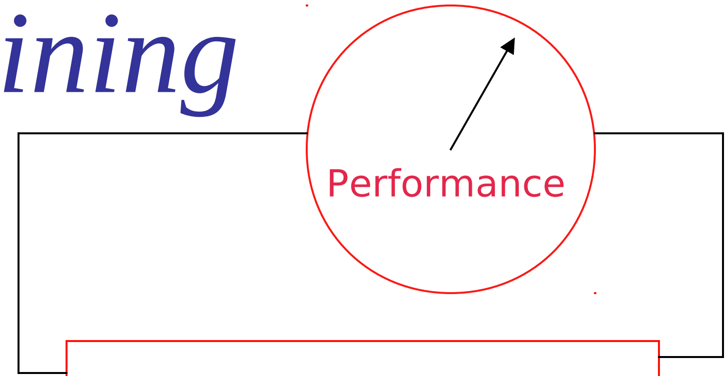
Machining Part 2

- Production Machining
  - Systems overview
  - Process Planning
  - Design for Machining
- New Developments
- Environmental Issues

Production Machining



Part Drawing ↔ **Process Plan** ↔ **Production System**

Part Drawing	Process Plan	Production System
dimensions	machines	machines
features	tools	arrangement
tolerances	fixtures	materials handling
material properties	operations	inspection/Q.C.
hardness	inspection	operator's/skill level
surface finish	sequence	

How to proceed…

- Know options available: machines, tools, systems etc.
- Know how to connect the dots
  - part drawing to process plans

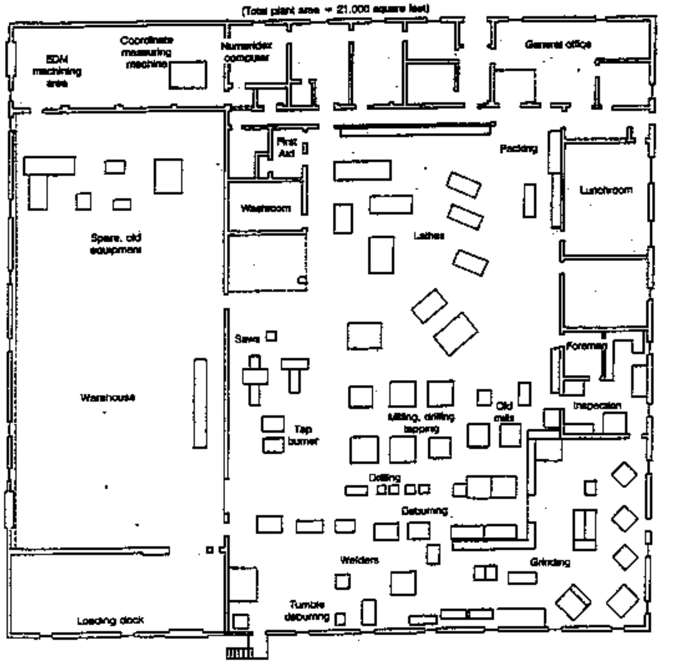
    ex. tight tolerances → extra operations (DFM)
  - process plans for systems

    ex. multiple steps need to be balanced to have smooth flow

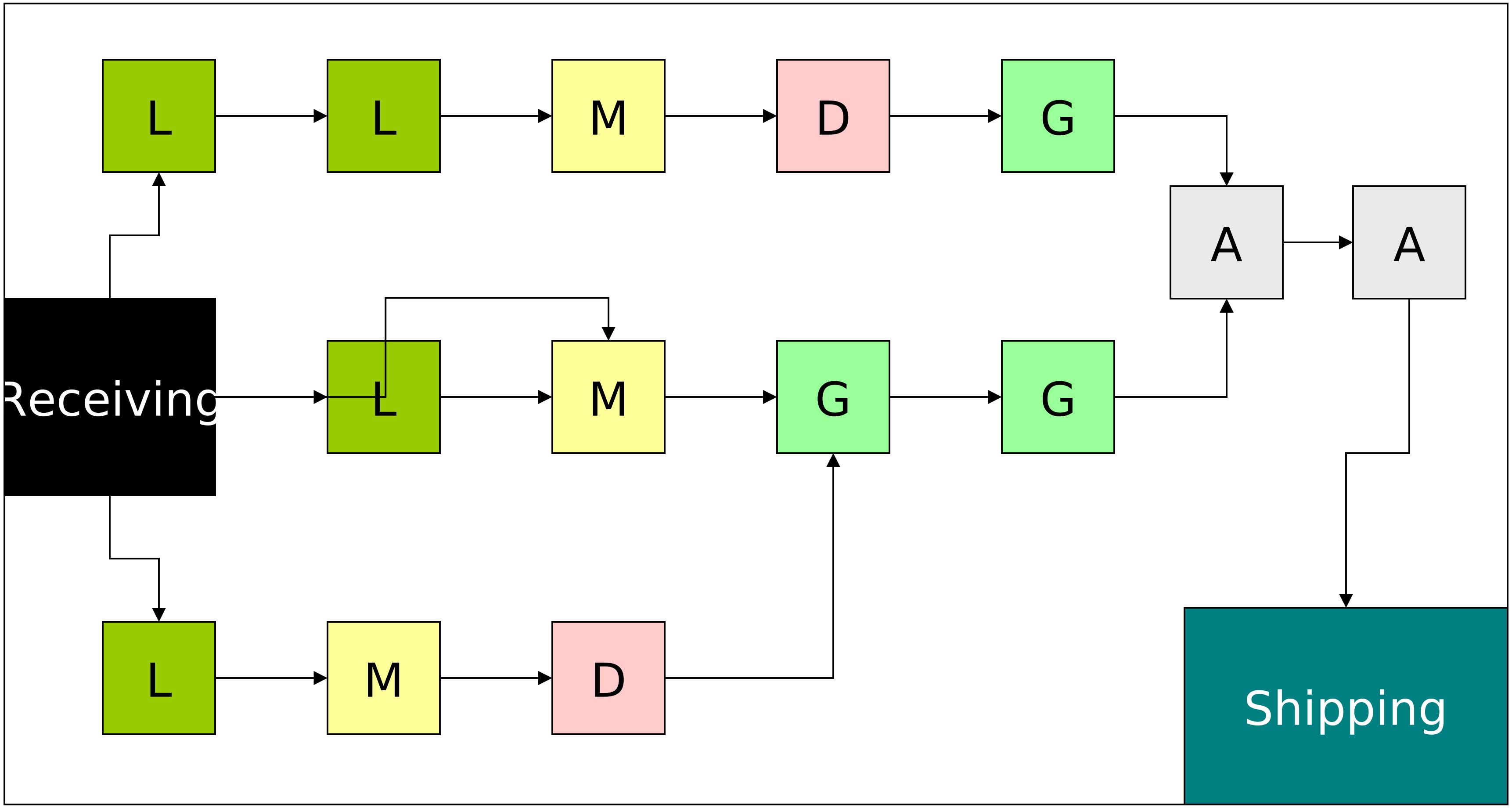
Picking Manufacturing Systems

- Job Shops – very flexible, low volumes, high variety
- Flow shops – arrange dedicated equipment in order of operations, balance flow, deskill jobs
- Transfer Lines – automated, hardwired flow shop
- Flexible Mfg. Systems (FMS) – automate transfer between machines, allow skipping and double back
- Toyota cell – special arrangement of flow shop with many machines per operator

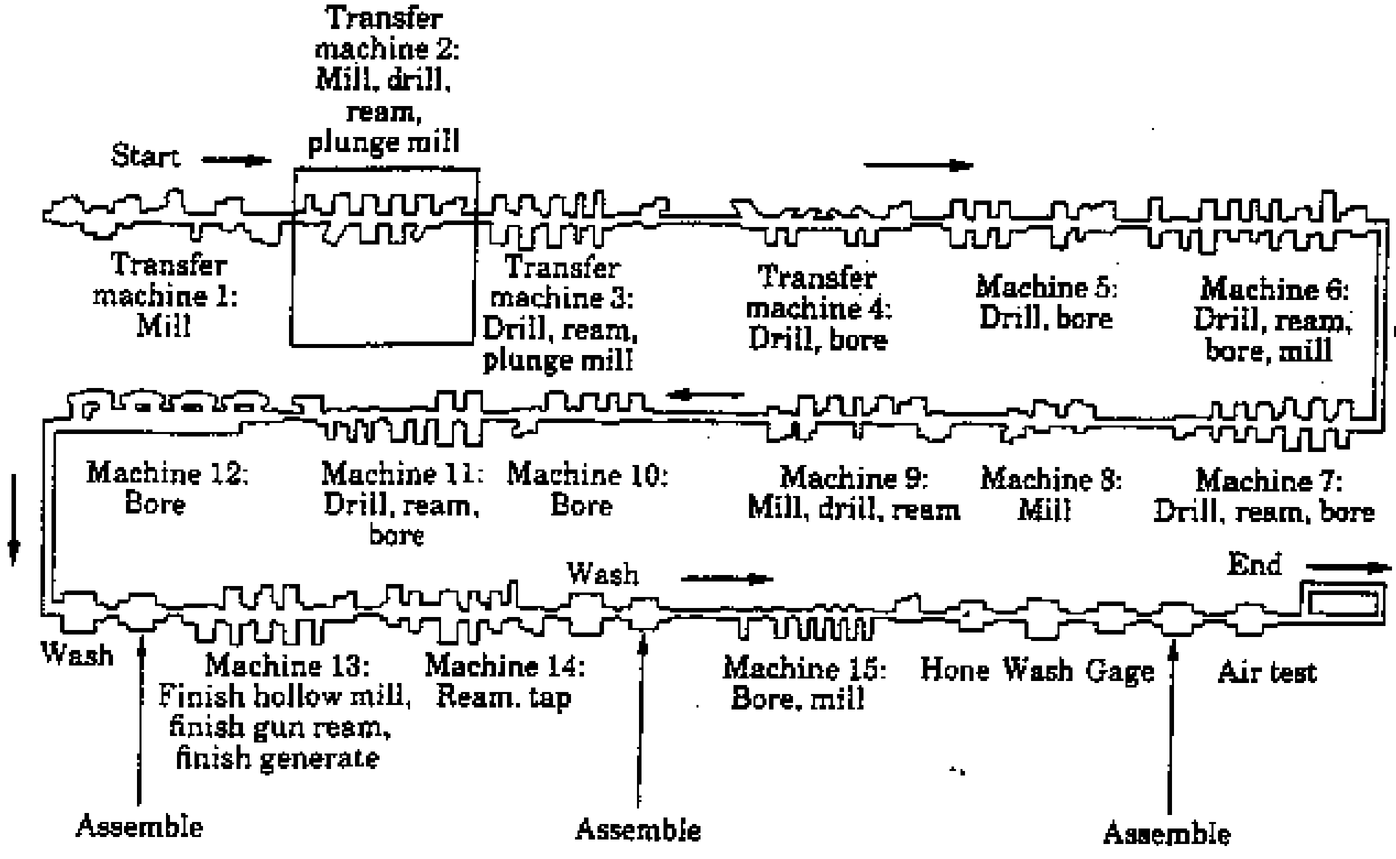
Job shops - flexible



Flow Shop - dedicated



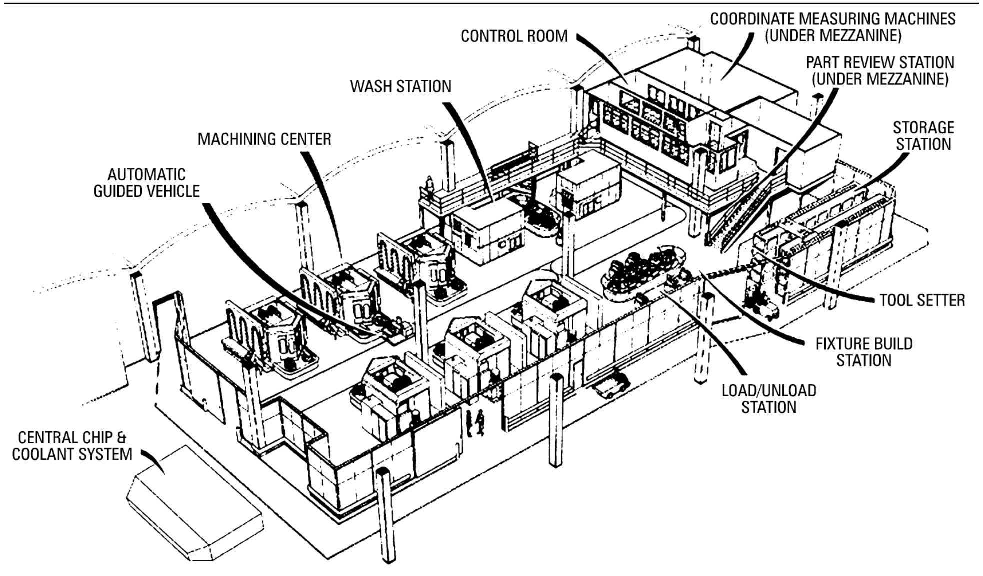
Transfer line - hardwired

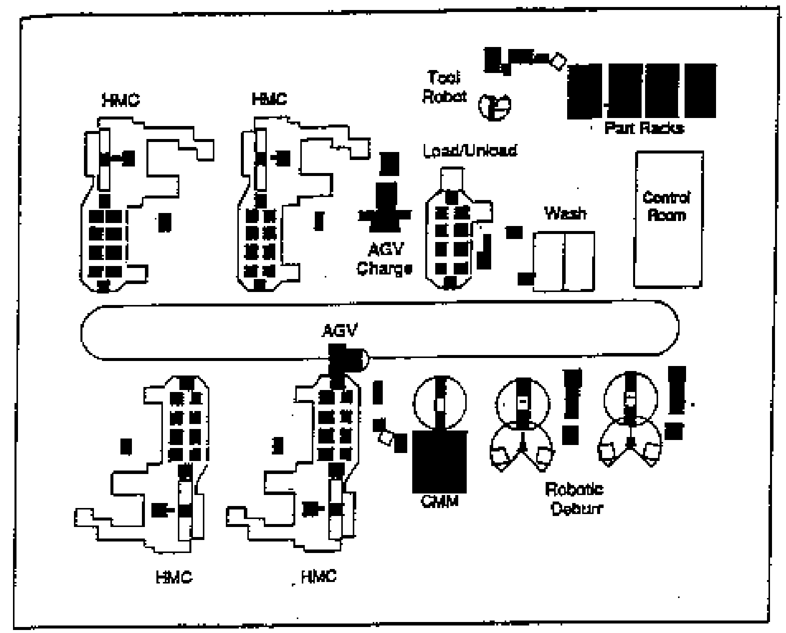


* Source: Kalpakjian, “Manufacturing Engineering and Technology”

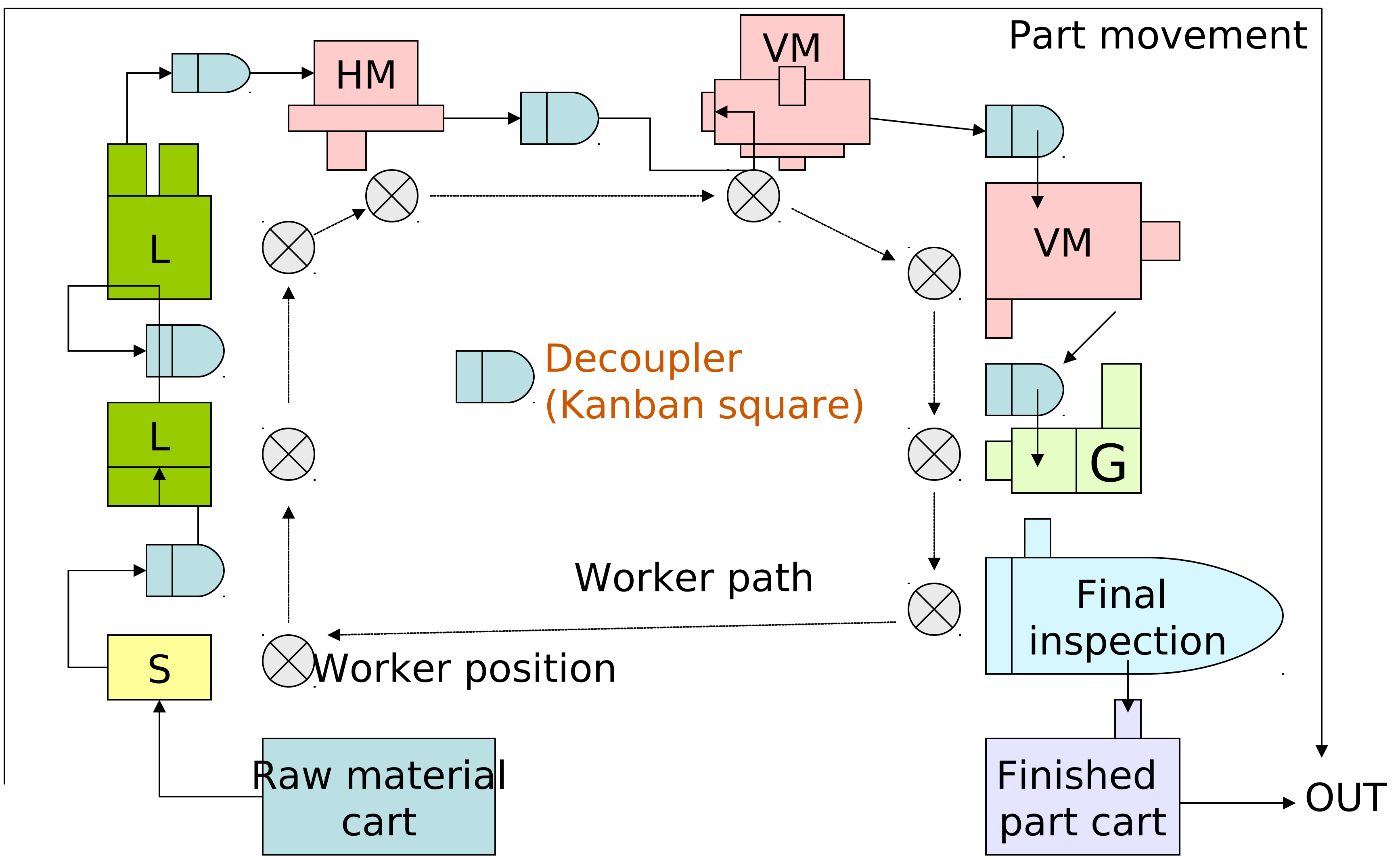
Flexible Manufacturing System (FMS)

Figure 1 AlliedSignal's flexible manufacturing system





Toyota Mfg Cell



Machining Systems Classification

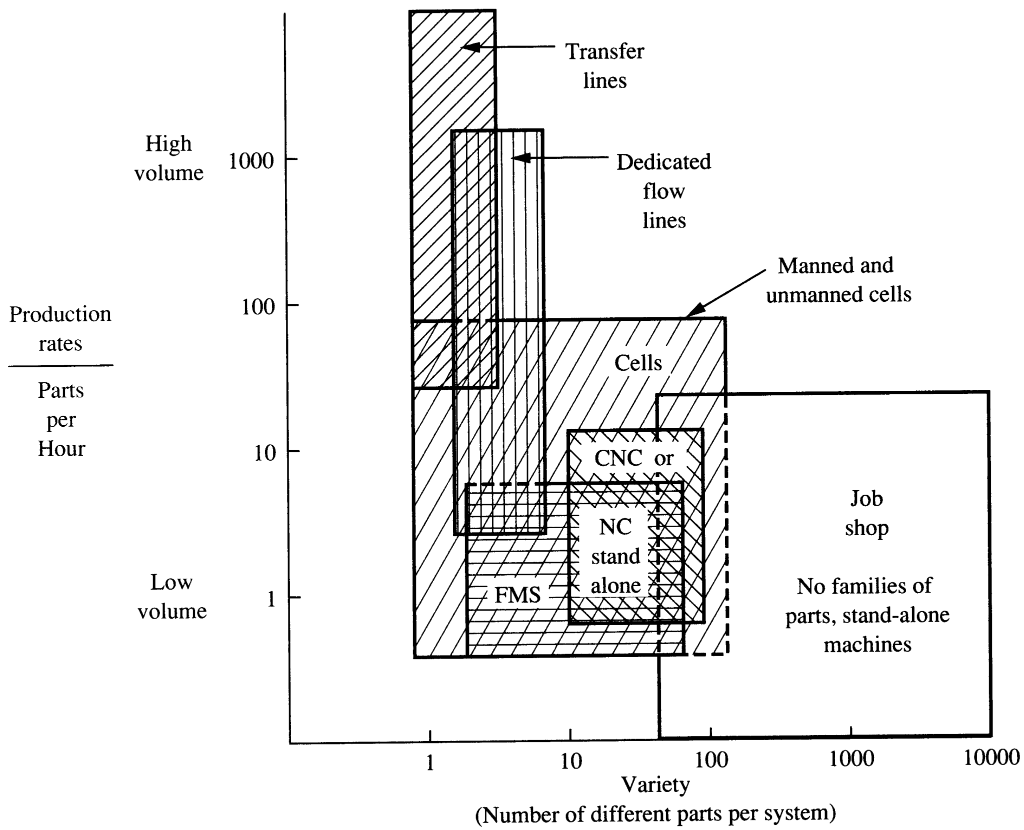


FIGURE 2-15
A comparison of different kinds of manufacturing systems with cells.

Ref J T. Black

Example Problem

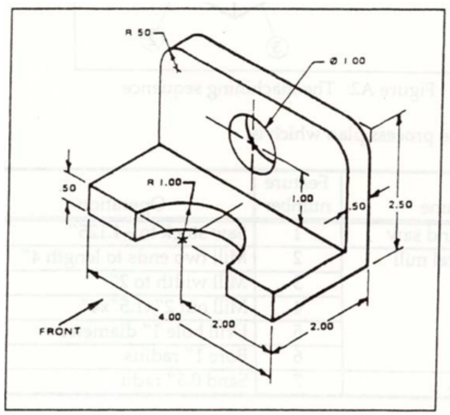
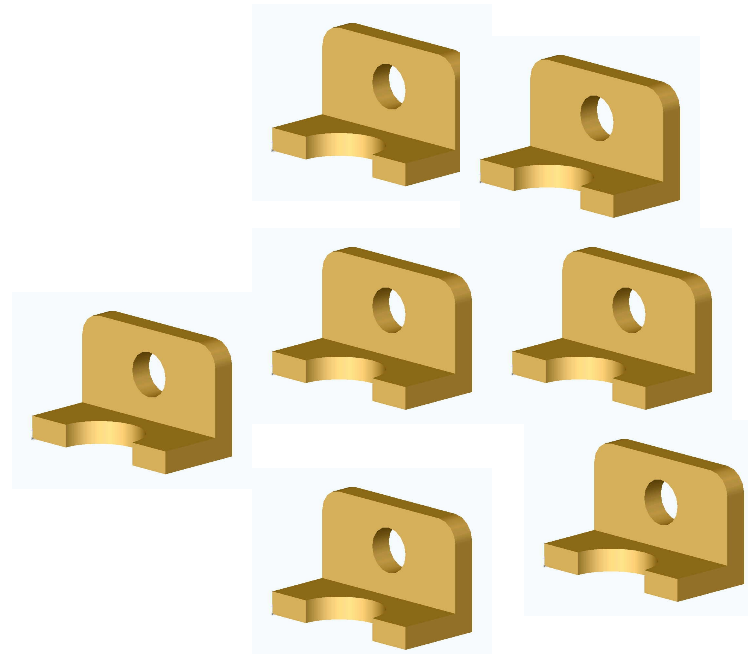


Figure A1: Rod support



Job Shop to large scale production

Appendix A

How to Use this Booklet

The following is a step-by-step example of a time estimate. It will illustrate the various steps involved and help explain the different sections of the time estimation tables. Consider the aluminum part below with a tolerarance of ±1/64" for the two 0.50" radii and ±0.005" otherwise:

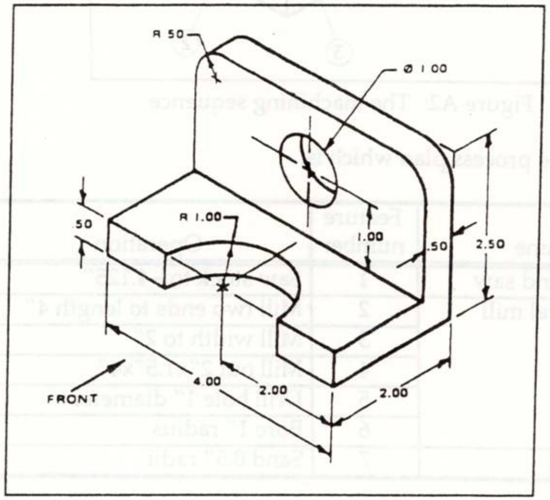


Figure A1: Rod support

The process plan

The first step is to generate a process plan. Let's assume we begin with a stock size of 2.5"x2.25"x12" and that this will be manufactured in a job shop for very low quantities. We will use:

-- A bandsaw to roughly cut the stock to size
-- A manual vertical mill to create the planar features and the holes
-- A belt sander to sand the radii (we can do this since the tolerance is not very high)

Process planning

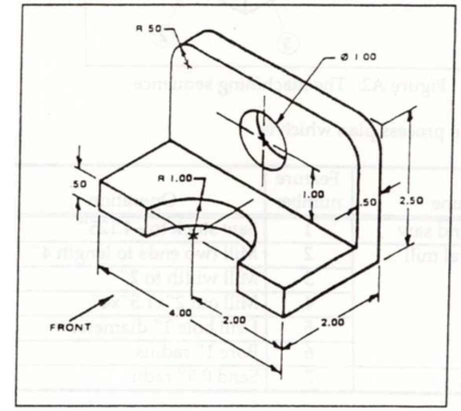
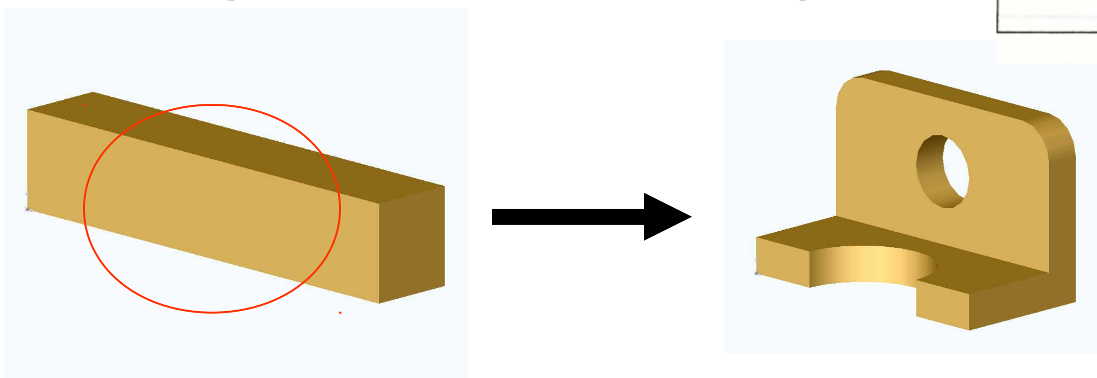


Figure A1: Rod support

How would you machine this part?



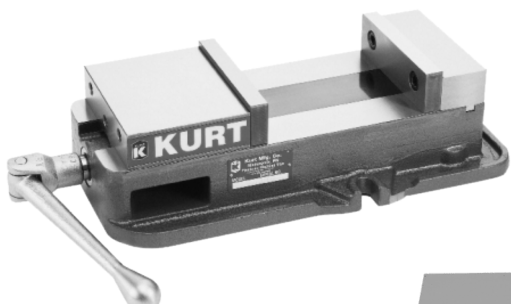
Assumption:

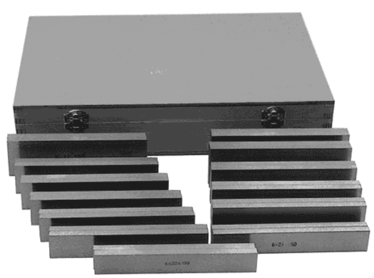
1. We begin with a stock size of 2.5” X 2.25” X 12”
2. This will be manufactured in a job shop for very low quantity

We will use:

- A bandsaw to roughly cut the stock to size
- A manual vertical mill to create the planar features and the holes
- A belt sander to sand the radii (assuming the tolerance is not very high)

Machines, tools, fixture





Machine	Operation
Horizontal band saw	Saw stock to ~4.125”
Manual vertical mill	Mill two ends to length 4”
	Mill width to 2”
	Mill out 2”X1.5”X4”
	Drill hole 1” diameter
	Bore 1” radius
Belt sender	Sand 0.5 radii

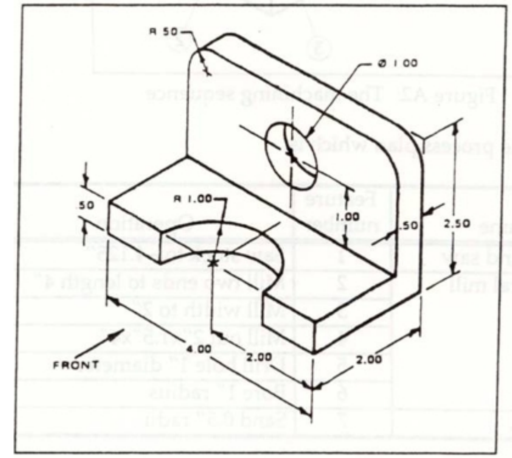


Figure A1: Rod support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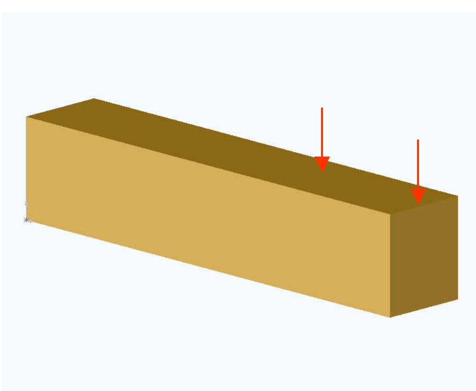

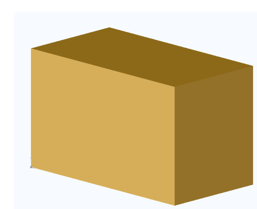

* Source: http://www.jettools.com/Catalog/Metalworking/CatalogPages/HVBS56M.html

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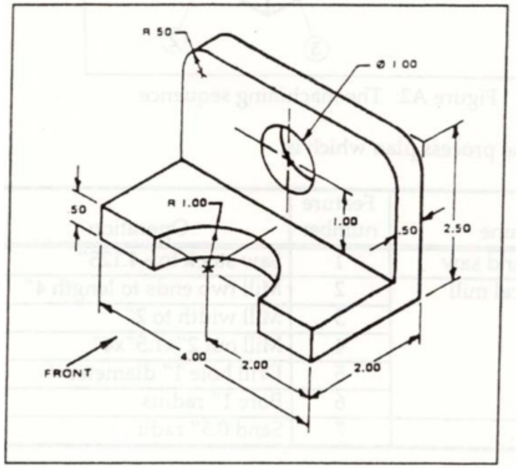

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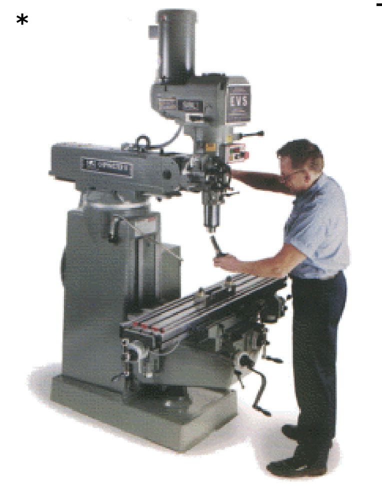

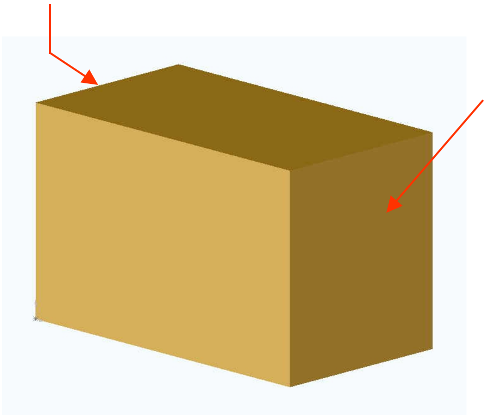

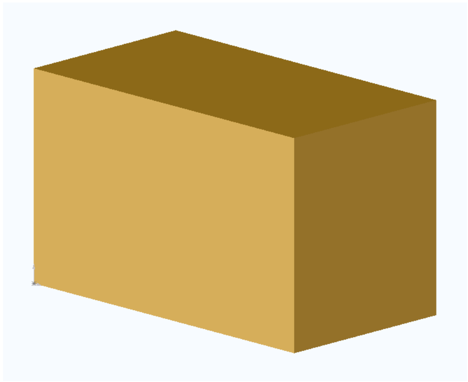

* Source: http://www.hemsaw.com/Videolinkpages/x-vVideopg.htm

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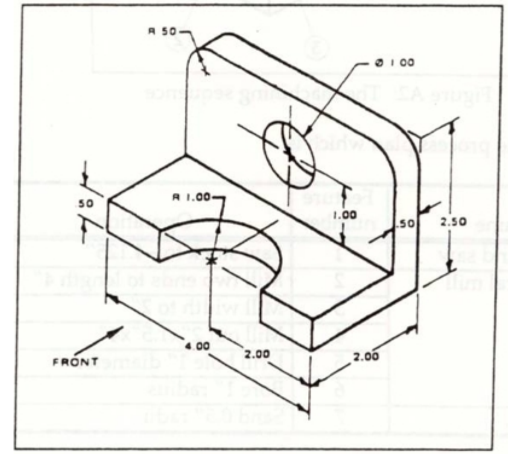

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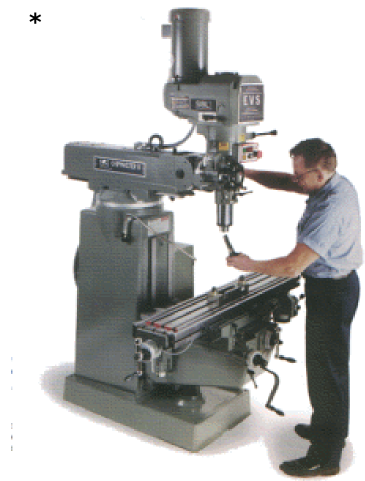

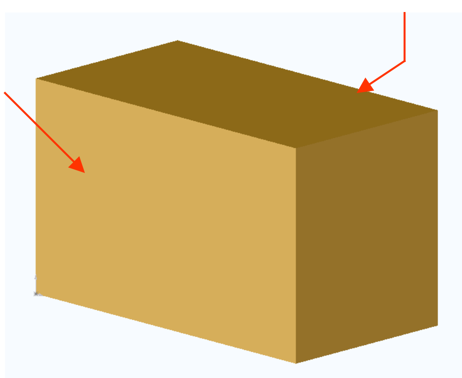

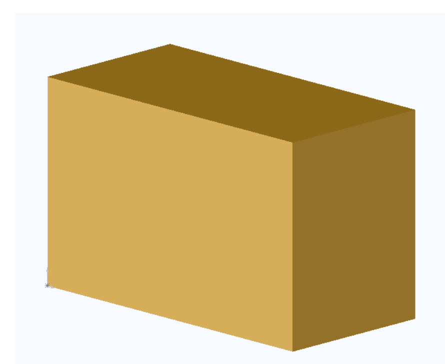

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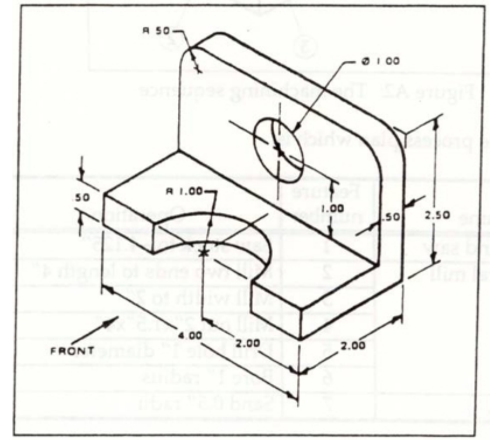

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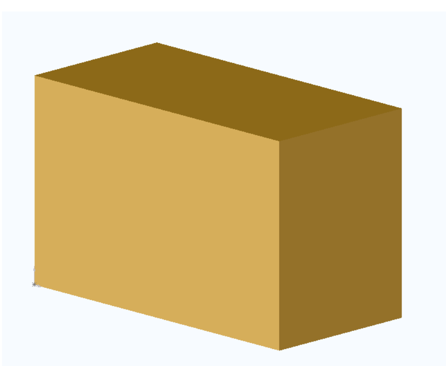

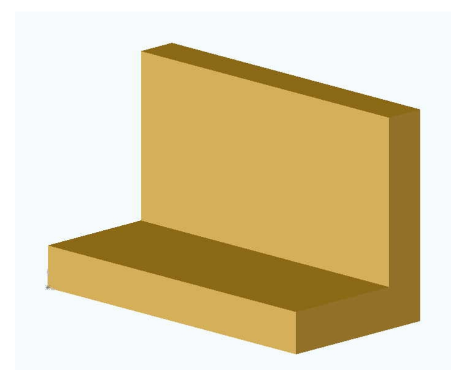

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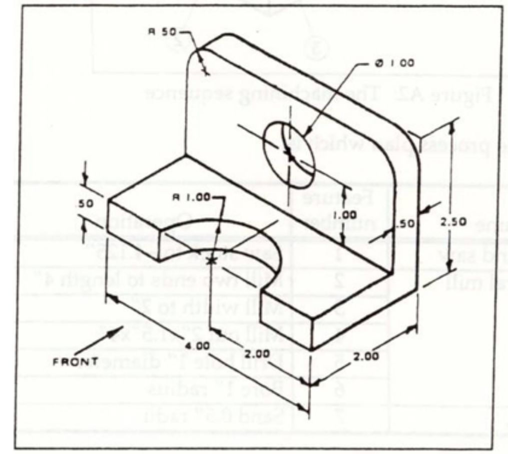

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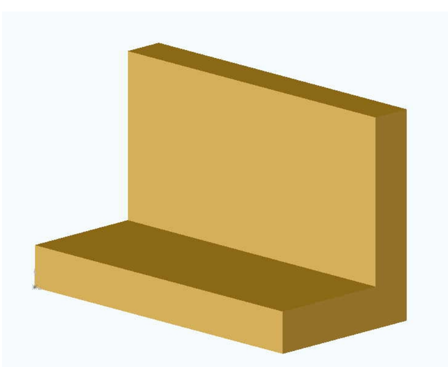

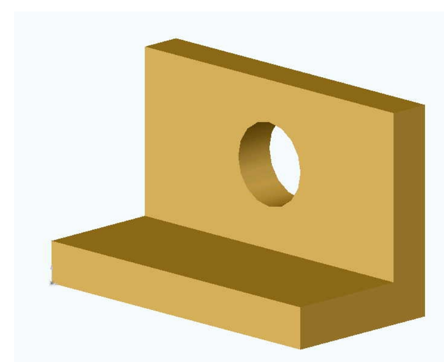

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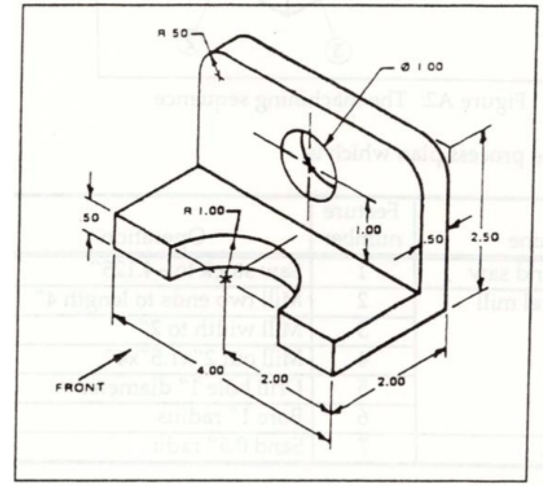

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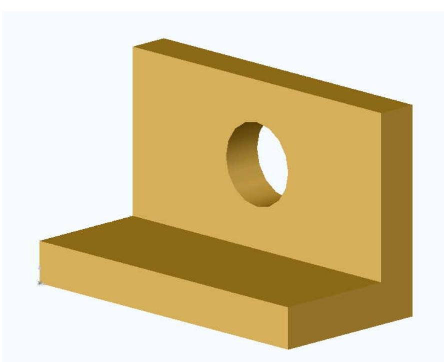

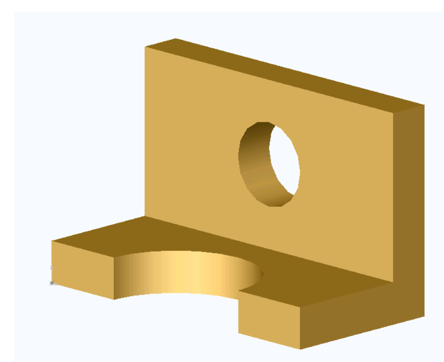

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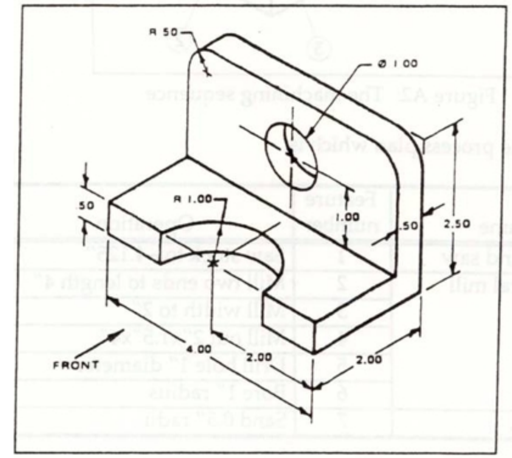

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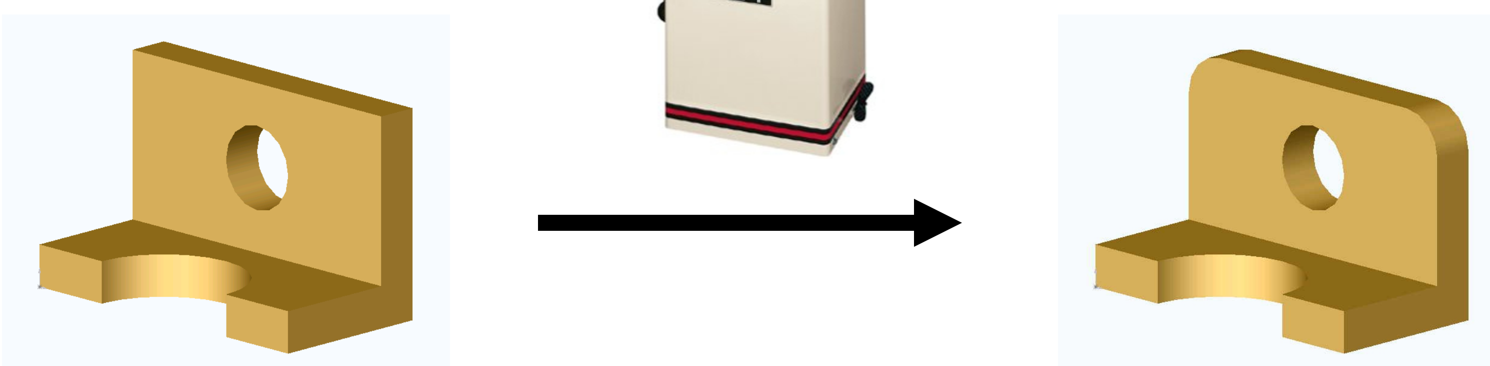
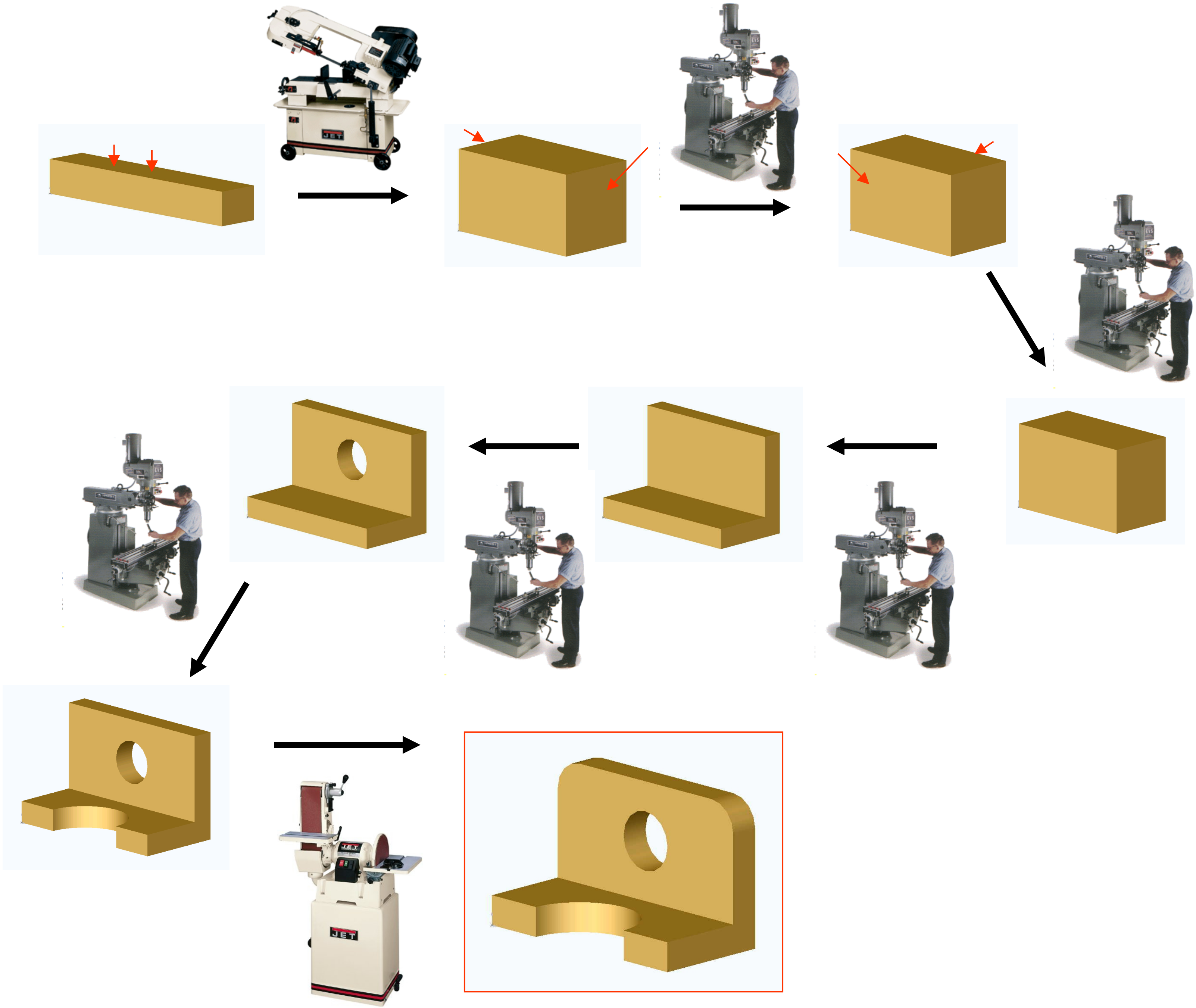


* Source: http://www.jettools.com/jet-index.html (WMH Tool Group)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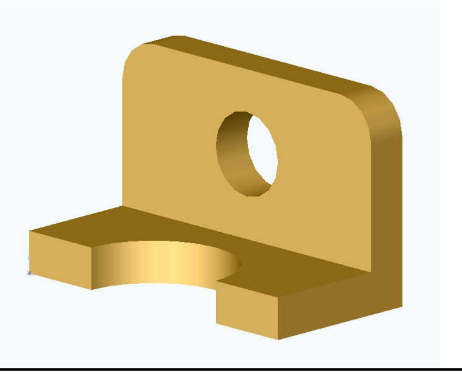
Process |



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Simplified Time Estimation Booklet for Basic Machining Operations

K. C. Polgar, T. G. Gutowski, G. W. Wentworth

Table of Contents:

Appendix A

How to Use this Booklet

The following is a step-by-step example of a time estimate. It will illustrate the various steps involved and help explain the different sections of the time estimation tables. Consider the aluminum part below with a tolerarance of ±1/64″ for the two 0.50″ radii and ±0.005″ otherwise:

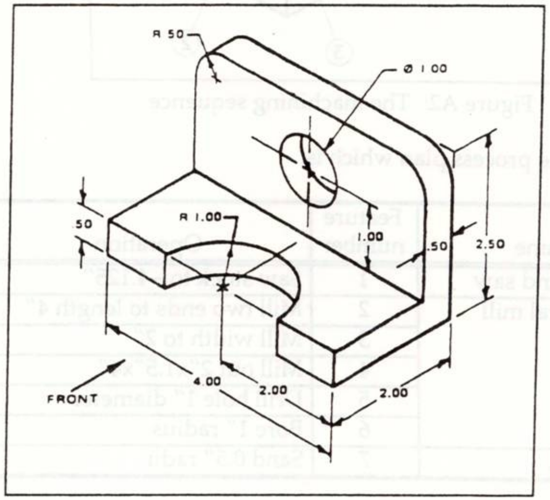


Figure A1: Rod support

The process plan

The first step is to generate a process plan. Let's assume we begin with a stock size of 2.5″x2.25″x12″ and that this will be manufactured in a job shop for very low quantities. We will use:

-- A bandsaw to roughly cut the stock to size
-- A manual vertical mill to create the planar features and the holes
-- A belt sander to sand the radii (we can do this since the tolerance is not very high)

Time Estimation Tables

The proposed time estimation method has the following sequence:

1. Begin with an engineering drawing
2. Develop a process plan
3. Estimate the times from simplified tables

The tables which follow are divided into three categories for each machine:

-- Machine setup time
-- Part fixturing time
-- Material removal time

Machine setup time: Includes such things as cleaning up the machine from the last time it was used, loading tools and fixtures, and zeroing axes.

Part fixturing time: These times scale with weight (heavier parts take longer to load) and represent the time to pick up a part and secure it in place for the machining operation.

Material removal time:

It is important to note that the removal rates in the tables are for high speed steel (HSS) tooling.

- For sawing: removal rate is based on cross-sectional area of the cut
- For milling, turning, grinding, and sanding: removal rate is based on volume removed for roughing passes, and surface area finished for finish passes
- For drilling and tapping: plunge feed rate is based on the diameter and the depth of the hole

Also included in the tables are times for tool changes, time to index parts (in a part indexer), time to index tools (advance turret on a turret lathe), and programming times for CNC equipment.

The Appendices will help explain how to select machines and generate a process plan from a part drawing. Appendix A is a detailed time estimate of a "rod support". Additional useful data tables are given in Appendix B.

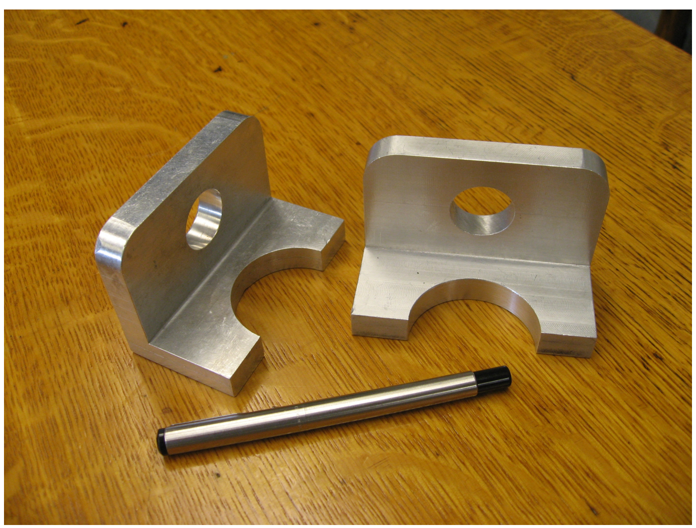
Time estimation (minutes)

Machine	Operation (V = Volume, A = Area, P = Perimeter)	Fixture	Tool Change	Run (R=Rough, F=Finish)	Deburr/Inspect/ Measure
Horizontal band saw	Saw stock to ~4.125” A = 5.6525 in^2, P = 9 in	0.23	-	2.02	0.30D, 0.05I
Manual vertical mill	Mill two ends to length 4” V = 0.703 in^3 A = 11.25 in^2, P = 19in	0.20 0.20	2	0.13R 0.75F	0.63D, 0.05I, 0.13M
	Mill width to 2” V = 2.5 in^3 A = 10 in^2, P = 13in	0.20	-	0.46R 0.67F	0.43D, 0.05I, 0.13M
	Mill out 2”X1.5”X4” V = 12 in^3 A = 14 in^2, P = 15in	-	-	2.19R 0.93F	0.50D, 0.05I 0.13M, 0.13M
	Drill hole 1” diameter -Center drill -Pilot drill ½” -Pilot drill 63/64” -Ream	0.20	2 2 2 2	0.03 0.05 0.04 0.01	0.21D, 0.05I 0.17M
	Bore 1” radius V = 0.79 in^3 A = 1.57 in^2, P = 7.28in	0.20	2	0.96R 0.01F	0.24D, 0.05I 0.06M
Belt sender	Sand 0.5 radii V = 0.05 in^3 A = 0.79 in^2, P = 3.14in	0.08	-	0.20R 0.21F	0.10D, 0.05I 0.06M, 0.06M

Summary Times (minutes)

Fixture	Tool Change	Run (R=Rough, F=Finish)		Deburr/Inspect/Measure
1.31	12	6.08	2.58	3.63

Total Time 25.6 minutes



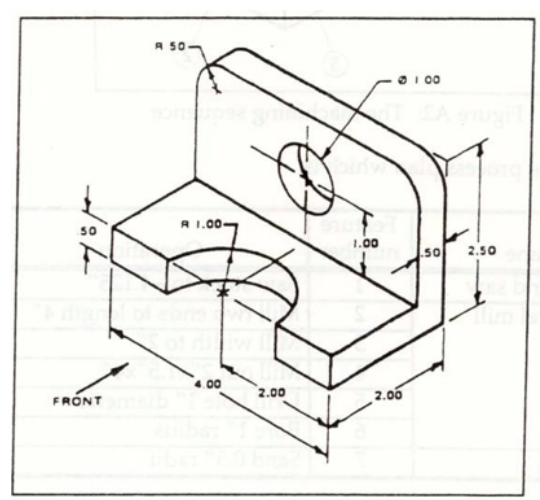


Figure A1: Rod support

Design for Machining

Design Rules for Machining
From "Product Design for Manufacture and Assembly"
by G. Boothroyd et al. (Dekker, 2002)

Standardization

1. Utilize standard components as much as possible.
2. Pre-shape the workpiece, if appropriate, by casting, forging, welding, etc.
3. Utilize standard pre-shaped workpieces, if possible.
4. Employ standard machined features whenever possible.

Raw Material

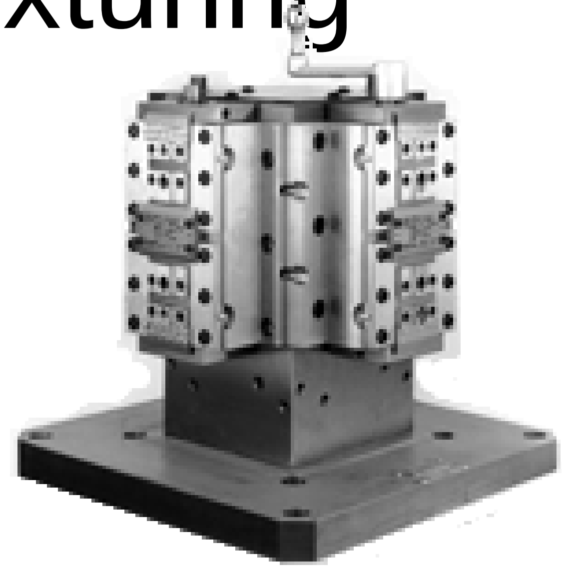
5. Choose raw materials that will result in minimum component cost (including cost of production and cost of raw material).
6. Utilize raw material in the standard forms supplied.

Handout on website

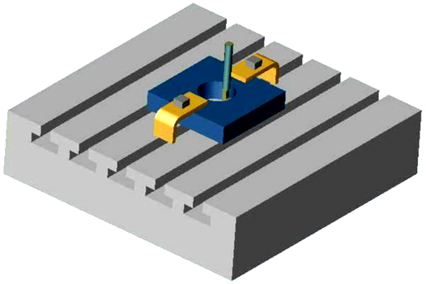
Production Fixturing

Vise

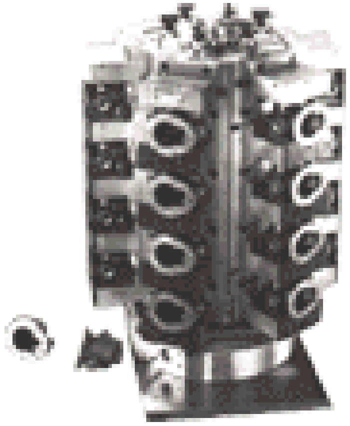
Soft jaws



"Tombstone"

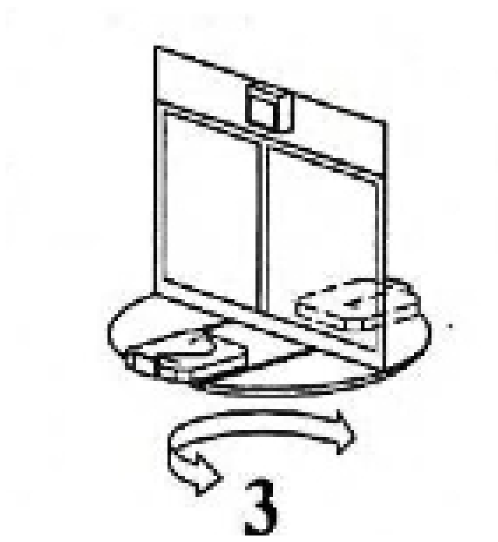


T-slot & clamps on mill

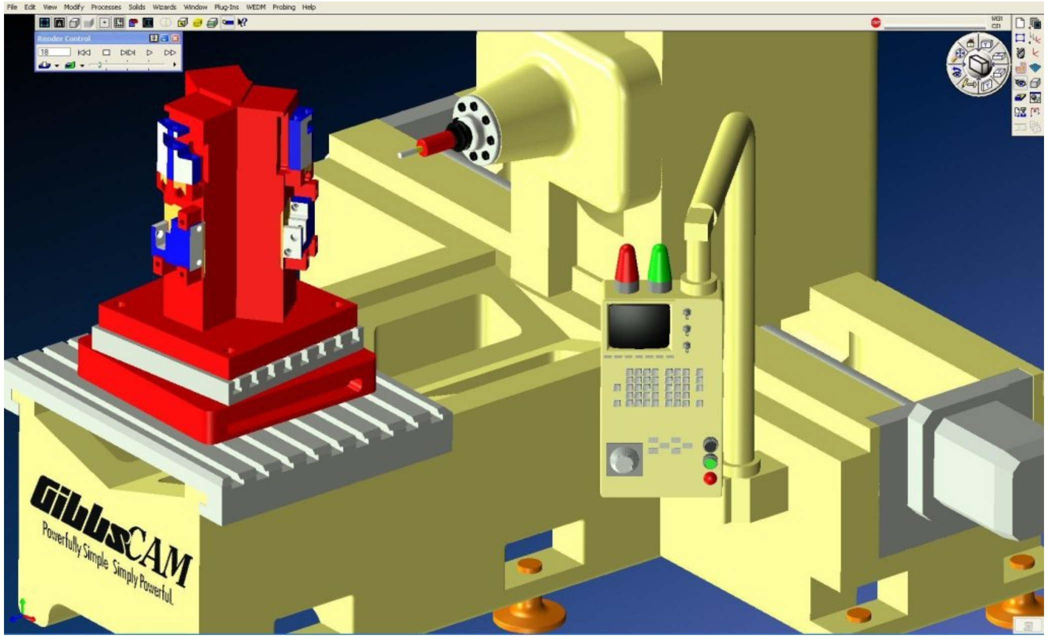


With hydraulic clamping

Horizontal Milling Machine with Pallets



Pallet changer



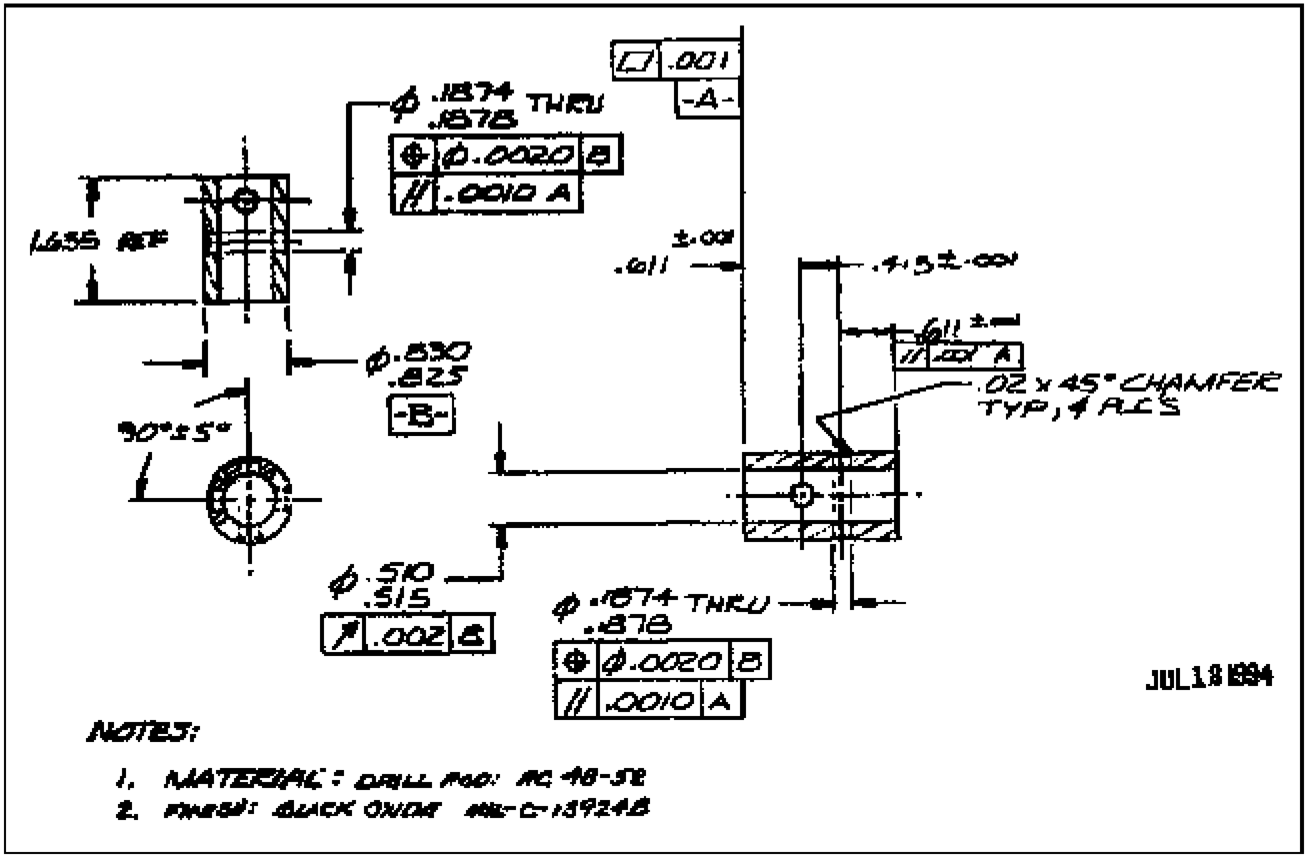
Horizontal Mill with tombstone mounted on pallet

Simplify set-up

– Have tools and fixtures available
– Identify Internal and External Setup
– Convert Internal to External Setup
– Streamlining all aspects of the setup operation

Standardized Fixtures

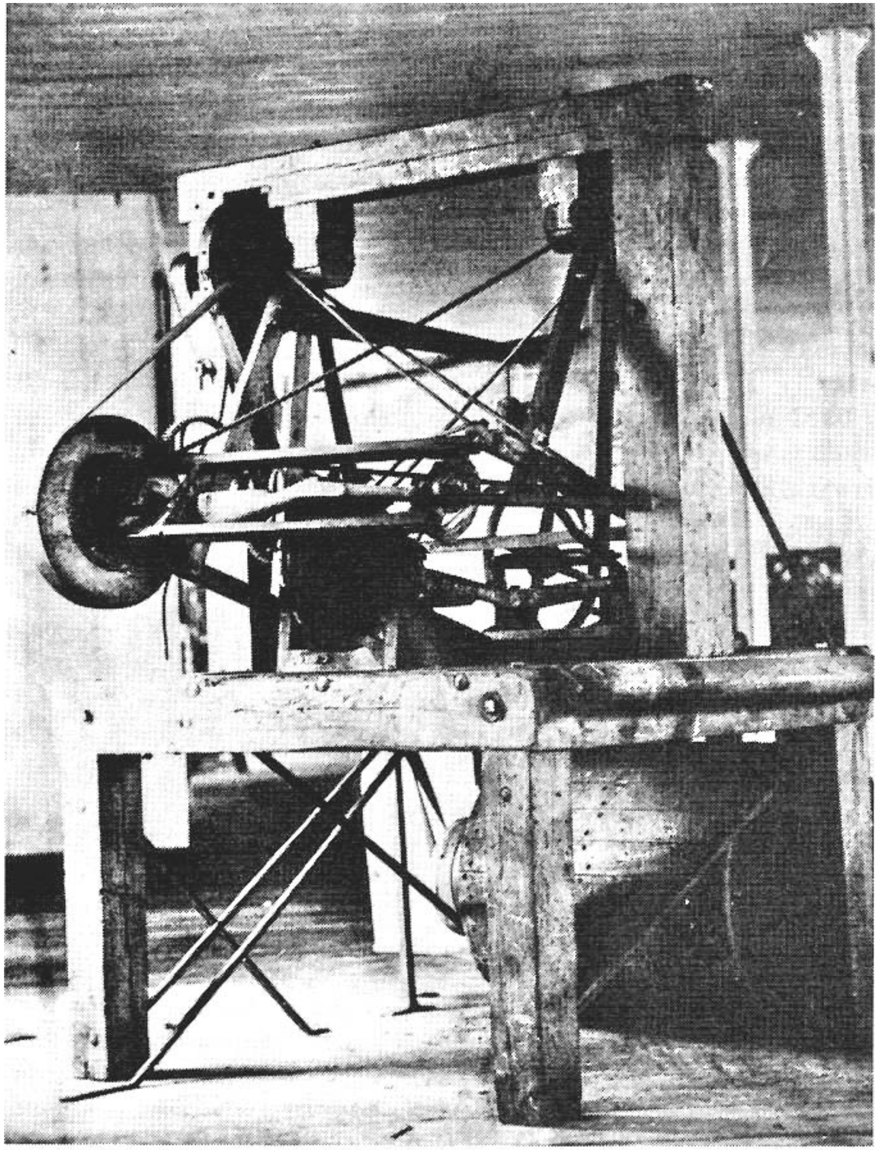
How would you make this part? Bill?



Pop quiz; how would you make a gun stock?

See video

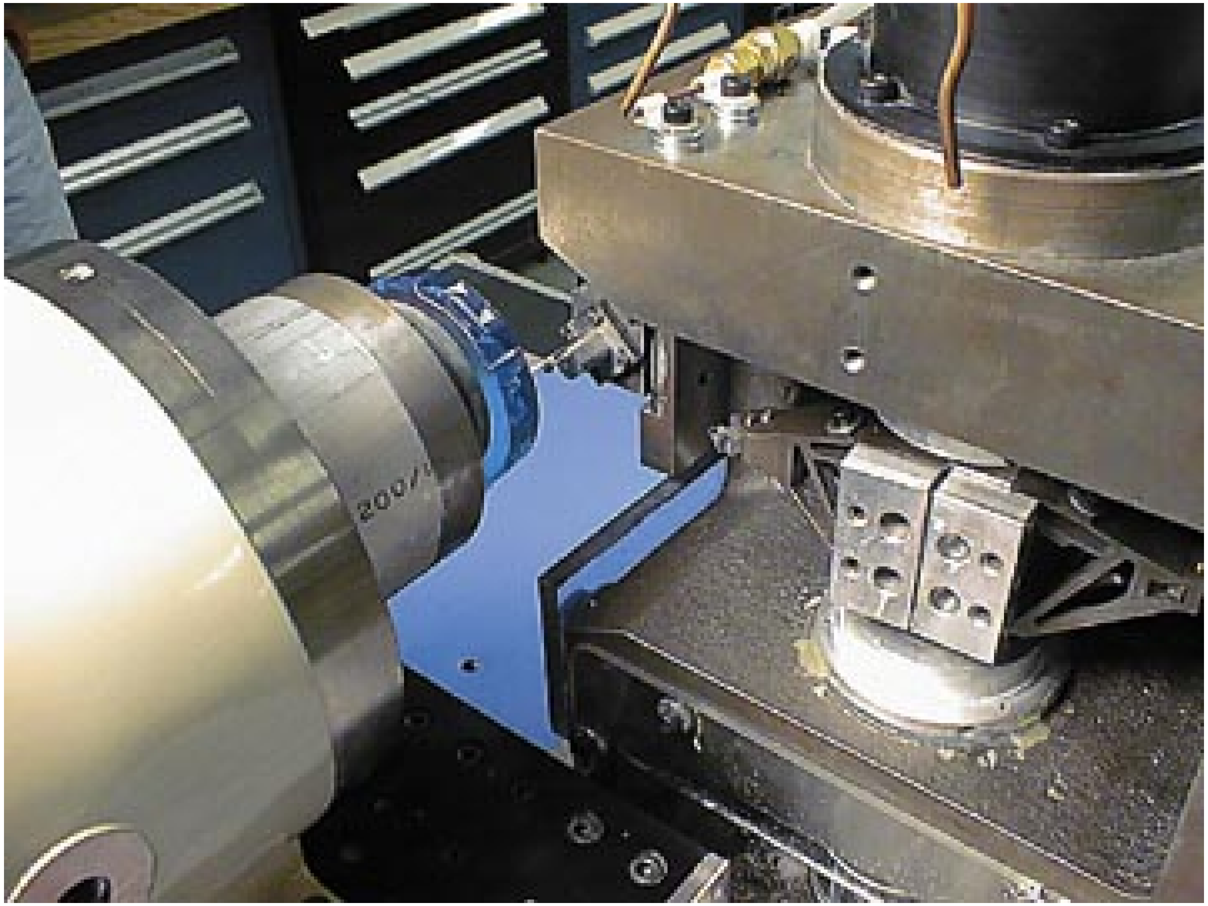
Blanchard's
Lathe
built in 1822
for the
Springfield
Armory

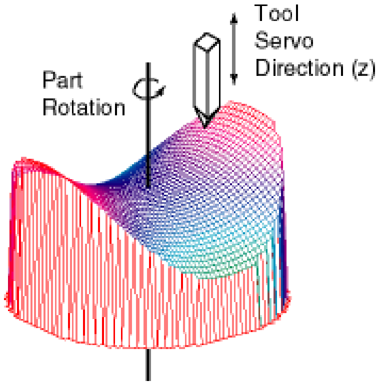


Blanchard's lathe, courtesy of the Springfield Armory National Historic Site.

Fast Tool Server

http://web.mit.edu/pmc/www/index.html





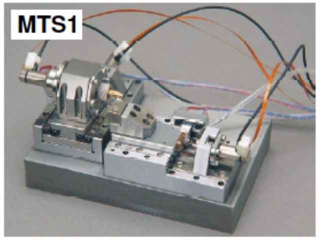
Molded Plastic and Composite Gun Stocks

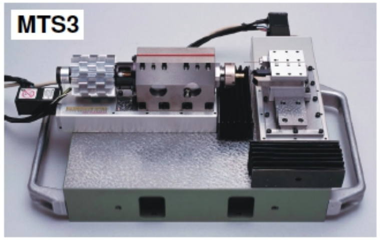
New Developments

- Diamond turning
- Hexapods
- Fast Tool Servers
- Cryogenic Machining

New developments:

Micro machines





Nano Corporation MTS1, MTS3, MTS5

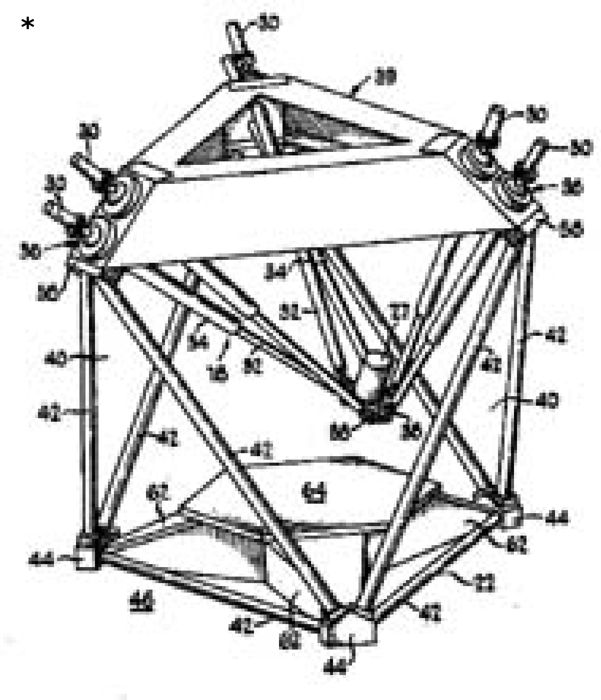
	MTS2	MTS3	MTS4	MTS5
Footprint [mm^2]	100 x 150	200 x 300	220 x 320	260 x 324
Spindle drive P_s [W]	11 DC	30 AC	30 AC	260 DC
Speed n_{max} [min^{-1}]	10,000	3,000	3,000	20,000
Feed drive P_r [W]	3 AC	30 AC	30 AC	30 AC

Source [NANO07]

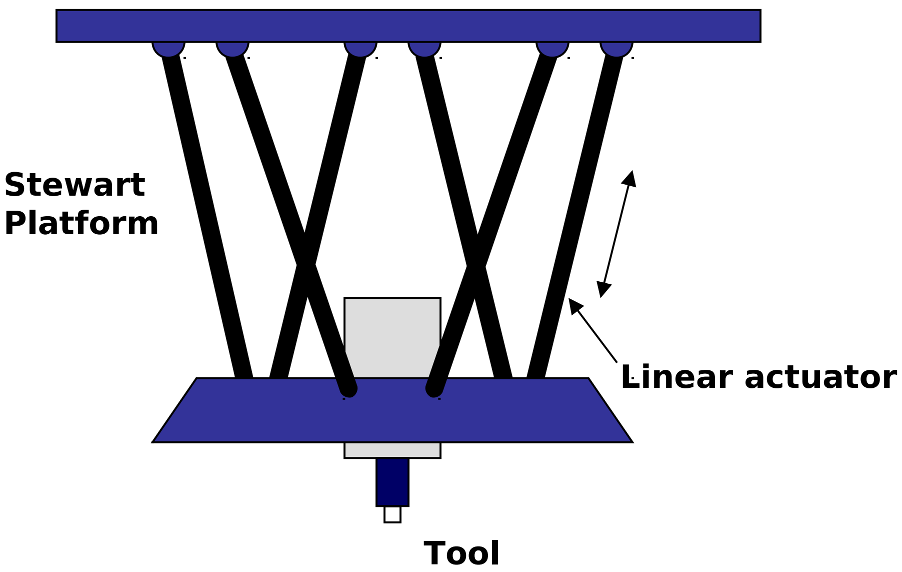
Figure 3.14: Nano Corporation micro machines

Diamond turning
And grinding of optical parts

Hexapod Milling Machines



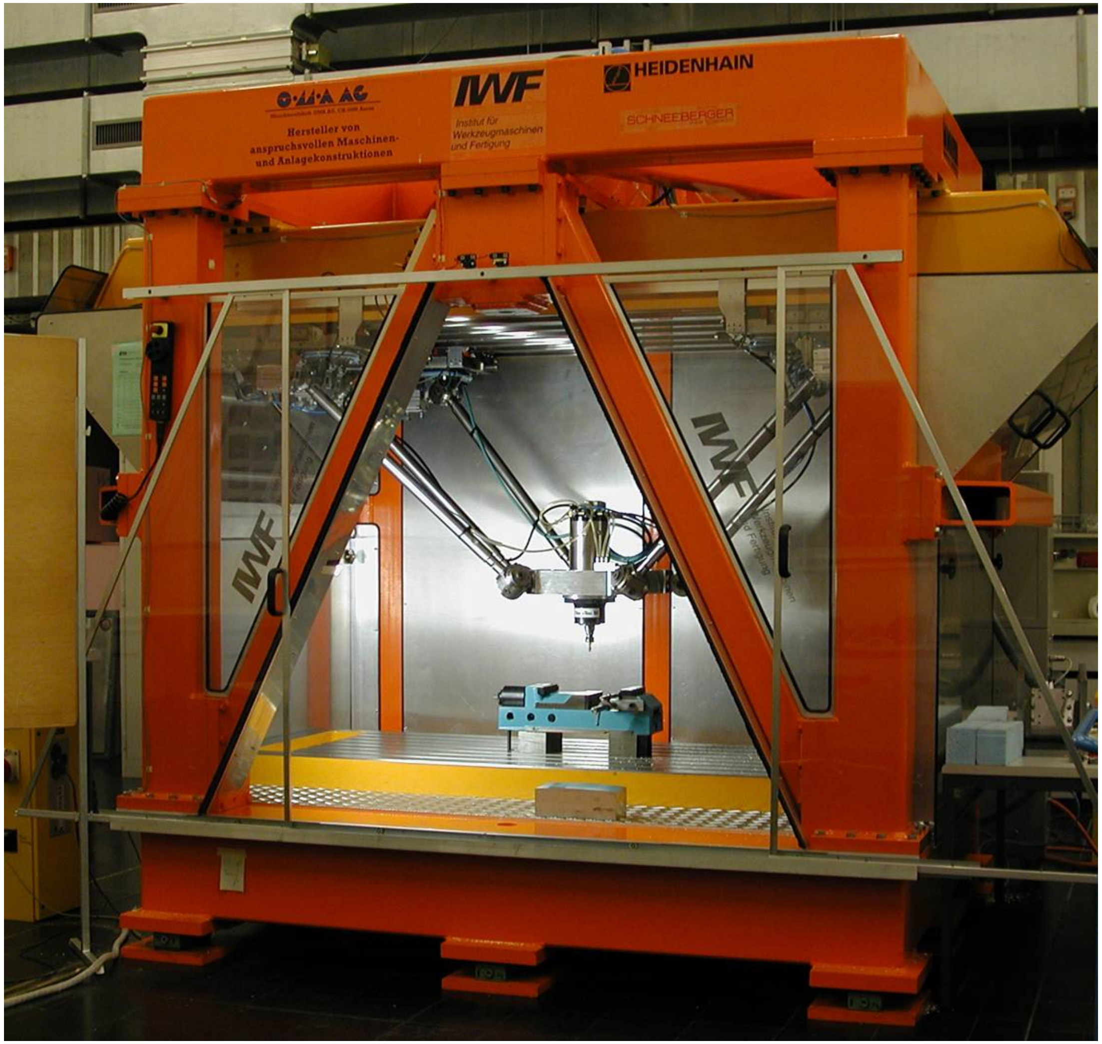
Hexapod machining center
(Ingersoll, USA)



Schematics

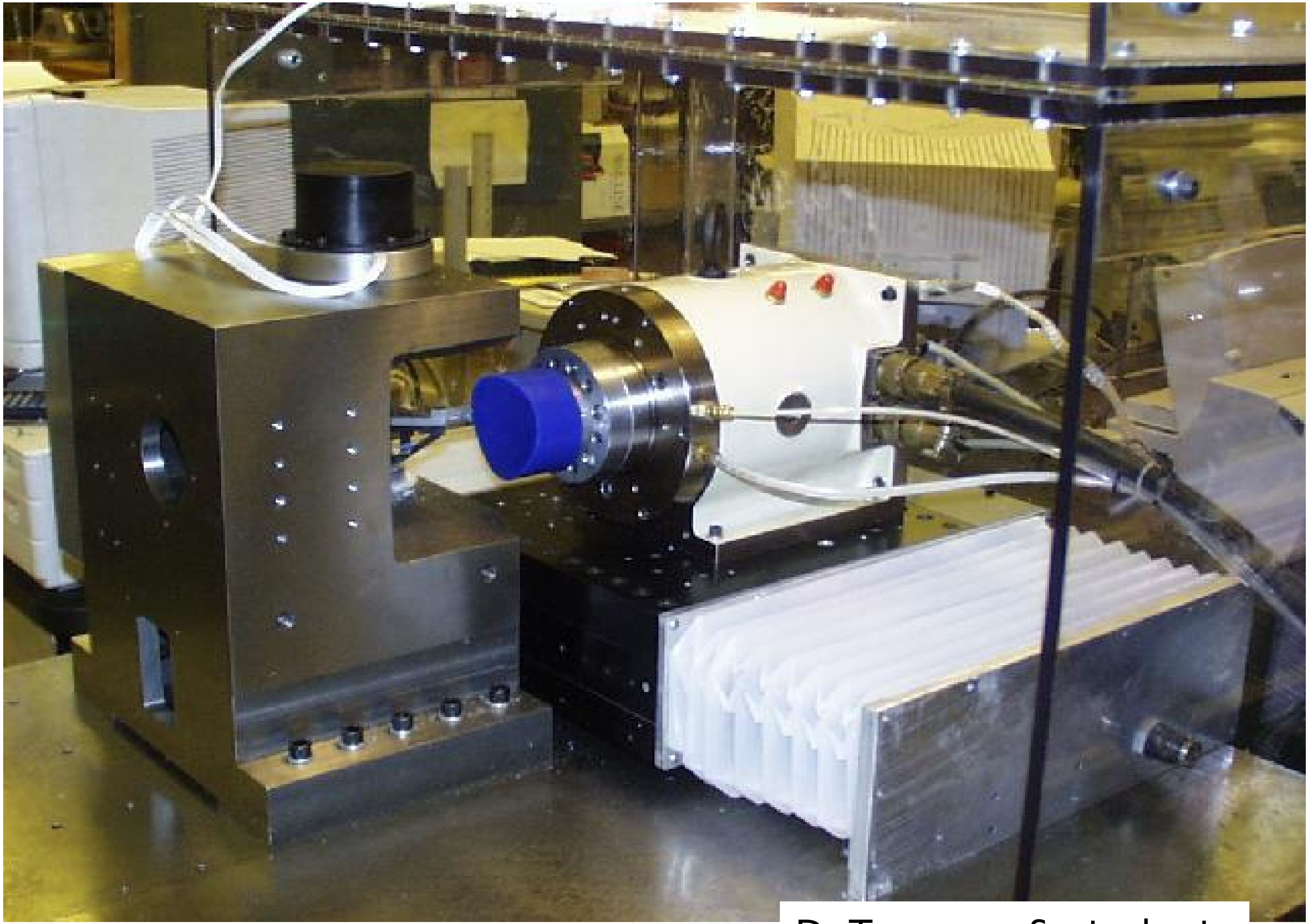
* Source: http://macea.snu.ac.kr/eclipse/background/background.html

Institut für Werkzeugmaschinen und Fertigung
Hexaglide from Zurich (ETH)



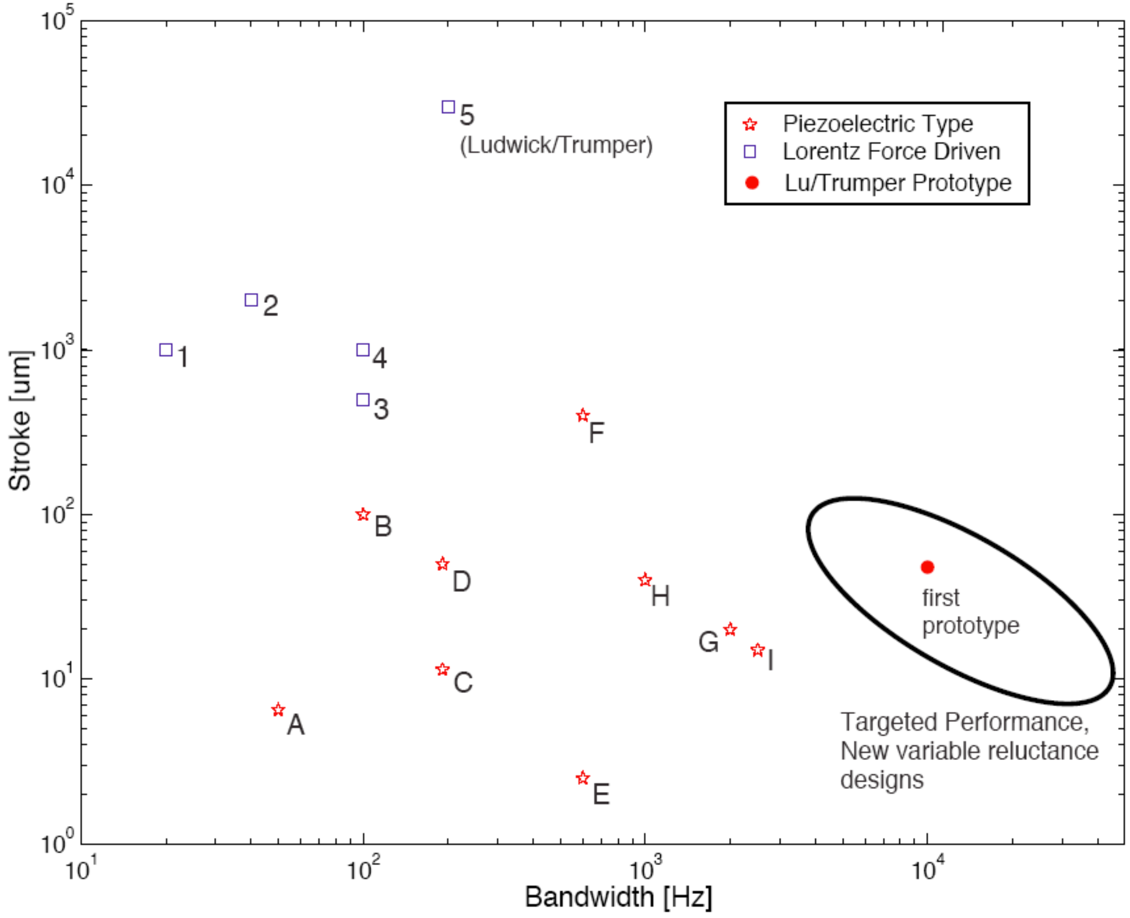
www.iwf.mavt.ethz.ch/

Rotary Fast Tool Servo Machine for Eyeglass Lenses



D. Trumper & students

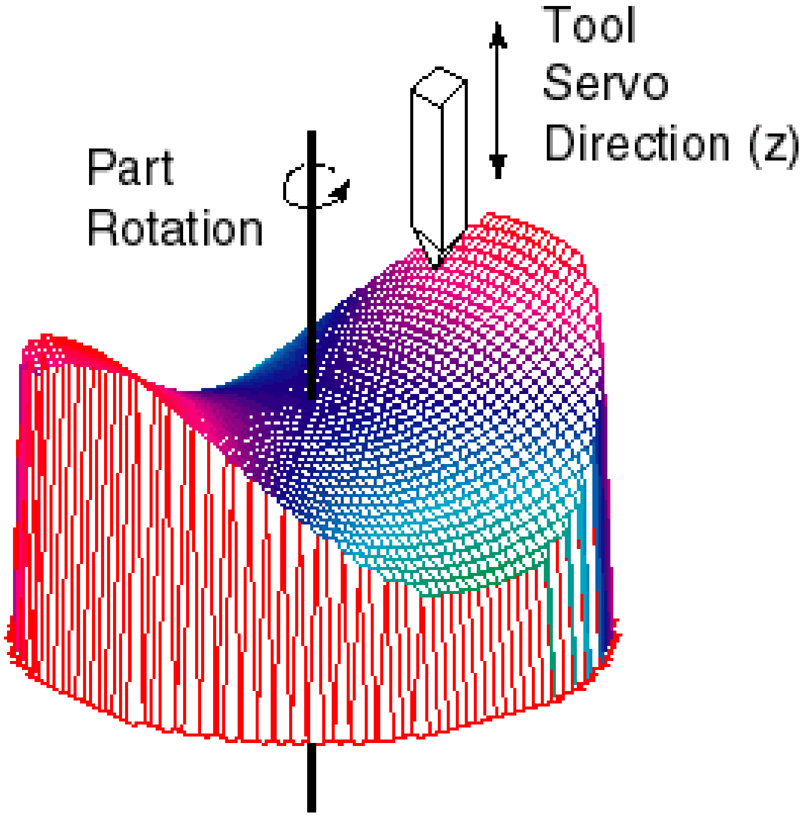
Fast Tool Servo State of the Art



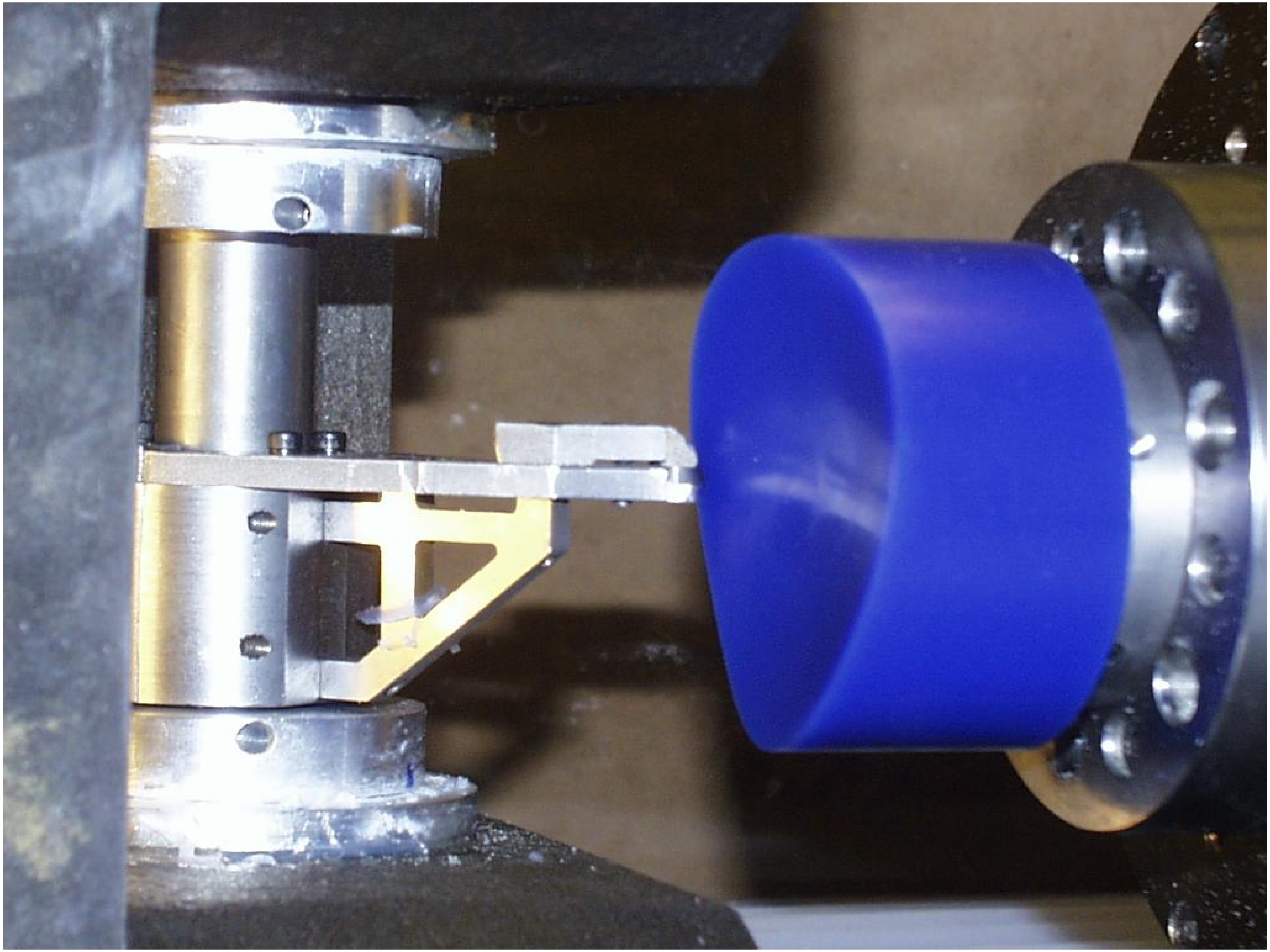
Lorentz FTS		*Piezoelectric FTS*			
1	Todd and Cuttino [19]	A	Kuuno [4]	F	Falter and Youden [10]
2	Weck [17]	B	Cuttino [13]	G	Dow [7]
3	Douglass [16]	C	Jared and Dow [9]	H	Weck [17]
4	Greene and Shinstock [18]	D	Rasmussen [5], [6]	I	Okazaki [12]
5	Ludwick and Trumper [20]	E	Patterson and Magrab [3]		

Asymmetric Turning Operation

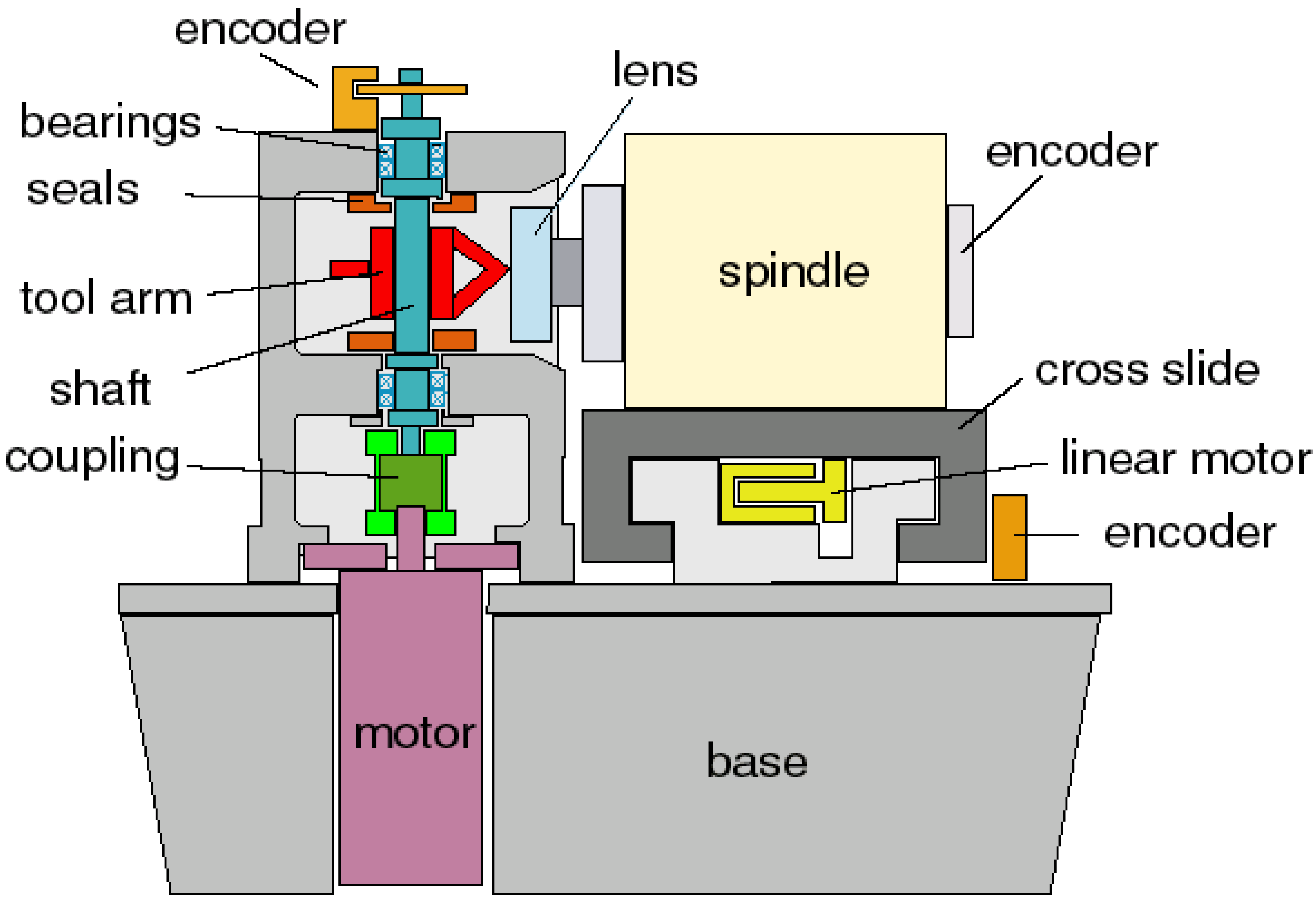
- Spectacle lenses
- Contact lenses
- Human lens implants
- Elements for laser vision correction surgery
- Camera lenses
- Image train elements in semiconductor processing
- Camshafts
- Not-round pistons



Tool at end of arm rotates about vertical axis

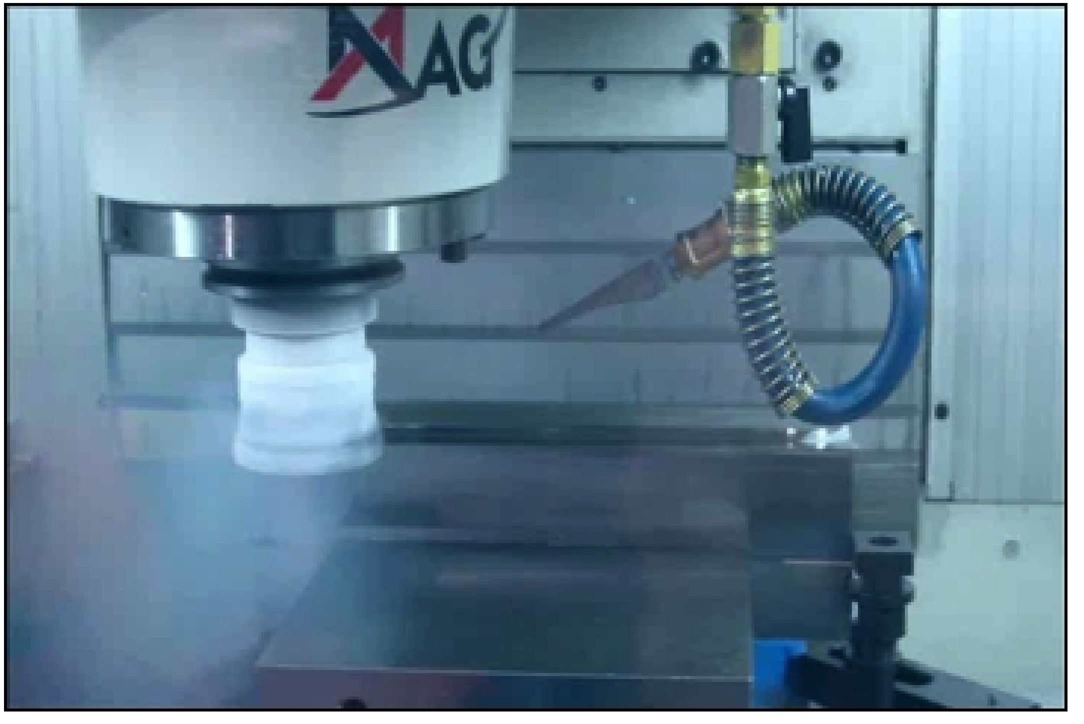


Diamond Turning Machine Cross Section



Cryogenic Machining

http://www.youtube.com/watch?v=GFOXbb7P2jc



NC machine tool developed at MIT mid 1950's

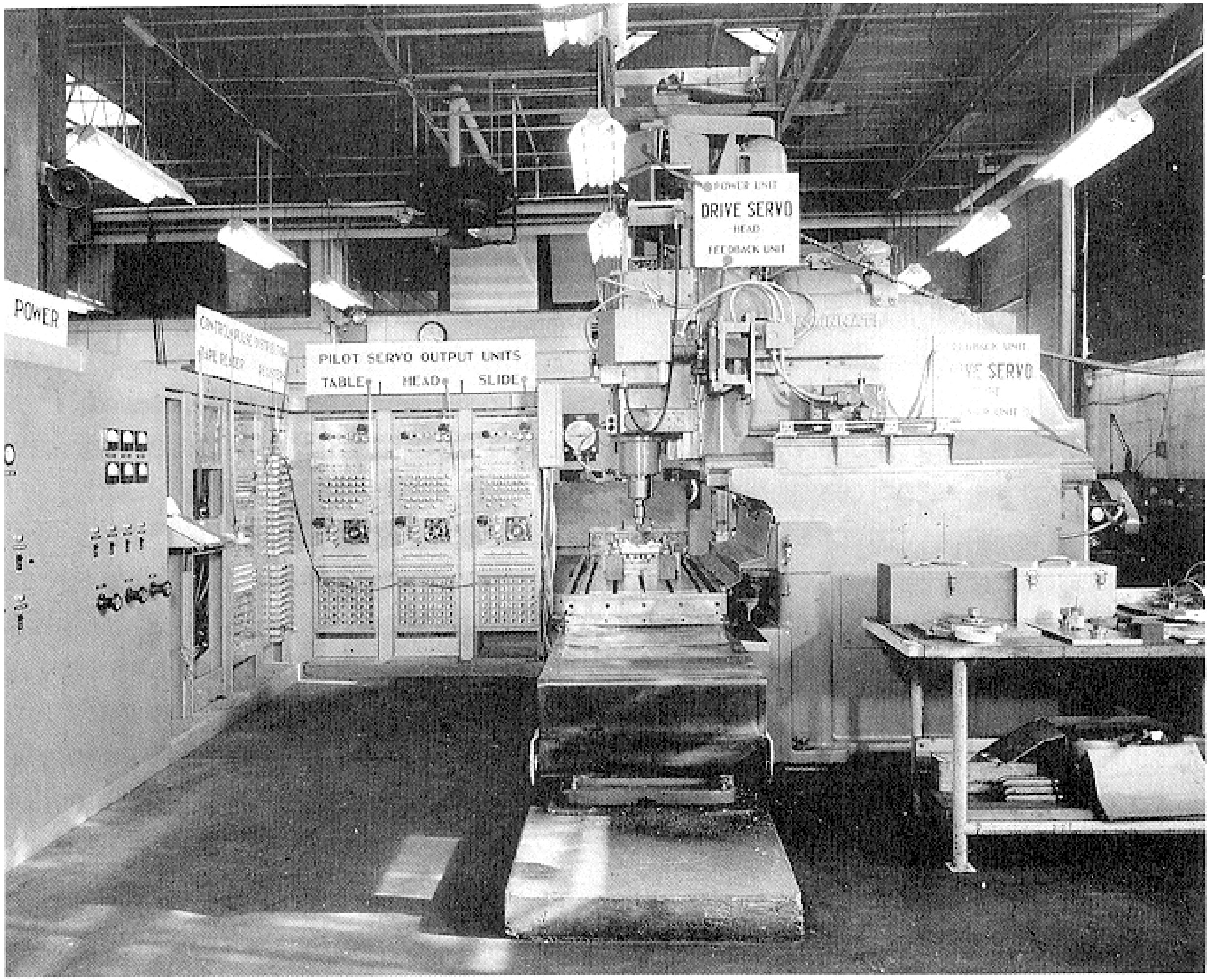


FIG. 2.2. The MIT numerically controlled milling machine.

* Source: Reintjes, "Numerical Control 1991"

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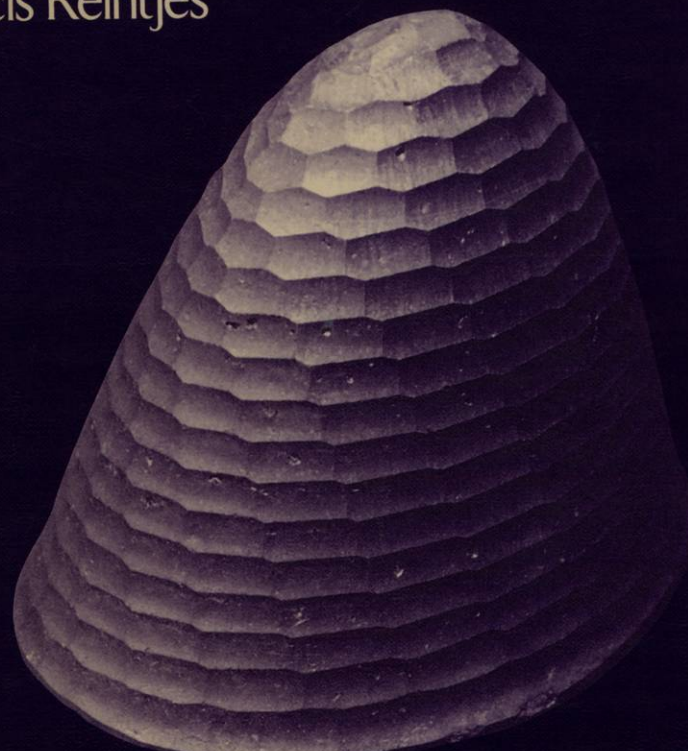
NUMERICAL CONTROL

Making a New Technology

J. Francis Reintjes

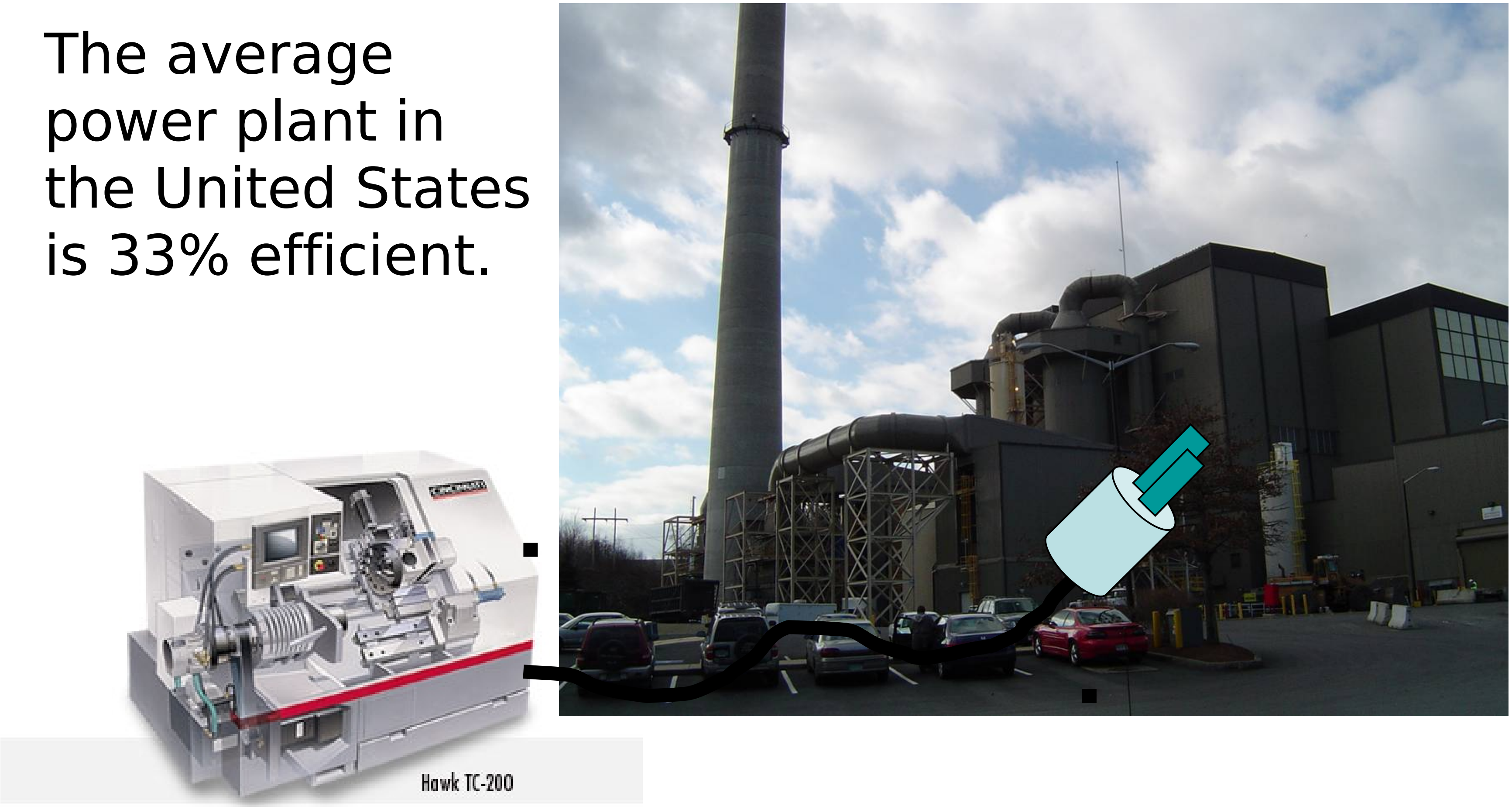


Environmental issues

- Waste material
- Energy
  - Machine, material (embodied energy), temperature controlled environment
- Lubricants and hydraulic fluids
- Cutting Fluids
  - Dry machining

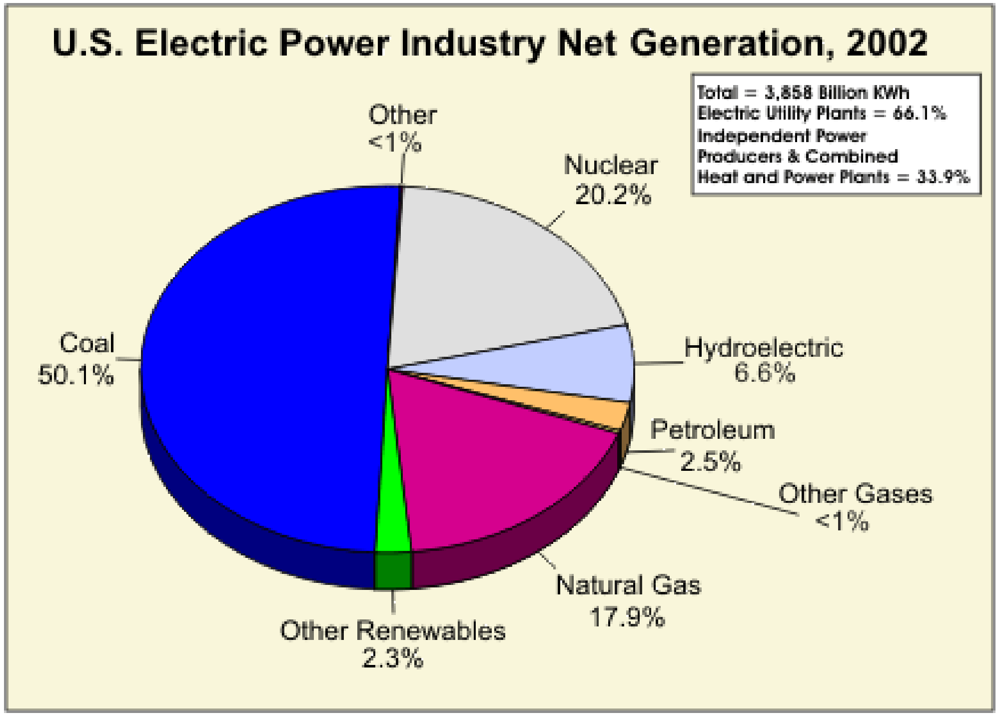
A Machine Tool Vs A SUV

The average power plant in the United States is 33% efficient.



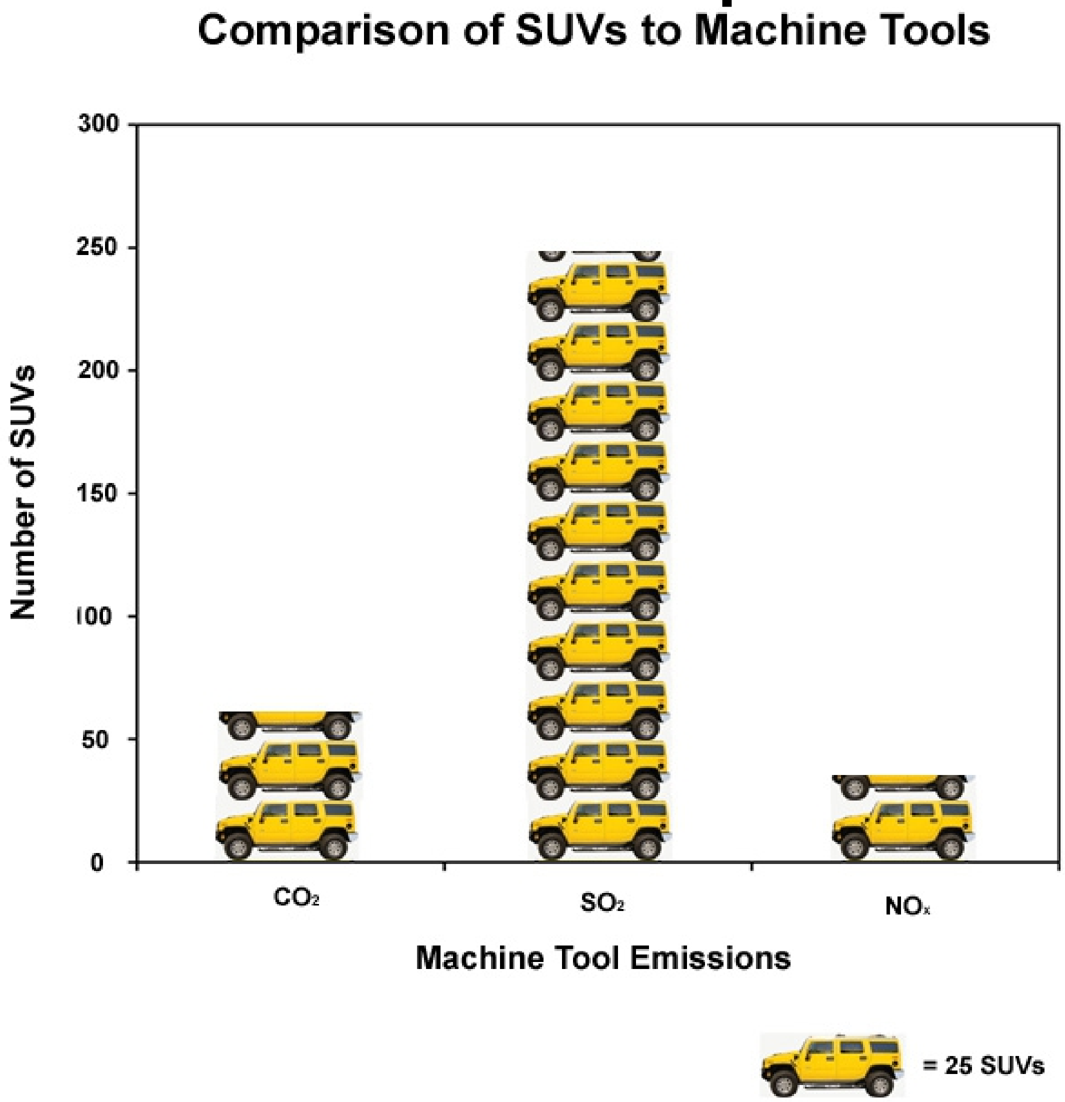
50% of the energy from the grid comes from coal

- electricity from the US grid comes with
  - 667 kg of CO_2/MWh
  - 2.75 kg of SO_2/MWh
  - 1.35 kg of NO_x/MWh
  - 12.3 g Hg/GWh
  - etc……..



Data from US Energy Information Administration, DOE 2002 & Klee & Graedel

annual SUV equivalents



the fine print

- Assumptions:

  Annual emissions resulting from the operation of a typical production machine tool

  (22 kW spindle, cutting 57% of the time, 2 shifts, auxiliary equipment, electricity from US grid)

  as measured in annual SUV equivalents (12,000 miles annually, 20.7 mpg)

- CO_2 – 61 SUV's
- SO_2 – 248 SUV's
- NOx – 34 SUV's

Production machining energy Vs production rate

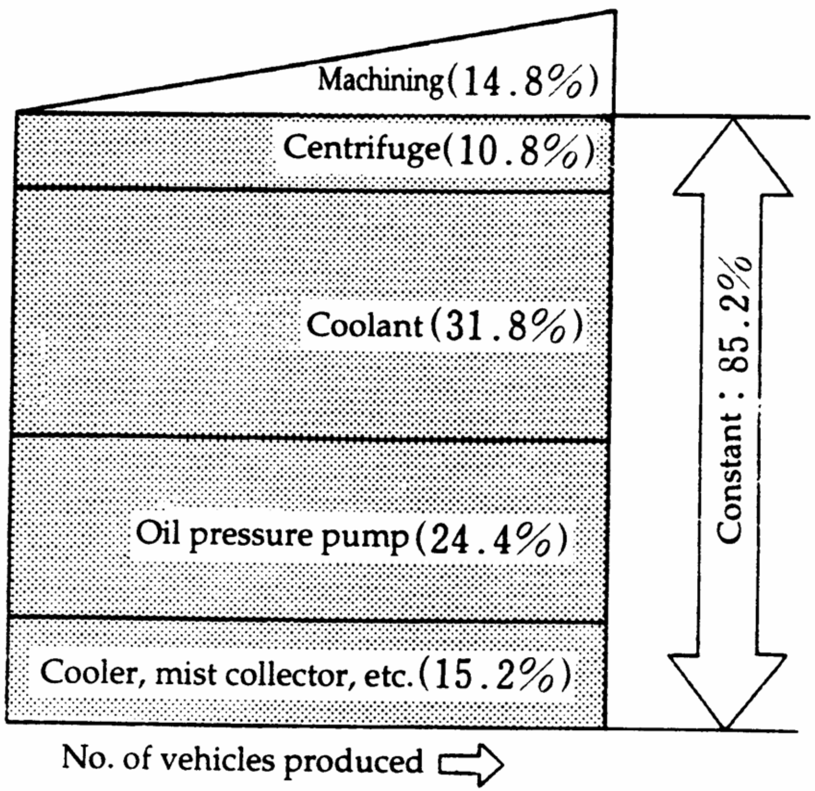


Figure 3.3 Energy Use Breakdown by Type

Ref. Toyota

eye chart for energy values

	Production Machining Center (2000)	Automated Milling Machine (1998)	Automated Milling Machine (1988)	Manual Milling Machine (1985)
Electricity Breakdown				
Constant start-up operations (idle)	85.2%	13.2%	27.0%	31.6%
Run-time operations (positioning, loading, etc)	3.5%	20.2%	24.9%	0% (manual)
Material removal operations (in cut)	11.3%	65.8%	48.1%	69.4%
Electricity Requirements				
Constant start-up operations (idle)	166 kW	1.2 kW	3.4 kW	0.7 kW
Run-time operations (positioning, loading, etc)	6.8 kW	1.8 kW	3.1 kW	0 kW
Material removal operations (in cut)	22 kW	5.8 kW	6.0 kW	2.1 kW
Machine Use Scenario				
Arbitrary Number of work hours	1000 hours	1000 hours	1000 hours	1000 hours
Machine uptime	90%	90%	90%	90%
Machine hours (idle, positioning, or in cut)	900 hours	900 hours	900 hours	900 hours
Percentage of machine hours spent idle	10%	35%	35%	65%
Machine hours spent idle	90 hours	315 hours	315 hours	585 hours
Active machine hours per 1000 work hours	810 hours	585 hours	585 hours	315 hours
Machining Scenario				
Percentage of machine hours spent positioning	30%	60%	60%	70%
Machine hours spent positioning	243 hours	351 hours	351 hours	221 hours
Percentage of machine hours spent in cut	70%	40%	40%	30%
Machine hours spent in cut	567 hours	234 hours	234 hours	94.5 hours
Electricity Use per 1000 work hours				
Constant start-up operations (idle)	149288 kWh	1038 kWh	3033 kWh	600 kWh
Run-time operations (positioning, loading, etc)	5471 kWh	1033 kWh	1818 kWh	0 kWh
Material removal operations (in cut)	6237 kWh	673 kWh	702 kWh	100 kWh
Total electricity use per 1000 work hours	160996 kWh	2744 kWh	5553 kWh	700 kWh

Electricity Used per Material Removed	Production Machining Center (2000)		Automated Milling Machine (1998)		Automated Milling Machine (1988)		Manual Milling Machine (1985)	
Material Machined	Aluminum	Steel	Aluminum	Steel	Aluminum	Steel	Aluminum	Steel
Material Removal Rate	20.0 cm^3/sec	4.7 cm^3/sec	5.0 cm^3/sec	1.2 cm^3/sec	5.0 cm^3/sec	1.2 cm^3/sec	1.5 cm^3/sec	0.35 cm^3/sec
Material removed per 1000 work hours	40824000 cm^3	9593640 cm^3	4212000 cm^3	1010880 cm^3	4212000 cm^3	1010880 cm^3	510300 cm^3	119070 cm^3
Electricity used/Material removed	**14.2 kJ/cm^3**	**60 kJ/cm^3**	**2.3 kJ/cm^3**	**10 kJ/cm^3**	**4.7 kJ/cm^3**	**20 kJ/cm^3**	**4.9 kJ/cm^3**	**21 kJ/cm^3**

Results are in terms of primary energy

	Production Machining Center (2000)		Manual Milling Machine (1985)	
Electricity Breakdown				
Constant start-up operations (idle)	85.2%		31.6%	
Run-time operations (positioning, loading, etc)	3.5%		0% (manual)	
Material removal operations (in cut)	11.3%		69.4%	
Electricity Requirements				
Constant start-up operations (idle)	166 kW		0.7 kW	
Run-time operations (positioning, loading, etc)	6.8 kW		0 kW	
Material removal operations (in cut)	22 kW		2.1 kW	
Machine Use Scenario				
Arbitrary Number of work hours	1000 hours		1000 hours	
Machine uptime	90%		90%	
Machine hours (idle, positioning, or in cut)	900 hours		900 hours	
Percentage of machine hours spent idle	10%		65%	
Machine hours spent idle	90 hours		585 hours	
Active machine hours per 1000 work hours	810 hours		315 hours	
Machining Scenario				
Percentage of machine hours spent positioning	30%		70%	
Machine hours spent positioning	243 hours		221 hours	
Percentage of machine hours spent in cut	70%		30%	
Machine hours spent in cut	567 hours		94.5 hours	
Electricity Use per 1000 work hours				
Constant start-up operations (idle)	149288 kWh		600 kWh	
Run-time operations (positioning, loading, etc)	5471 kWh		0 kWh	
Material removal operations (in cut)	6237 kWh		100 kWh	
Total electricity use per 1000 work hours	160996 kWh		700 kWh	
Electricity Used per Material Removed				
Material Machined	Aluminum	Steel	Aluminum	Steel
Material Removal Rate	20.0 cm^3/sec	4.7 cm^3/sec	1.5 cm^3/sec	0.35 cm^3/sec
Material removed per 1000 work hours	40824000 cm^3	9593640 cm^3	510300 cm^3	119070 cm^3
Electricity used/Material removed	**14.2 kJ/cm^3**	**60 kJ/cm^3**	**4.9 kJ/cm^3**	**21 kJ/cm^3**

Table 8 Typical Energy Costs of Common Materials (MJ/kg)

Material	Energy cost	Made or extracted from
Aluminum	227–342	Bauxite
Bricks	2–5	Clay
Cement	5–9	Clay and limestone
Copper	60–125	Sulfide ore
Glass	18–35	Sand, etc.
Iron	20–25	Iron ore
Limestone	0.07–0.1	Sedimentary rock
Nickel	230–70	Ore concentrate
Paper	25–50	Standing timber
Polyethylene	87–115	Crude oil
Polystyrene	62–108	Crude oil
Polyvinylchloride	85–107	Crude oil
Sand	0.08–0.1	Riverbed
Silicon	230–235	Silica
Steel	20–50	Iron
Sulfuric acid	2–3	Sulfur
Titanium	900–940	Ore concentrate
Water	0.001–0.01	Streams, reservoirs
Wood	3–7	Standing timber

Ref Smil

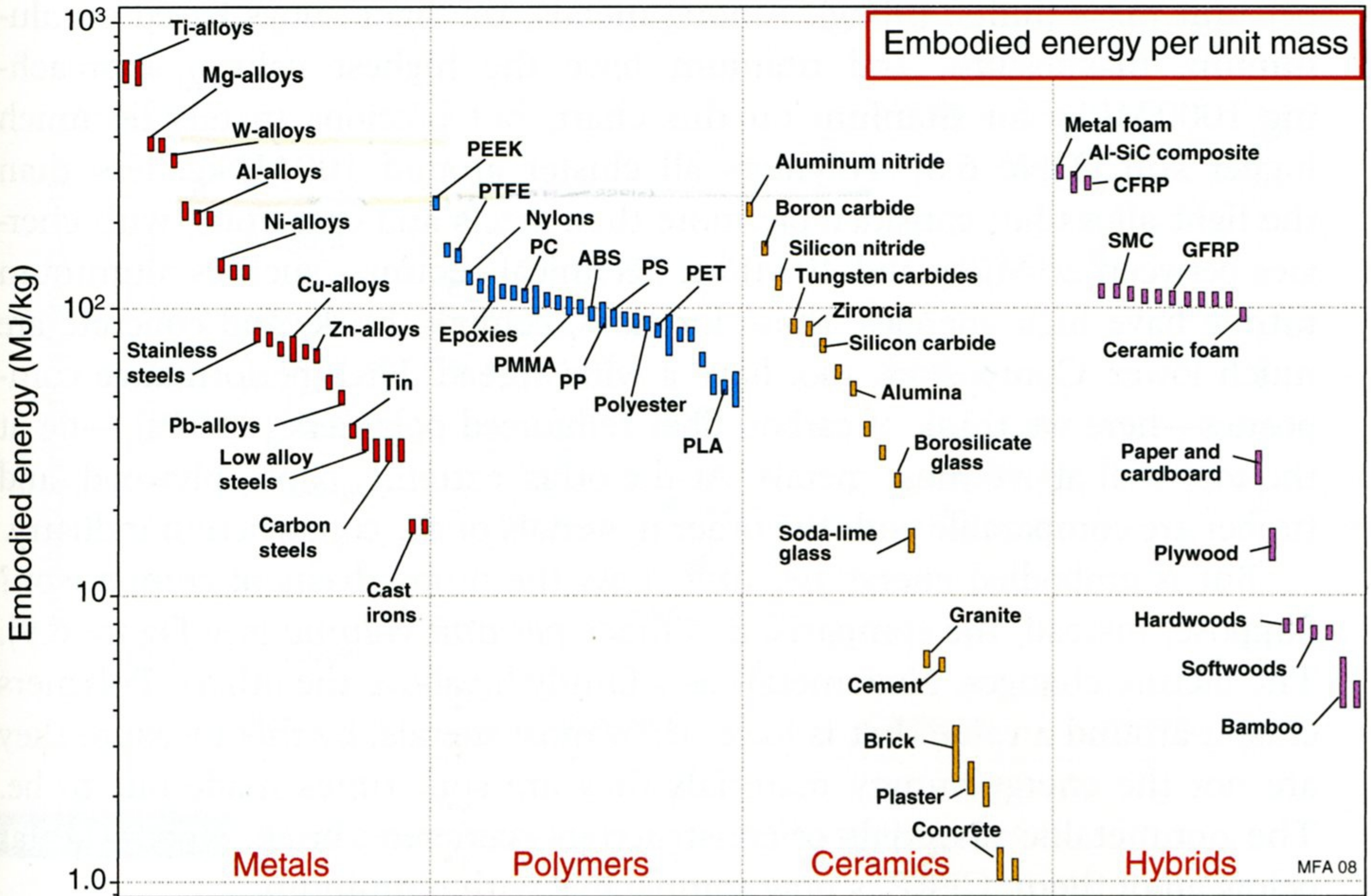


FIGURE 6.8 *A bar chart of the embodied energies of materials per unit mass.*

Ashby 2009

Sample calculation

- 1 kg part made from 2 kg of aluminum stock 2024
- production machining 14.2 kJ/cm^3
- 1000 g /2.7 g/cm^3 = 370 cm3

(14.2 X 370 = 5.25 MJ) X 3 = 15.8 MJ

- material production

(284.5 MJ/kg X 2 kg = 569 MJ)+15.8 =
585 MJ/ kg of part

Power plant efficiency

Box 3.1

Efficiency of a power station

For a typical coal-fired power station, the steam reaches about 500°C = 773 K: this is T_h. The cold temperature, T_c, is not less than ambient temperature: it can be taken as 300 K (27°C). Carnot efficiency is given by Equation (3.13):

$$\eta = 1 - 300/773$$
$$= 0.61$$

This is the theoretical limit, and once other losses are accounted for, most power stations end up with overall efficiency around 35 per cent. The remaining energy is lost as low grade heat and is generally dissipated by cooling towers, or into a lake, river or the sea.

For a nuclear station, temperatures are cooler, to restrict corrosion for safety reasons. At T_h = 300°C = 573 K, the Carnot efficiency will be:

$$\eta = 1 - 300/573$$
$$= 0.52$$

Again there are heat losses elsewhere, giving overall efficiency of 25–30 per cent. Thus the waste heat of 65–75 per cent of heat input contains between two and three times as much energy as the electricity produced.

C. Smith 2001

emissions for the power station

- 585 MJ of primary energy (195 MJ of electricity / efficiency = .33), or .06 MWh. This gives:
  - 33.35 kg of CO_2
  - 140 g of SO_2
  - 0.6 g of Hg

  all for a 1 kg part