Course Objective

- Having knowledge about machine tools industry. Defining optimal and economical machine tools selection criteria according to machining process.

- Designing of driving systems and mechanism in machine tools according to machine tool construction.

- Choosing proper machine tool and equipments according to machining quality. Having knowledge about machine tools and their operation areas.
Course Content

- Driving systems and construction of machine tools, power and efficiency in machine tools, design principles of machine tools, turning machines, milling machines, sawing machines, drilling machines, broaching machines, grinding machines, gear cutter machines, super finish machines.
Recommended Books

☐ In English,
- **Machine tools : design, reliability and safety**
- *Handbook of machine tools*, Manfred Weck, New York : Wiley, c1984 (Volume 1,2,3,4)

☐ In Turkish
- *Talas Kaldirma Bilimi ve Teknolojisi CNC Takim Tezgahlari ve Uretim Otomasyonu*, Mustafa AKKURT, Birsen Yaynevi, 2009
- *Takim Tezgahlari Tasarimi*, Faruk MENDI, Gazi Kitapevi, 1999
- *Takim Tezgahlari*, H. Oktay BODUR, Birsen Yaynevi, 1984
- *Takim Tezgahlari*, Faruk AKUN, ITU Yayınlari, 1973-1978, Cilt 1 ve 2
Course Learning Outcomes

- Gaining knowledge about design, production and application of machine tools.
- Gaining knowledge about turning machines, milling machines, sawing machines, drilling machines, broaching machines, grinding machines, gear cutter machines, super finish machines.
- Having ability of choosing appropriate machine tool for machining operations by making power and time analyses.
The General Plan of the Course

Dr. Orhan Çağır’s Section
- Turning Machines
- Drilling Machines
- Milling Machines
- Shaping Machines
- Grinding Machines
- Sawing Machines and Broaching Machines
- Gear Cutter Machines and Super Finish Machines

Dr. Mihrigül Altan’s Section
- General Definitions, Basic Concepts
- Classification of Machine Tools
- Installation and Foundation of Machine Tools
- Constructive and Auxiliary Machine Tool Elements
- Driving Systems and Mechanisms in Machine Tools
- Power and Efficiency in Machine Tools
Evaluation and Exams

- Two midterms; in the 8th week and 13th week of the term.
  The exact dates will be announced by Department of Mechanical Engineering.
  (effectiveness of each midterm is 25%)

- One homework  (effectiveness is about 10%)
  Details about the content of the homework will be given in following weeks.

- One final exam  (effectiveness is 40%)
What is machine tool?

Machine tools are machines that give special forms to the materials in desired shapes and tolerances.

These can be metal forming, machining, welding, casting machines or plastic processing machines, non-traditional manufacturing machines...
What is manufacturing?

Manufacturing is the industrial activity that changes the form of raw materials to create products. The derivation of the word *manufacture* reflects its original meaning: *to make by hand.*

As *the power of* the hand tool is limited, manufacturing is done largely by machinery today. Manufacturing technology constitutes all methods used for shaping the raw metal materials into a final product.
Manufacturing technology

- Forming
  - Bulk forming
  - Sheet metal
    - Forging
    - Rolling
    - Extrusion
    - Rolling
    - Blanking
    - Piercing
    - Bending
    - Embossing
    - Coining

- Casting
  - Sand
    - Investment
    - Die
    - Centrifugal
  - Squeeze

- Welding
  - Gas Arc
  - Resistance
  - Friction
  - Laser
  - Plasma
  - Electron beam

- Machining
  - Traditional
    - Chip removal
    - Abrasion
  - Nontraditional
    - Erosion
    - Abrasion
Classification of machining processes. AJM, abrasive jet machining; WJM, water jet machining; USM, ultrasonic machining; APM, abrasive flow machining; MAF, magnetic abrasive finishing; CHM, chemical machining; ECM, electrochemical machining; EDM, electrodischarge machining; LBM, laser beam machining; PBM, plasma beam machining.
*Parts manufactured by plastic forming, casting, sintering, and molding are often finished by subsequent machining operations.

*So machining is not only for shaping materials but also it is for to obtain a finished product of the desired dimensions and surface quality.
If we classify them in general;

1- Machine tools for machining (lathes, milling machines, drilling etc.)
2- Metal forming machines (press, rolling, extrusion machines)
3- Thermoplastic machines (injection molding, blow molding machines)
4- Chemical and physical non-traditional machining machines (EDM)
Short history of machine tools in machining
The development of metal cutting machines (once briefly called machine tools) started from the invention of the cylinder, which was changed to a roller guided by a journal bearing. The ancient Egyptians used these rollers for transporting the required stones from a quarry to the building site.

The first deep hole drilling machine was built by Leonardo da Vinci (1452–1519).

In 1840, the first engine lathe was introduced. Maudslay (1771–1831) added the lead screw, back gears, and the tool post to the previous design.
Wooden planer machine (1855).

- Cutting tool
- Operator
- Frame
- WP
- Base
Further developments for these conventional machines came via the introduction of copying techniques, cams, attachments, and automatic mechanisms that reduced manual labor and consequently raised product accuracy.

Machine tool dynamometers are used with machine tools to measure, monitor, and control forces generated during machining operations. Such forces determine the method of holding the tool or WP and are closely related to product accuracy and surface integrity.

In 1953, the introduction of numerical control (NC) technology opened doors to computer numerical control (CNC) and direct numerical control (DNC) machining centers that enhanced product accuracy and uniformity.
Machining technology covers a wide range of aspects that should be understood for proper understanding and selection of a given machining technology. Tooling, accessories, and the machine tool itself determine the nature of machining operation used for a particular material.

** The main objective of the technology adopted is to utilize the selected machining resources to produce the component economically and at high rates of production. Parts should be machined at levels of accuracy, surface texture, and surface integrity that satisfy the product designer and avoid the need for post machining treatment, which, in turn, maintains acceptable machining costs.
Metal cutting machines (machine tools) are characterized by higher production accuracy compared with metal forming machines. They are used for the production of relatively smaller number of pieces; conversely, metal forming machines are economical for producing larger lots.

Machine tools constitute about 70% of the total operating manufacturing machines in industry.

### Percentage of Different Types of Operating Machine Tools

<table>
<thead>
<tr>
<th>Type of Machine Tool</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lathes including automatics</td>
<td>34</td>
</tr>
<tr>
<td>Grinding</td>
<td>30</td>
</tr>
<tr>
<td>Milling</td>
<td>15</td>
</tr>
<tr>
<td>Drilling and boring</td>
<td>10</td>
</tr>
<tr>
<td>Planers and shapers</td>
<td>4</td>
</tr>
<tr>
<td>Others</td>
<td>7</td>
</tr>
</tbody>
</table>
The successful design of machine tool requires the following fundamental knowledge:

1. Mechanics of the machining processes to evaluate the magnitude and direction and to control the cutting forces
2. The machinability of the different materials to be processed
3. The properties of the materials used to manufacture the different parts of the machine tool
4. The manufacturing techniques that are used to produce each machine tool part economically
5. The durability and capability of the different tool materials
6. The principles of engineering economy.
The productivity of a machine tool is measured either by the number of parts produced in a unit of time, by the volumetric removal rate, or by the specific removal rate per unit of power consumed.

Productivity levels can be enhanced using the following methods:

1. Increasing the machine speeds and feed rates
2. Increasing the machine tool available power
3. Using several tools or several WPs machined simultaneously
4. Increasing the traverse speed of the operative units during the non machining parts of the production time
5. Increasing the level of automation for the machine tool operative units and their switching elements
6. Adopting modern control techniques such as NC and CNC
7. Selecting the machining processes properly based on the machined part material, shape complexity, accuracy, and surface integrity
8. Introducing jigs (for WP) and fixtures (for tool) that locate and clamp the work parts in the minimum possible time

Machine tools are designed to achieve the maximum possible productivity and to maintain the prescribed accuracy and the degree of surface finish over their entire service life.
Therefore, the machine tools must also provide the following general requirements:

1. High static stiffness of the different machine tool elements such as structure, joints, and spindles
2. Avoidance of unacceptable natural frequencies that cause resonance of the machine tool
3. Acceptable level of vibration
4. Adequate damping capacity
5. High speeds and feeds
6. Low rates of wear in the sliding parts
7. Low thermal distortion of the different machine tool elements
8. Low design, development, maintenance, repair, and manufacturing cost
CLASSIFICATION OF MACHINE TOOLS IN MACHINING

A- According to the geometrical shapes of the workpieces.
B- According to the number of the workpieces.
C- According to the functions of the machines.
A- According to the geometrical shapes of the workpieces.

1- Machine tools for machining flat surfaces (shapers, planers)
2- Machine tools for machining cylindrical surfaces (lathes)
3- Machine tools for making holes (drilling machines)
4- Machine tools for machining profiles (milling, hobbing machine tools)
B-According to the number of the workpieces.

1- Simple Machine Tools
2- Universal Machine Tools \( (\text{general purpose}) \)
3- Production Machine Tools \( (\text{special purpose}) \)
4- Special Machine Tools \( (\text{limited purpose}) \)
5- Transfer Machine Tools
6- Numerical Controlled Machine Tools
A simple machine
Universal Machine Tools

- These machines can be used for many aims. The capacity and the efficiency of these machines are low, the amortized value is high and the necessity of qualified workers are the disadvantages of these machines. For example; universal turning machines or universal milling machines.
Production Machine Tools

- These machines are only for special usage or aim. These machines provide the work to be done in a short time without the necessity of qualified worker. These kind of machines can be used for bulk production in small scales. For example, revolver turning machine.
Special Machine Tools

- These machines can be used for special aims and these machines are more economic and have high efficiency.
Transfer Machine Tools

- They are for net shape bulk production. They are the groups of machine tools designed in a special range of next to each other. They are generally automatic. They can have one station or multi station.
Numerical Controlled (NC) Machine Tools

- These machines can be used to machine complex geometrical parts in high amount. The manufacturing time is short and the efficiency is high.

- The demand of fixturing, controlling and measurement equipments is low in NC machine tools.
C-According to the functions of the machines

- Turning Machines
- Drilling Machines
- Milling Machines
- Shaping Machines
- Grinding Machines
- Sawing Machines
- Broaching Machines
- Gear Cutter Machines
- Super Finish Machines
EFFECTIVE FACTORS IN SELECTION OF THE MACHINE TOOLS

- The machine tools should be selected that can reduce labor cost and other general charges to minimum.
- Constructively, one motor should be present to drive the workpiece and the machine tool itself. (A secondary motor can be also for coolant or some other necessities).
- The slides should be machined precisely. They must have high wear resistance and be hardened.

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Revolutions should be arranged by a command. Some auxiliary equipments should be present for minimising the manufacturing time in bulk productions.

The elements of the machine tool, e.g., gears must be made from high quality materials.

Big and heavy workpieces should be machined in one fixturing.
Small workpieces should be machined in small machine tools. If they are machined on bigger machine tools, this will increase cost. On the contrary, if the big workpieces are machined on small machine tools then, vibrations may occur and this will shorten the life of the machine tool.
The usage of commands, switches and buttons should be easy. Some symbols or signs can be used on machines.

Safety precautions must be considered and the design of the machine tool is important for the easy working of the employee.
The sections of the machine tools:

1. A structure that is composed of bed, column, or frame
2. Slides and tool attachments
3. Spindles and spindle bearings
4. A drive system (power unit)
5. Work holding and tool holding elements
6. Control systems
7. A transmission linkage
Stresses produced during machining, which tend to deform the machine tool or a WP, are usually caused by one of the following factors:

1. **Static loads** that include the weight of the machine and its various parts
2. **Dynamic loads** that are induced by the rotating or reciprocating parts
3. **Cutting forces** generated by the material removal process
Structure of the Machine Tools

The machine tool structure includes a body, which carries and accommodates all other machine parts.

The main functions of the machine structure include the following:

1. Ability of the structure or the bed to resist distortion caused by static and dynamic loads
2. Stability and accuracy of the moving parts
3. Wear resistance of the guideway
4. Freedom from residual stresses
5. Damping of vibration
Driving Units in Machine Tools

There are two main types of motions that are effective;

1. Rotational motion
2. Lineer (forward-backward motions)
The extreme spindle speeds of a machine tool main gearbox \( n_{\text{max}} \) and \( n_{\text{min}} \) can be determined by

\[
\begin{align*}
  n_{\text{min}} &= \frac{1000V_{\text{min}}}{\pi d_{\text{max}}} \\
  n_{\text{max}} &= \frac{1000V_{\text{max}}}{\pi d_{\text{min}}}
\end{align*}
\]

where

\( V_{\text{max}} = \) maximum cutting speed (m/min) used for machining the most soft and machinable material with a cutting tool of the best cutting property

\( V_{\text{min}} = \) minimum cutting speed (m/min) used for machining the hardest material using a cutting tool of the lowest cutting property or the necessary speed for thread cutting

\( d_{\text{max}}, d_{\text{min}} = \) maximum and minimum diameters (mm) of WP to be machined

The speed range \( R_n \) becomes

\[
R_n = \frac{n_{\text{max}}}{n_{\text{min}}} = \frac{V_{\text{max}}}{V_{\text{min}}} \cdot \frac{d_{\text{max}}}{d_{\text{min}}} = R_v \cdot R_d
\]

where

\( R_v = \) cutting speed range

\( R_d = \) diameter range
Driving mechanisms that arrange revolutions can be classified into two categories:

A- Steppless speed drives
B- Stepped speed drives
STEPPING OF SPEEDS

Arithmetic progression

Let \( n_1, n_2, \ldots, n_z \) be arranged according to arithmetic progression. Then
\[
 n_1 - n_2 = n_3 - n_2 = \text{constant}
\]

Accordingly, for an economical cutting speed \( v_0 \), the lowest speed \( v_1 \) is not constant; it decreases with increasing diameter. Therefore, the arithmetic progression does not permit economical machining at large diameter ranges.

If the revolutions are stepped, then we use some diagrams and progressions. This diagram is called sawtooth diagram.
--- The percentage drop from one step to the other is constant, and the absolute loss of economically expedient cutting speed $\Delta v$ is constant all over the whole diameter range.

--- The relative loss of cutting speed $\Delta v_{\text{max}}/v_o$ is also constant. Geometric progression, therefore, allows machining to take place between limits $v_o$ and $v_u$ independent of the WP diameter, where $v_o$ is the economical cutting speed and $v_u$ is the allowable minimum cutting speed.
<table>
<thead>
<tr>
<th>Basic Series</th>
<th>Derived Series</th>
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<tbody>
<tr>
<td>R20</td>
<td>R20/2</td>
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<tr>
<td>$\phi = 1.12$</td>
<td>$\phi = 1.25$</td>
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<td>100</td>
<td>112</td>
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</table>
Usage of both progression together
To obtain a machined part by a machine tool, coordinated motions must be imparted to its working members. These motions are either primary (cutting and feed) movements, which removes the chips from the WP or auxiliary motions that are required to prepare for machining and ensure the successive machining of several surfaces of one WP or a similar surface of different WPs.

Principal motions may be either rotating or straight reciprocating. In some machine tools, this motion is a combination of rotating and reciprocating motions. Feed movement may be continuous (lathes, milling machine, drilling machine) or intermittent (shapers, planers).
STEPPED SPEED DRIVES

- Stepped Speed Drives with Two Axes.
  These kind of stepped mechanisms are compose of one belted transmission mechanism or a couple of gear.
Classification of transmission of rotary motion

Rotary motion

Stepped
- Belt (slip)
- Gearing (positive)
- Mechanical

Stepless
- Hydraulic
- Electrical
STEPPED SPEED DRIVES

1- Mechanism with Belting Transmission

A belted transmission is composed of a belt and tombours. It is possible to change the location of the belt according to the selected revolution.
2- Mechanisms with gear transmission

Gear mechanisms can be grouped into 3 categories;
1- Mechanisms with couplings
2- Mechanisms with sliding key
3- Mechanisms with sliding gears
Illustrations of gears with keys and couplings
Main mechanism with coupling and two axises
Main mechanism of sliding gears with two axises
Mechanism for reverse variable transmission
Stepped mechanisms with multi axises
DIAGRAMS OF REVOLUTIONS IN STEPPED MECHANISMS AND THE FORCE LINES
A mechanism with 12 outputs and 4 spindles
STEPLESS SPEED DRIVES

- Mechanical stepless speed drives
- Hydraulic stepless speed drives
- Electric stepless speed drives
Mechanical stepless speed drives

5 categories;
1. Friction stepples drives with wheels
2. Friction stepples drives with conical wheels
3. Friction stepples drives with spheres and discs

Continues ........
Kopp stepless speed mechanism: (a) $n_2 < n_1$, (b) $n_2 = n_1$, and (c) $n_2 > n_1$.

4-Friction stepples drives with spherical friction component
5-Friction stepples drives with conical wheels

(positive infinitively variable-PIV)
An example of combination of stepped and steppless drive mechanisms on a turning machine
Hydraulic steppless drives

The advantages of the hydraulic systems are as follows:
1. Has a wide range of speed variation
2. Changes in the magnitude and direction of speed can be easily performed
3. Provides smooth and quiet operation
4. Ensures self-lubrication
5. Has automatic protection against overloads
Types of Hydraulic Steppless Drive Mechanisms

- Open looped: Oil turns back to tank
- Closed looped: Oil travels on the system without turning back to tank.
Open looped hydraulic cycle

1- Worktable of the machine tool
2- Safety-valve
3- Pump with adjustable flow
4- Tank
5- Cylinder
6- Counter valve
Closed looped hydraulic cycle

1-Pump with constant flow
2-Transfering valve
3- Oil tank
4- Cylinder
5- Pump with adjustable flow
Open looped with directional valve

1- Pump with adjustable pump
2- Safety valve
3- Counter pressure valve
4- Tank
5- Cylinder
6- Directional valve
Elements of hydraulic cycles

1- Pumps
A- Gear pumps
B- Adjustable pumps
   B1- Tracked valve
   B2- Pump with pistons
      B2.1- Radial piston pumps
      B2.2- Axial piston pumps
2- Adjusting elements
   A- Gates  B- Valves

3- Directional elements (D.E.)
   A- Manual bolts
   B- D.E. with mechanic controls
   C- D.E. with hydraulic controls
   D- D.E. with electromagnetic controls

4- Pipe plant

5- Hydraulic motors
PUMPS

Input

Output

GEAR PUMPS
TRACKED PUMPS
A- Internal feeder
B- External feeder
-Electrical stepless speed drives-

1- Direct current and alternative current motors
2- Step motors
3- Tri-phase current motors
CONSTRUCTIVE ELEMENTS OF MACHINE TOOLS
1- BODY AND GUIDEWAYS
2- SPINDLES AND BEARINGS
3- COUPLINGS
A crisscross rib structure for long bodies
This figure shows a typical machine tool bed of the lathe and a frame of the drilling machines.
Machine tool structures are classified by layouts into open (C-frames) and closed frames. Open frames provide excellent accessibility to the tool and the WP. Typical examples of open frames are found in turning, drilling, milling, shaping, grinding, slotting, and boring machines.
Closed frames find application in planers, jig boring, and double-spindle milling machines.
Machine tool frames can be produced as **cast** or **welded construction**. Welded structures ensure great saving of the material and the pattern costs. Figure shows typical cast and fabricated machine tool structures. A cast iron (CI) structure ensures the following advantages:
- Better lubricating property (due to the presence of free graphite); most suitable for beds in which rubbing is the main criterion,
- High compressive strength,
- Better damping capacity,
- Easily cast and machined.

Cast and fabricated structures: (a) cast and (b) welded machine tool bases.
GUIDEWAYS

Guideways are required to perform the necessary machine tool motion at a high level of accuracy under severe machining conditions. Generally guideways, therefore, control the movement of the different parts of the machine tool in all positions during machining and non-machining times.
Sliding friction guideways

Types of guideways: (a) vee, (b) flat, (c) dovetail, (d) cylinder, (e) cylindrical-cylindrical, and (f) cylindrical-flat.

Wear compensation in guideways: (a) flat and (b) dovetail guideways. $F$ is the side force acting on the carriage.
(a) Mechanically secured and (b) welded guideways.
Rollers, needles, or balls are inserted between the moving parts to minimize the frictional resistance, which is kept constant irrespective of the traveling speed.
Externally pressurized guideways
SPINDLES

Machine tool spindles are supported inside housings by means of ball, roller, or antifriction bearings. Precision bearings are used for a precision machine tool. The geometrical accuracy and surface finish of the machined components depend on the quality of the spindle bearings.
COUPLINGS

(a) With pin
(b) Cardan coupling

Demountable coupling