Evolving Design

Development of Production Technology and Machine Tools

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Production Technology?
Machine Tools?

- **Wow! Cool!**

- **Saai!**

- **Why Are They Relevant to Design?**
    - I Know They Are Important, But…

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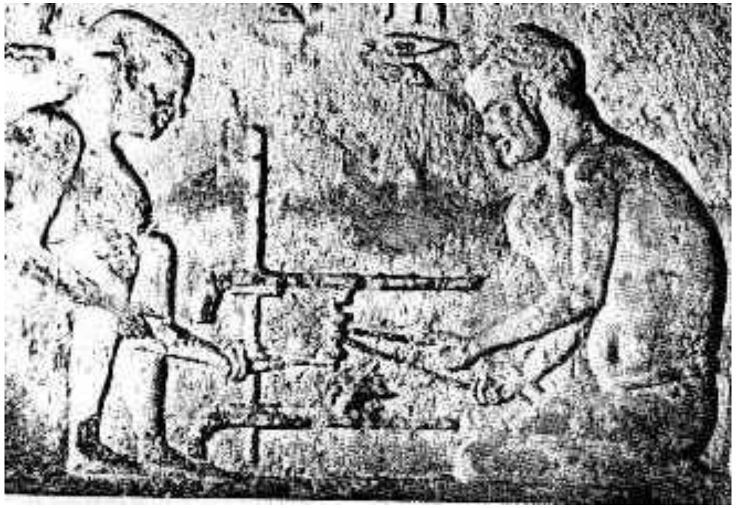
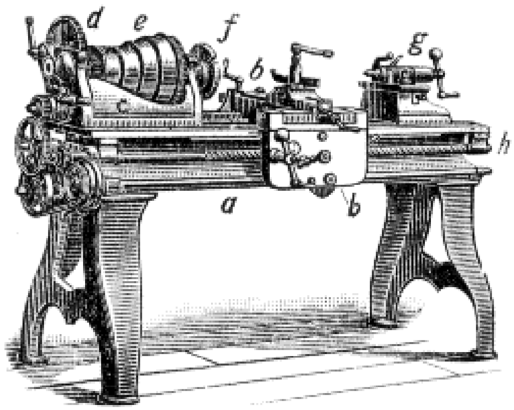
Machine Tools

- **Mother Machines**
  - Machines to Make Machines
  - The Accuracy of the Mother Machine is Copied onto Parts Made with the Mother Machine





Lathe, p. 1218.

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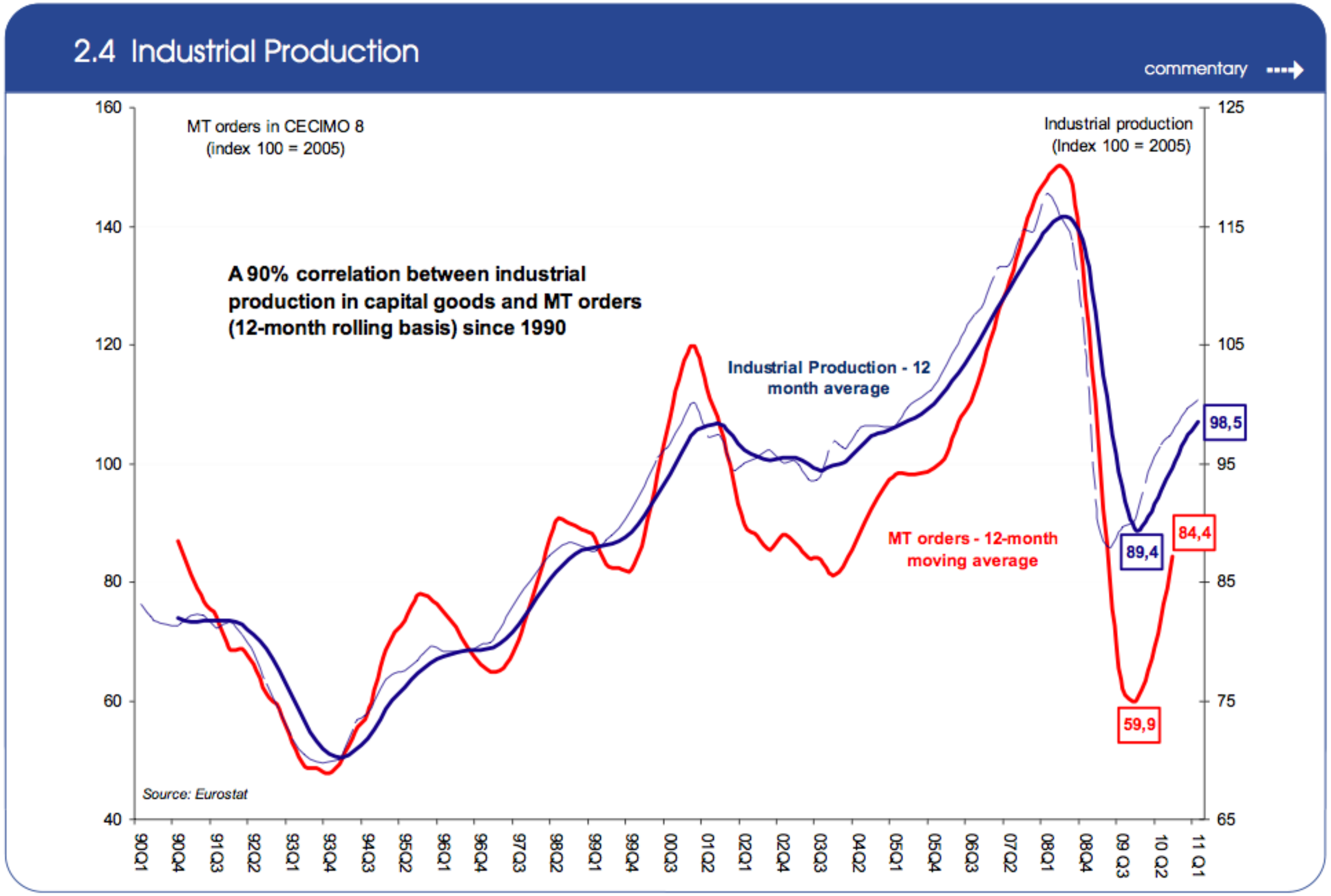
Machine Tools are a Basis of Industry



http://www.cecimo.eu/images/stories/statisticaltoolbox/cecimo%20statistical%20toolbox%20march%202011.pdf

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So, the Reality is…

- **Mechanical Engineering**
  - What: Design
  - How: Production Technology, Machine Tools
  - Why: Science

Question 1

- **With Analytical Methods, Lines and Planes are Easier than Circles and Cylinders**
- **Geometrical Methods (Rulers and Compasses), Only Lines and Circles**
- **In Mechanical Engineering, What is the Easiest Type of Surface?**

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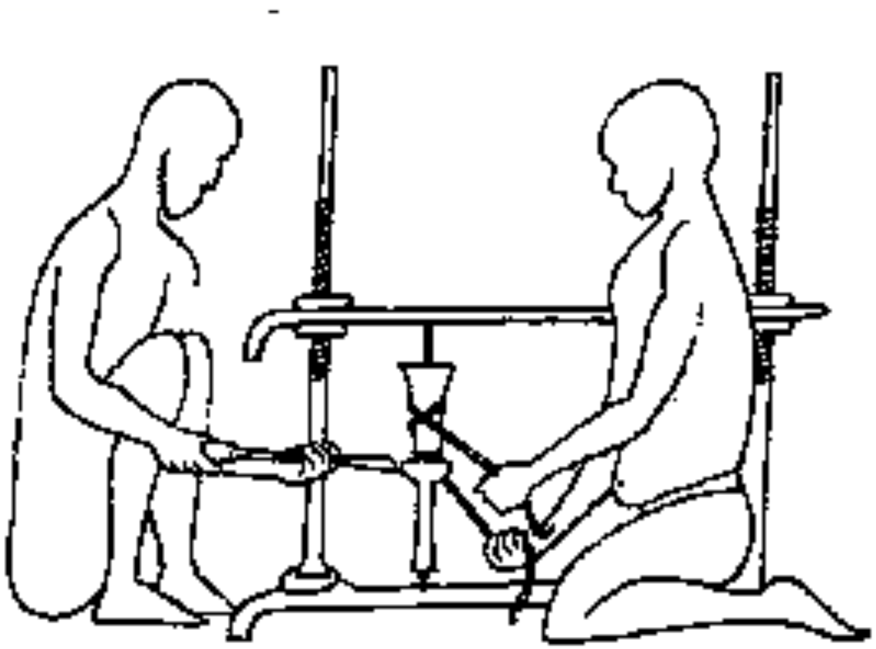
Egyptian Lathe ca. 300 BC



Prehistoric British Pole Lathe

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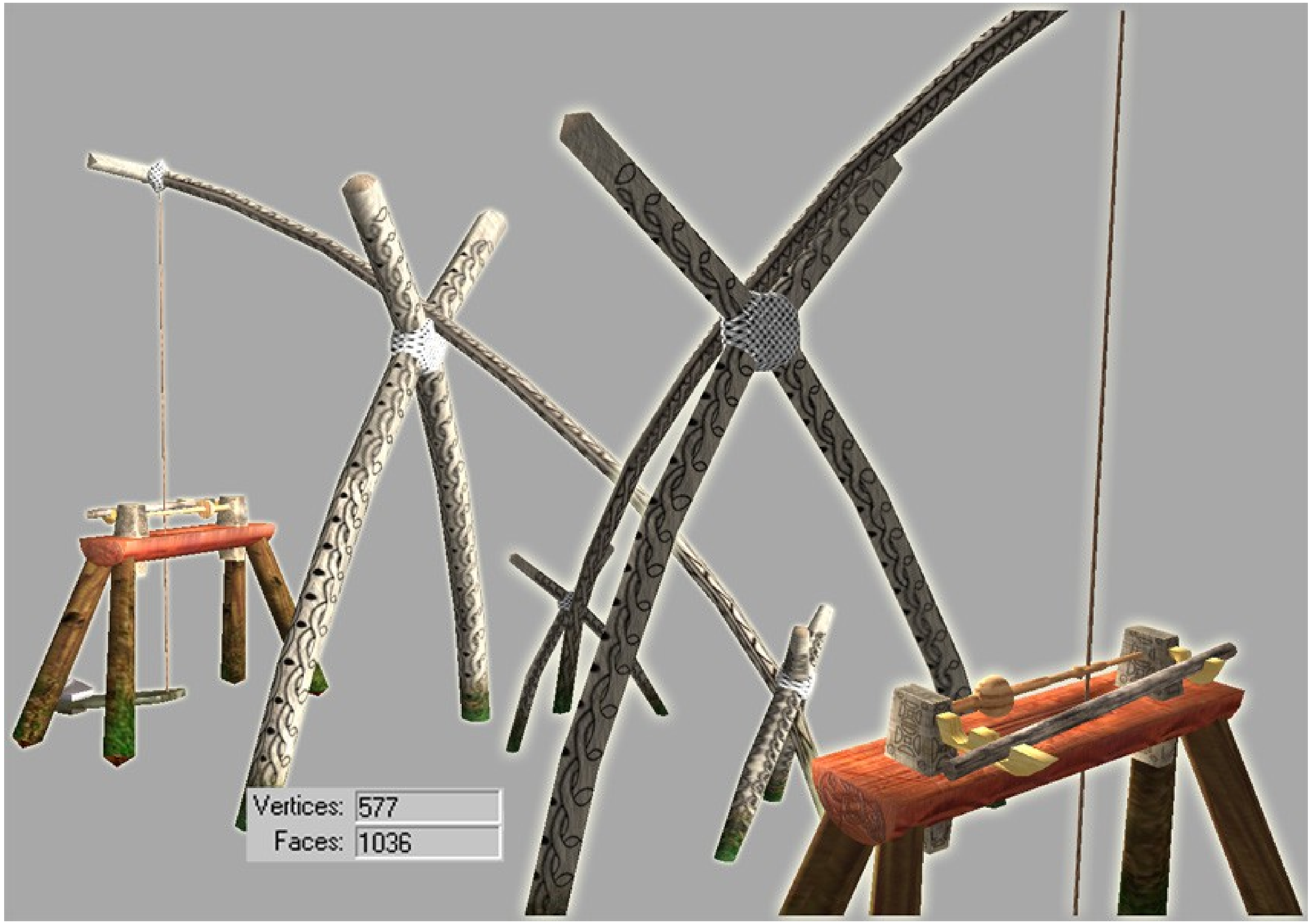
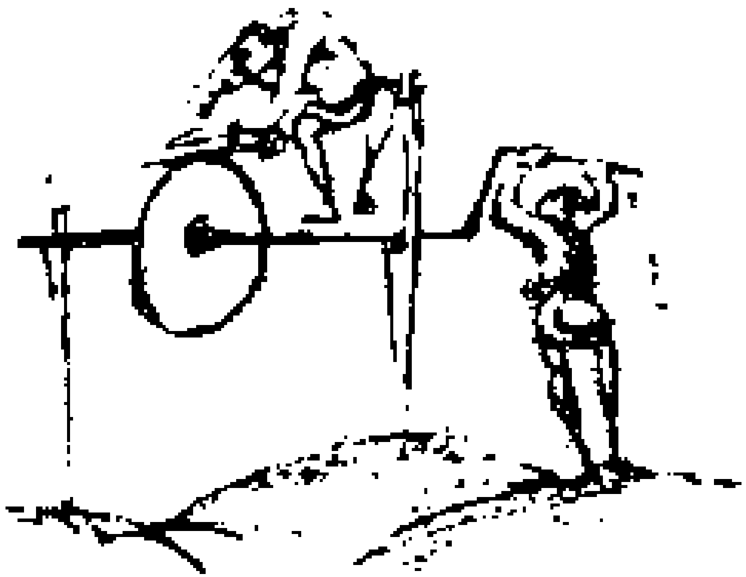
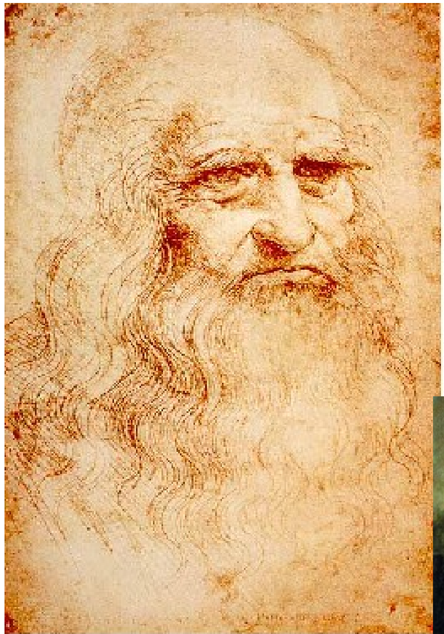
Pole Lathe

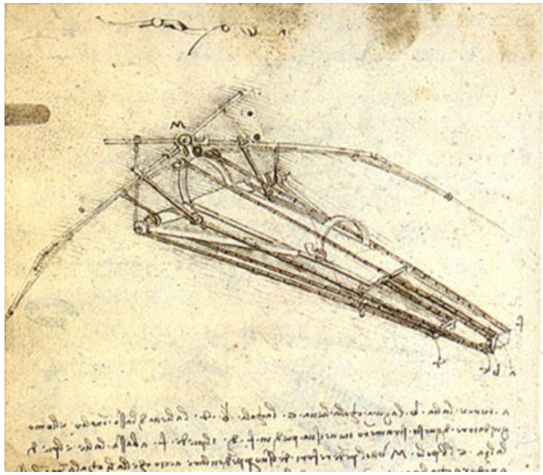


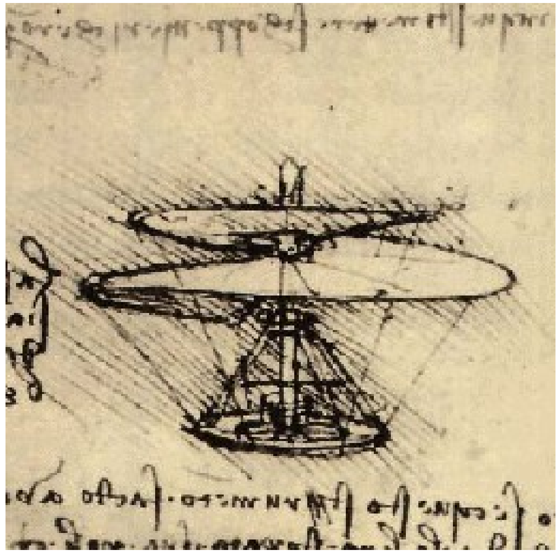
Medieval

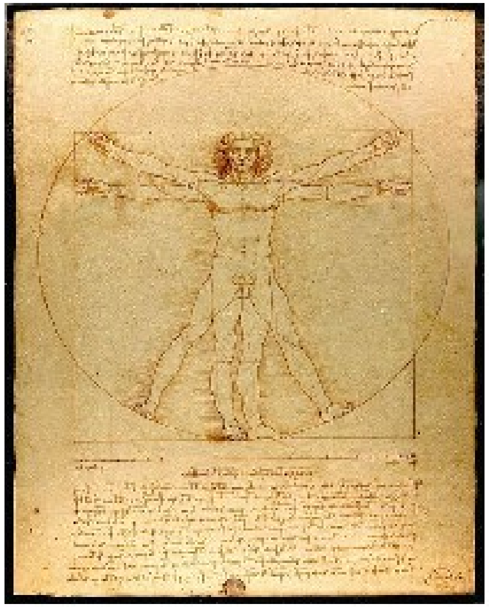


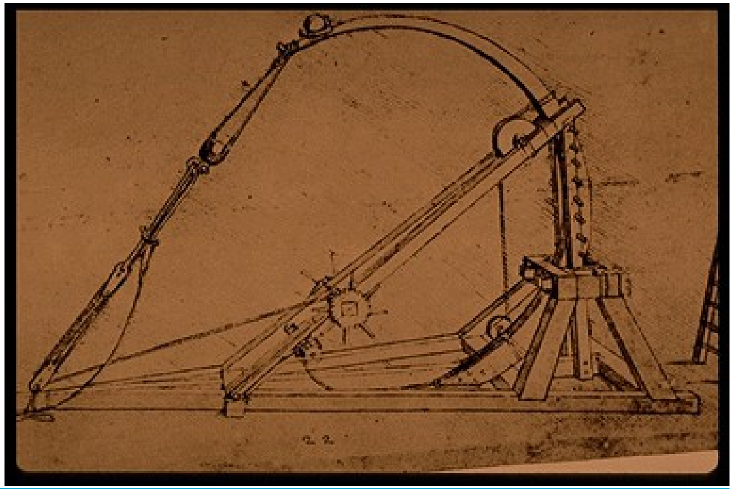
Leonardo Da Vinci (1452-1519)



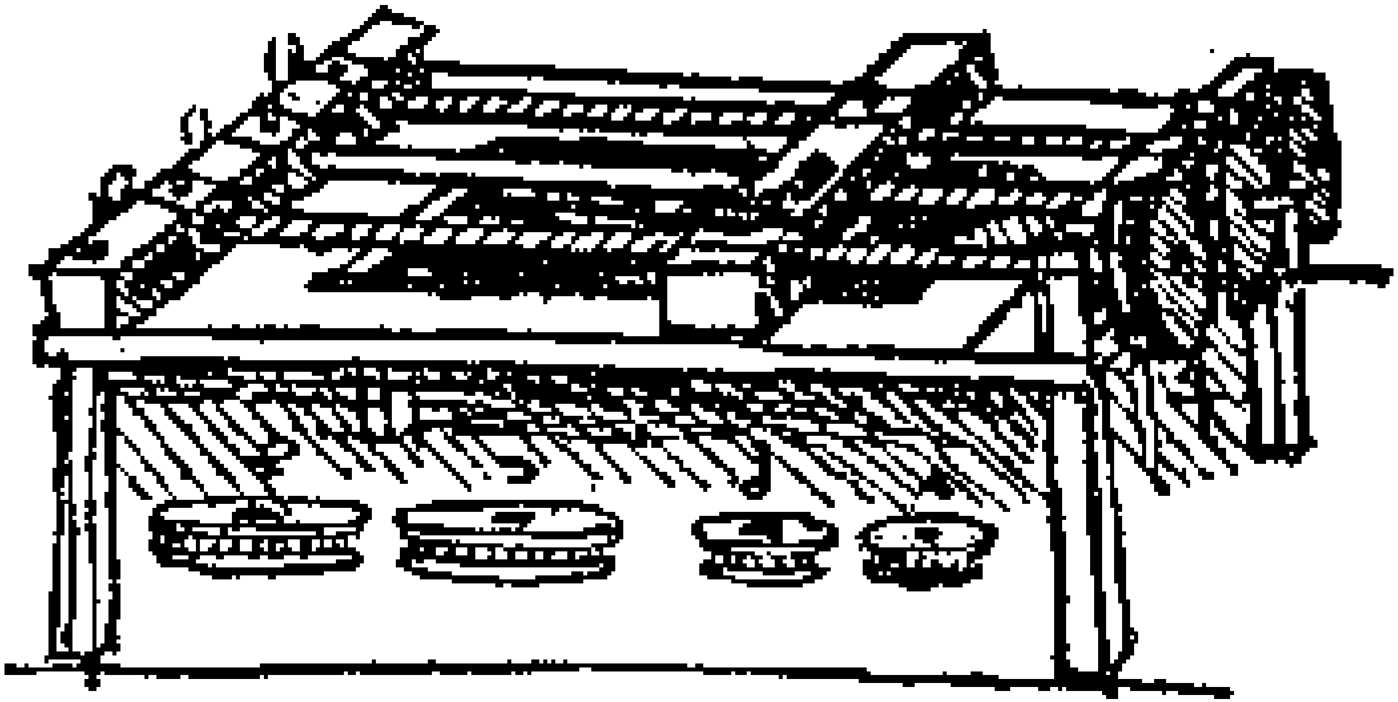








Da Vinci's Screw Cutter



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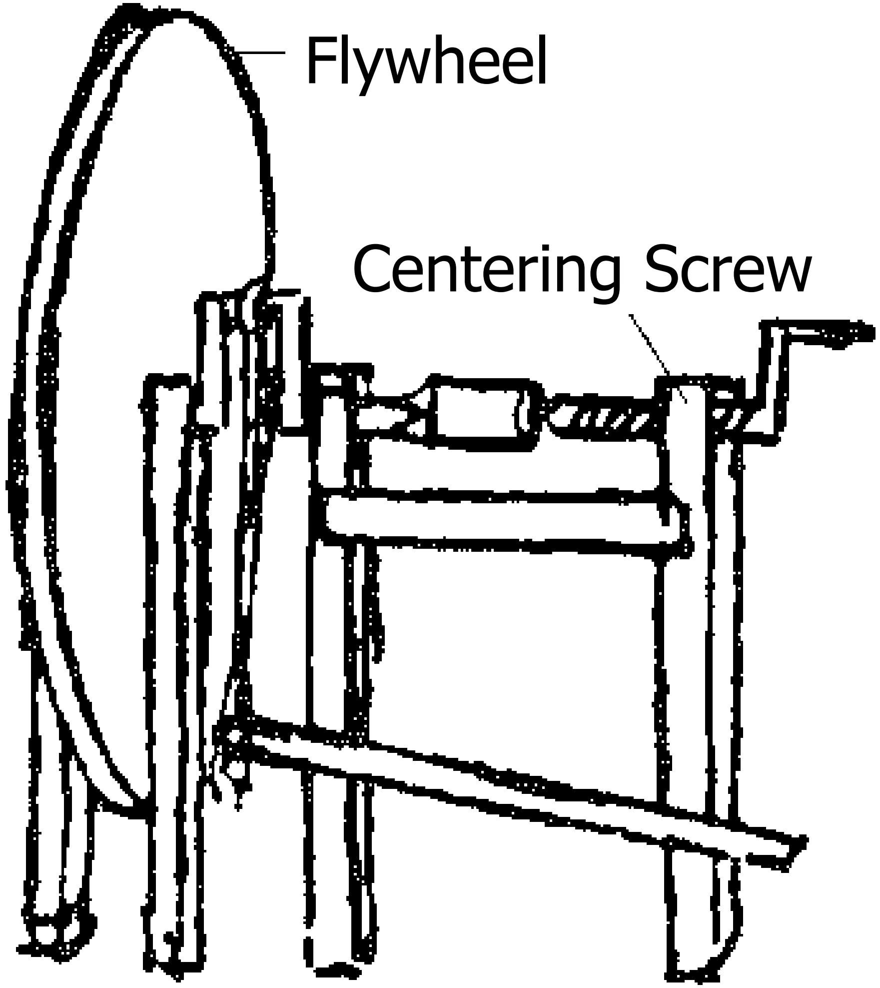
Da Vinci's Lathe



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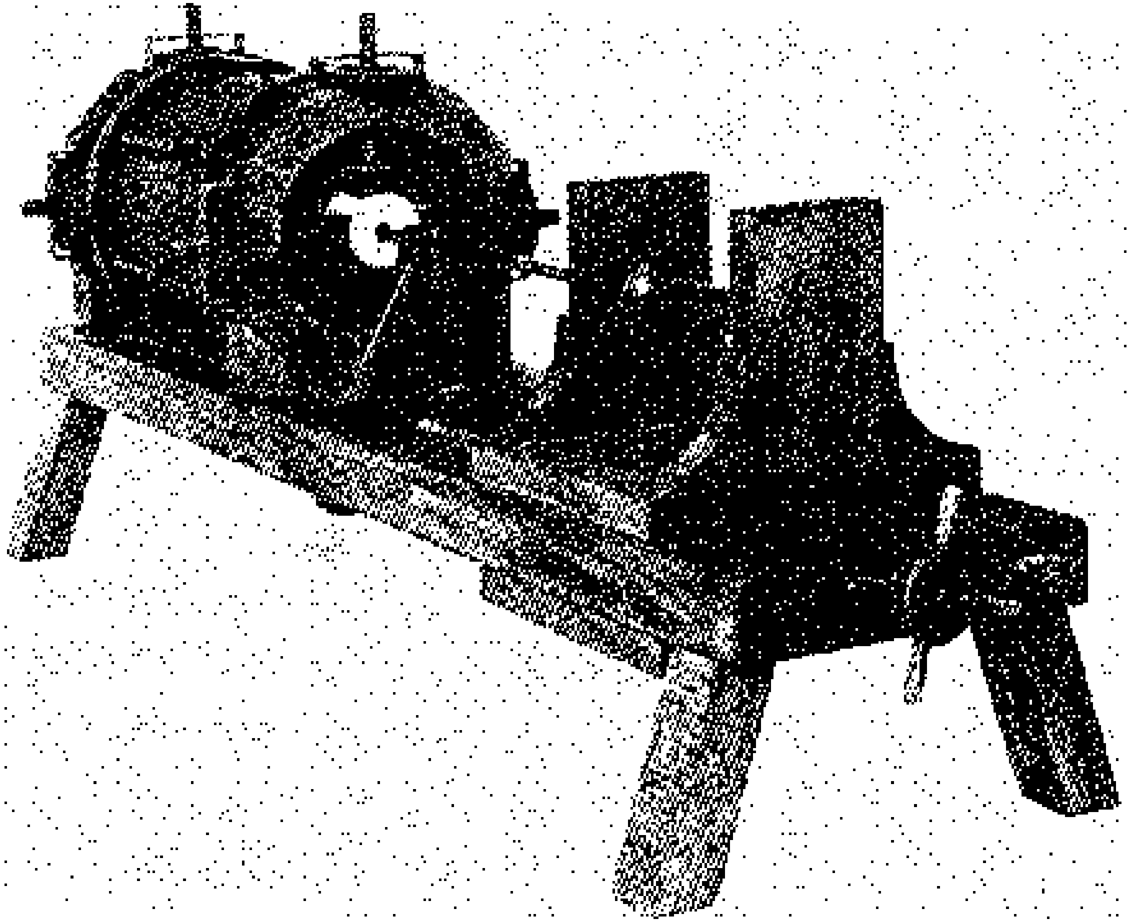
Da Vinci's Boring Machine with a Self-Aligning Chuck



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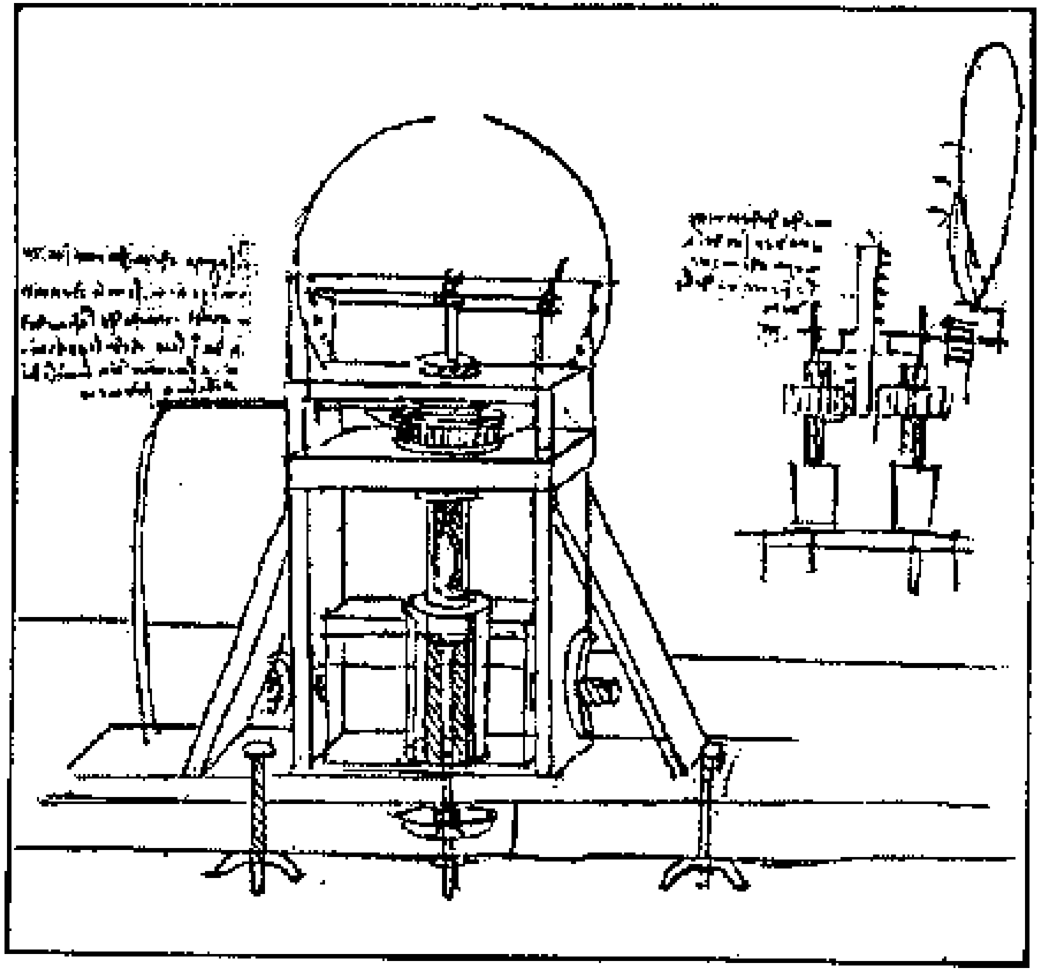
Da Vinci's Internal Grinder



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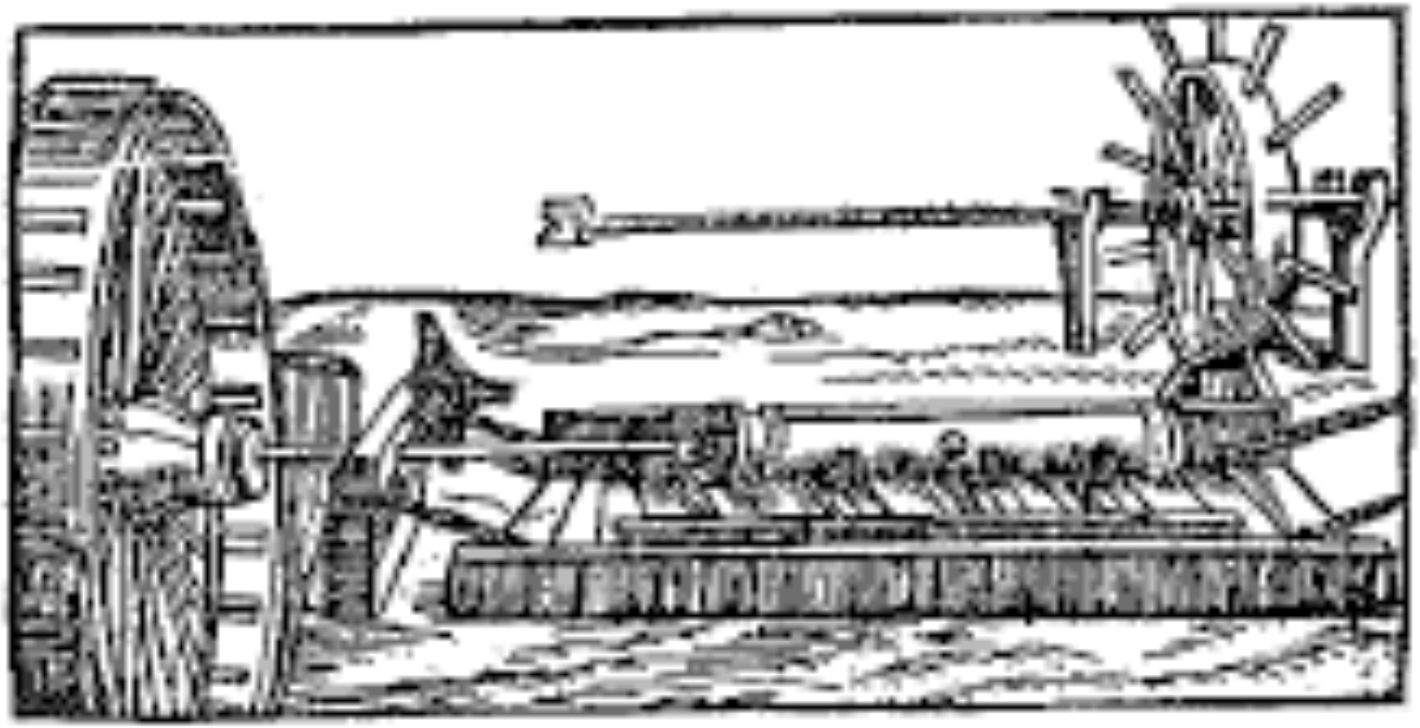
Vannoccio Biringuccio (1480?-1539): Boring Machine for Cannons

- **Rather Horizontal "Polisher"**
  - Barrel was Cast Bronze/Brass with a Cylindrical Core
- **But Difficult to Precisely Cast**



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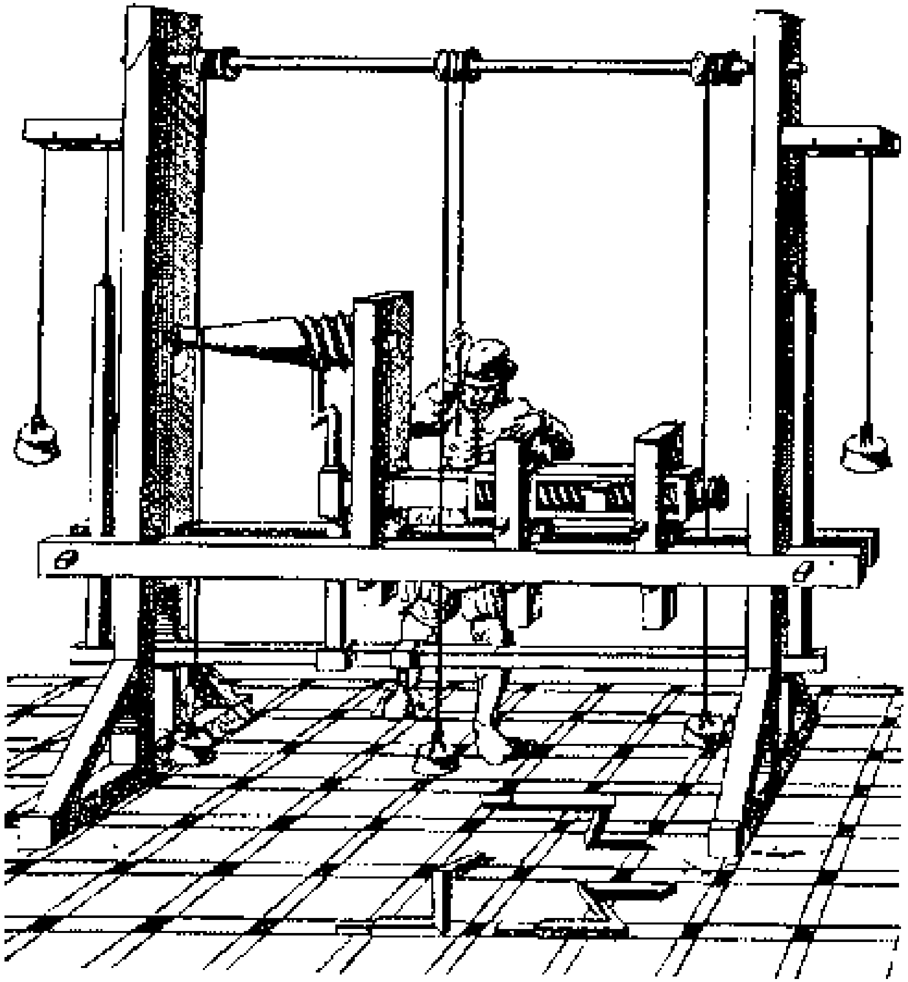
Jacques Besson (1540-1576): Screw Cutter



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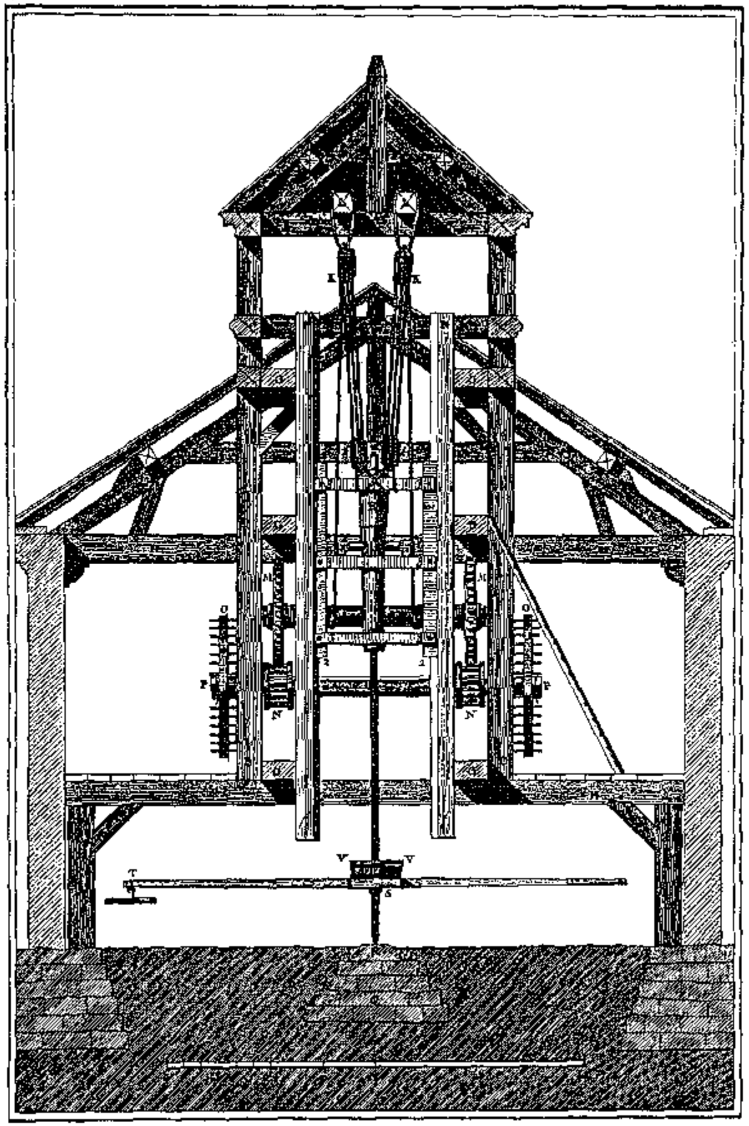
Artillerie Inrichtingen

- **1679, in Houttuijnen, Delft**
  - 1664 Nieuw Amsterdam ➔ New York
  - 1672 Rampjaar
  - 1672-1674 Derde Engelse Oorlog
  - 1715 Johann Maritz (Burgdorf, Switzerland)
    - Invented "Solid Cannon Barrel, Then Boring"
    - France and Spain Successful with the Invention
  - 1747 AI Decided to Employ This Method
  - 1755 Jan Verbruggen (1712-1781), Master Founder at AI
  - 1770 Jan Verbruggen Escaped to England with his Son Pieter Verbruggen (1734-1786) and Became Master Founder at Woolwich Arsenal
  - 1776 Independence War (USA)

Vertical Cannon Boring Machine of Maritz

- **Cannon Barrel Sits on the Table and Rotates**
  - Driven by Horse
  - Tool Doesn't Move
- **Homogenous Organization of the Barrel**



L'Encyclopédie, (D. Diderot, et al.)

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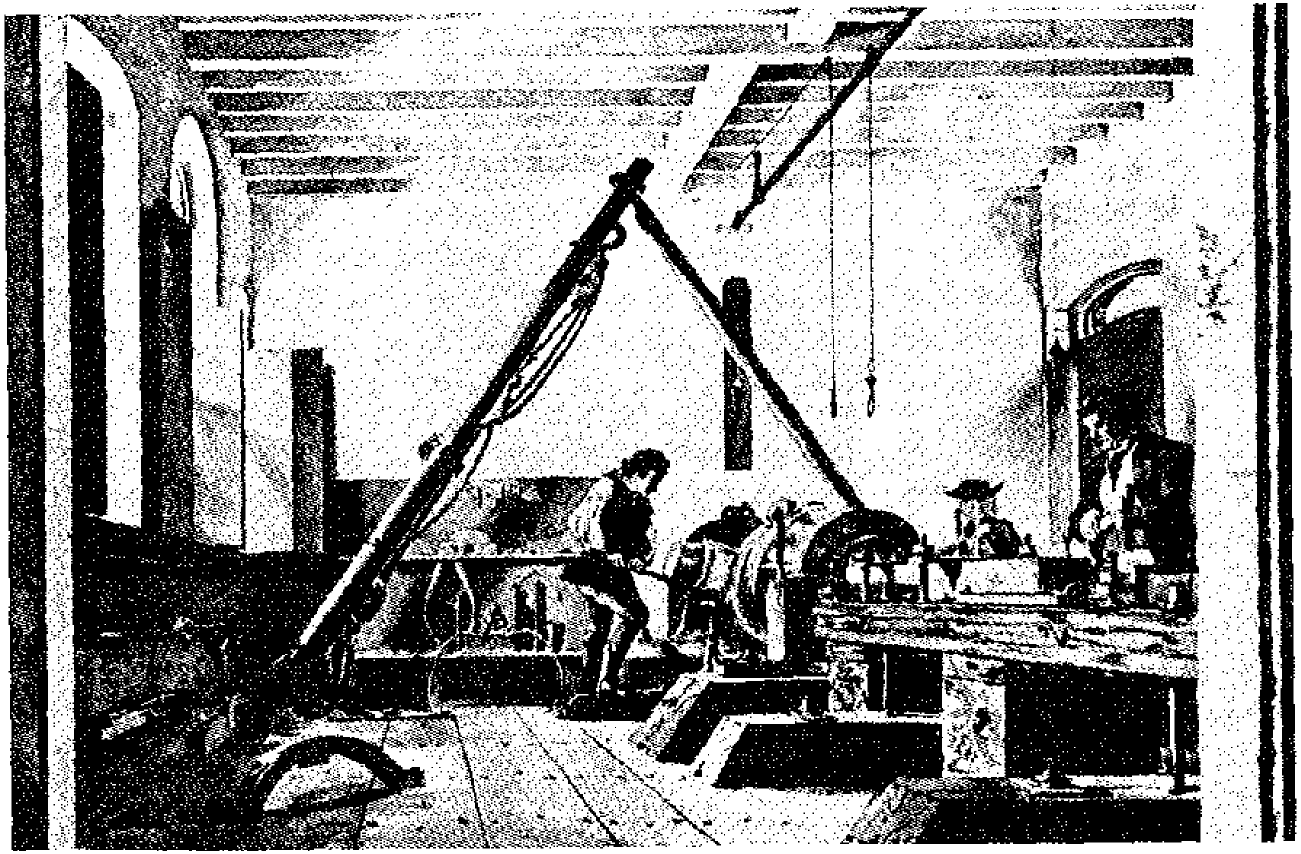
Jan Verbruggen's Mortar Boring Machine at Woolwich Arsenal

- **Horizontal**
- **Solid Barrel Casting**
- **Rotating Barrel**



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Woolwich Royal Arsenal

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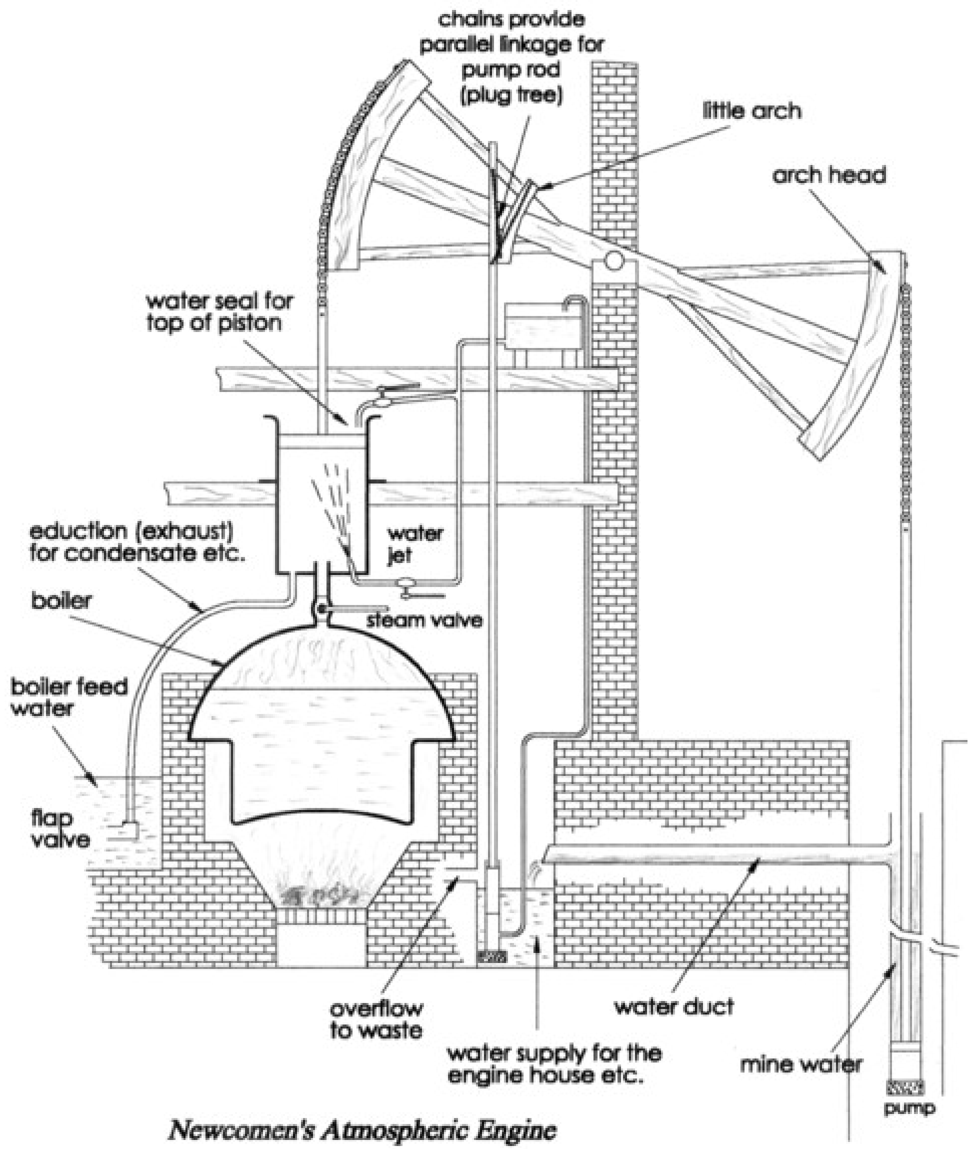
Atmospheric Engine (1712): Thomas Newcomen

- **At Most, 1 Bar**
- **Used for Pumping Up Water in Coal Mines**
  - Length 10.5 Feet
  - Diameter 74 Inches
- **Inefficient**
  - Heating Up, Cooling Down
  - Steam Leak!



Newcomen's Atmospheric Engine

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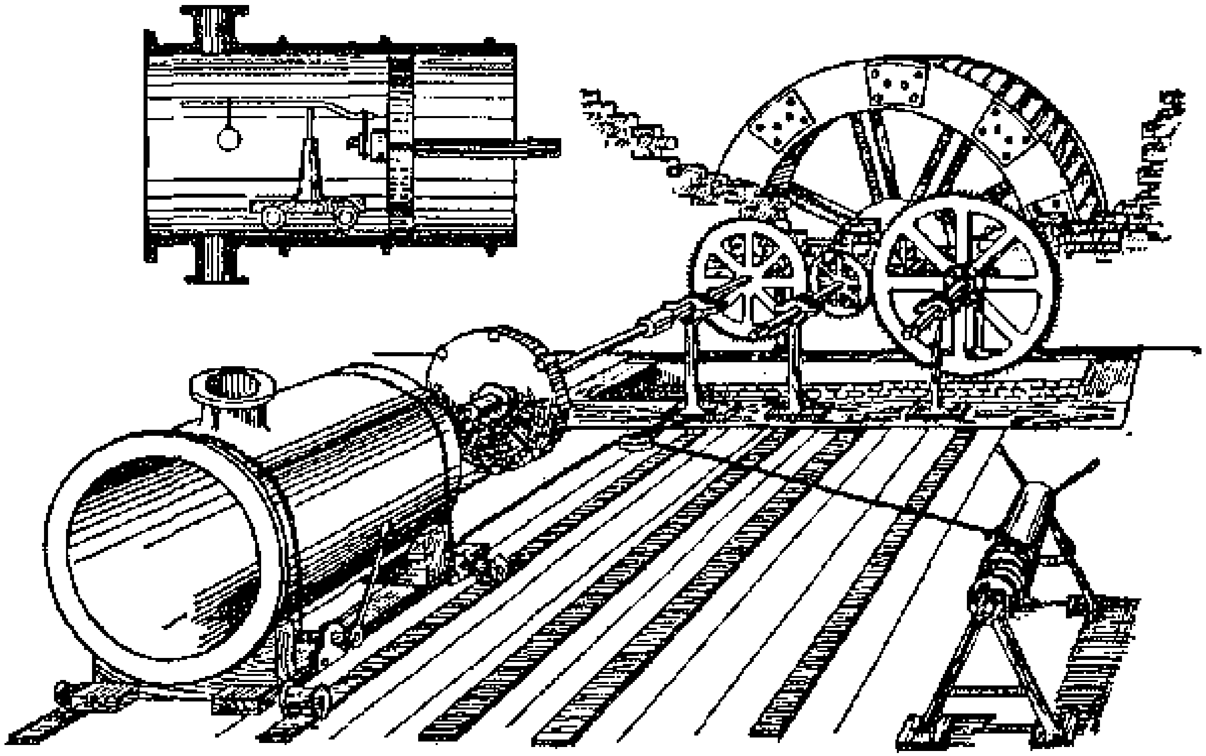
John Smeaton

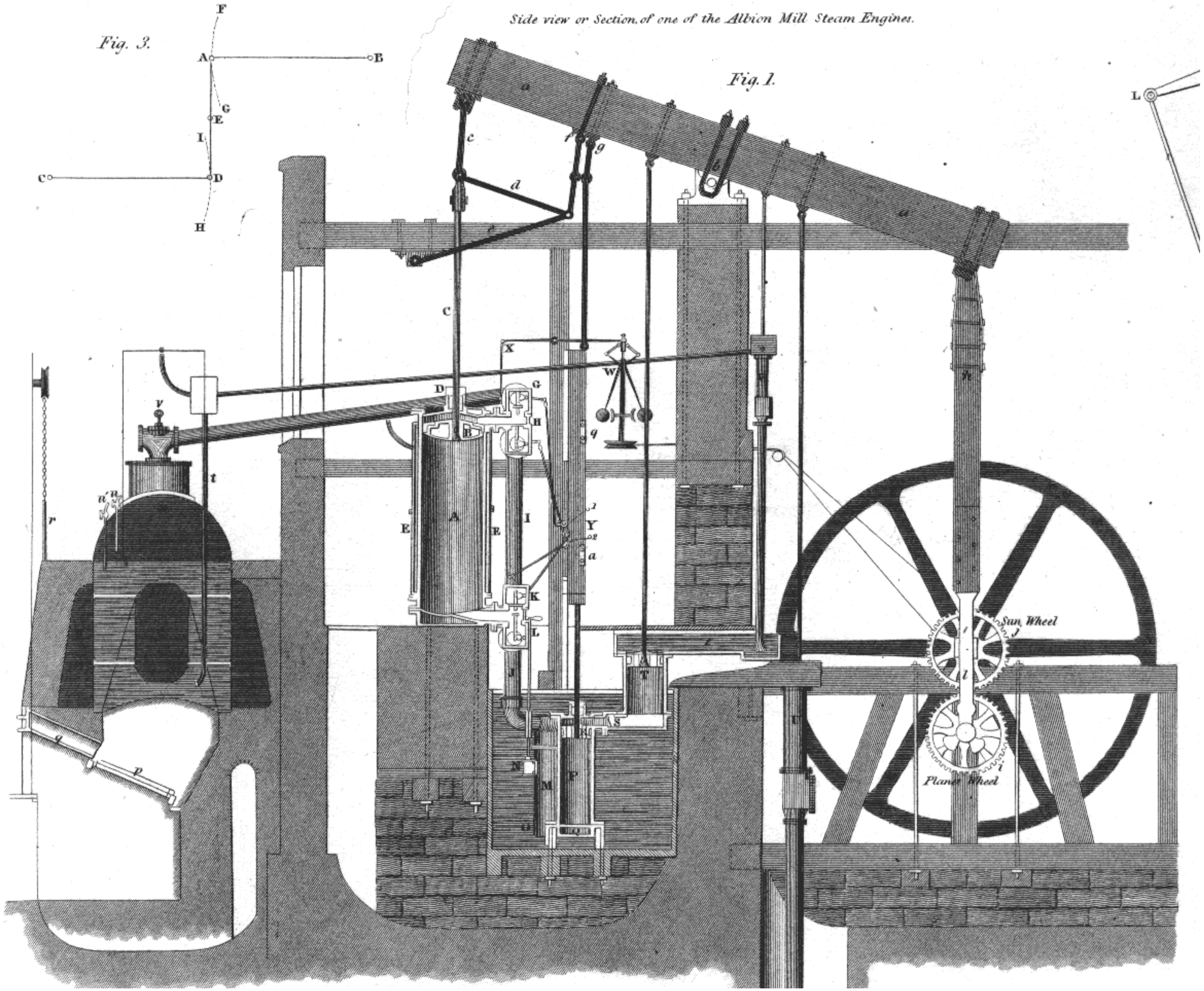
- **Circularity Error 1/2 Inch for a 28 Inch-Diameter Cylinder**



- **Also a Civil Engineer**
- **Coined the Term "Civil Engineering"**

Steam Engine (1776): James Watt

- **Efficient**
  - Higher Pressure
  - External Condenser
- **Needed Accuracy**
  - John Wilkinson's Boring Machine
  - 72 Inches Diameter
  - "6 Pence Coin" Accuracy



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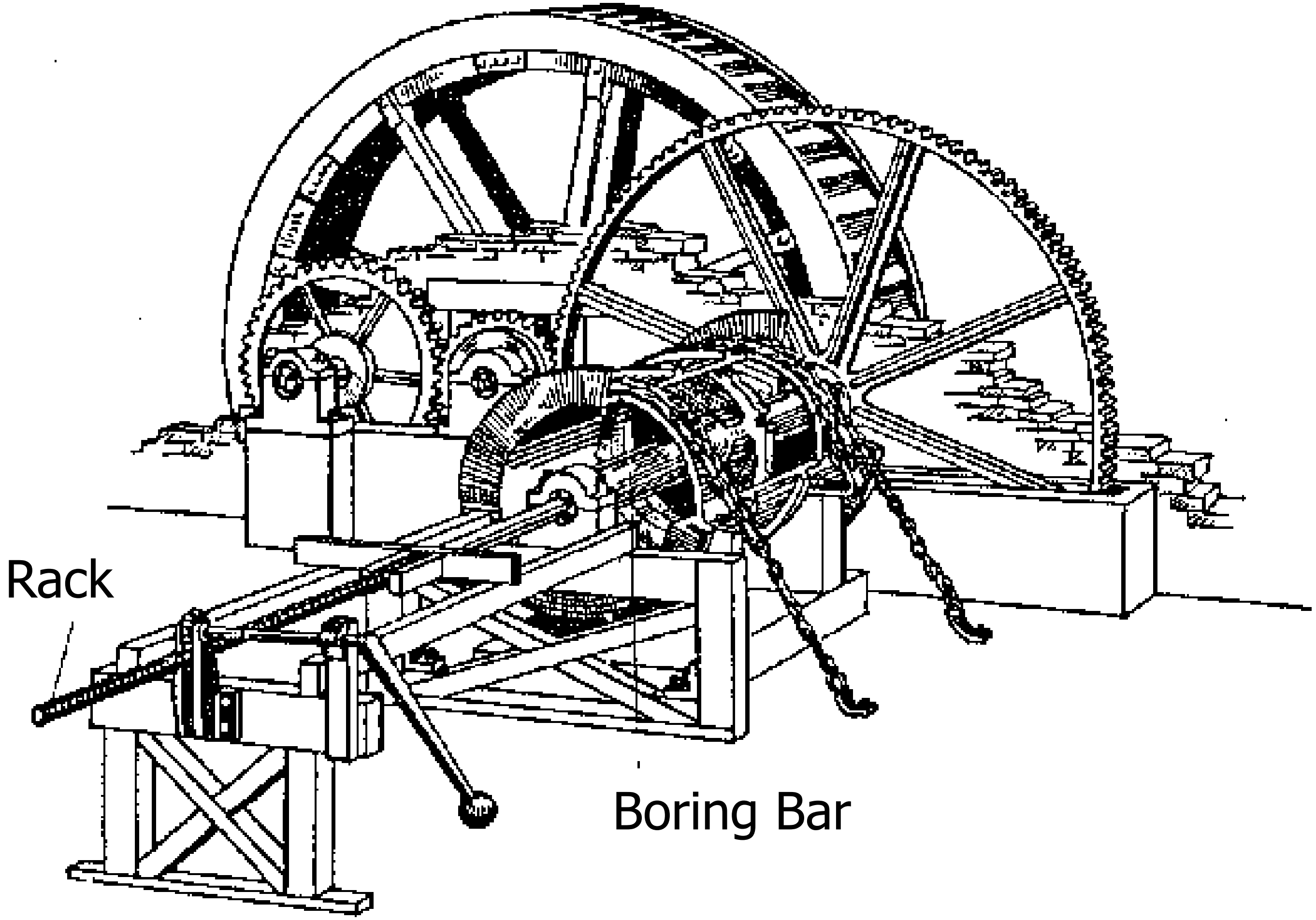
John (Iron-Mad) Wilkinson

- **Double Supported Rotating Boring Bar**



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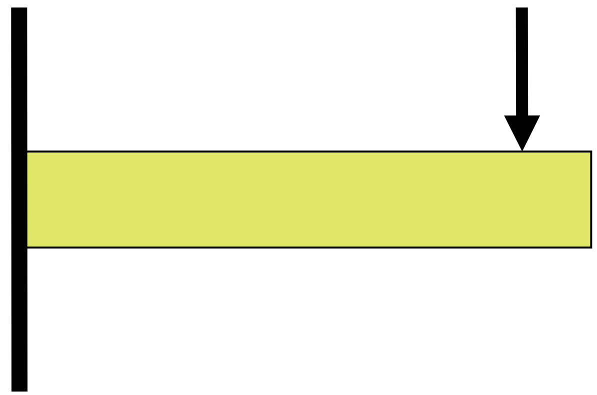
Question 2

- **Good Design and Bad Design**

- **Example: Beam**
  - Avoid Single Supported Beam
    - Deformation
    - Vibration
    - But, a Cantilever is a Minimum Mechanism
  - Double Supported Beam is OK
  - Triple Supported Shaft is Not Good



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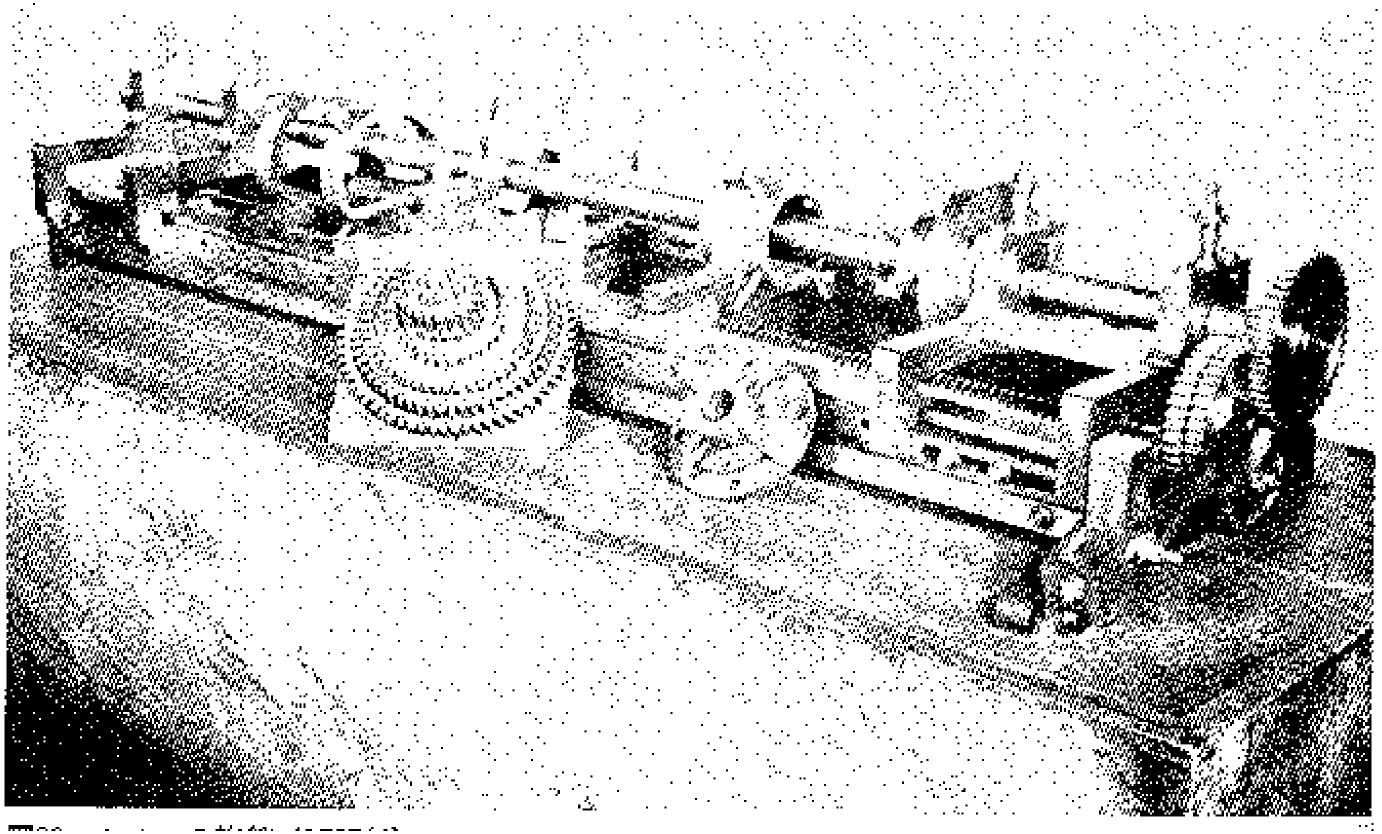
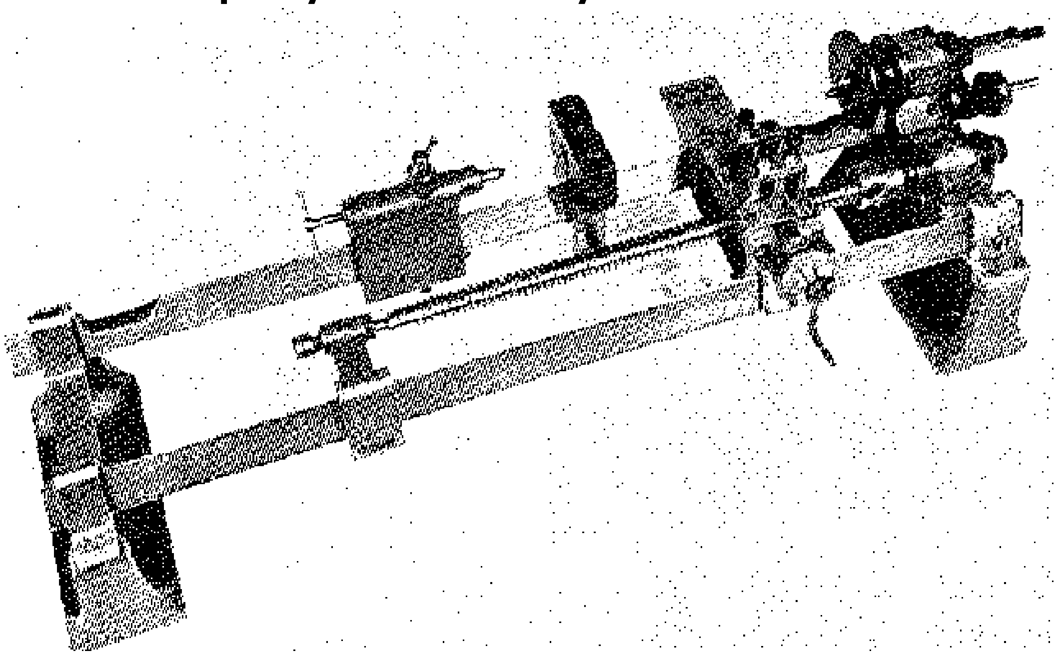
Senot's Lathe (1795)

- **Side Rest**



Henry Maudslay (1771-1831)

- **Screw Cutter (ca. 1800)**
  - Lead Screw Driving the Tool
  - Mother Machine!
  - Employed at Royal Arsenal



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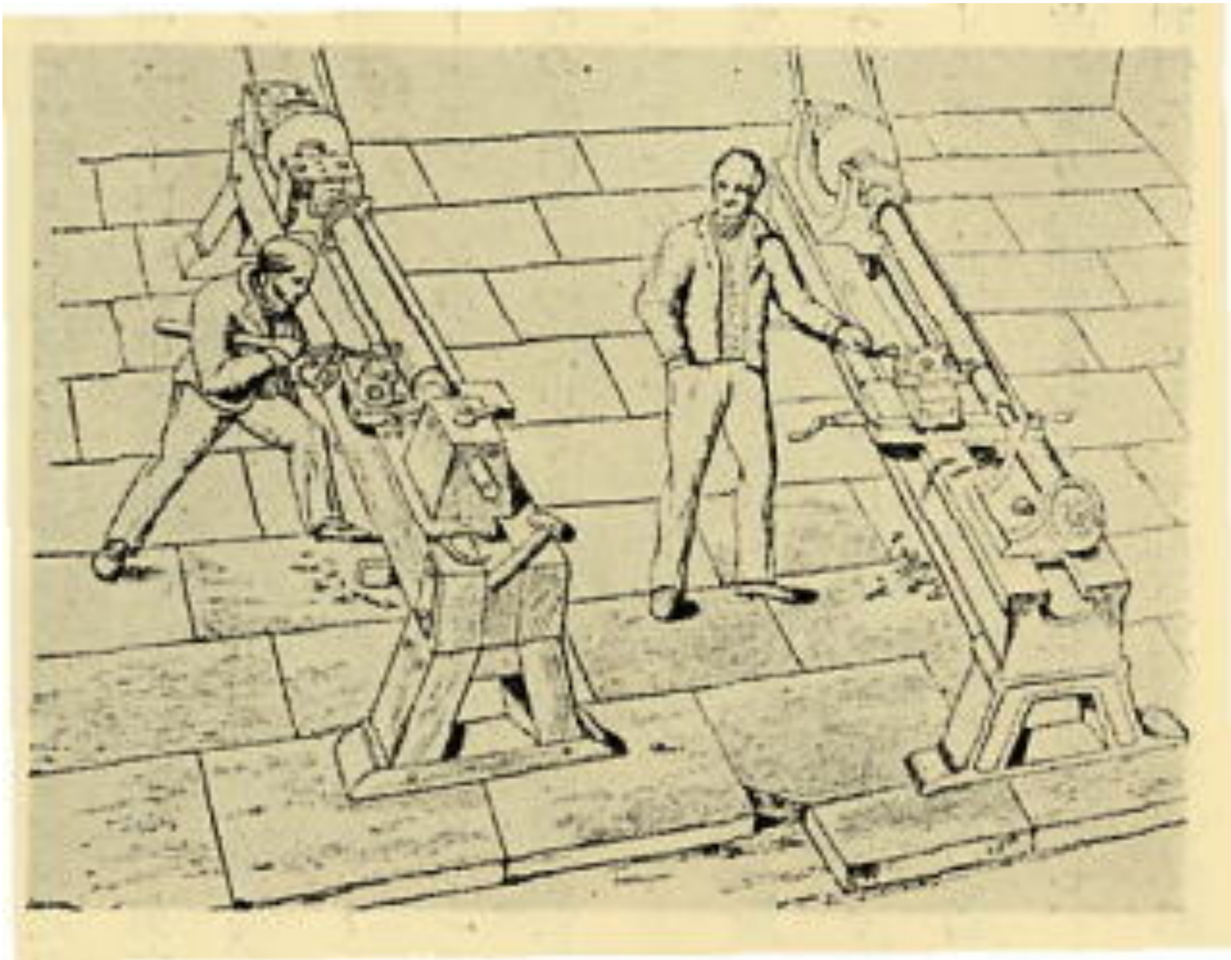
Lathe Before and After



Factory Built By Maudslay

Eli Whitney (1765-1825, USA)

- **Cotton (En)Gin(e) (1793)**
- **Interexchangeable Parts by Mass Production**
  - In 1798, With Nothing, Obtained a Contract to Build 15,000 Muskets
  - Jean Baptiste Vaquette de Gribeauval, John H. Hall Through Honoré Blanc, Thomas Jefferson, via Louis de Tousard
  - Go-NoGo Gauge
- **Connection to Colt**

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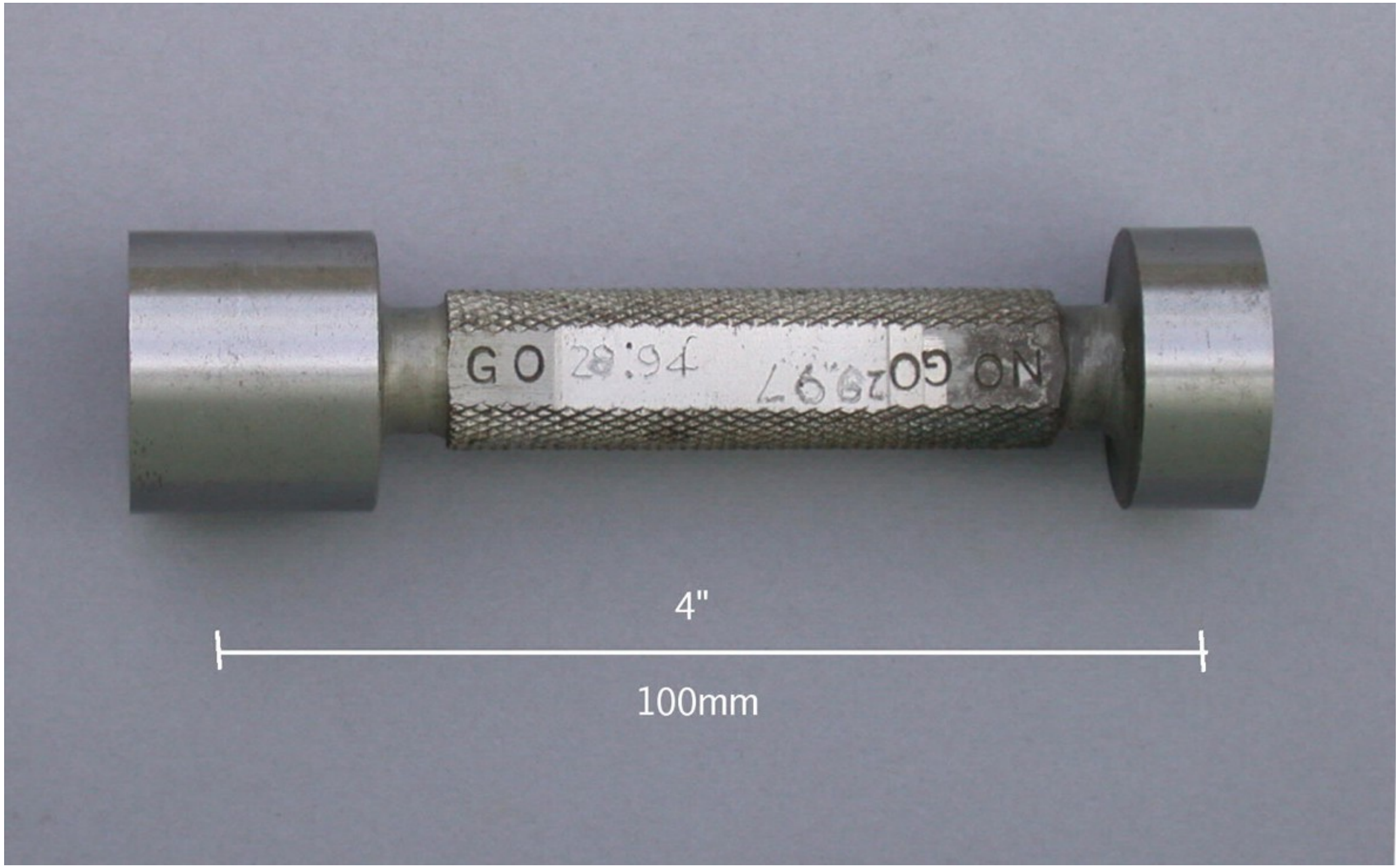
Go-NoGo Gauge



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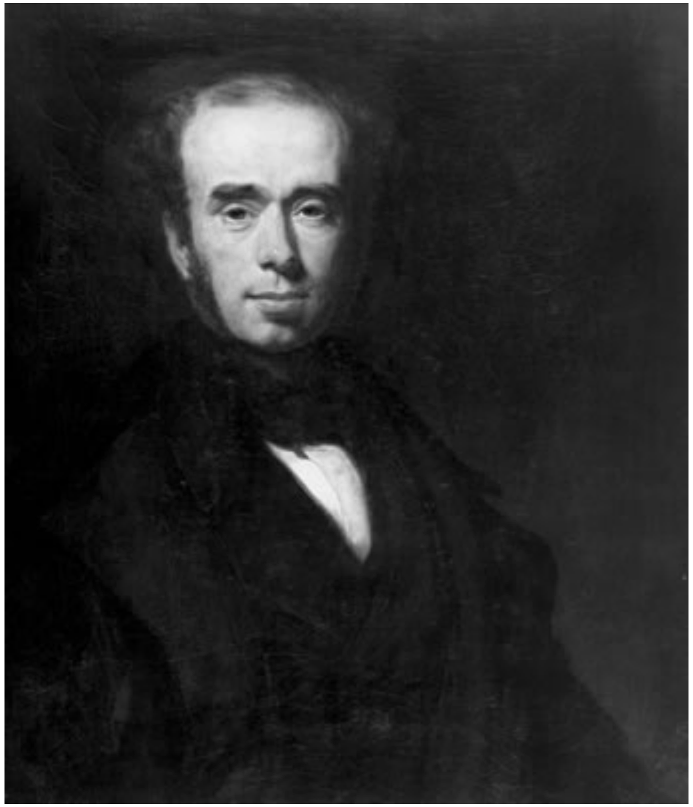
Joseph Whitworth (1803-1887)



- **Accurate Flat Surfaces**
  - Engineer's Blue and Scraping Techniques
- **End Measurements With a Precision Flat Plane and Measuring Screw**
  - 1/1,000,000 of an Inch
- **Whitworth Standard for Screw Threads**
  - A Fixed Thread Angle of 55°
  - A Standard Pitch for a Given Diameter
  - British Standard Whitworth (BSW)
- **Whitworth-Armstrong**
  - Major British Manufacturer in the 20th Century

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Scraping

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Frederik Winslow Taylor (1856-1915, USA)

- **While Working at Midvale Steel Works in Pennsylvania, Started "Science of Machining" (Cutting Theory)**
- **Taylorism**
  - Stopwatch
  - Taylor's Scientific Management
    - Replace Rule-of-Thumb Work Methods With Methods Based on a Scientific Study of the Tasks
    - Scientifically Select, Train, and Develop Each Employee Rather Than Passively Leaving Them to Train Themselves.
    - Provide "Detailed Instruction and Supervision of Each Worker in the Performance of That Worker's Discrete Task"
    - Divide Work Nearly Equally Between Managers and Workers, So That the Managers Apply Scientific Management Principles to Planning the Work and the Workers Actually Perform the Tasks

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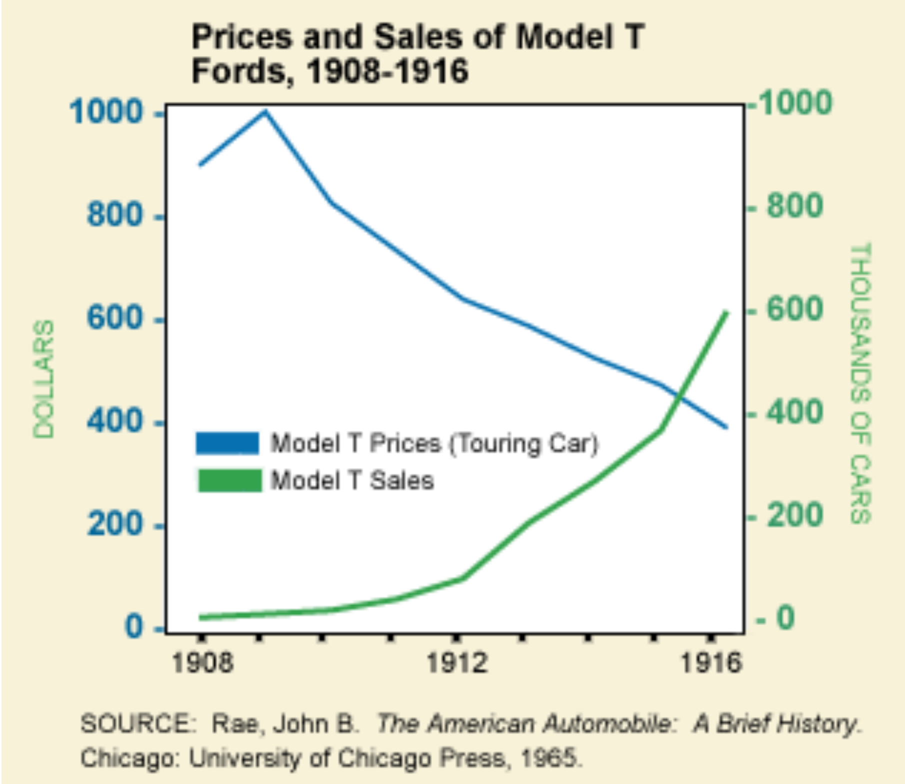
Ford Model T (1908-1927)

Ford Model T (1908-1927)

- **Fordism: Mass Production**
  - Single Design
    - "Any Customer Can Have a Car Painted Any Color That He Wants So Long As It Is Black”
  - Mass Production System (Belt Conveyor)
    - Total 15,000,000 Model Ts Produced
    - Not Really Ford’s Invention
  - Vertical Integration



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Henry Ford (1863-1947)

- **First Mechanical Engineer at Various Companies, Later Engineer at Edison Illuminating Company**
- **In 1914, $5-per-Day Program (from $2.34)**
- **In 1926, 8 Hours/Day, 5 Days/Week**

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Modern Times (Charles Chaplin, 1936)

Modern Times

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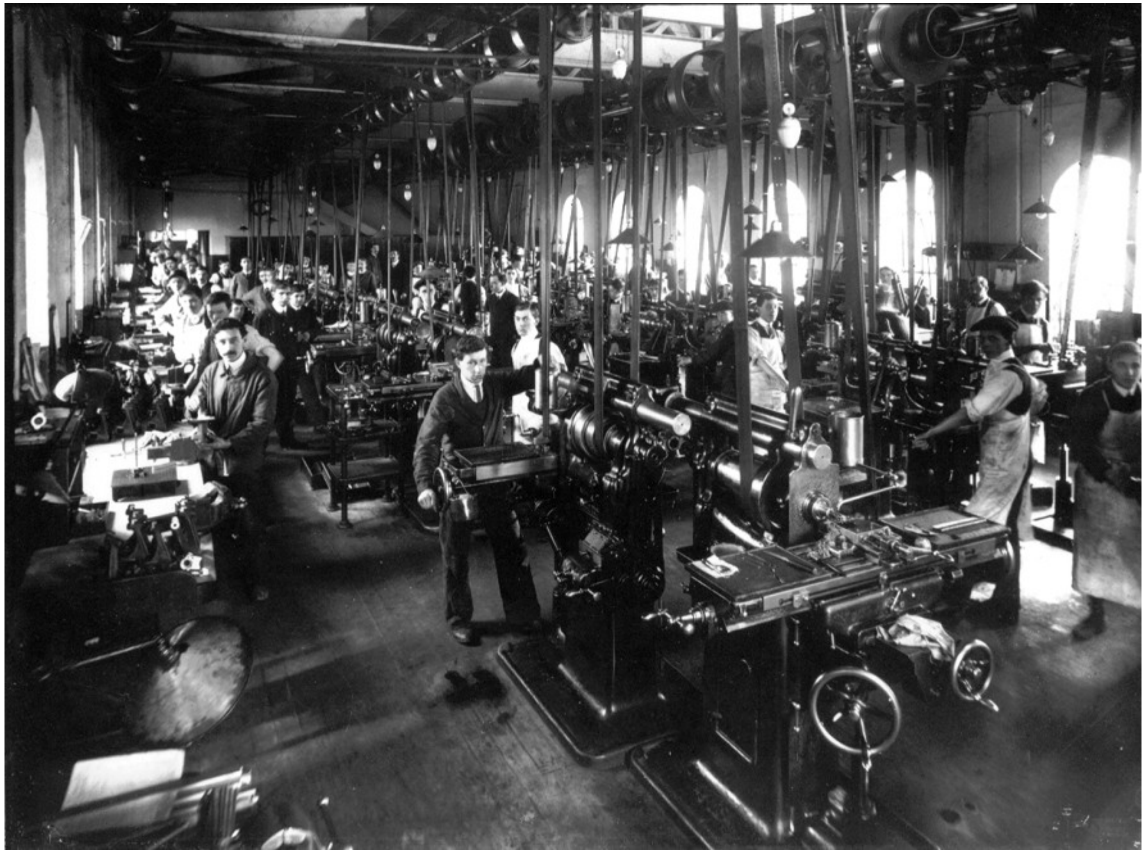
The Power to Drive Factory

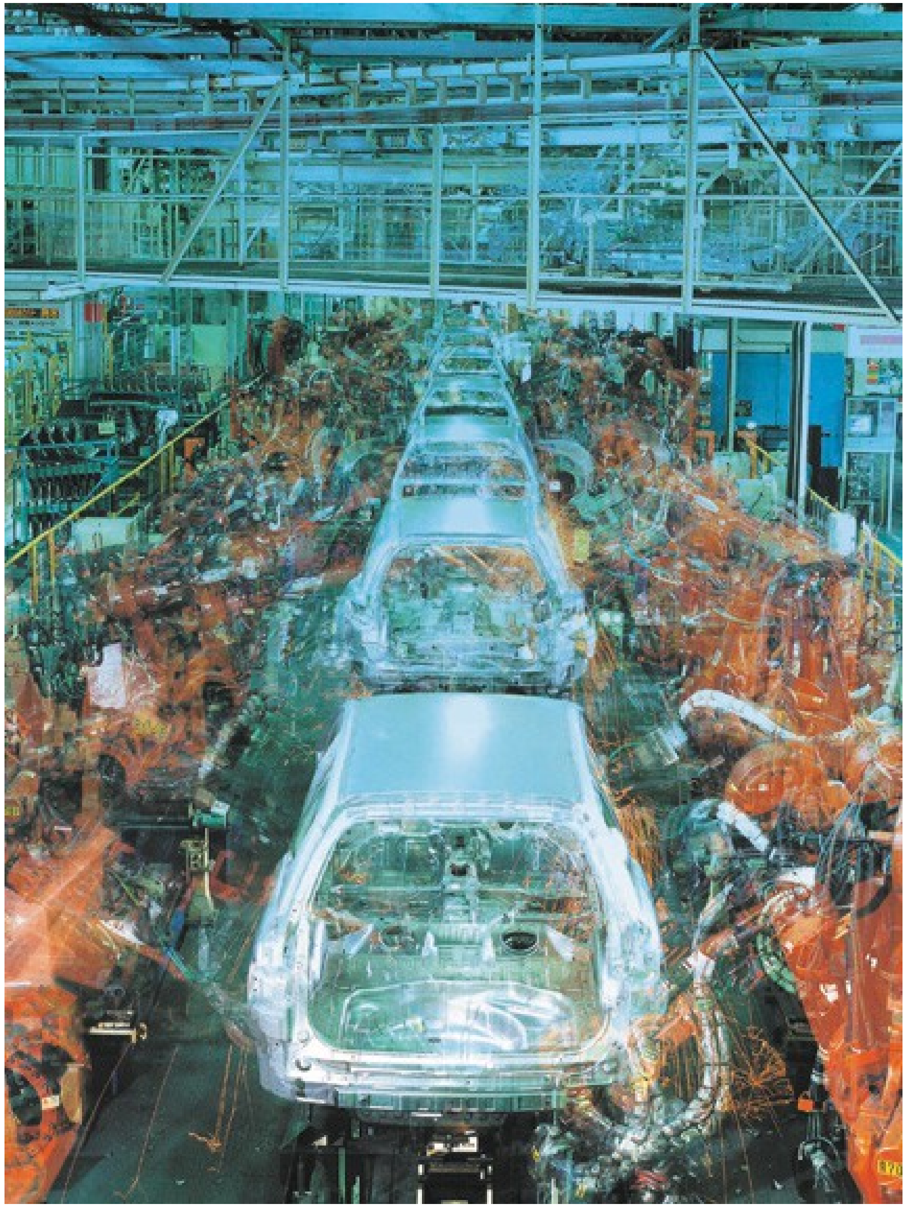
- **Ancient**
  - Human
  - Animals
  - Water (Water Wheel)
  - Wind (Windmill)
- **After Industrial Revolution**
  - Steam Engine
- **After Electricity**
  - Electric Motor
  - But Still Belt Driven
- **Built-In Motors**
  - Mechatronics
  - Individual Actuators



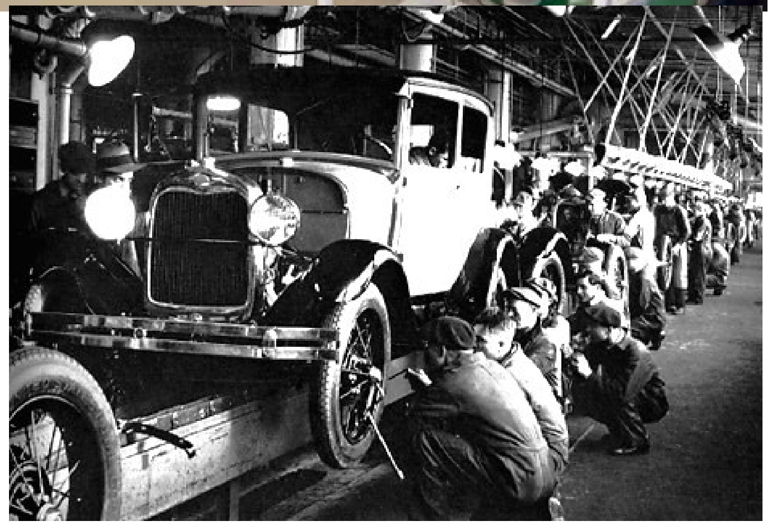
Ca. 1928, Monotype Corp., UK

After Fordism

- Automation
- NC (1952)
- CNC
- FMS (Flexible Manufacturing Systems)
- CIM (Computer Integrated Manufacturing)
- Unmanned Factory
- Cellular Manufacturing



Cellular Production



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VW Transparent Factory in Dresden

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VW Phaeton

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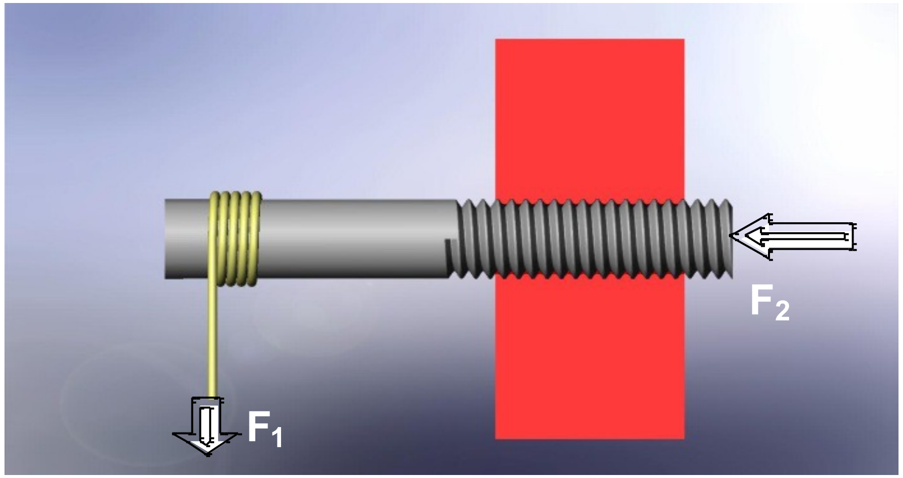
Conclusions

- **Technology Advanced**
  - More Powerful, More Accurate, Faster, Cheaper, Quicker, Easier
  - Tool ➔Machine ➔ System
- **Technology Pushes Societal Changes, Societal Needs Pulls Technology**
  - Coal ➔ Atmospheric Engine ➔ Steam Engine ➔ More Coal ➔
  - Different Applications
  - War, Revolutions, Societal Changes, Industrial Changes
  - "Cars and Typewriters Changed the US Society"
- **Design Principles**
  - Mechatronics Changes Traditional Mechanical Design Principles
    - Rigid Body to Flexible Controlled Structure

About the Final Exams

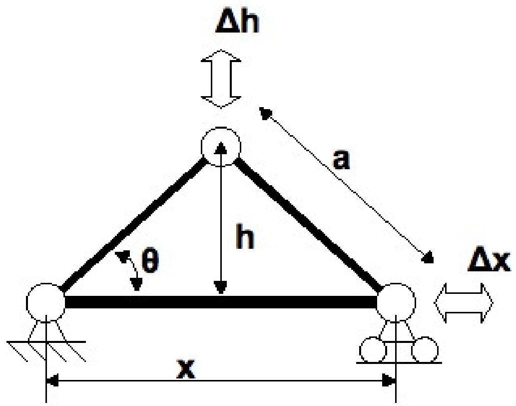
- **My Question is Always about**
  - A Mechanism You Have Seen in the Lecture
  - Understanding Fundamentals
  - Building a Model Based on Principles
  - Simple Calculation
  - Design Applications

Exam 2009 (1)



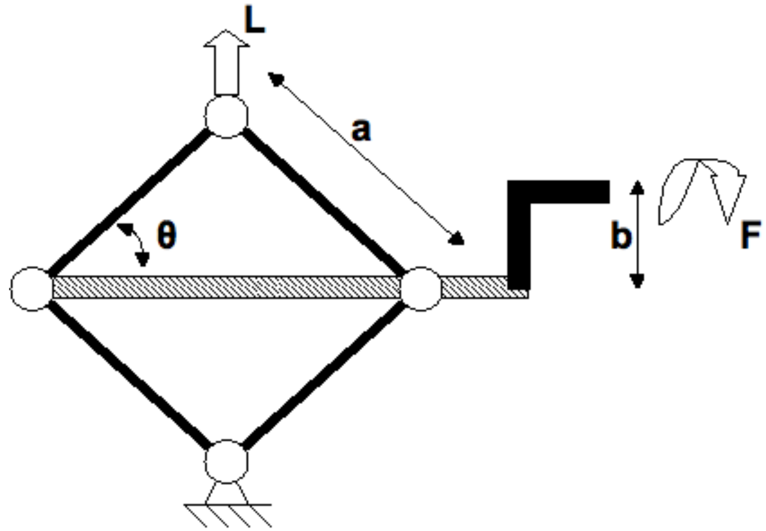
- What are functions of a screw pair? How can you use this as a machine element? Describe separately when friction can be neglected and when cannot.
- A cord is wound around the screwed shaft and is pulled with force F_1. For the sake of simplicity, consider that the diameters of the screw and of the shaft are D and the pitch of the screw is P. Obtain the force F_2 the screw creates in the axial direction. Ignore any frictions and the cord is mass-less and size-less.

Exam 2009 (2)



- You are going to design a mechanical jack of a diamond shape shown in Figure 2. A screw shaft is used in the middle of the mechanism. At one end a screw pair is formed and at the other end the screw rotates freely. The screw is rotated by hand with a handle. From the viewpoint of mechanism, this jack can be simplified as depicted in Figure 3. The length of one edge of the rhombus is a. Imagine the jack is tightened up by Δx. Represent the vertical displacement Δh with Δx.

Exam 2009 (3)



- Imagine a jack illustrated in Figure 4. Obtain the relationship between the force applied at the handle F and the lifting force L. Again ignore any friction.
- To lift an object with mass of 1000 (kg), how much force F (N) at the handle do you need when $\theta = 45°$? Assume a=0.2(m), b=0.1(m), D=0.02 (m), P=0.002 (m), and ignore friction.

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Reference

- Rolt, L.T.C.: Tools for the Job; a Short History of Machine Tools, Batsford, London (1965), First Edition.
- Rolt, L. T. C.: Tools for the Job: A History of Machine Tools to 1950, Her Majesty's Stationary Office (HMSO), (1986), Revised Edition. (ISBN: 0112904335)
- Ceccarelli, Marco (Series ed.): History of Mechanism and Machine Science, Vol. 1-14, Springer, ISSN: 1875-3442.

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