МИНИСТЕРСТВО ОБРАЗОВАНИЯ И НАУКИ УКРАИНЫ

ХАРЬКОВСКИЙ НАЦИОНАЛЬНЫЙ АВТОМОБИЛЬНО-ДОРОЖНЫЙ УНИВЕРСИТЕТ

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Учебное пособие предназначено для студентов при изучении дисциплины «Детали машин и основы конструирования» на английском языке.

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Lecture 1

INTRODUCTION

Contents

1. Introduction into the theory of machine elements

The full name of the course is "**Machine Elements and the Design Principles**".

The course "Machine Elements", as the main branch of engineering, outlines the methods, rules and standards for designing elements on the basis of the conditions of their operation in a machine, with a view to giving them the most advantageous forms and sizes, choosing the required materials, the degree of accuracy and surface finish, and providing for adequate conditions of manufacture.

Component is an elementary part of a machine made as one block from one and the same material without assembly operation.

Assembly is a combination of units and components fitted together.

Machine elements are all these parts, their joints and assemblies that perform the simplest functions

2. Relation to other engineering disciplines

The theory of **machine elements** (**ME**) is closely related to:

a) **theoretical mechanics** (**TM**) and the **theory of mechanisms and machines** (**TMM**) which enable the forces acting on the elements and the laws of their motion to be determined;

b) the theory of the **strength of materials** (**SM**), by means of which the strength, rigidity (stiffness) and stability of machine elements can be calculated;

c) the course of **material science** (**MS**) which provides necessary information on the rational choice of materials;

d) the **materials technology** (**MT**) which contains methods of casting, forging and welding, heat treatment, machining and assembly of machine elements;

e) **technical drawing** (**TD**) and **computer graphics** (**CG**) which enable engineers create correct projects.

3. Machine elements classification

All machine elements can be classified into ten groups:

1) Joints

All joints can be divided into 2 groups – sliding joints (kinematic pairs which are introduced in TMM course) and fixed joints (permanent and detachable joints).

a) **Permanent joints** do not allow a work to be disassembled without destroying the connecting components.

Permanent joints can be made by:

- Mechanical methods – riveting, expanding and interference fit.

Expanding and interference fit may be assembled using pressure, temperature or its combination. The example of this permanent joint is a rail-road wheel set.

- Physico-chemical adhesion – welding, brazing and soldering, adhesive bonding.
- Combination joints (e.g. rivets and threads).

One of the most widely spread permanent joint is welding. There are two main types of welding – butt (jam) welding and overlap (lap) welding.

b) **Detachable joints** allow the disassembly of a unit without damaging fastened elements and connecting components.

Types of joints:

- Threaded joints – one of the most widely spread type of detachable joints. More detailed information about threads and their types will be given later. The basic elements of threaded joins are bolts, screws, studs and nuts.

- Cotter joints
- Keyed joints

  There are three basic types of keys:
  - feather, parallel or prismatic key;
  - circular, semicircular (Whitney) key;
  - taper or wedge key
- Pin joints
- Splined joints
- Wedged joints

2) Power transmissions

Power transmissions can be electric, hydraulic, pneumatic and mechanical. Electric, hydraulic and pneumatic power transmissions are studied in special courses. Mechanical power transmission or mechanical drive is studied in the course of machine elements.

There are two basic physical principles of mechanical drive or gearing:

a) Transmission by friction (friction gearing):

- friction gear;
- belt drive (with flexible connection);
- cable / rope drive (with flexible connection).

b) Transmission by mesh (toothed gearing):

- spur gear, helical gear, herring-bone gear – cylindrical gear;
- rack gear;
- bevel gear;
- worm gear, hypoid gear, screw gear;
- tooth-belt drive (with flexible connection);
- chain drive (with flexible connection).

3) Elements for revolving motion

There are four basic groups of elements for revolving motion:

a) axels (intended for supporting revolving parts);
b) shafts (also transmit torque);

c) clutches and coupling (permanent coupling; clutch or claw (dog) clutch);
d) bearings.

Contact types of bearings:
- sliding contact bearing (with sleeves or insert liner);
- rolling contact bearing.

Direction of the load in bearings:
- radial;
- thrust;
- combination,

Types of rolling elements in bearings:
- ball bearings;
- roller bearings.

4) Frames, bases, bodies, housings

Design of frames, bases and housings (bodies) begins when the other elements of a mechanism have been already designed in every detail: with the shafts and axles and their supports, with all dimensions of the parts and their motion paths. Then can dimensions of the bearing bosses, possible location of partings, hatches, and other elements of the housing be defined.

The housing is almost always the biggest part of a mechanism. It is usually made as a closed box, so that the rest of the parts are safely mounted inside it. In this reason, the housing also serves as a guard.

5) Lever and cam mechanisms

Lever and cam mechanisms are studied in the course of TMM.

6) Springs, leaf (bow) springs, elastic joints

Elastic elements are usually studied in the course of theoretical mechanics or theory of vibration.

7) Flywheels, floating levers, pendulums, loads

Flywheels, floating levers, pendulums, loads are studied in the course of TMM and in such special courses as theory of internal combustion engine.

8) Protective and lubricate elements

9) Elements of control mechanisms

10) Special purpose elements (valves, wheels, turbine blades, etc…).

It is necessary to denote that only the first four groups (joints, power transmissions, elements for revolving motion and housings) are usually studied in the course of machine elements.

4. Engineering materials

Material is a very important aspect of any design. A wrong choice of material may lead to its failure, over or undersized product or expensive items. The choice of materials is thus dependent on suitable properties of the material for each component, their suitability of fabrication or manufacture and the cost.

The choice of materials for a machine element depends very much on its properties, cost, availability and other factors. It is therefore important to have some idea of the common engineering materials and their properties before learning the details of the design procedure. This issue is in the domain of material science or metallurgy but at this stage some relevant explanations should be given.

Common engineering materials are normally classified into **metals** and **nonmetals**. Metals are divided into **ferrous** and **non-ferrous metals**. At present we are interested in the following ferrous metals:

1. **Wrought iron;**
2. **Steel**:
a) plain carbon steel;
b) alloy steel;
3. **Cast iron**:
a) grey cast iron;

b) white cast iron;
c) malleable cast iron;
d) nodular cast iron.

Some of the important non-ferrous metals used in engineering design are:

1. Light metal group such as aluminium and its alloys (duralumin, silumin), magnesium and manganese alloys.
2. Copper based alloys such as brass (Cu-Zn) and bronze (Cu-Sn).
3. White metal group such as nickel, silver, ect.

Non-metallic materials are also used in engineering practice mostly due to principally their low cost, flexibility and resistance to heat and electricity. Though there are many suitable non-metals, the following ones are important from the point of view of design:

Timber is a relatively low cost material and a bad conductor of heat and electricity. It also has good elastic and frictional properties and is widely used in foundry patterns and water lubricated bearings.

Leather is used in engineering due to its flexibility and wear resistance. It is widely used for belt drives, washers and such other applications.

Rubber has high bulk modulus and is used for drive elements, sealing, vibration isolation and other similar applications.

Plastics are synthetic materials which can be moulded into desired shapes under pressure with or without application of heat. They are now extensively used in various industrial applications because of their corrosion resistance, dimensional stability and relatively low cost.

There are two main types of plastics:

(a) **Thermosetting plastics** are formed under heat and pressure. They initially soften and with increasing heat and pressure, polymerisation takes place. This results in hardening of the material. These plastics cannot be deformed or remoulded again under heat and pressure. Some examples of thermosetting plastics are phenol formaldehyde (Bakelite), phenol-furfural (Durite), epoxy resins, phenolic resins etc.

(b) **Thermoplastics** do not become hard with the application of heat and pressure and no chemical changes take place. They remain soft at elevated temperatures until they are hardened by cooling. These can be re-melted and remoulded by application of heat and pressure. Some examples of thermoplastics are cellulose nitrate (celluloid), polythene, polyvinyl acetate, polyvinyl chloride (PVC) etc.

5. References

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6. Comprehension questions

1) What does component mean?
2) How many groups are machine elements classified into?
3) What are basic groups studied in machine elements course?
4) What are the differences between permanent and detachable joints?
5) What does shaft mean?
6) How many contact types of bearings are there?
7) How are common engineering materials normally classified?
8) Enumerate important ferrous metals.

Lecture 2

BASIC REQUIREMENTS TO MACHINE AND THEIR ELEMENTS

Contents

1. Criteria of machine elements

All requirements to machine and their elements are divided in two groups – the basic and additional requirements.

These are the basic requirements:

– **Operating capacity**

– **Reliability** (the ability of a system or component to perform its required functions under stated conditions for a specified period of time)

– **Efficiency** (in economic meaning)

There are additional requirements to machine:

- maintenance ability;
- serviceability;
- cost;
- aesthetics;
- and other

2. Operating capacity

Operating capacity is the status of an object (component, machine or structure) when it is possible to perform the required functions preserving values of the required parameters in certain limits. (GOST 13377-75).

Main criteria of operating capacity are:

1) **Strength** is the ability of a material to withstand loading forces without damage.

2) **Rigidity (stiffness)** is the property of a solid body to resist deformation by an applied force.

3) **Wear resistance**, **endurance**, **durability** is the ability of machine elements to resist wear during their work.

Wear is the process of gradual destruction of the working surface of a component changing its size and form.

4) **Heat resistance, heat endurance** is the ability of machine elements to resist wear under high temperature.

5) **Vibration resistance** is the ability of machine elements to resist a prohibitive vibration or vibration resonance.

3. Strength

The design of machine elements is made using special parameters of materials, which usually called allowable stress

$$[\sigma] = \frac{\sigma_{\lim}}{[n]}, \ [\tau] = \frac{\tau_{\lim}}{[n]},$$

where

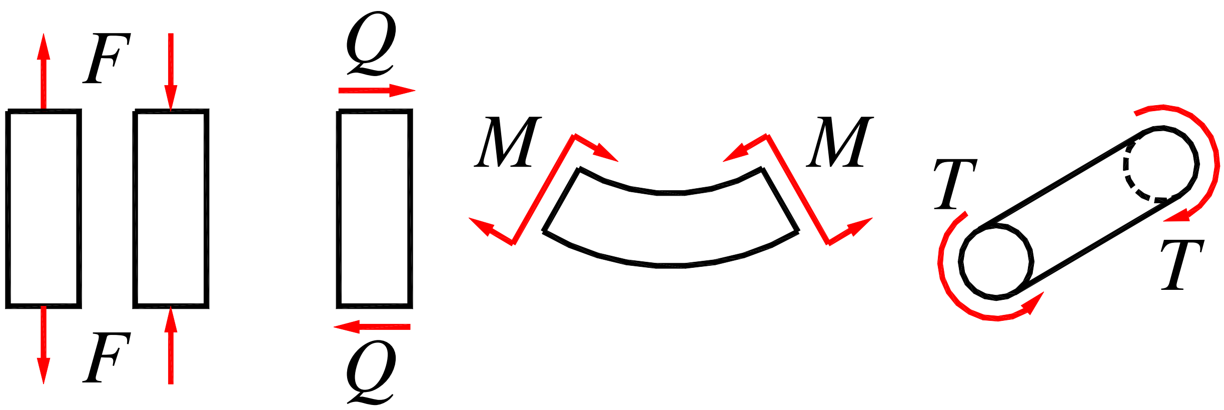
$\sigma_{\lim}, \tau_{\lim}$ – limit stress;

$[\sigma]$, $[\tau]$ – allowable stress;

$[n]$ – safety factor.

There are four basic types of deforming:

- tensile/ compressive
- shear
- bending
- torsion



1) 2) 3) 4)

1) Tensile/ compressive stress

$$\sigma = \frac{F}{A} < [\sigma],$$

where

F is longitudinal *force* [N];

A is *area* [m^2];

σ is normal stress.

2) Shear stress

$$\tau = \frac{Q}{A} < [\tau],$$

where

Q is lateral (shear, transverse) *force* [N];

τ is tangential stress.

3) Bending stress

$$\sigma = \frac{M}{W} < [\sigma],$$

where

M is *bending moment* [Nm];

W is *section modulus*, moment of resistance [m^3].

4) Torsion stress

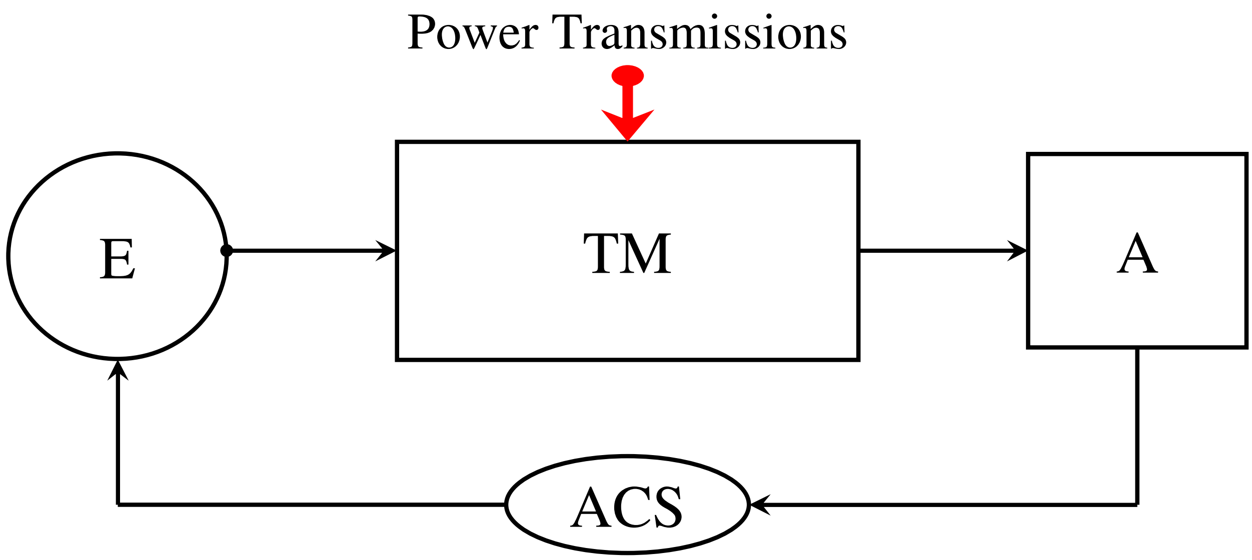
$$\tau = \frac{T}{W_p} < [\tau]$$

where

T is *torque* [Nm];
$\mathbf{W_p}$ is *section modulus of torsion*, modulus of twist [m^3].

4. Standard machine and mechanical drive parameters

Machine is a device intended to modify energy (materials).



Scheme of standard machine

E – engine, motor, mover;
TM – transmission mechanism;
A – actuator, actuating device, executing (operating) mechanism;
ACS – automatic control system

Mechanical drive parameters

ω is angular velocity /rotating speed/ (rad/s), (1/s);
n is rotating frequency, rate of turn
(revolutions per minute, rounds per minute = rpm)

$$\omega = \frac{\pi \cdot n}{30}.$$

V is circumferential velocity, peripheral velocity (m/s):

$$V = \omega \cdot r = \omega \cdot \frac{d}{2},$$

where

r is radius (m);

d is diameter (m).

T is torque (Nm);

F_t is peripheral force (N):

$$T = F_t \cdot r = F_t \cdot \frac{d}{2}.$$

P, N is power (W):

$$P = T \cdot \omega = F_t \cdot V.$$

u, i is transmission ratio, angular speed ratio, gear ratio:

$$u_{1-2} = \frac{\omega_1}{\omega_2} = \frac{n_1}{n_2},$$

$$u = u_1 \cdot u_2 \cdot u_3 \cdot \ldots = \prod_i u_i,$$

hence

1 – driving gear, power gear, driver pinion;

2 – driven gear, follower gear (slave unit).

η is efficiency factor (coefficient), output-input ratio:

$$\eta_{1-2} = \frac{N_2}{N_1},$$

$$\eta = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \ldots = \prod_i \eta_i$$

6. Comprehension questions

1) What does strength mean?
2) What does rigidity mean?
3) Enumerate the basic criteria of machine elements.
4) Enumerate three additional criteria of machine elements.
5) What are the basic types of deforming?
6) What does machine mean?
7) Enumerate most important mechanical drive parameters.
8) What does transmission ratio mean?

Lecture 3

BELT DRIVE

Contents

1. Application area

Belt drives are called flexible machine elements. They are used:

1) In conveying systems for transportation of coal, mineral ores etc. over a long distance;

2) for transmission of power. Mainly used for running of various industrial appliances using prime movers like electric motors, I.C. Engine etc.;

3) for replacement of rigid type power transmission system (A gear drive may be replaced by a belt transmission system.).

2. Advantages and disadvantages of belt drives

There are four basic advantages of belt drives:

a) distance between axes of driving and driven shafts is large;

b) belt drives operate smoothly and without knocking;

c) belt drives transmit only definite load which, if exceeded, will cause the belt to slip over the pulley (thus protect the other parts of the drive against overload);

d) simple design and rather low initial cost.

These are the disadvantages of belt drives:
a) large dimensions;
b) certain inconstancy of the velocity ratio because of belt slippage;
c) heavy loads on the shafts and bearings;
d) comparatively short service life of the belts.

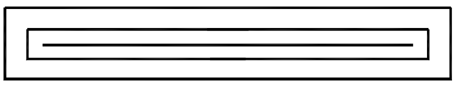
3. Belt materials, types of belts and structure of V-belt

Belt materials:

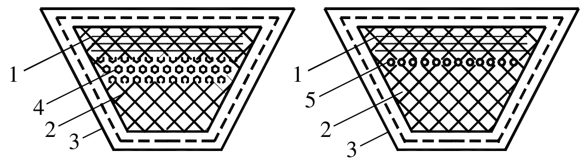
- Leather
  (Oak tanned or chrome tanned);
- Rubber
  (Canvas or cotton duck impregnated with rubber. For greater tensile strength, rubber belts are reinforced with steel cords or nylon cords);
- Plastics
  (Thin plastic sheets with rubber layers);
- Fabric
  (Canvas or woven cotton ducks. The belt thickness can be built up with a number of layers. The number of layers is known as ply.).

Types of belts:

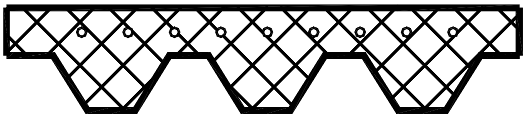
- Flat belt



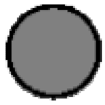
- V-belt



- Poly-V-belt



- Rope



Types of V-belts

Section	kW range	Minimum pulley pitch diameter (mm)	Width (mm)	Thickness (mm)
A	0.4 - 4	125	13	8
B	1.5 -15	200	17	11
C	10 -70	300	22	14
D	35-150	500	32	19
E	70-260	630	38	23

$\frac{b_0}{h} = 1.2$ – narrow belts;

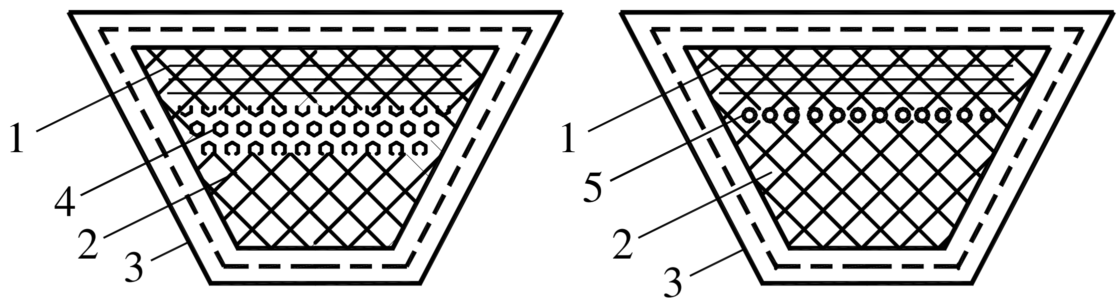
$\frac{b_0}{h} = 1.6$ – normal belt;

$\frac{b_0}{h} = 2.5 - 3.5$ – wide belts (for variators).

Types of Poly-V-belts

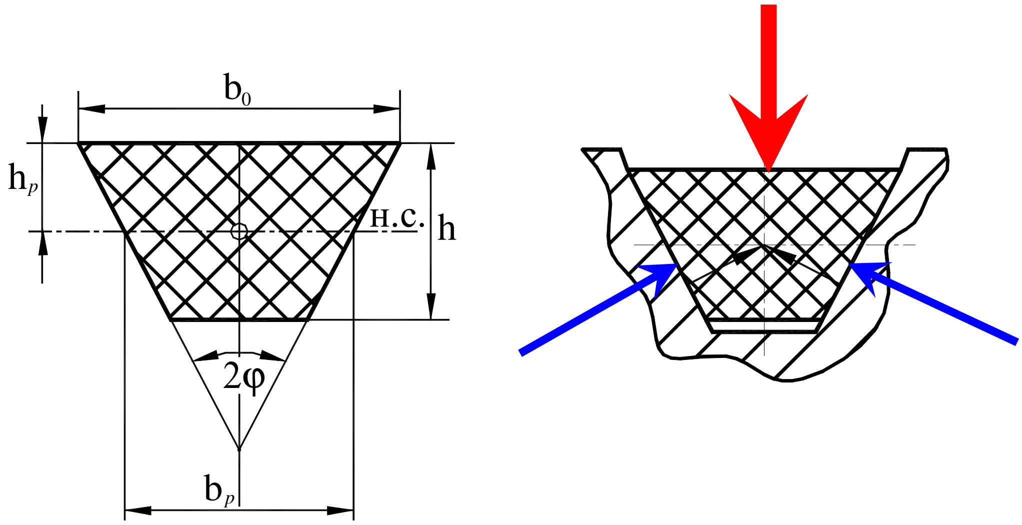
Poly-V-belts can be **K**, **L**, **M** with number of edges z = 2 – 50.

Structure of V-belt



1 – rubber layer for tension;
2 – rubber layer for compression (base rubber);
3 – a couple of wrapping rubberized fabric layers;
4 – multi-cord (e.g. rubber-fabric);
5 – single-cord.

Improved pulling capacity of V-belt

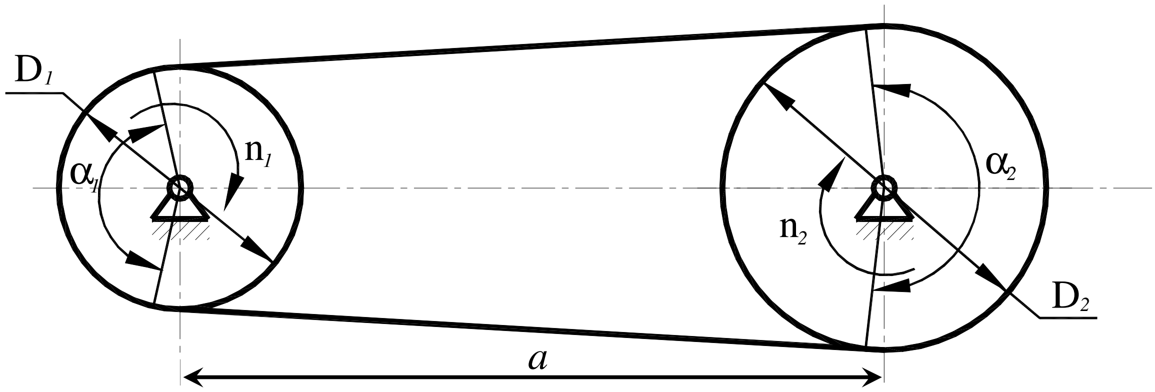


Superficial friction factor $f' = \dfrac{f}{\sin\varphi}$,

$$f' = \frac{f}{\sin 20^\circ} \approx 3 \cdot f,$$

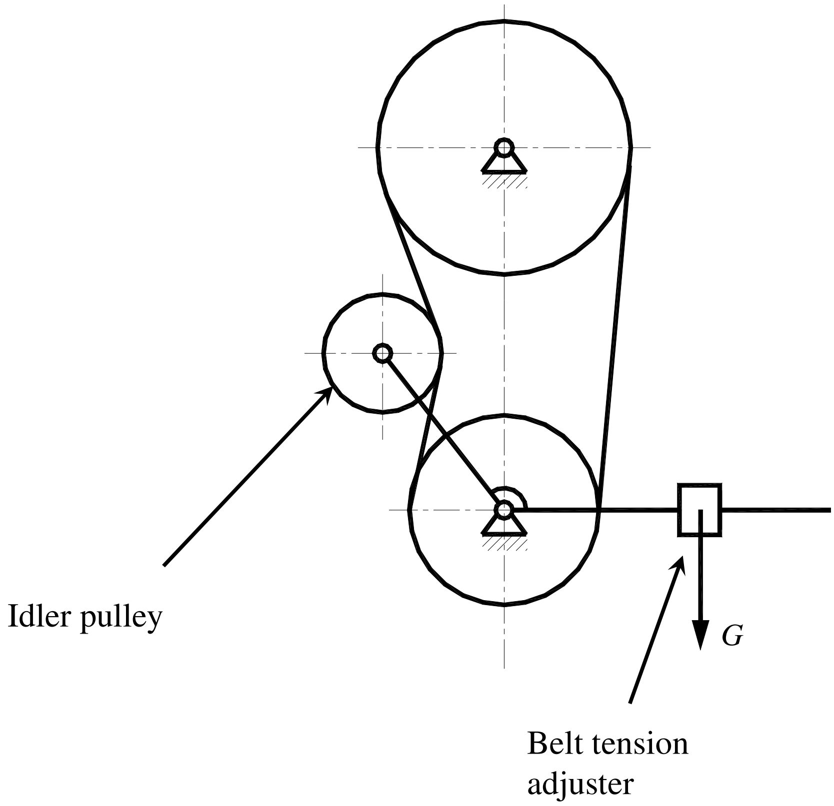
4. Parameters and geometry of belt drive

Simple belt drive

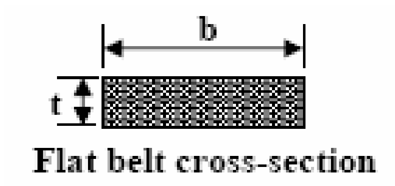


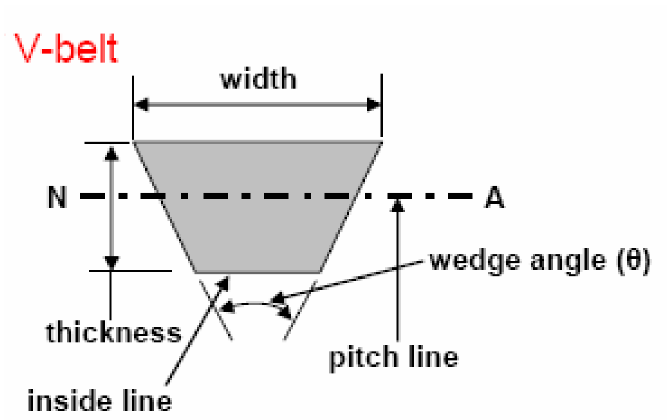
D_1 – diameter of the smaller pulley (driving pulley);
D_2 – diameter of the lager pulley (driven pulley);
α – angle of wrap;
a – center distance between the two pulleys.

Belt drive with tension adjuster



Belt geometry parameters





Parameters of belt drive:

Angular speed ratio:

$$u = \frac{n_1}{n_2} = \frac{D_2}{D_1(1-\xi)},$$

where

n_1, n_2 – rotating frequency;

$\xi = 0.01 \div 0.02$ – belt slip factor.

Angle of wrap:

$$\alpha_1 = 180° - \frac{D_2 - D_1}{2} \cdot 57°,$$

Length of the belt:

$$L = \pi \frac{D_2 + D_1}{2} + a\left[2 + \left(\frac{D_2 - D_1}{2a}\right)^2\right]$$

Center distance between the two pulleys (exact center distance):

$$a = \frac{1}{4}\left[\left(L - \pi\frac{D_1 + D_2}{2}\right) + \sqrt{\left(L - \pi\frac{D_1 + D_2}{2}\right)^2 - 2\left(D_2 - D_1\right)^2}\right]$$

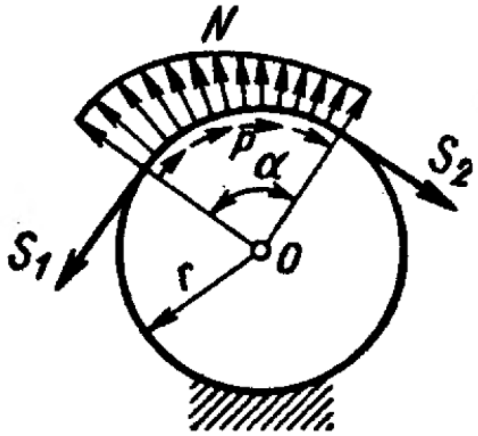
5. Steps for the design of a belt drive:

a. Select the types of the belt using initial data.
b. Determine diameters of pulleys and center distance.
c. Calculate peripheral velocity and angular speed ratio.
d. Find the length of the belt and decide on the standard belt size.
e. Calculate exact center distance using standard length.
f. Calculate modified power rating of a belt.
g. Determine the number of the belts.

If number of belts proves to be unsuitable for some reason or other (e.g. z>8) then repeat the calculations with another type of belt (not A – then B, C….)

h. Determine loads carried by drive shafts and other parameters.

Forces in belts



Scheme of a flexible cord winding on cylinder

The following relation was established by L. Euler 1775:

$$\frac{S_1}{S_2} = e^{f\alpha},$$

where
S_1, S_2 – forces applied to the cord ends;
f – friction factor between the cord and the cylinder surface;
α – angle of contact arc between the cord and the cylinder.

There are four basic relations between forces in belt:

$$F_1 = F_t \frac{e^{f\alpha}}{e^{f\alpha} - 1}; \quad F_2 = F_t \frac{1}{e^{f\alpha} - 1};$$

$$F_1 + F_2 = F_0; \quad F_1 - F_2 = F_t,$$

where
F_1, F_2 – tensions in driving and driven sides of the belt;
F_0 – initial tension;
F_t – peripheral force.

Stresses in belts

Stress due to initial tension:

$$\sigma_0 = \frac{F_0}{A},$$

where A – area.

Stress due to peripheral force:

$$\sigma_t = \frac{F_t}{A},$$

Stress due to tension:

$$\sigma_1 = \frac{F_1}{A}; \;\; \sigma_2 = \frac{F_2}{A},$$

$$\sigma_1 = \sigma_0 + 0.5 \cdot \sigma_t; \;\; \sigma_2 = \sigma_0 - 0.5 \cdot \sigma_t,$$

Stress due to centrifugal force:

$$\sigma_c = \frac{\rho V^2}{10g} \approx \frac{V^2}{100},$$

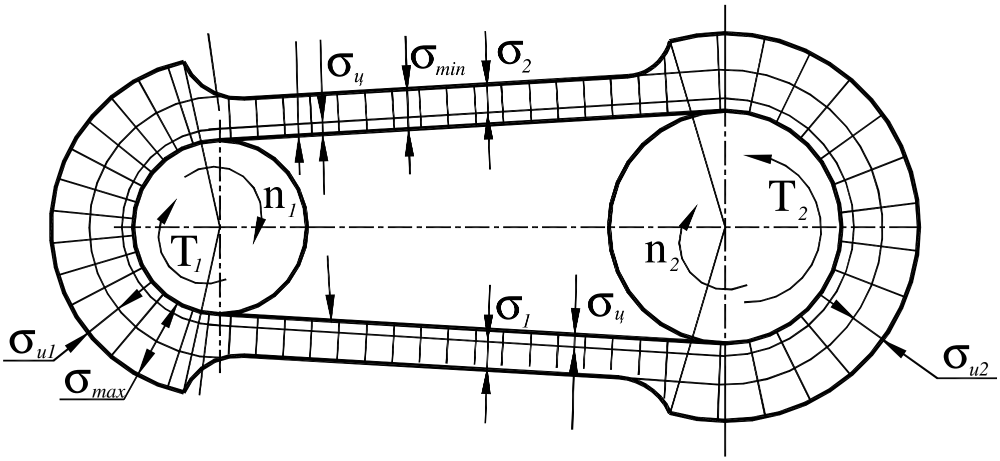
where V is peripheral velocity.

Stress due to bending:

$$\sigma_b = E \cdot \varepsilon = E \cdot \frac{h}{D_1},$$

where
E is Young's modulus;
$\varepsilon = \frac{h}{D_1}$ – strain.
Hence *h* is height of the belt, D_1 is diameter of smaller pulley.

The maximum stress is $\sigma_{\max} = \sigma_1 + \sigma_c + \sigma_b$,
and the minimum stress is $\sigma_{\min} = \sigma_2 + \sigma_c$.



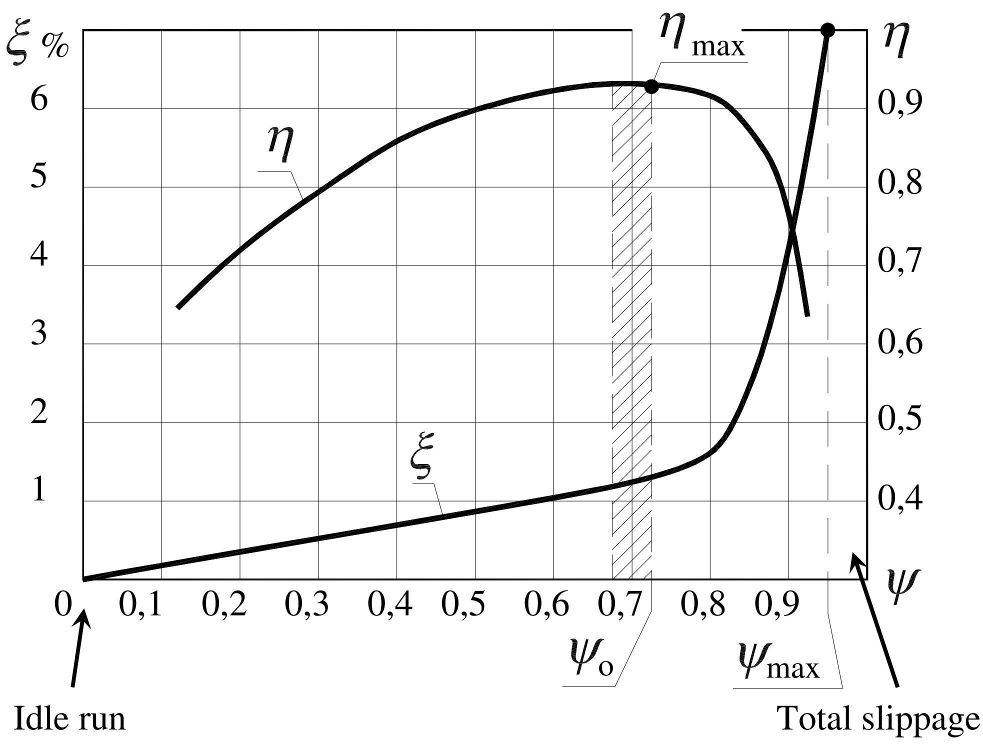
Scheme of the stresses in belt

Basic factors of a belt drive

Belt slip factor: $\xi = \frac{V_2 - V_1}{V_1} \cdot 100\%$.

Efficiency factor: $\eta = \frac{N_2}{N_1} \cdot 100\%$.

Pulling factor: $\psi = \frac{F_t}{F_1 + F_2} = \frac{F_t}{2F_0}$.



Relation between three basic factor of the belt drive

6. Comprehension questions

1) What is idler pulley used for?
2) What are the basic advantages of belt drive?
3) Enumerate materials of belts.
4) Enumerate types of belts.
5) What does initial tension mean?
6) What does peripheral force mean?
7) Enumerate the stresses in belts.
8) What does pulling factor mean?

Test

№1

Name:

1. Translate the following words:

rack gear	
cam mechanism	
	машина
	эксплуатация
keyed joints	

2. Put down the equation of *tensile/ compressive stress* and give a detailed explanation of every element in it.

№2

Name:

1. Translate the following words:

surface finish	
threaded joints	
	косозубая зубчатая передача
plain carbon steel	
	надежность

2. Put down the equation of *shear stress* and give a detailed explanation of every element in it.

№3

Name:

1. Translate the following words:

	сборочная единица
splined joints	
	вал
malleable cast iron	
endurance	

2. Put down the equation of *bending stress* and give a detailed explanation of every element in it.

№4

Name:

1. Translate the following words:

degree of accuracy	
bonding	
	подшипник
	сплав
moment of resistance	

2. Put down the equation of *angular velocity (if **n** is known)* and give a detailed explanation of every element in it.

№5

Name:

1. Translate the following words:

	деталь
power transmissions	
	нагрузка, груз
operating capacity	
peripheral force	

2. Put down the equation of *torsion stress* and give a detailed explanation of every element in it.

№6

Name:

1. Translate the following words:

	прочность
	ременная передача
rolling elements	
timber	
rope	

2. Put down the equation of *circumferential velocity* and give a detailed explanation of every element in it.

№7

Name:

1. Translate the following words:

rigidity (stiffness)	
friction gear	
	рамы, фермы
	крутящий момент
allowable stress	

2. Put down the equation of *angular speed ratio* and give a detailed explanation of every element in it.

№8

Name:

1. Translate the following words:

strength of materials	
tooth-belt drive	
	оси
leaf (bow) spring	
	клиновый ремень

2. Put down the equation of *efficiency factor* and give a detailed explanation of every element in it.

№9

Name:

1. Translate the following words:

sliding joints	
	сила
chain drive	
	червячная передача
nodular cast iron	

2. Put down the equation of *torque (if* $\boldsymbol{F_t}$ *is known)* and give a detailed explanation of every element in it.

№10

Name:

1. Translate the following words:

riveting	
flexible connection	
	серый чугун
	изгиб
angle of wrap	

2. Put down the equation of *superficial friction factor* and give a detailed explanation of every element in it.

№11

Name:

1. Translate the following words:

design principles	
	прямозубая цил. зубч. передача
copper	
pulling capacity	
	частота вращения

2. Put down the equation of *tensile/ compressive stress* and give a detailed explanation of every element in it.

№12

Name:

1. Translate the following words:

	неподвижные соединения
clutches, couplings	
	легированная сталь
heat resistance	
belt tension adjuster	

2. Put down the equation of *shear stress* and give a detailed explanation of every element in it.

№13

Name:

1. Translate the following words:

interference fit	
	сварка
sliding contact bearing	
bodies	
	пружина

2. Put down the equation of *bending stress* and give a detailed explanation of every element in it.

№14

Name:

1. Translate the following words:

permanent joints	
	упорный подшипник
limit stress	
wrought iron	
	шкив

2. Put down the equation of *angular velocity (if* ***n*** *is known)* and give a detailed explanation of every element in it.

№15

Name:

1. Translate the following words:

	устойчивость
combination bearing	
floating lever	
	число оборотов в минуту
wedge angle	

2. Put down the equation of *torsion stress* and give a detailed explanation of every element in it.

№16

Name:

1. Translate the following words:

	разъемные соединения
	шариковый подшипник
flywheels	
serviceability	
section modulus of torsion	

2. Put down the equation of *circumferential velocity* and give a detailed explanation of every element in it.

№17

Name:

1. Translate the following words:

	штифтовые соединения
	винтовая передача
pure iron	
driven gear	
lateral (shear, transverse) force	

2. Put down the equation of *angular speed ratio* and give a detailed explanation of every element in it.

№18

Name:

1. Translate the following words:

transmission by friction	
	коническая передача
	радиальный подшипник
brass	
leather	

2. Put down the equation of *efficiency factor* and give a detailed explanation of every element in it.

№19

Name:

1. Translate the following words:

rolling contact bearing	
	стоимость (затр. на произв.-во)
shear stress	
belt slippage	
	исходные данные

2. Put down the equation of *torque (if* $\boldsymbol{F_t}$ *is known)* and give a detailed explanation of every element in it.

№20

Name:

1. Translate the following words:

lever mechanisms	
	роликовый подшипник
	белый чугун
torsion	
actuator	

2. Put down the equation of *superficial friction factor* and give a detailed explanation of every element in it.

Machine Elements

The full name of the course is "**Machine Elements and the Design Principles**"

The course "**Machine Elements**", as the main branch of **engineering**, outlines the *methods*, *rules* and *standards* for designing elements on the basis of the conditions of their operation in a machine, with a view to giving them the most advantageous forms and sizes, choosing the required materials, the degree of accuracy and surface finish, and providing for adequate conditions of manufacture.

Component is an elementary part of a machine made as one block from one and the same material without assembly operation

Assembly is a combination of units and components fitted together

Machine Elements are all these parts, their joints and assemblies that perform the simplest functions

Machine Elements

The theory of **machine elements** (**ME**) is closely related to:

(a) **theoretical mechanics** (**TM**) and the **theory of mechanisms and machines** (**TMM**) which enable the forces acting on the elements and the laws of their motion to be determined;

(b) the theory of the **strength of materials** (**SM**), by means of which the strength, rigidity (stiffness) and stability of machine elements can be calculated;

(c) the course of **material science** (**MS**) which provides necessary information on the rational choice of materials;

(d) the **materials technology** (**MT**) which contains methods of casting, forging and welding, heat treatment, machining and assembly of machine elements;

(e) **technical drawing** (**TD**) and **computer graphics** (**CG**) which enable engineers create correct projects.

Machine Elements Classification

1) **Joints – sliding** joints (**kinematic pairs** – studying in TMM) and **fixed** joints **/ permanent** and **detachable** joints **/**

a) **Permanent joints** do not allow a work to be disassembled without destroying the connecting components

Can be made by:

- Mechanical methods – riveting, expanding and interference fit;
- Physico-chemical adhesion – welding, brazing and soldering, adhesive bonding;
- Combination joints (e.g. rivets and threads)

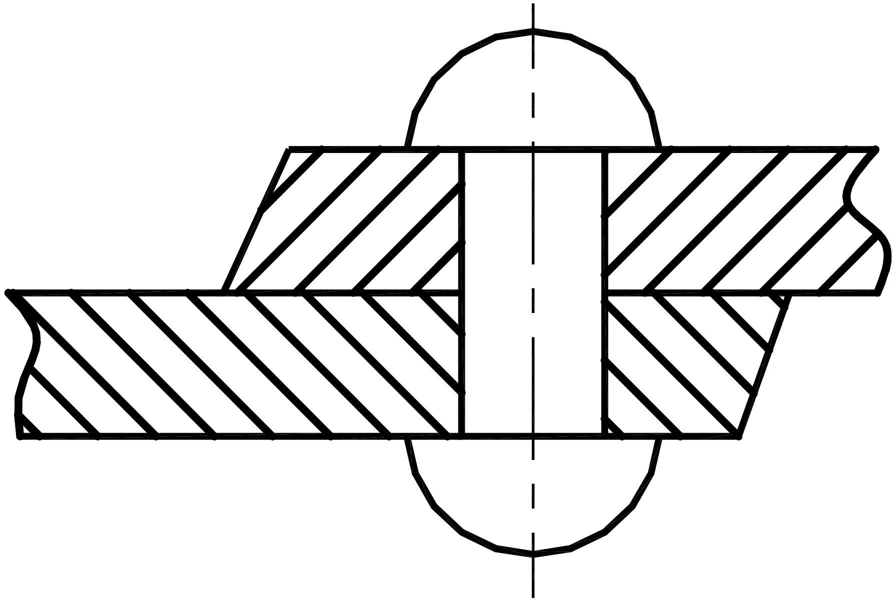
b) **Detachable joints** allow the disassembly of a unit without damaging the fastened elements and the connecting components

- Threaded joints,
- Cotter joints,
- Keyed joints
- Pin joints,
- Splined joints,
- Wedged joints.

Machine Elements Classification

Permanent joints

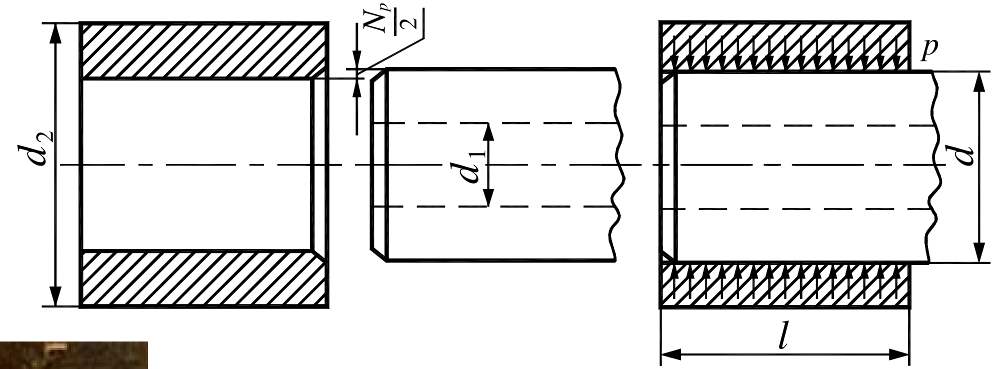
Riveting

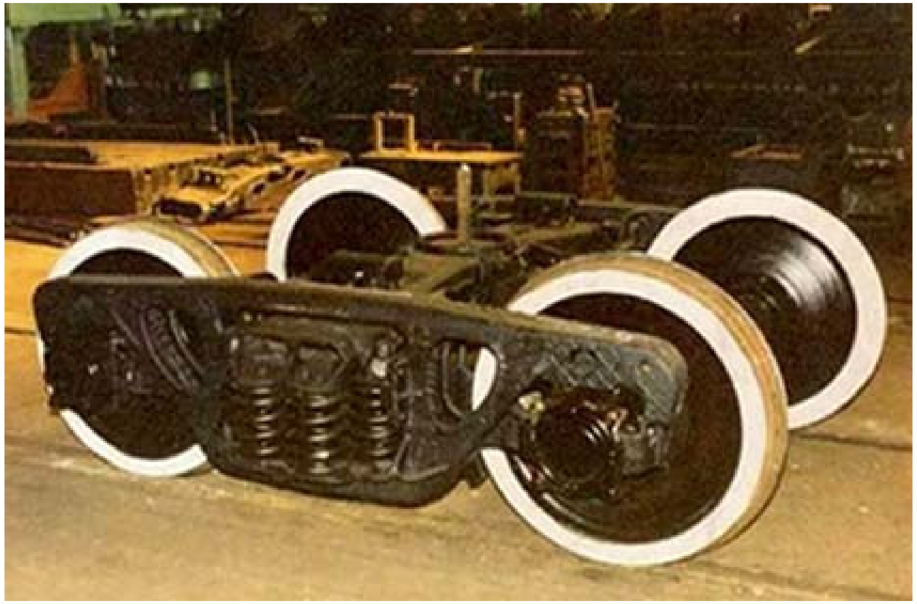


Machine Elements Classification

Permanent joints

Expanding and interference fit





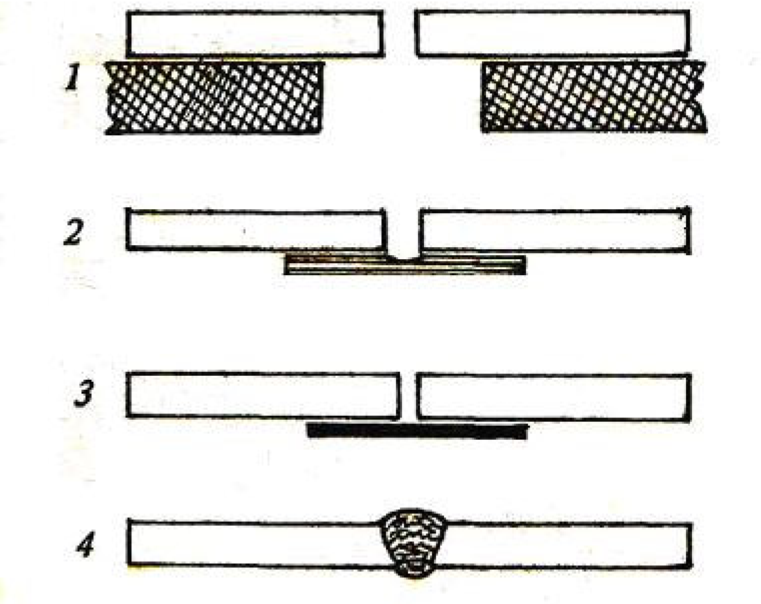
Assembled by:

- Pressure
- Temperature

Machine Elements Classification

Permanent joints

Welding



Main types of welding:

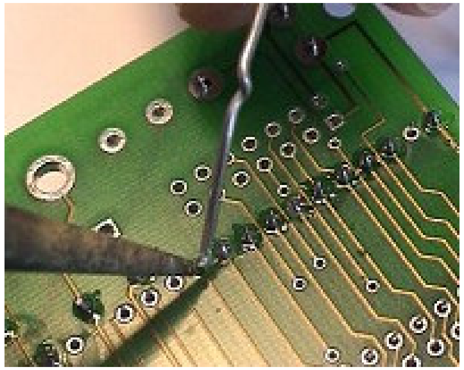
overlap (lap) welding

butt welding, jam welding

Machine Elements Classification

Permanent joints

Brazing and soldering



Machine Elements Classification

Permanent joints

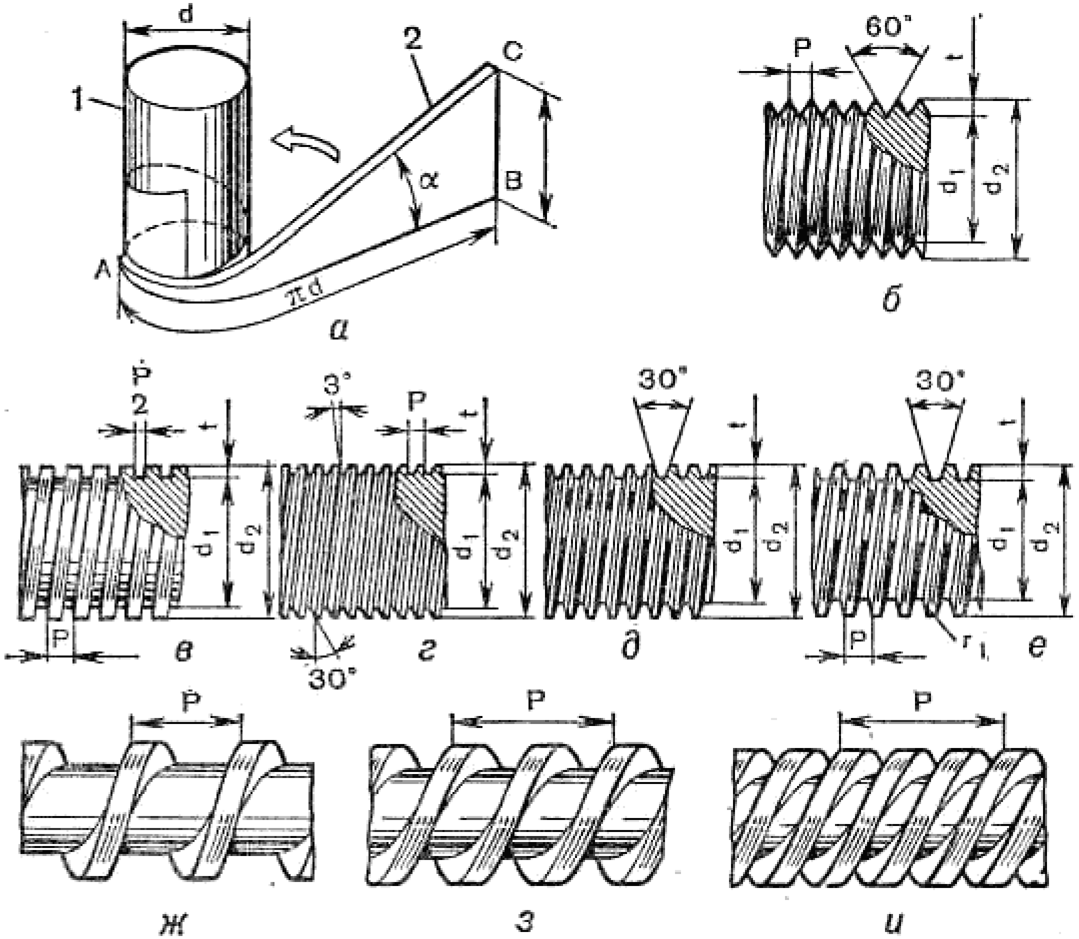
Adhesive bonding

Glue
Paste
Gum
…

Machine Elements Classification

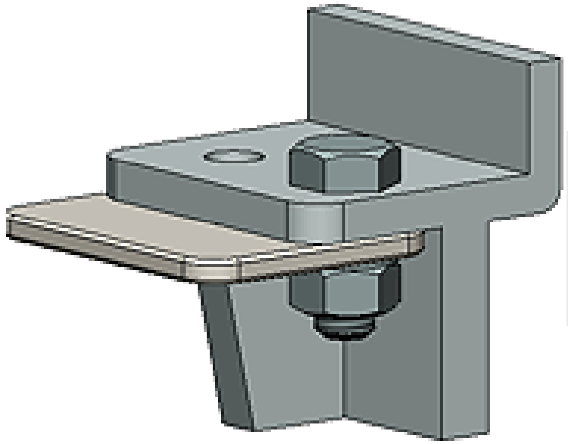
Detachable joints

Threaded joints



Bolt, Screw and Stud

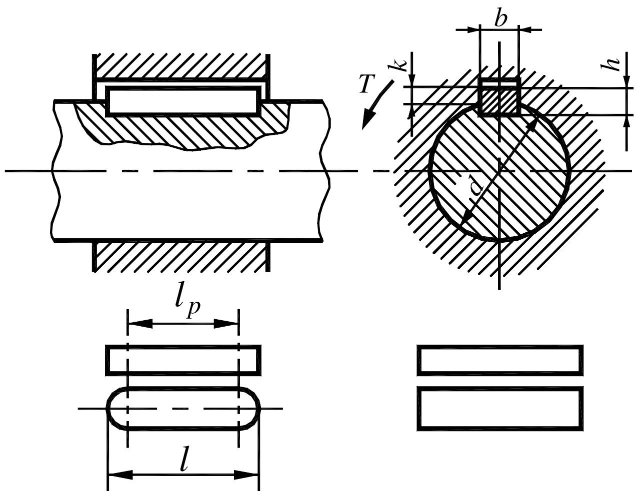
Bolt, Nut and Washer



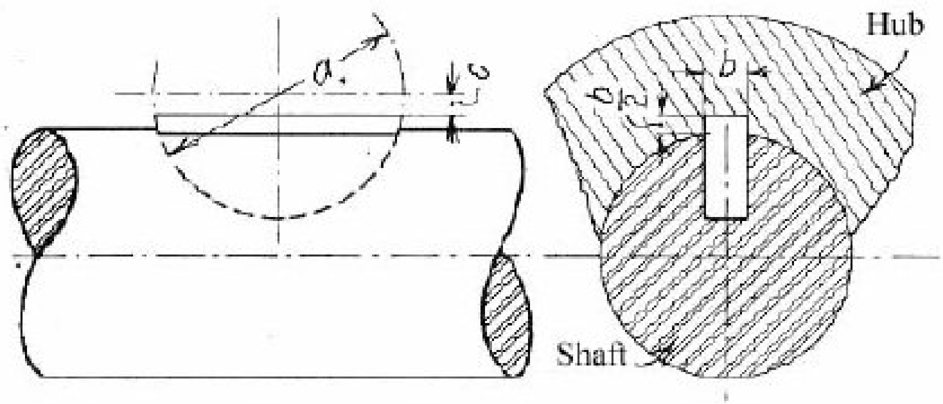
Machine Elements Classification

Detachable joints

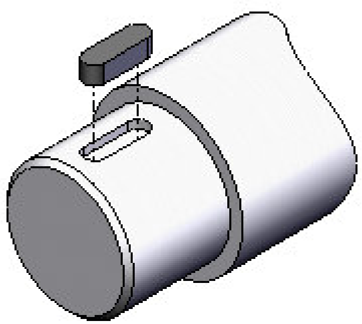
Keyed joints



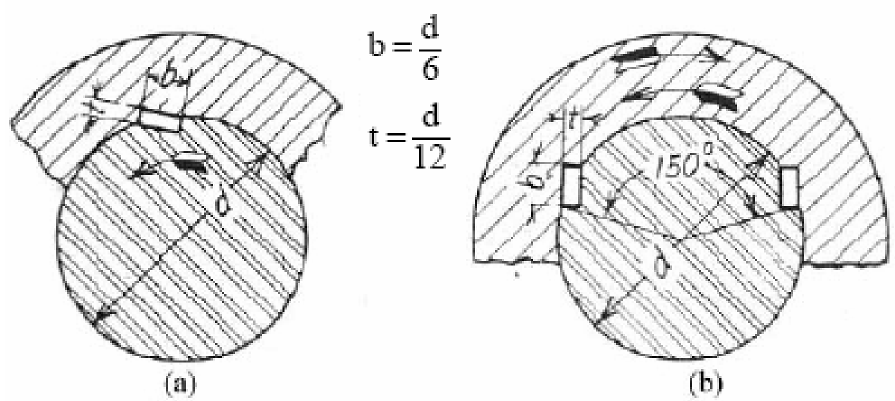
a) б)



circular key, semicircular key, Whitney key



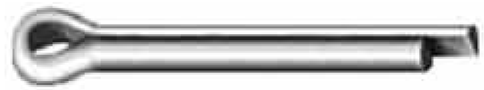
feather key, parallel key, prismatic key

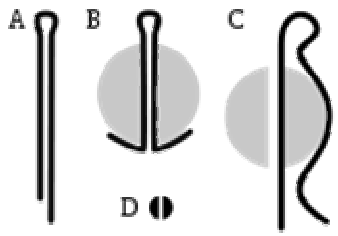


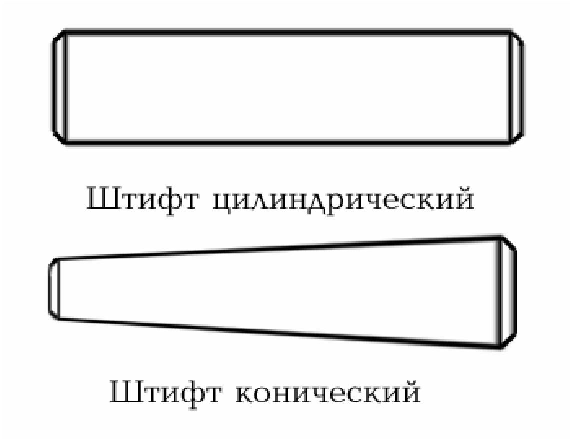
taper(ed) key, wedge key

Machine Elements Classification

Detachable joints
Pin joints



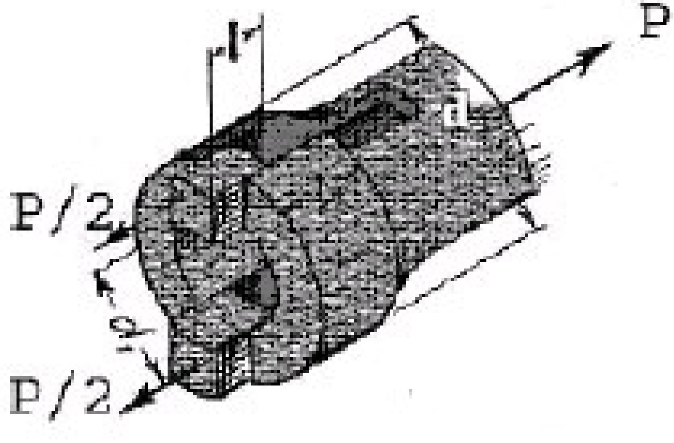


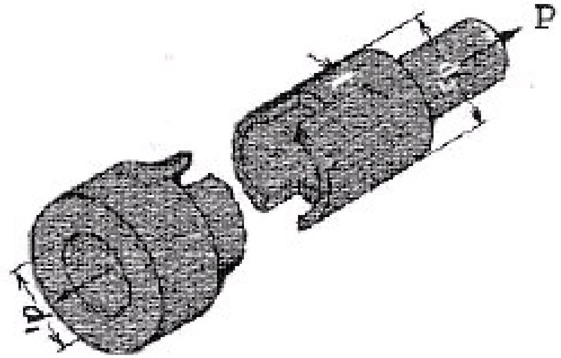


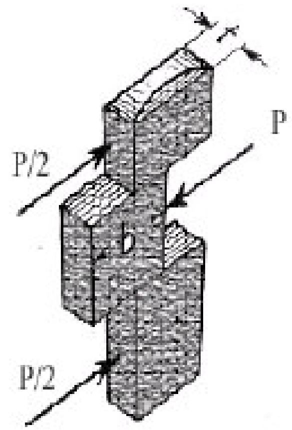
Machine Elements Classification

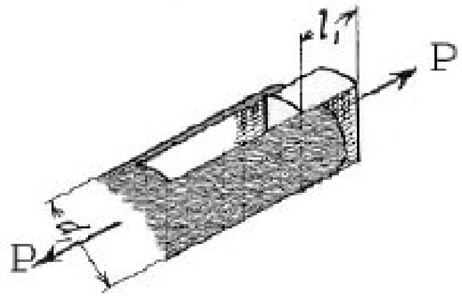
Detachable joints

Cotter joints





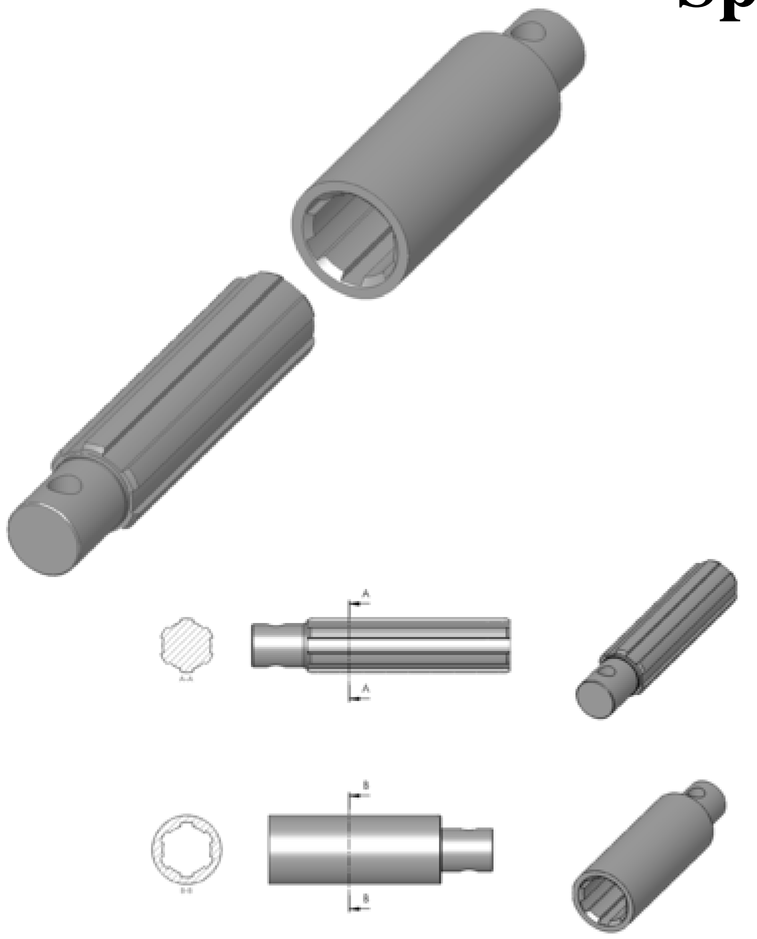


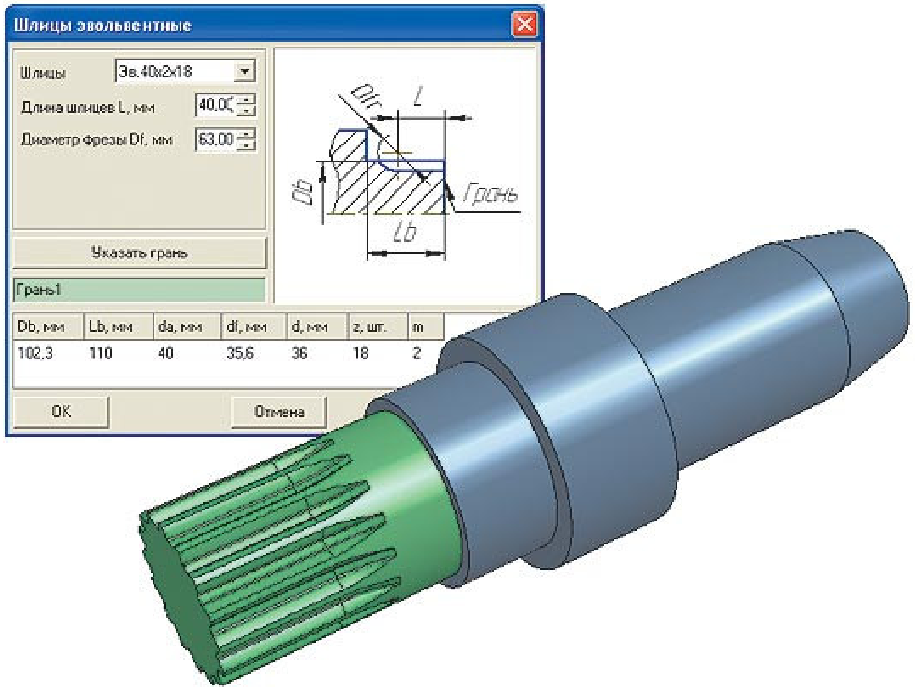


Machine Elements Classification

Detachable joints

Splined joints

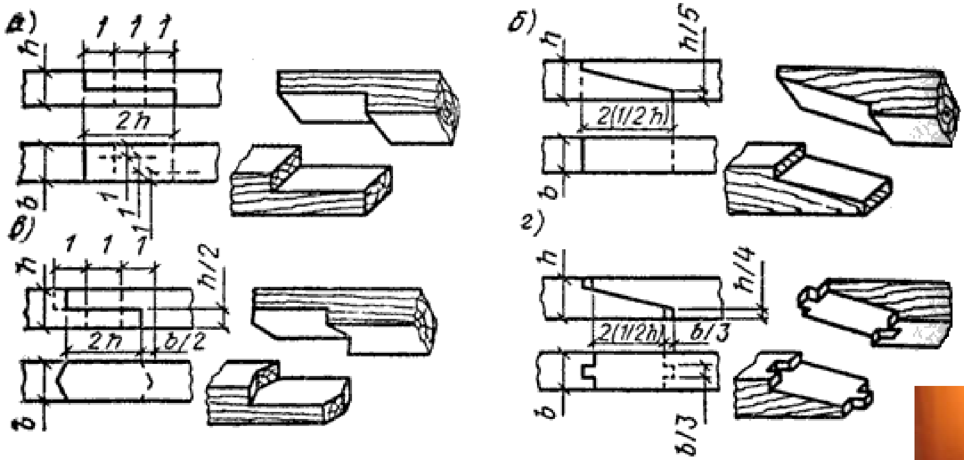




Machine Elements Classification

Detachable joints

Wedged joints



Machine Elements Classification

2) Power transmissions:
Electric, Hydraulic, Pneumatic, Mechanical

Mechanical Drive (Gearing) :

a) Transmission by friction (Friction Gearing):

- friction gear;
- belt drive (with flexible connection);
- cable / rope drive (with flexible connection);

b) Transmission by mesh (Toothed Gearing):

- spur gear; helical gear; herring-bone gear
- rack gear;
- bevel gear;
- worm gear; hypoid gear; screw gear;
- tooth-belt drive (with flexible connection);
- chain drive (with flexible connection).

Machine Elements Classification

Friction gear

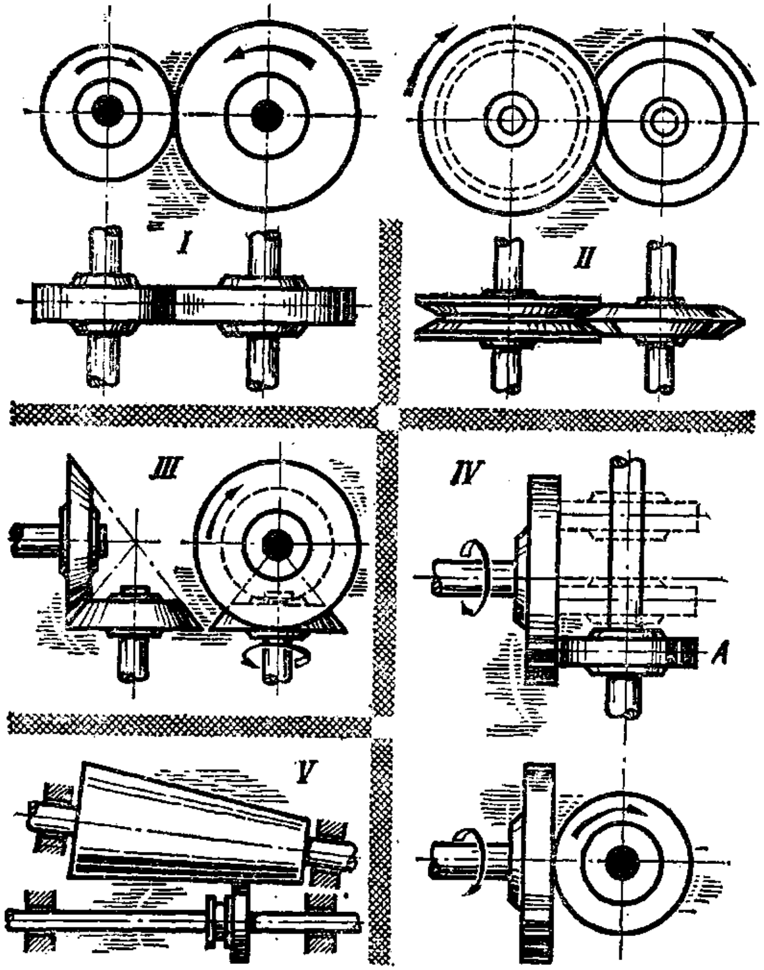
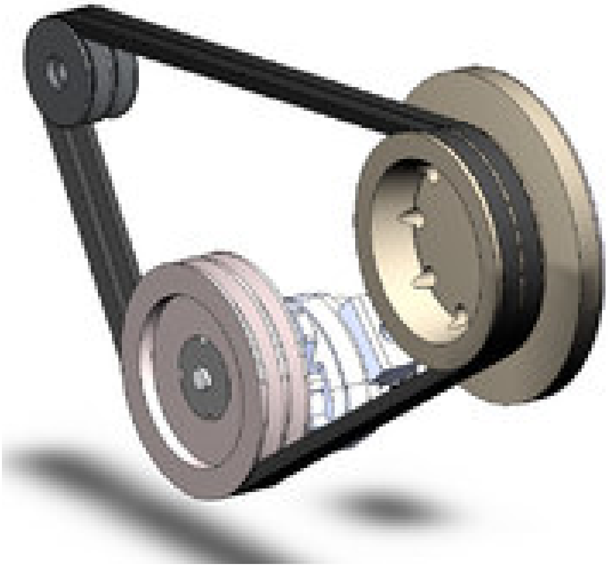
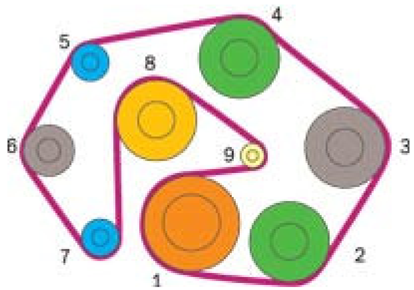


Рис. 64. Фрикционные передачи: *I* — цилиндрическая с прямым ободом; *II* — цилиндрическая с клинчатым ободом; *III* — коническая; *IV* — лобовая; *V* — с передвижным цилиндрическим колесом.

Machine Elements Classification

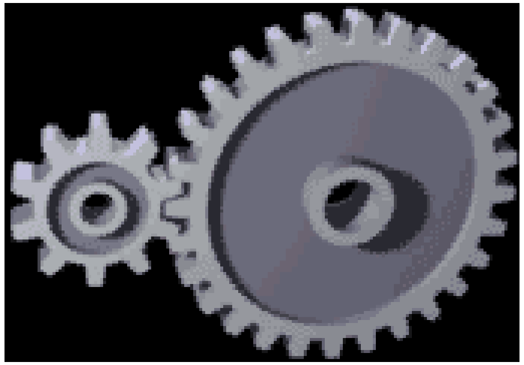
Belt drive





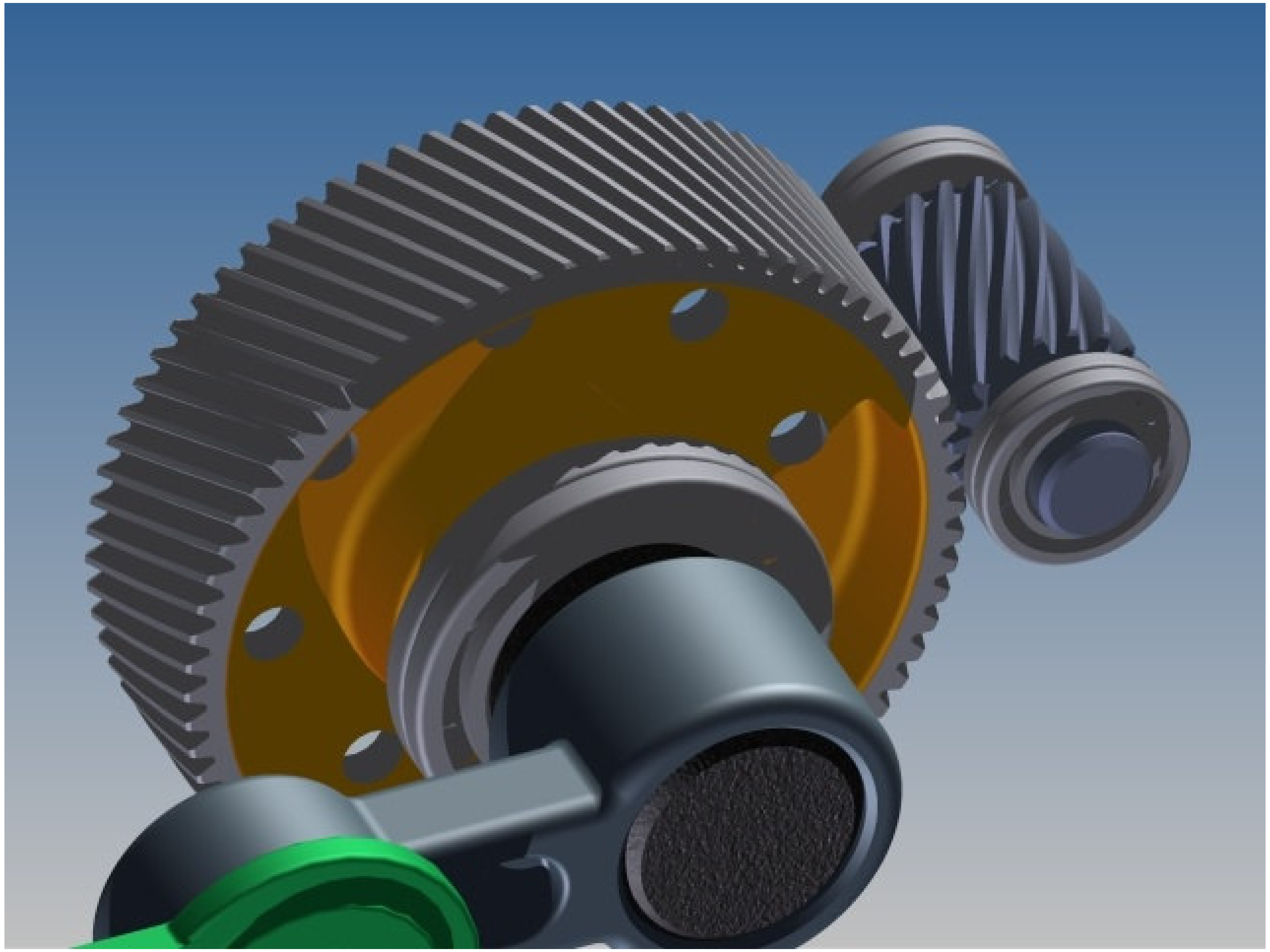
Machine Elements Classification

Spur gear



Machine Elements Classification

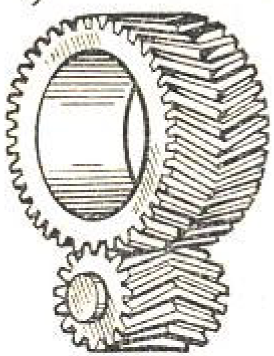
Helical gear

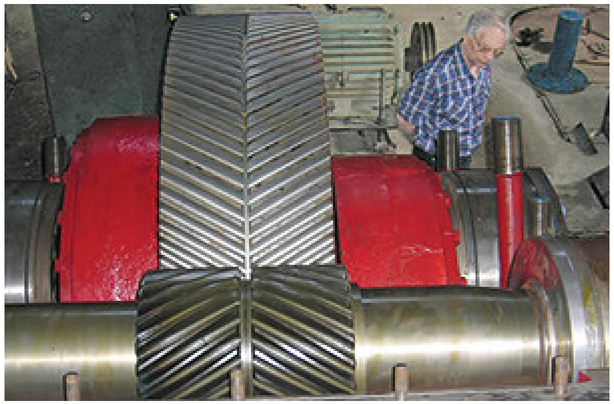


Machine Elements Classification

Herring-bone gear

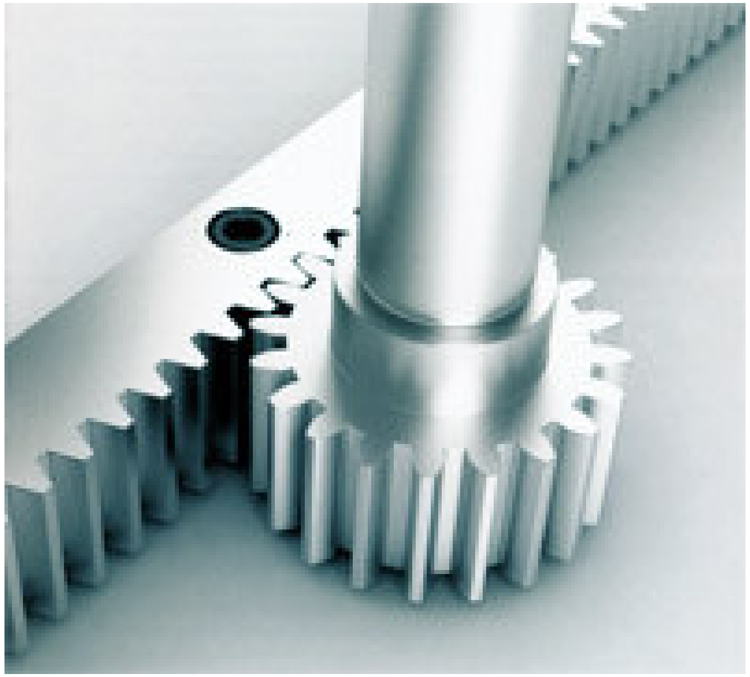
в)





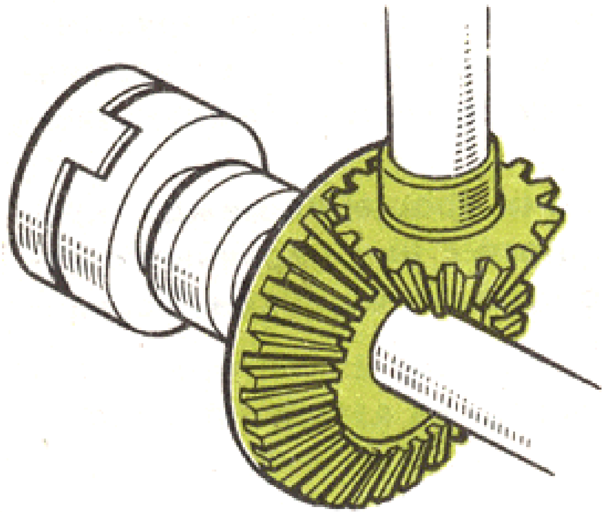
Machine Elements Classification

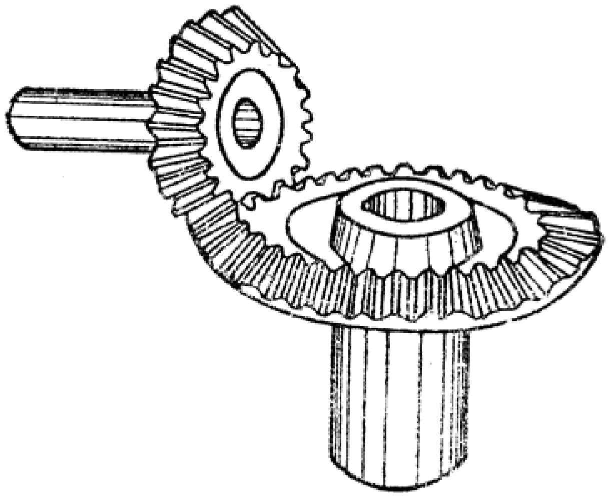
Rack gear

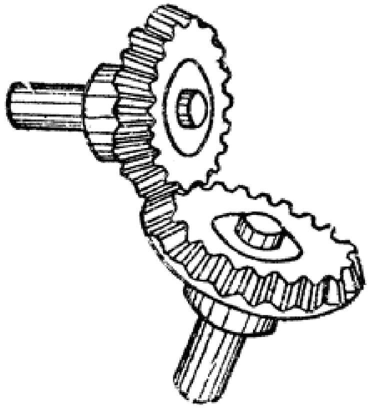


Machine Elements Classification

Bevel gear

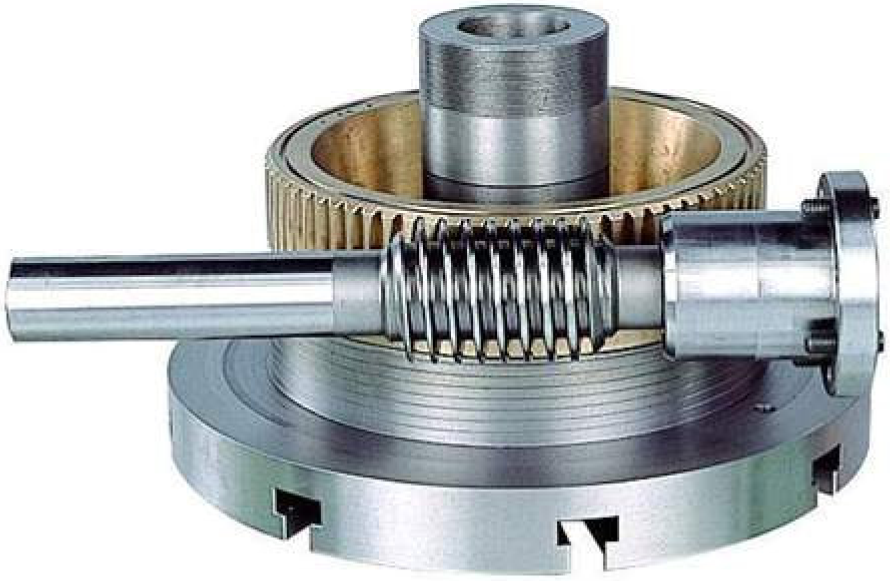


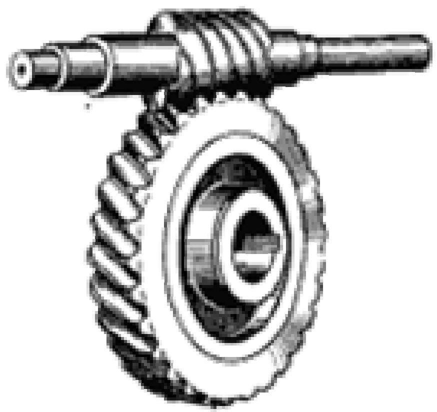


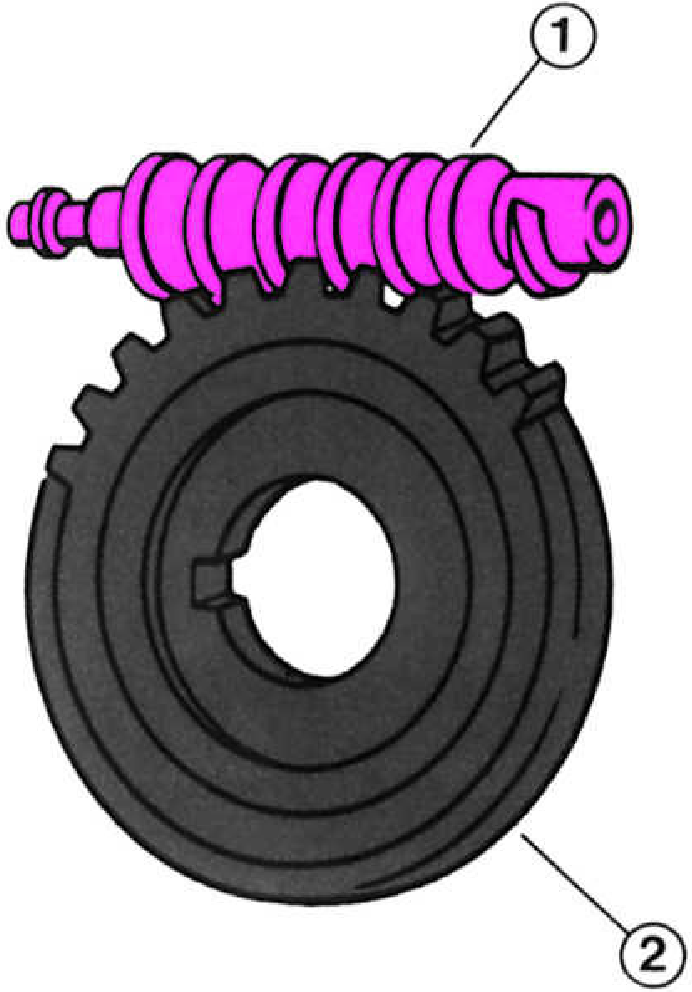


Machine Elements Classification

Worm gear

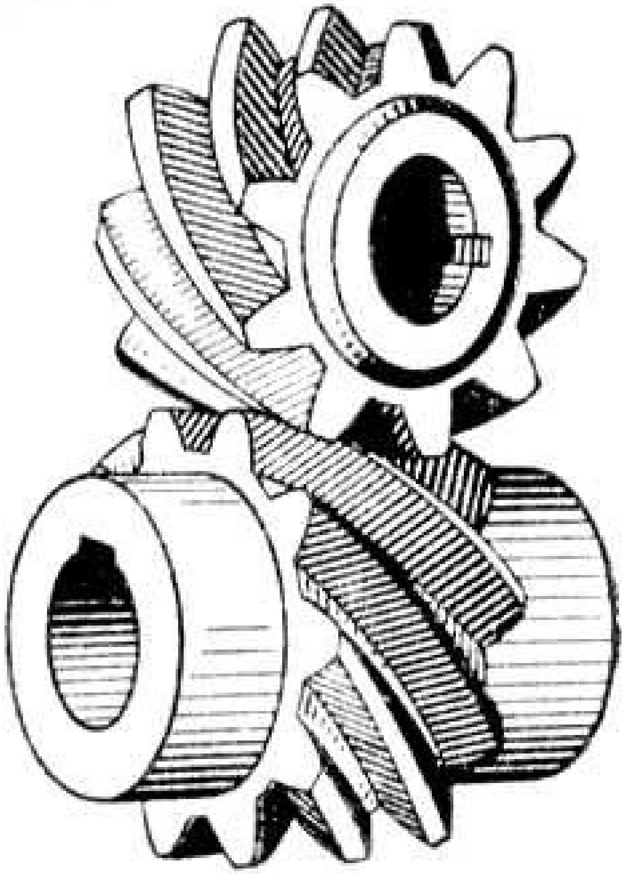






Machine Elements Classification

Screw gear

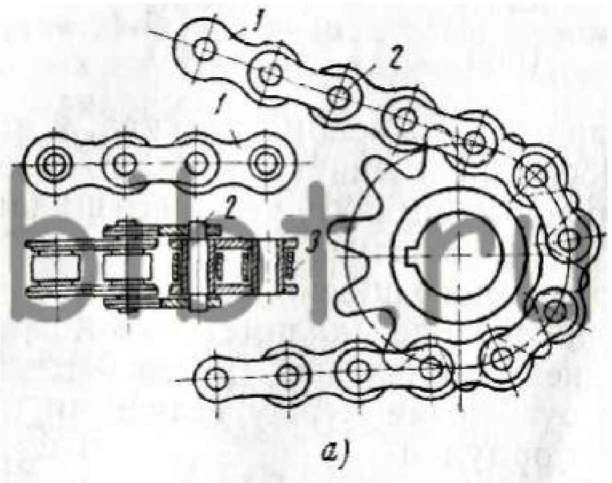


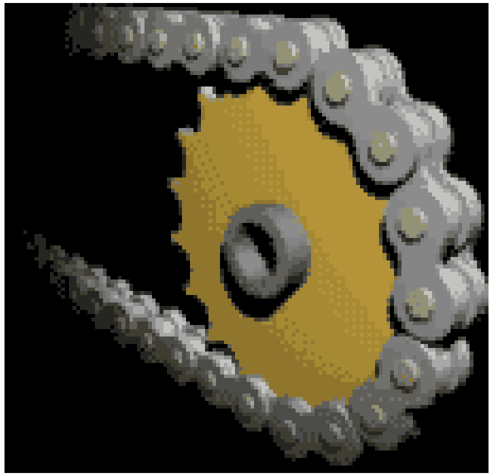
Machine Elements Classification

Tooth-belt drive

Machine Elements Classification

Chain drive





Machine Elements Classification

3) Elements for revolving motion

a) Axels (intended for supporting revolving parts);
b) Shafts (also transmit torque);
c) Clutches and coupling;
   Permanent coupling;
   Clutch, claw (dog) clutch;
d) Bearings

Contact types of bearings:

- sliding contact bearing (with sleeves or insert liner);
- rolling contact bearing,

Direction of the load in bearings:

- Radial;
- Thrust;
- Combination,

Types of rolling elements in bearings:

- Ball bearings;
- Roller bearings.

Machine Elements Classification

4) Frames, bases, bodies, housings;

5) Lever and cam mechanisms;

6) Springs, leaf (bow) springs, elastic joints;

7) Flywheels, floating levers, pendulums, loads;

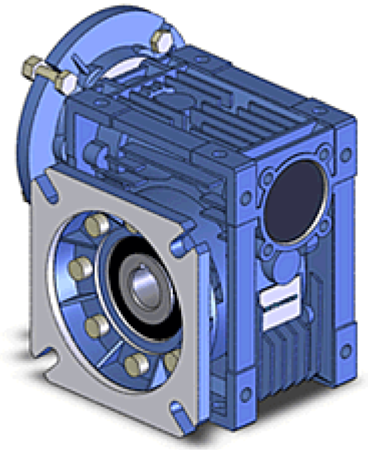
8) Protective and lubricate elements;

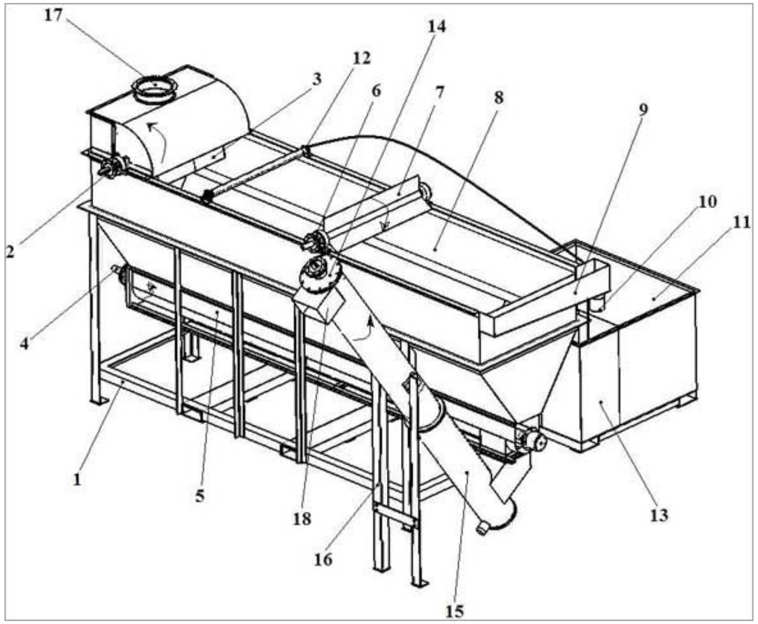
9) Elements of control mechanisms;

10) Special purpose elements (valves, wheels, turbine blades, etc…)

Machine Elements Classification

4) Frames, bases, bodies, housings;





Machine Elements Classification

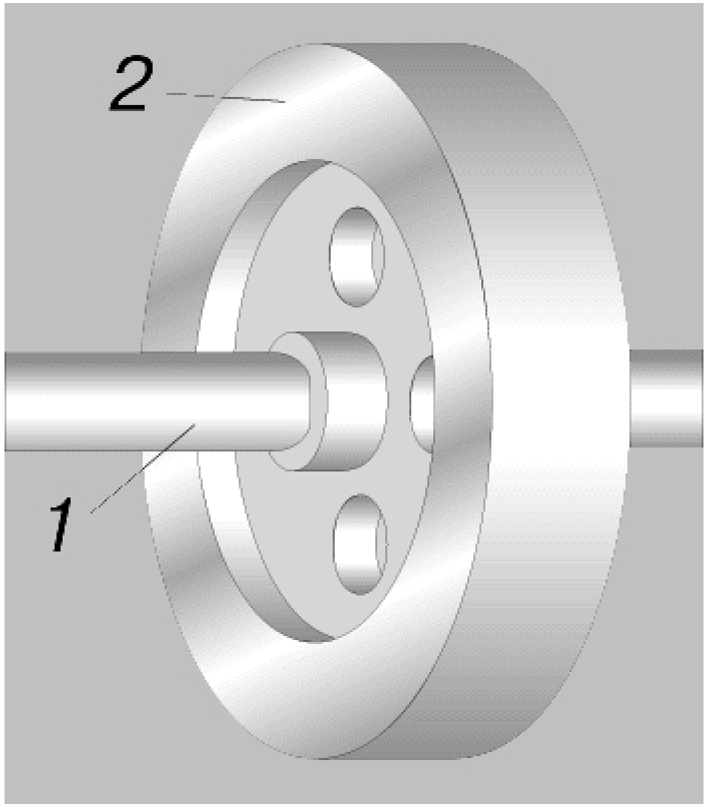
5) Lever and cam mechanisms;

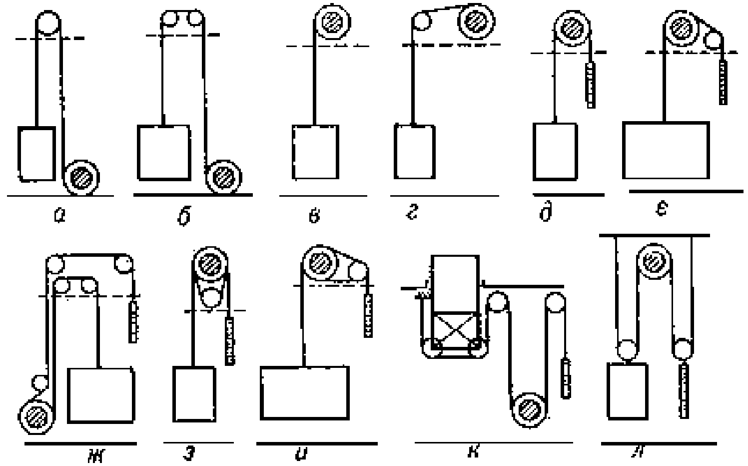
Machine Elements Classification

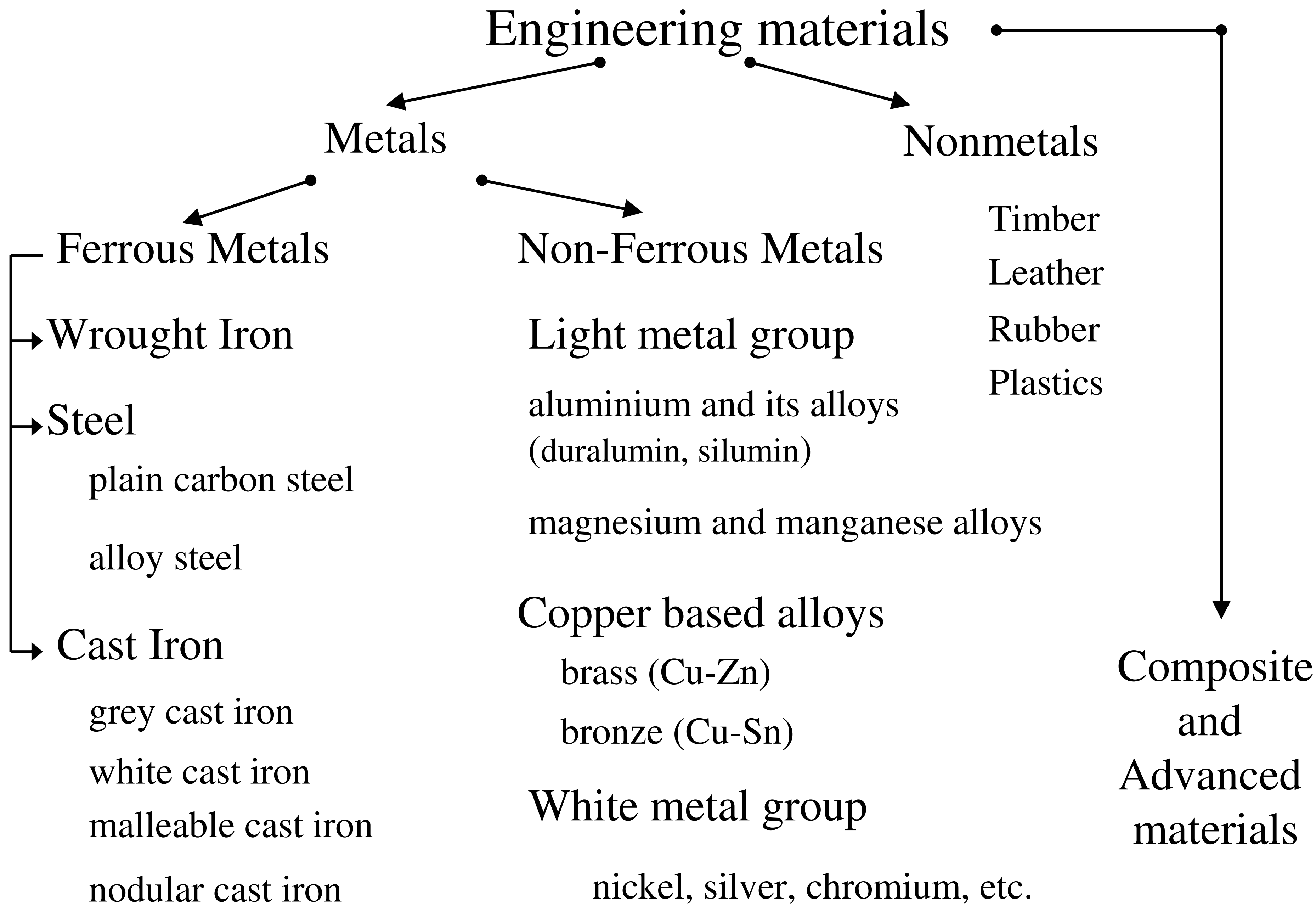
6) Springs (helical), leaf / bow / springs, elastic joints;

Machine Elements Classification

7) Flywheels, floating levers, pendulums, loads;







Engineering materials
Metals
Nonmetals
Ferrous Metals
Wrought Iron
Steel
plain carbon steel
alloy steel
Cast Iron
grey cast iron
white cast iron
malleable cast iron
nodular cast iron
Non-Ferrous Metals
Light metal group
aluminium and its alloys
(duralumin, silumin)
magnesium and manganese alloys
Copper based alloys
brass (Cu-Zn)
bronze (Cu-Sn)
White metal group
nickel, silver, chromium, etc.
Timber
Leather
Rubber
Plastics
Composite
and
Advanced
materials

Basic Requirements to Machine and their Elements

A. **Operating capacity**:

Strength is the ability of a material to withstand loading forces without damage

Rigidity (Stiffness) is the property of a solid body to resist deformation by an applied force

Wear resistance, **Endurance**, **Durability** is the ability of machine elements to resist a wear during their work

Heat resistance, Heat endurance is the ability of machine elements to resist a wear under high temperature

Vibration resistance is the ability of machine elements to resist a prohibitive vibration or vibration resonance

B. **Reliability** is the ability of a system or component to perform its required functions under stated conditions for a specified period of time

C. **Efficiency** (economy meaning) – minimal cost of component with saving all other criteria of operating capacity

Additional Requirements to Machine

Maintenance ability , Serviceability, Cost and Aesthetics

Strength

$$[\sigma] = \frac{\sigma_{\lim}}{[n]}, \quad [\tau] = \frac{\tau_{\lim}}{[n]},$$

$\sigma_{\lim}, \tau_{\lim}$ - limit stress

$[\sigma]$, $[\tau]$ - allowable stress

$[n]$ - safety factor

F, Q is the forces
acting on an *area* **A** [m^2]

F - is longitudinal *force* [N]

Q - is lateral (shear, transverse) *force* [N]

M - is bending *moment* [Nm]

T - is *torque* [Nm]

W - is *section modulus*, moment of resistance [m^3]

Wp - is *section modulus of torsion*, modulus of twist [m^3]

Types of deforming

Tensile/ compressive stress:

$$\sigma = \frac{F}{A} < [\sigma]$$

Shear stress:

$$\tau = \frac{Q}{A} < [\tau]$$

Bending stress:

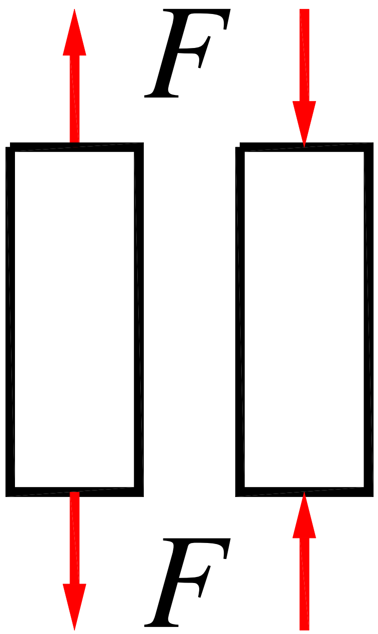
$$\sigma = \frac{\mathrm{M}}{\mathrm{W}} < [\sigma]$$

Torsion stress:

$$\tau = \frac{\mathrm{T}}{\mathrm{W_p}} < [\tau]$$

Strength

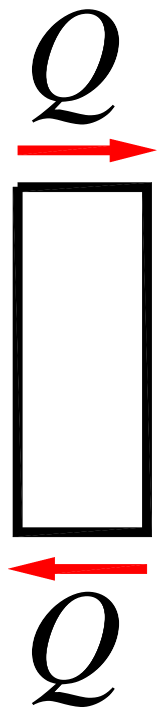
Types of deforming



Tensile/ compressive stress: $$\sigma = \frac{F}{A} < [\sigma]$$

Strength

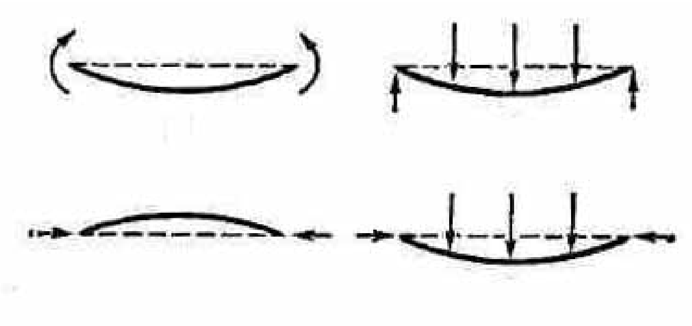
Types of deforming

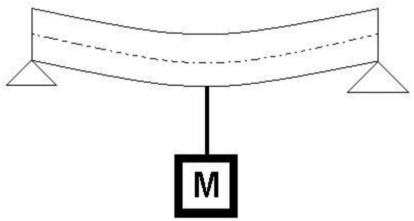


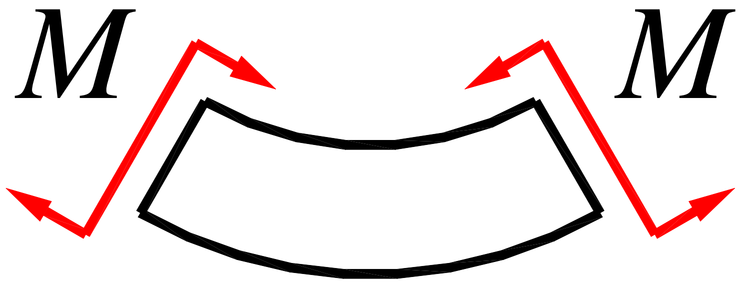
Shear stress: $$\tau = \frac{Q}{A} < [\tau]$$

Strength

Types of deforming





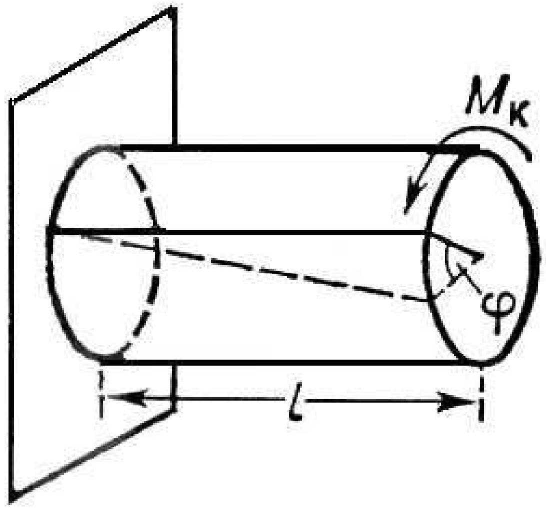


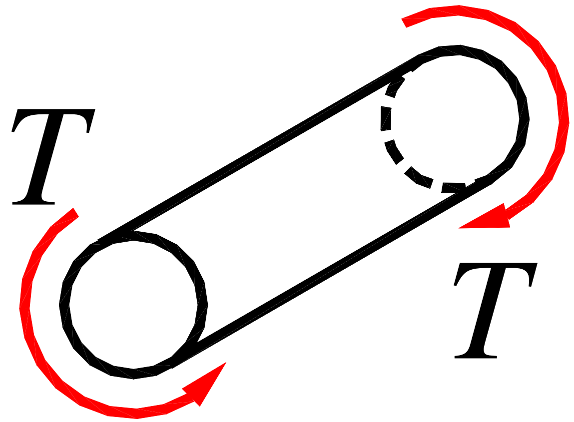
Bending stress:

$$\sigma = \frac{M}{W} < [\sigma]$$

Strength

Types of deforming





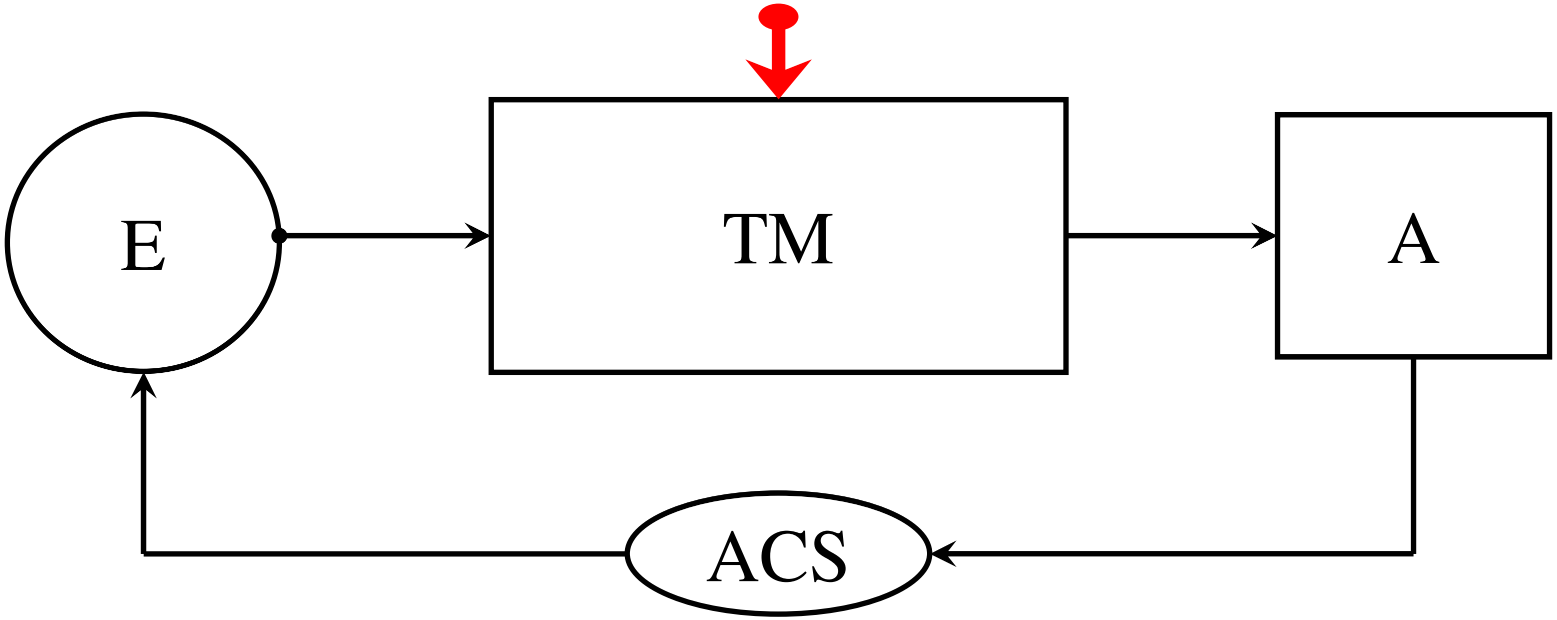
Torsion stress:

$$\tau = \frac{T}{W_p} < [\tau]$$

Machine

Machine is a device intended to modify energy (materials)

Power Transmissions



Schema of Standard Machine

E – engine, motor, mover;
TM – transmission mechanism;
A – actuator, actuating device, executing (operating) mechanism;
ACS – automatic control system

Mechanical Drive Parameters:

ω is angular velocity /rotating speed/ (rad/s), (1/s)

n is rotating frequency, rate of turn (revolutions per minute, rounds per minute = rpm)

$$\omega = \frac{\pi \cdot n}{30},$$

V is circumferential velocity, peripheral velocity (m/s)

$$V = \omega \cdot r = \omega \cdot \frac{d}{2},$$

r is radius (m)
d is diameter (m)

T is torque (Nm)

F_t is peripheral force (N)

$$T = F_t \cdot r = F_t \cdot \frac{d}{2},$$

N, P is power (W)

$$N = T \cdot \omega = F_t \cdot V,$$

Mechanical Drive Parameters:

1 – driving gear, power gear, driver pinion
2 – driven gear, follower gear (slave unit)

u, *i* is transmission ratio, angular speed ratio, gear ratio

$$u_{1-2} = \frac{\omega_1}{\omega_2} = \frac{n_1}{n_2},$$

$$u = u_1 \cdot u_2 \cdot u_3 \cdot \ldots = \prod_i u_i,$$

η is efficiency factor (coefficient), output-input ratio

$$\eta_{1-2} = \frac{N_2}{N_1},$$

$$\eta = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \ldots = \prod_i \eta_i,$$

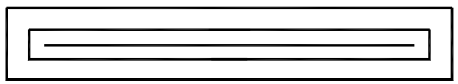
Belt Drive

Belt drives are called flexible machine elements.

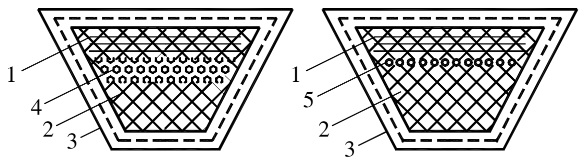
1. Used in conveying systems
   Transportation of coal, mineral ores etc. over a long distance
2. Used for transmission of power.
   Mainly used for running of various industrial appliances using prime movers like electric motors, I.C. Engine etc.
3. Replacement of rigid type power transmission system.
   A gear drive may be replaced by a belt transmission system

Types of belts:

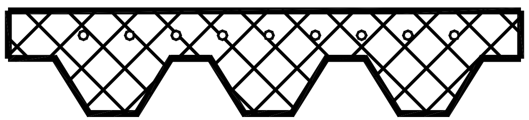
- Flat belt



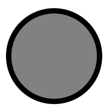
- V-belt



- Poly-V-belt



- Rope



Belt Drive

Advantages of belt drives:

- distance between axes of driving and driven shafts is large;
- operate smoothly and without knocking;
- transmit only definite load which, if exceeded, will cause the belt to slip over the pulley (thus protect the other parts of the drive against overload);
- simple design and rather low initial cost.

Disadvantages of belt drives:

- large dimensions;
- certain inconstancy of the velocity ratio due to belt slippage;
- heavy loads on the shafts and bearings;
- comparatively short service life of the belts

Belt Drive

Belt Material:

- **Leather**
  (Oak tanned or chrome tanned)

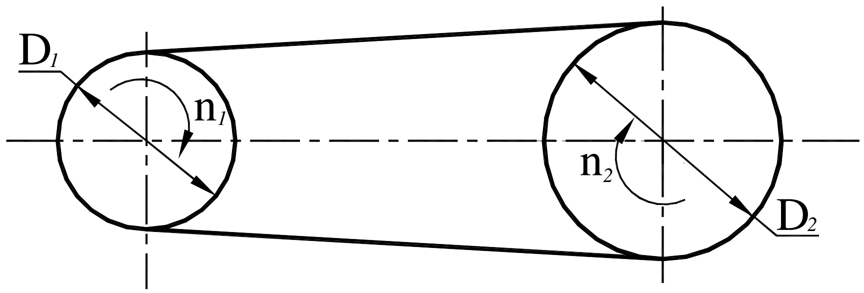
- **Rubber**
  (Canvas or cotton duck impregnated with rubber. For greater tensile strength, the rubber belts are reinforced with steel cords or nylon cords)

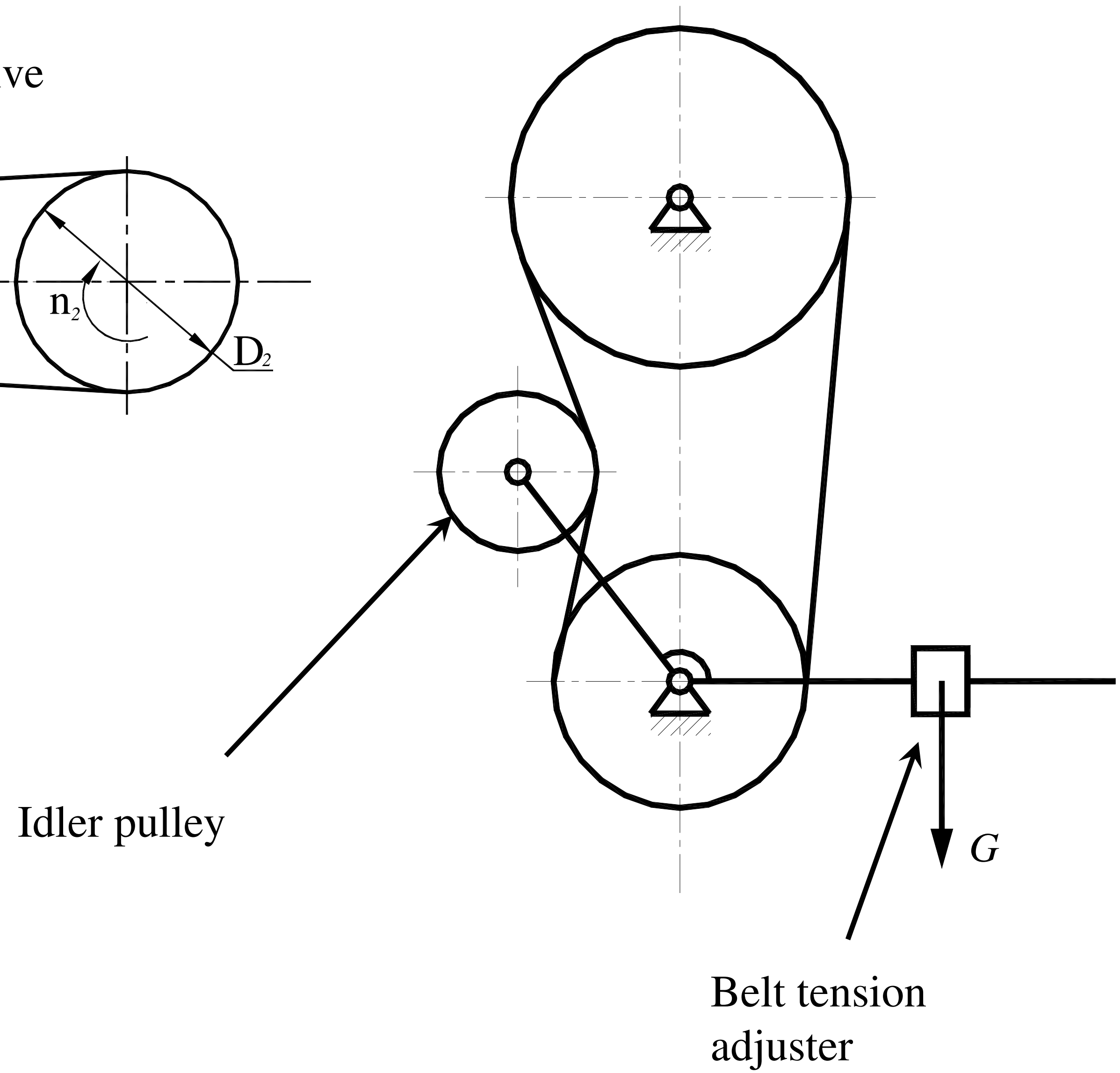
- **Plastics**
  (Thin plastic sheets with rubber layers)

- **Fabric**
  (Canvas or woven cotton ducks. The belt thickness can be built up with a number of layers. The number of layers is known as ply.)

Belt Drive

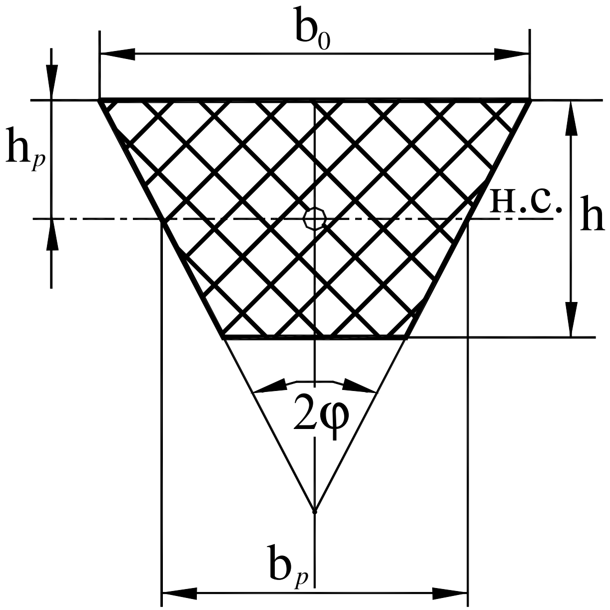
Simple belt drive

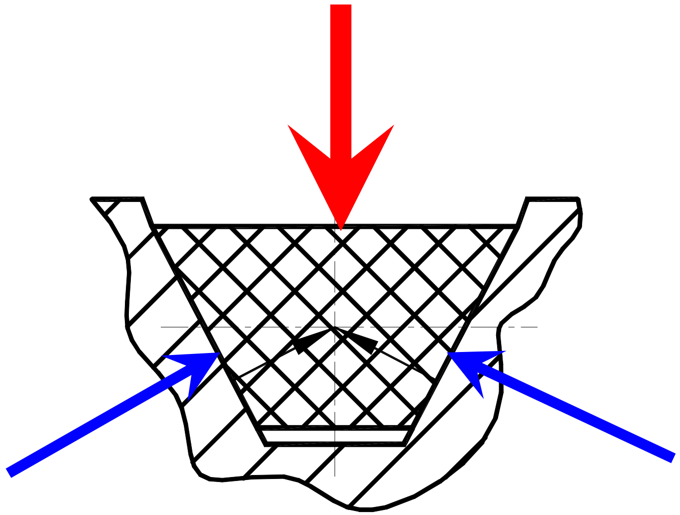




Belt Drive

Improved pulling capacity of V-belt





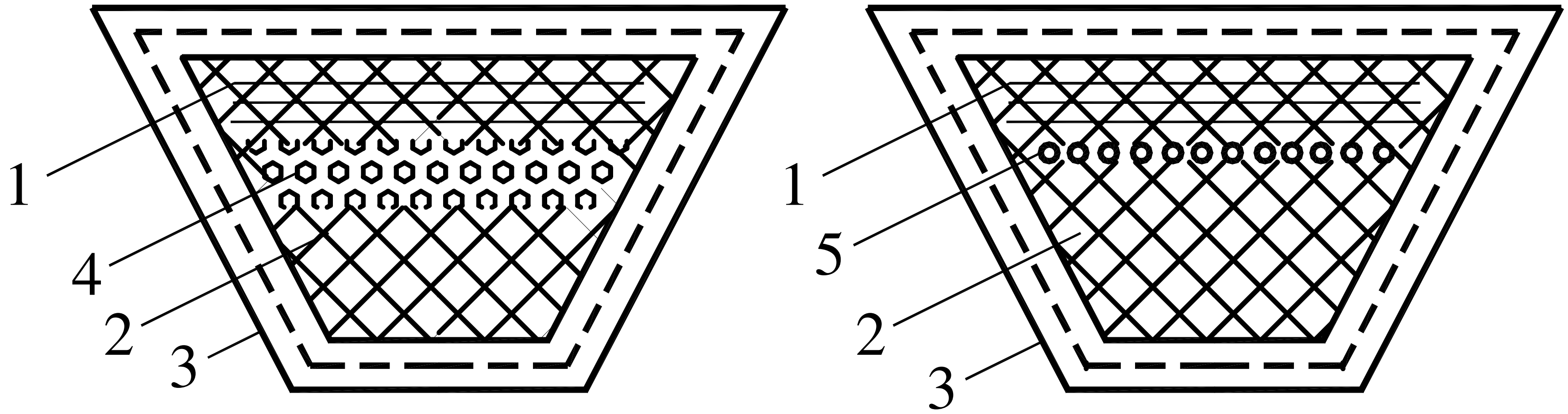
Superficial friction factor

$$f' = \frac{f}{\sin\varphi}$$

$$f' \approx \frac{f}{\sin 20°} \approx 3 \cdot f,$$

Belt Drive

Structure of V-belt



1 – rubber layer for tension;
2 – rubber layer for compression (base rubber);
3 – a couple of wrapping rubberized fabric layers;
4 – multi-cord (e.g. rubber-fabric);
5 – single-cord.

Belt Drive

Types of V-belts

Section	kW range	Minimum pulley pitch diameter (mm)	Width (mm)	Thickness (mm)
A	0.4 - 4	125	13	8
B	1.5 -15	200	17	11
C	10 -70	300	22	14
D	35-150	500	32	19
E	70-260	630	38	23

Тип ремней	Обозначение	Размеры сечения, мм (рис. 2.6, *а*, *б*)				F_1, см²	Расчетная длина *L*, мм	d_p min, мм	$T_б$, Н м	*q*, кг/м
		b_p	*h*	b_0	y_0					
Нормальные	О	8,5	6,0	10	2,1	0,47	400...2500	63	<30	0,07
	А	11,0	8,0	13	2,8	0,81	560...4000	90	15...60	0,10
	Б	14,0	10,5	17	4,0	1,38	1000...6300	125	50...150	0,18
	В	19,0	13,5	22	4,8	2,30	1800...10600	200	120...600	0,3
	Г	27,0	19,0	32	6,9	4,76	3150...15000	315	450...2400	0,62
Узкие	УО	8,5	8	10	2	0,56	630...3550	63	<150	0,07
	УА	11,0	10	13	2,8	0,95	800...4500	90	90...400	0,12
	УБ	14,0	13	17	3,5	1,58	1250...8000	140	300...2000	0,2
	УВ	19,0	18	22	4,8	2,78	2000 ..8000	224	>1500	0,37

Belt Drive

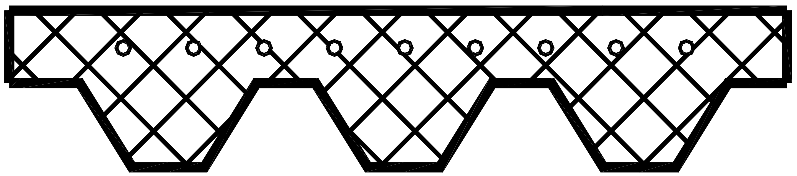
Types of V-belts

$$\frac{b_0}{h} = 1.2$$ – narrow belts

$$\frac{b_0}{h} = 1.6$$ – normal belts

$$\frac{b_0}{h} = 2.5 \div 3.5$$ – wide belts (for variators)

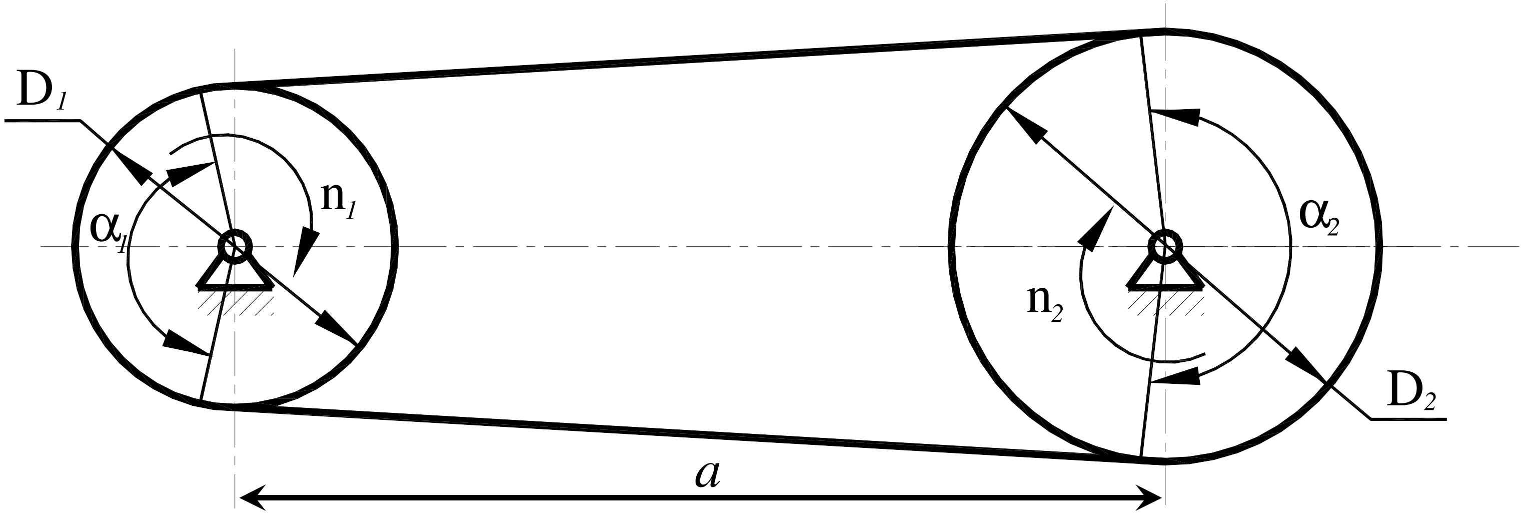
Types of Poly-V-belts



Poly-V-belts can be **K**, **L**, **M** (our standarts)
PH, PJ, PK, PL, PM (foregin standarts)
with number of edges z = 2 - 50

К - PJ; Л - PL; М - PM

Belt Drive

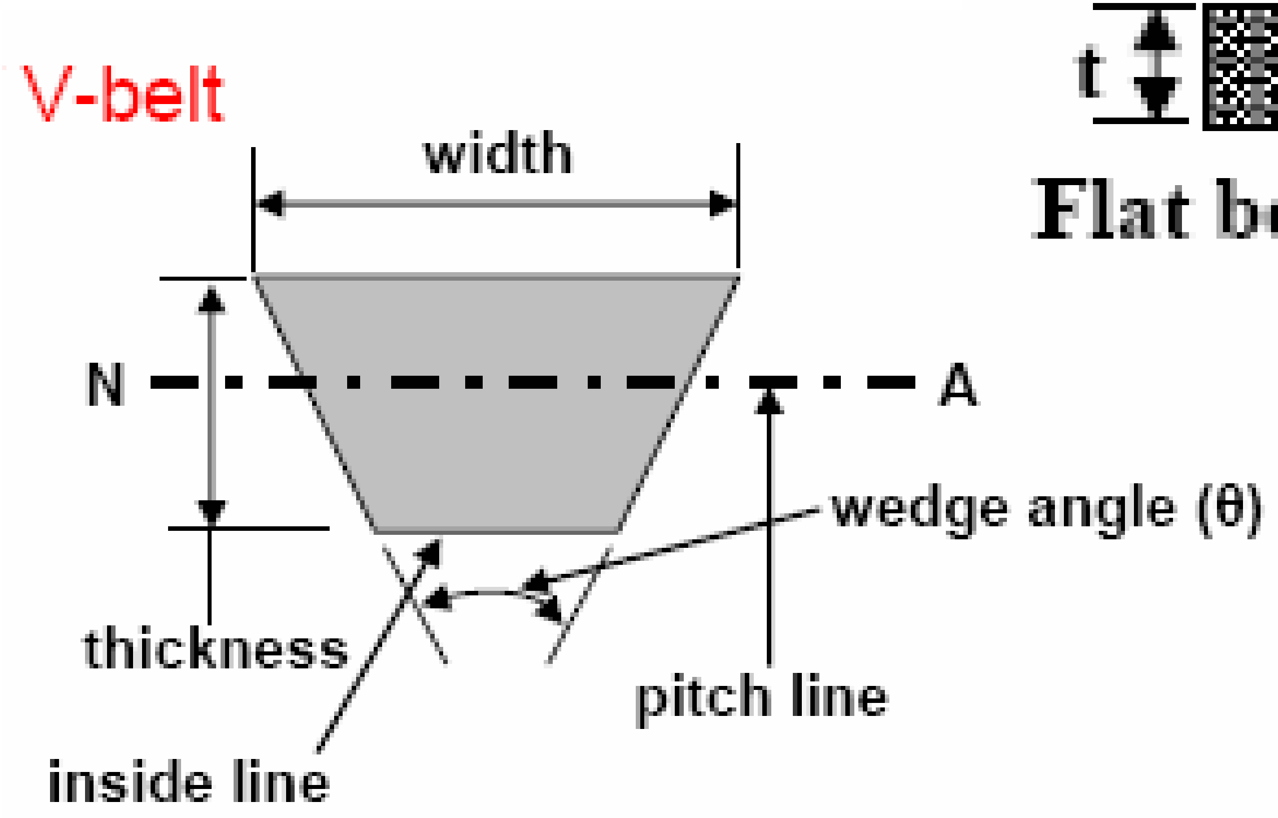


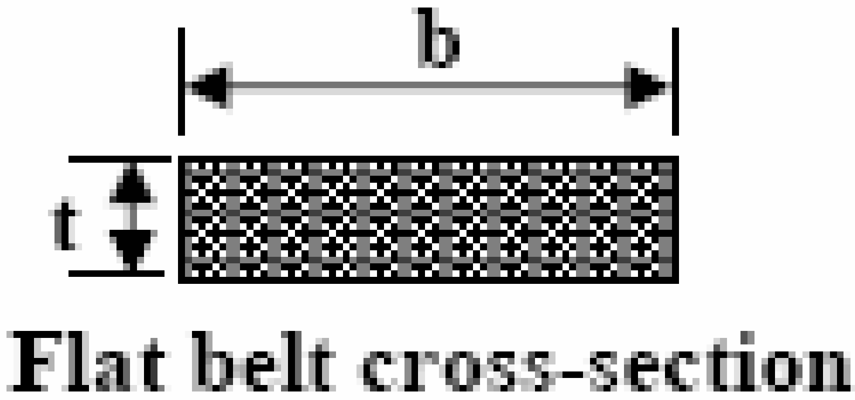
Parameters of belt drive:

D_1 – diameter of the smaller pulley (driving pulley);
D_2 – diameter of the lager pulley (driven pulley);
α – angle of wrap;
a – center distance between the two pulleys.

Belt Drive

Belt geometry parameters





Belt Drive

Angular speed ratio: $$u = \frac{n_1}{n_2} = \frac{D_2}{D_1(1-\xi)}$$

n_1, n_2 – rotating frequency

$\xi = 0.01 \div 0.02$ – belt slip factor

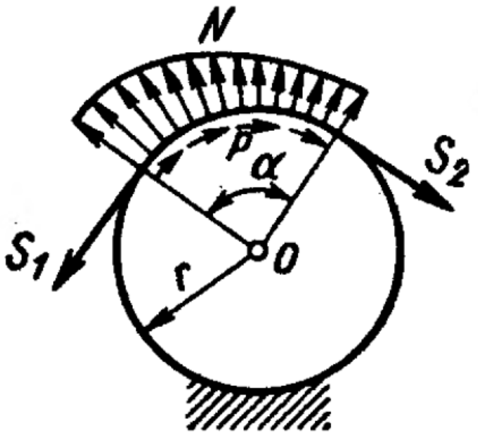
Angle of wrap: $$\alpha_1 = 180° - \frac{D_2 - D_1}{2} \cdot 57°,$$

Length of the belt: $$L = \pi \frac{D_2 + D_1}{2} + a\left[2 + \left(\frac{D_2 - D_1}{2a}\right)^2\right]$$

Center distance between the two pulleys (exact center distance):

$$a = \frac{1}{4}\left[\left(L - \pi\frac{D_1 + D_2}{2}\right) + \sqrt{\left(L - \pi\frac{D_1 + D_2}{2}\right)^2 - 2(D_2 - D_1)^2}\right]$$

Belt Drive



Scheme of a flexible cord winding on cylinder

Relation was established by L. Euler 1775

$$\frac{S_1}{S_2} = e^{f\alpha},$$

S_1, S_2 – forces applied to the cord ends

f – friction factor between the cord and the cylinder surface

α – arc of contact between the cord and the cylinder

Forces in belts

$$F_1 = F_t \frac{e^{f\alpha}}{e^{f\alpha} - 1} \qquad F_2 = F_t \frac{1}{e^{f\alpha} - 1}$$

F_1, F_2 – tensions in driving and driven sides of the belt

$F_1 + F_2 = 2F_0$ $\quad F_0$ – initial tension

$F_1 - F_2 = F_t$ $\quad F_t$ – peripheral force

Belt Drive

Stresses in belts

$$\sigma_1 = \frac{F_1}{A}, \qquad \sigma_2 = \frac{F_2}{A},$$

σ_1, σ_2 – stress due to tension

$$\sigma_1 = \sigma_0 + 0.5 \cdot \sigma_t,$$

$$\sigma_2 = \sigma_0 - 0.5 \cdot \sigma_t,$$

$$\sigma_0 = \frac{F_0}{A},$$

σ_0 – stress due to initial tension

$$\sigma_t = \frac{F_t}{A},$$

σ_t – stress due to peripheral force

$$\sigma_c = \frac{\rho V^2}{10g} \approx \frac{V^2}{100},$$

V – peripheral velocity

σ_c – stress due to centrifugal force

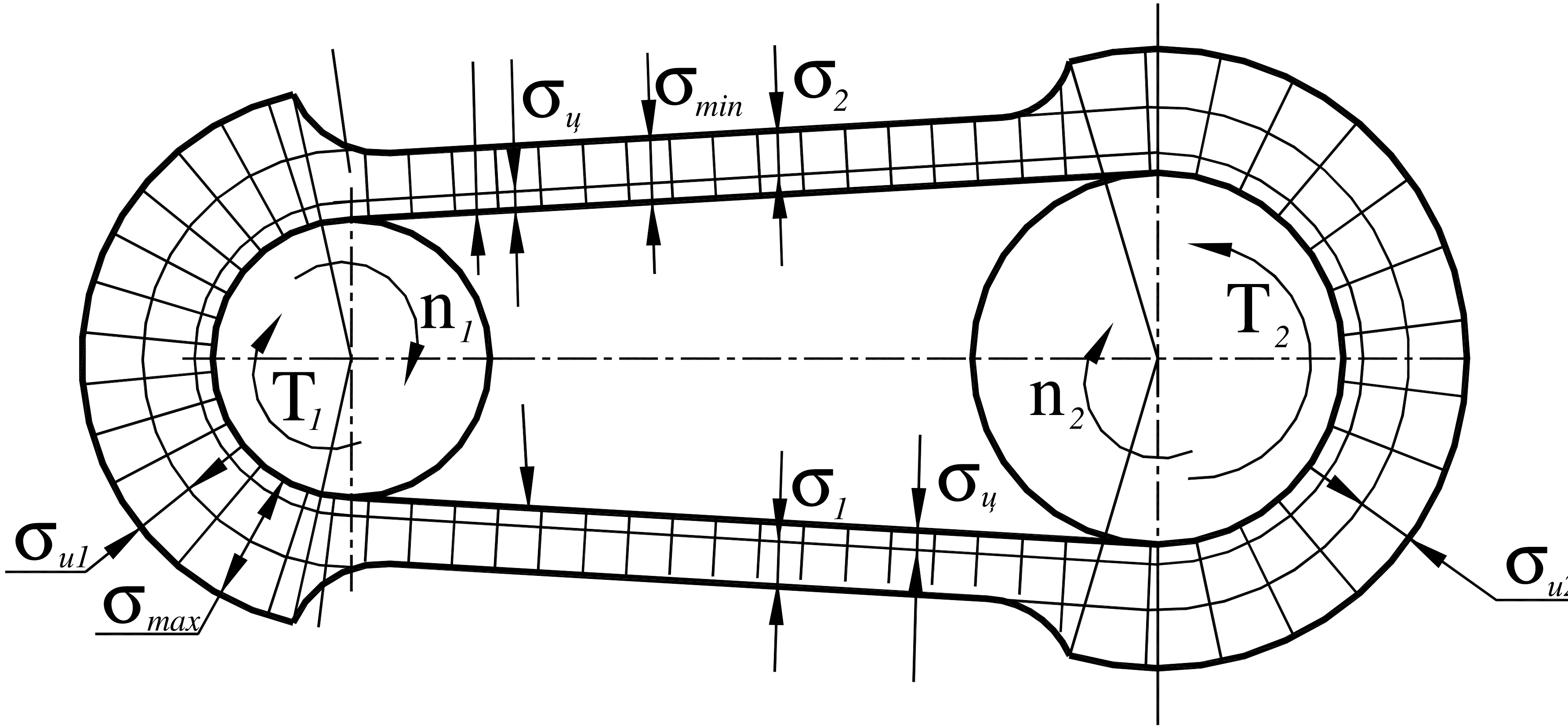
$$\varepsilon = \frac{h}{D_1},$$

$$\sigma_b = E \cdot \varepsilon = E \cdot \frac{h}{D_1},$$

σ_b – stress due to bending

Belt Drive

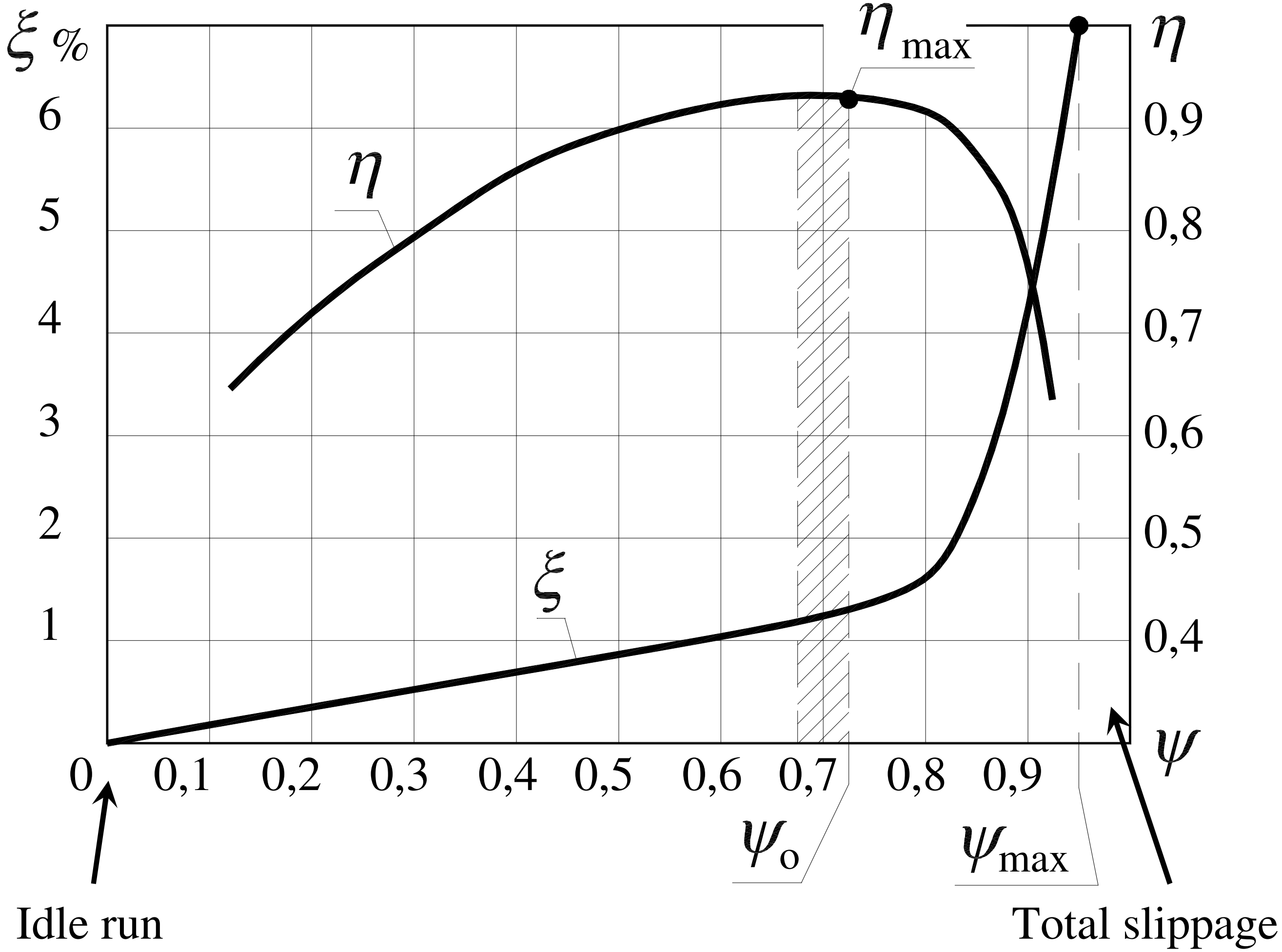
Stresses in belts



$$\sigma_{min} = \sigma_2 + \sigma_c,$$

$$\sigma_{max} = \sigma_1 + \sigma_c + \sigma_b,$$

Belt Drive



Belt slip factor:

$$\xi = \frac{V_2 - V_1}{V_1} \cdot 100\%,$$

Efficiency factor:

$$\eta = \frac{N_2}{N_1} \cdot 100\%,$$

Pulling factor: $$\psi = \frac{F_t}{F_1 + F_2} = \frac{F_t}{2F_0}$$

Belt Drive

Design of Belt Drives

1. Select the types of the belt using initial data

2. Determine diameters of pulleys and center distance

3. Calculate peripheral velocity and angular speed ratio

4. Find the length of the belt and accept standard belt size

5. Calculate exact center distance using standard length

6. Calculate modified power rating of a belt

7. Determine the number of the belts

If number of belts proves unsuitable for some reason or other (e.g. $z>8$) then repeat the calculations with another type of belt (not A – then B, C….)

8. Determine loads carried by drive shafts and other parameters.