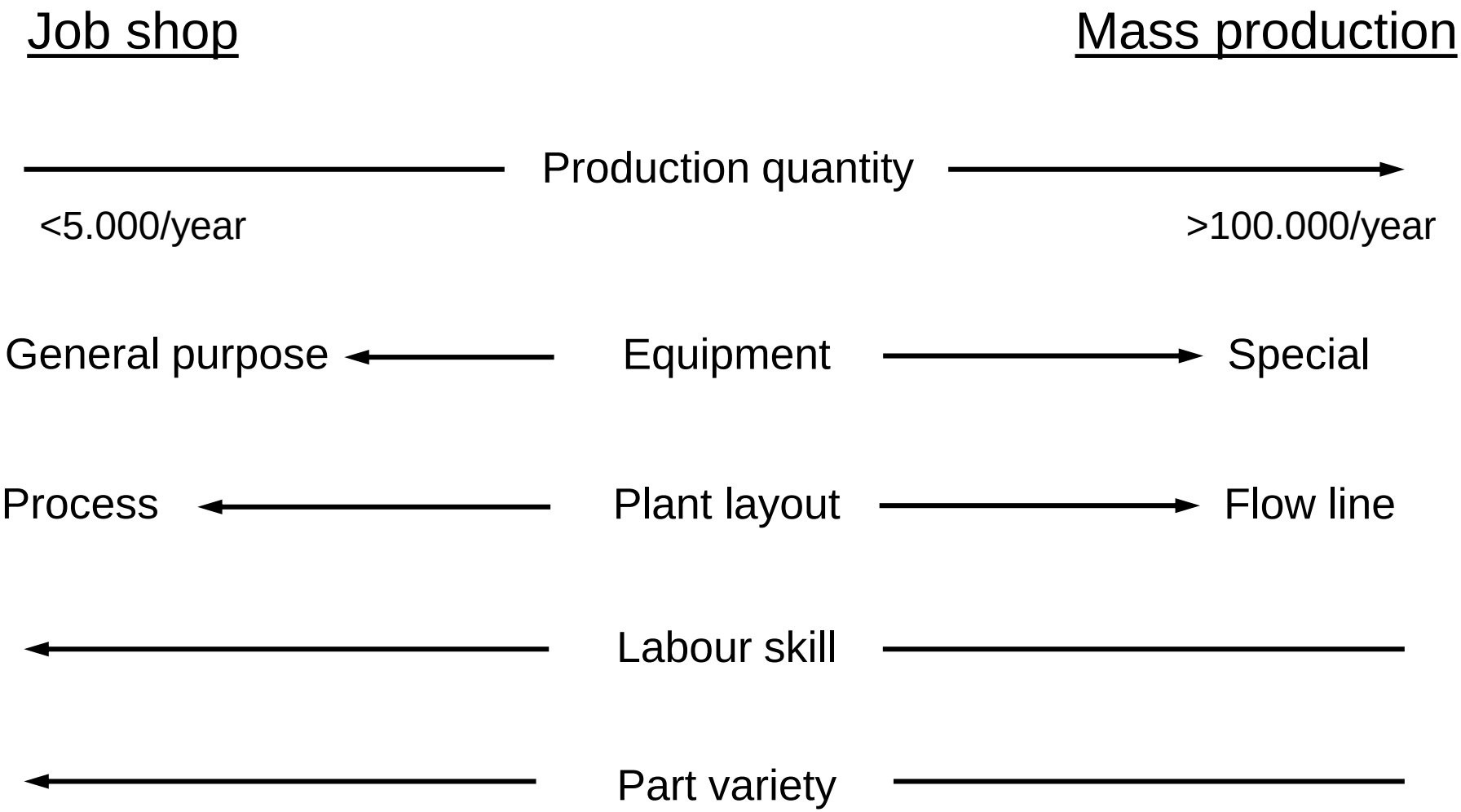
[5]

Production paradigms



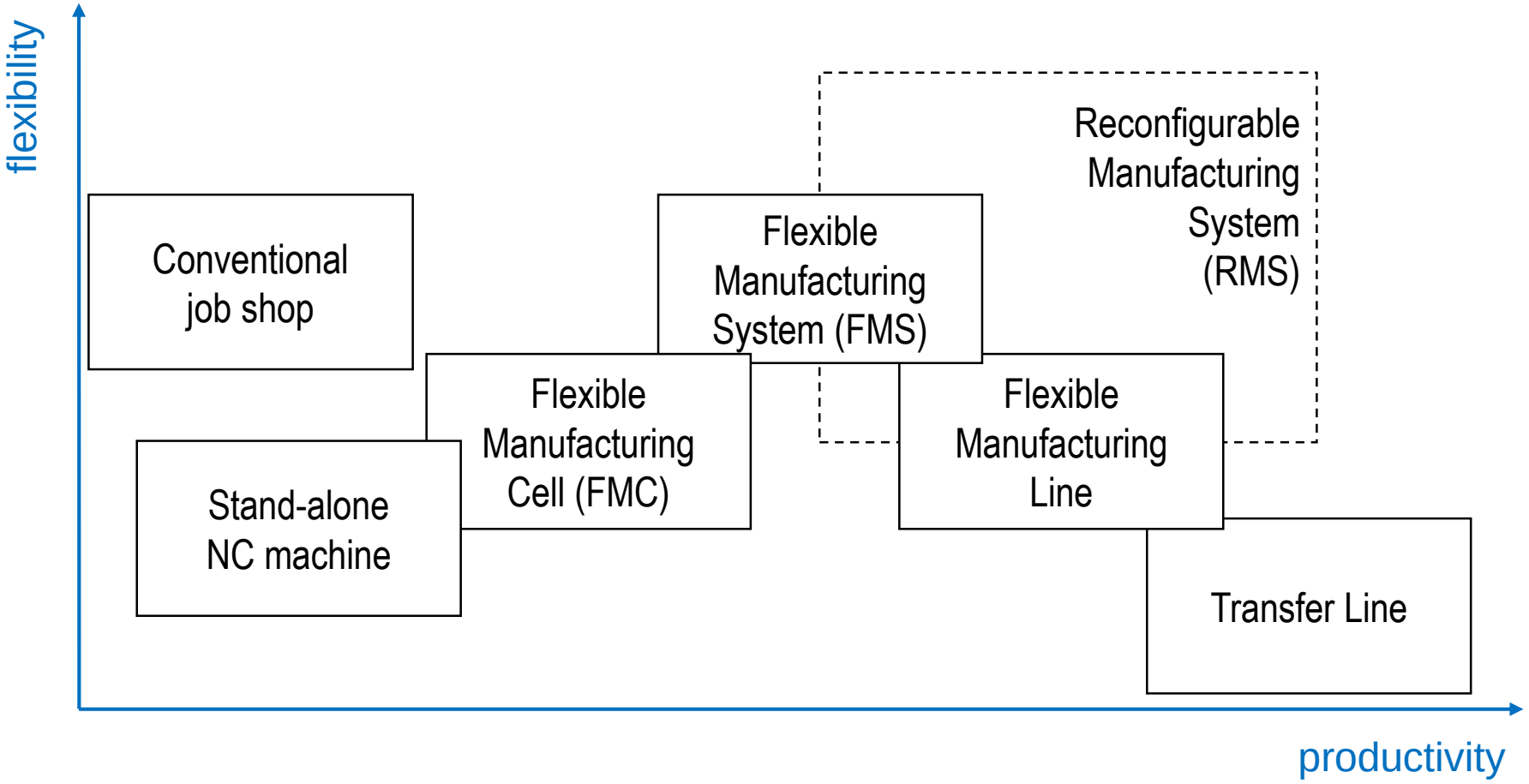
[3]

Production Categories



[5]

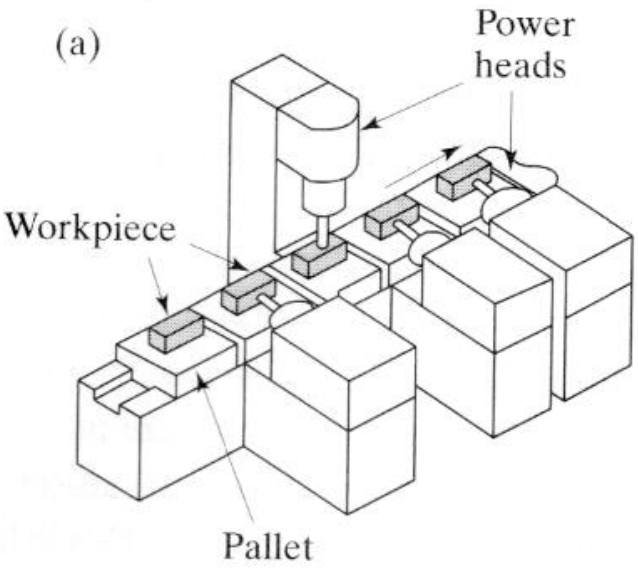
Categories of Manufacturing Systems (1)



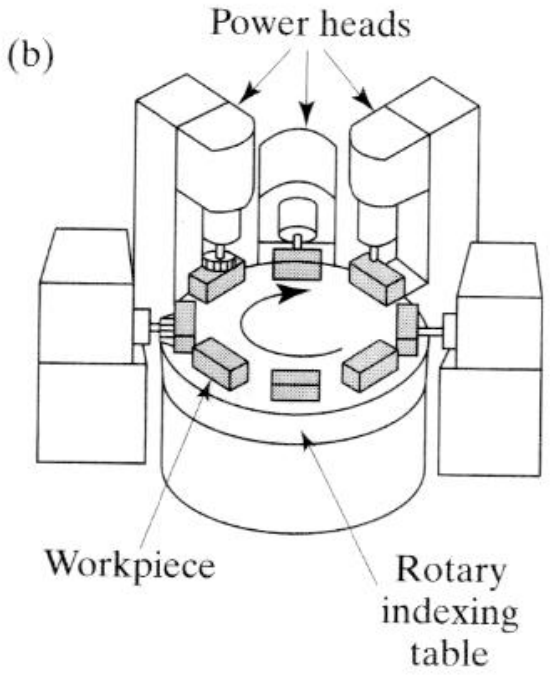
Categories of Manufacturing Systems (2)

- Job shop
  - a set of independent general purpose machine tools
- Flexible Manufacturing Cell (FMC)
  - Cell around a machine tool (mini-cell)
  - Cell of few machine tools
- Flexible Manufacturing System (FMS)
  - Integration of several machine tools and material handling equipment
  - Integration of manufacturing cells

Hard Automation: Transfer Machines, Transfer Lines



Strait pattern



Circular pattern

[5]

Components of Flexible Manufacturing Automation

- NC, CNC machine tools and/or machining units
- Automatic tool and workpiece change
- Computerised system control
- Sensors
- Automatic (flexible) material handling
- Automatic (flexible) fixturing

Flexible Manufacturing System (FMS)

- CNC machine tools
- Automatic material handling system
- Central computer control
- Flexibility in
  - product variety
  - production quantity
- Random input → smaller inventory
- Tool store, tool management
- Higher level integration: integration of several manufacturing processes (e.g. cutting + assembly)

Transfer line vs. Flexible Manufacturing System

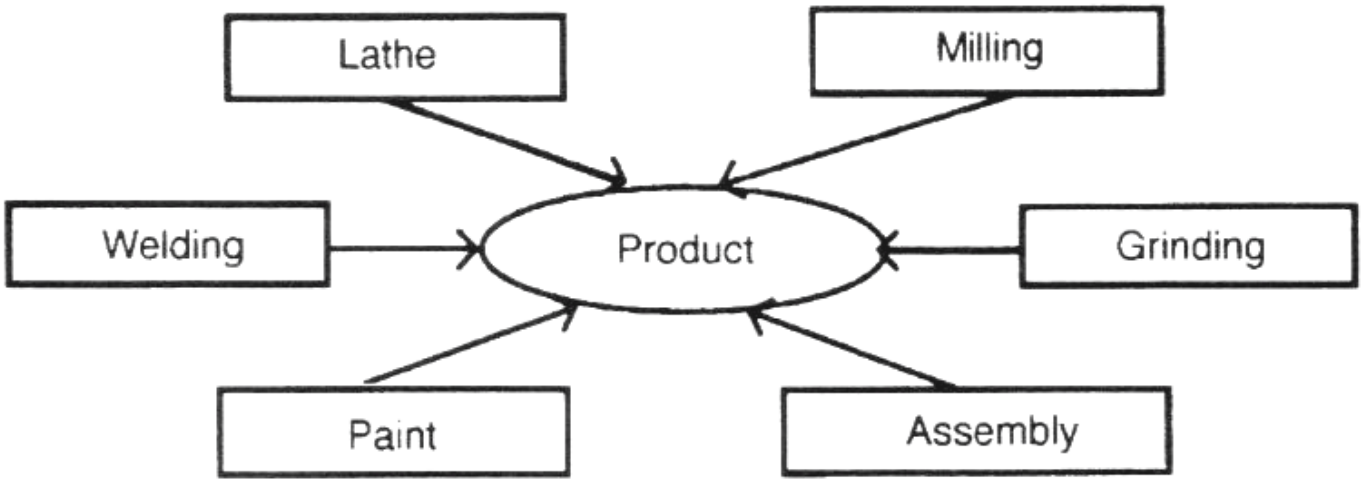
Characteristic	**Transfer line**	**FMS**
Types of parts made	Generally few	Infinite
Lot size	>100	1-50
Part changing time	0,5 – 8 hour	1 minute
Tool change	Manual	Automatic
Adaptive control	Difficult	Possible
Inventory	High	Low
Production during break down	None	Possible
Justification for capital expenditure	Simple	Difficult

[5]

Manufacturing System Layouts

- Static
- Product
- Process
- Group technology

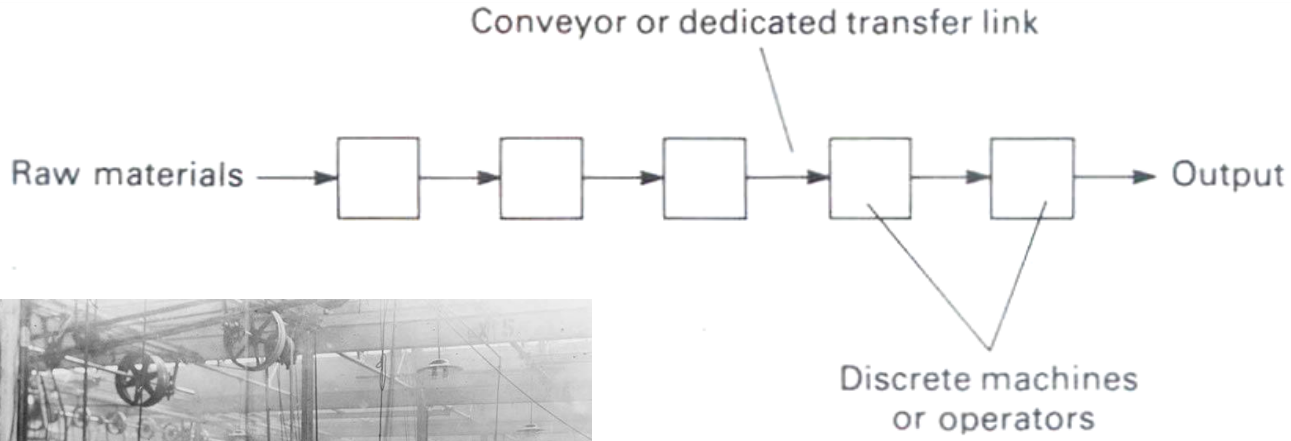
Manufacturing System Layouts:
1. Static Layout (fixed position product)



- Manufacturing equipment move to product (e.g. ship, aircraft).
- Flexible layout: easy to change for new product.
- High personnel skill requirements.

[13]

Manufacturing System Layouts:
2. Product Layout

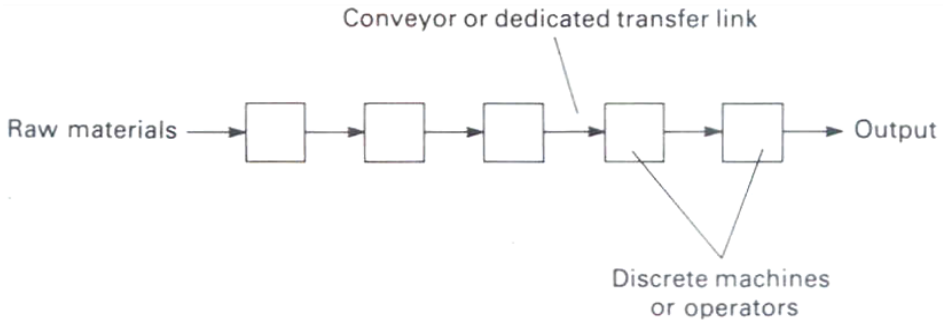


[4]

Ford Model T assembly line, 1913 [21]

Manufacturing System Layouts:
2. Product Layout

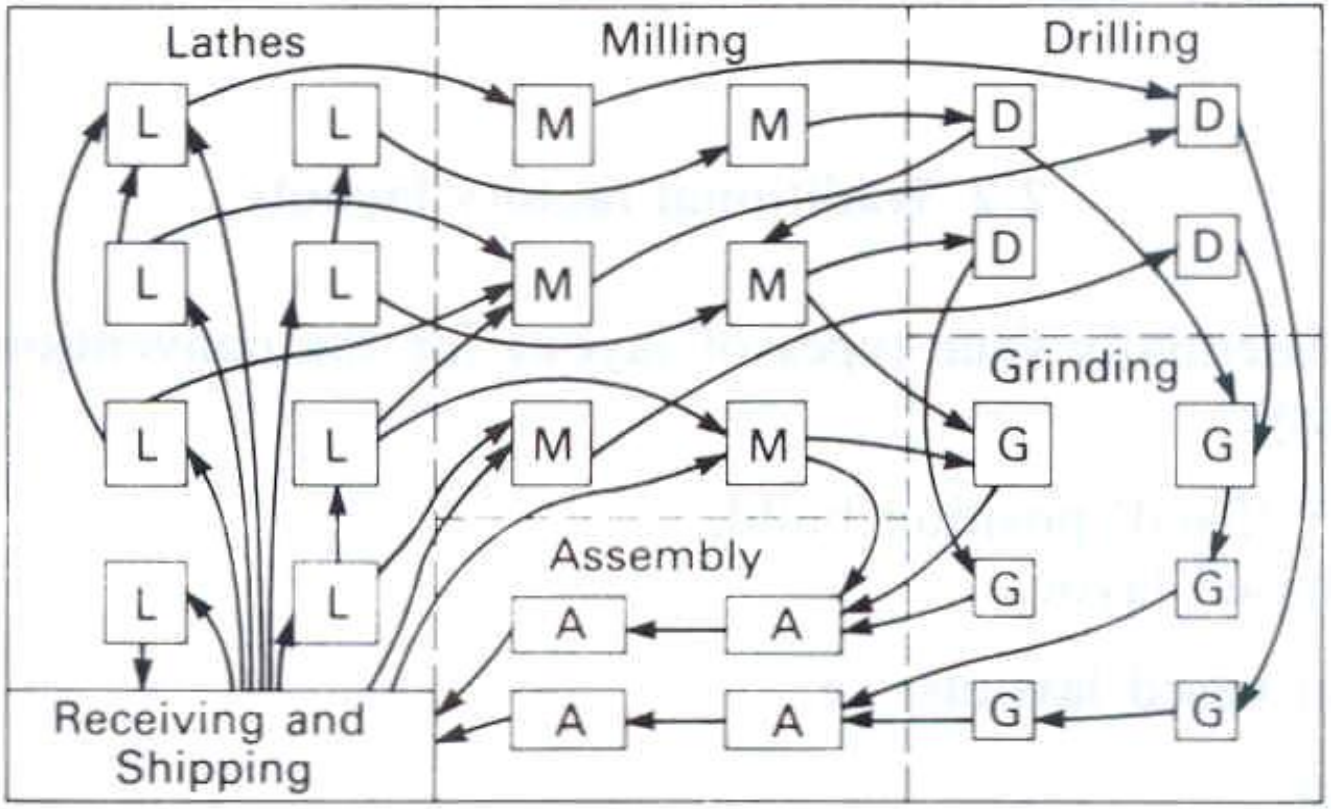
- Most of the production plants has this layout
- Typical application area:
  - High volume, low variety



- Need for special-purpose equipment
- Low flexibility: if the product changes, it may require changes in the layout, which may be costly.
- Labour skill requirement is low as most of the tasks are simple.
- Material flow is smooth, simple and logical → simple production control.
- Requires highly reliable equipment since failure at one workstation may cause the stoppage of the whole line.

[4], [13]

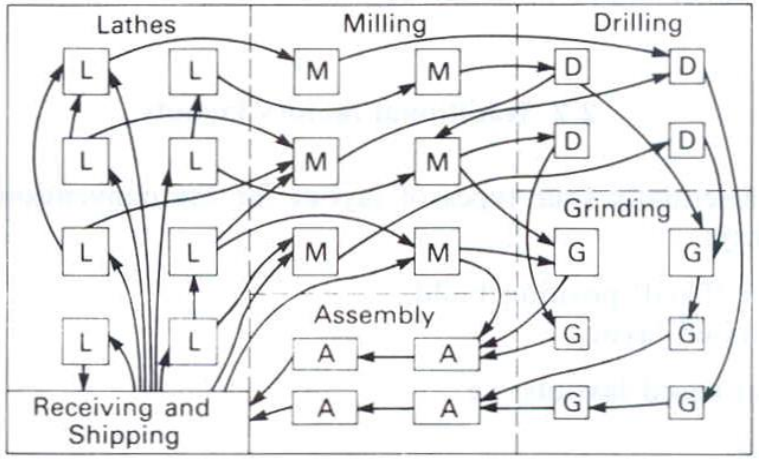
Manufacturing System Layouts:
3. Process Layout



[4]

3. Process Layout

- Typical application area:
  - Low volume, high product variety
  - Batch or job-shop manufacturing system
- General-purpose equipment grouped according to the manufacturing processes.
- Labour skill requirement is high.
- More complex material flow.
- Higher flexibility, but lower efficiency.
- Investment in equipment is higher but utilisation is lower.
- More complex production control.
- Higher inventory level.

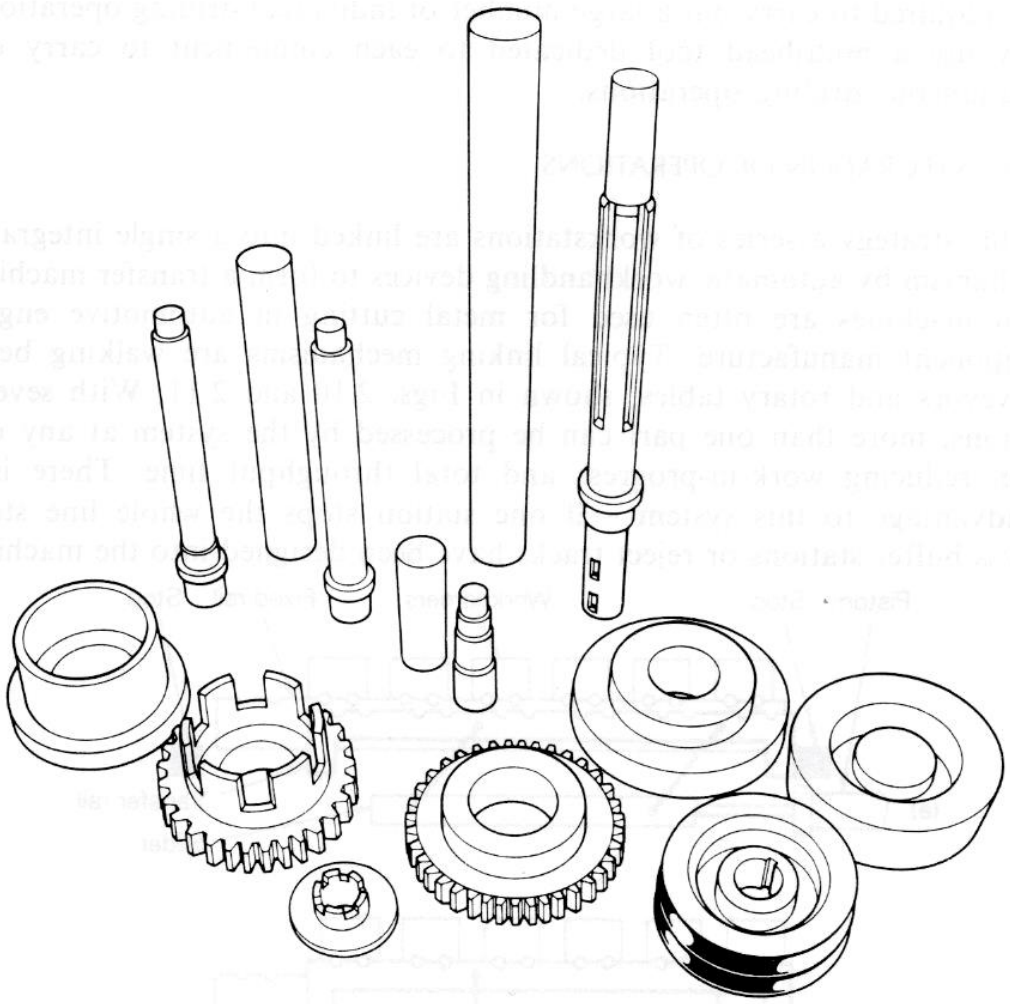


[4], [13]

Group Technology (GT) (Design & Production !!)

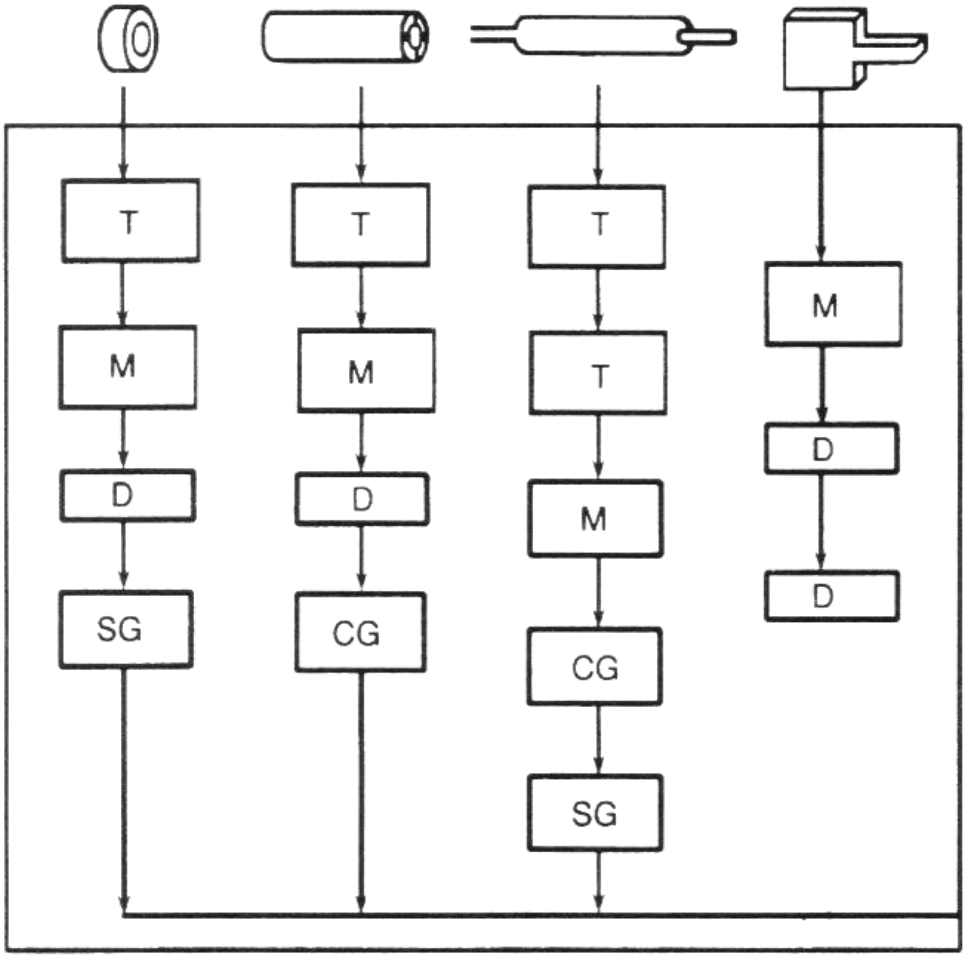
- Grouping the parts according to similarities:
  - Design similarities:
    - shape
    - size
    - functions
  - Manufacturing process similarities
    - process type
    - surface roughness, tolerances
    - machine tool types
- Classification and coding using IT tools
- GT connects the design and production databases

GT example: groups of shafts and disc parts



[5]

Manufacturing System Layouts:
4. Group Technology Layout



(T: Turning; M: Milling; D: Drilling; SG, CG: Grinding)

[13]

4. Group Technology Layout

- Products are grouped in part families.
- Each part family is assigned to a group of machines and this machine group along with the material handling equipment form a **cell**.
- Integration of the cells into a **system**
- GT layout combines the advantages of mass production and job shop production → higher volume + more flexibility
  - economic, efficient (mass production; product layout)
  - flexible (job-shop production; process layout)

[13]

Advantages of Group Technology

- For Design
  - Standardisation of design
  - Fast design (drawing) retrieval
  - Fast adaptation of new designs
- For Production Planning
  - Reduction of the number and planning time of process plans
  - Reduction of the number and creation time of NC codes
  - Simplified machinability analysis
  - Reduction of the number and types of tools and fixtures; easier design of tools and fixtures
- For Manufacturing
  - Lower setup times
  - More efficient equipment design
  - Better utilisation of manufacturing equipment
  - More flexible and faster supply of urgent orders
  - Better quality
  - Easier production control (capacity planning, load balancing, scheduling)

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Examples of Test Questions

1. What are the aims of manufacturing automation?
2. What are the selection criteria of machine tools?
3. What are the primary motion and secondary motions of a lathe and a milling machine?
4. What sort of machine tools are called as 'machining centres'?
5. What sort of machine tools are called as 'turning centres'?
6. List two intermittent operation material handling equipment and two continuous operation material handling equipment.
7. Give the name of four manufacturing system categories and show their place in the 'productivity – flexibility' (x-y) coordinate system.
8. Compare the transfer lines and the flexible manufacturing systems according to given characteristics.
9. Characterise the 'static layout' type of manufacturing systems.
10. Characterise the 'product layout' type of manufacturing systems.
11. Characterise the 'process layout' type of manufacturing systems.
12. Characterise the 'group technology' type of manufacturing systems.
13. What is group technology?