Transmissions
Purposes for which transmissions are used

Why do we use transmissions?

a) Usually torque of the motor/engine is different from the torque required to drive the machine

Examples....
Winch: electric motor power 2.2 kW n=1450 rpm
Torque = ?
Steel wire rope 8 mm + rope drum 200 mm
Weight to carry = force in rope = ?
Speed of the load = ?

Car: torque of the engine
Wheel radius
Force on wheel circumference (if no gear)
Speed at 4000 rpm
Force required to accelerate to 100 km/h (30 m/s) in 11 s

b) Sometimes direction of rotation has to be changed
c) Sometimes rotational speed has to be changed
d) Location of the engine/motor with respect to the machine
Purposes for which transmissions are used

Usually it is convenient to produce mechanical energy in high speed motors, on the other hand in the drive systems a lower speed is required. Therefore most often we use transmissions which reduce rotational speed - reducers.

For $H=100$ mm
Available rated powers are:
3 kW if 2850 rpm
2.2 kW if 1450 rpm
1.5 kW if 940 rpm
0.75 kW if 705 rpm

If we need a 3 kW AC motor we will have to pay 77 EUR, 81, 112 or 160 EUR.

In case of cage AC motors (induction motors) there is a problem of changing its rotational speed – then the driving systems may require transmissions with variable ratio.
Nowadays also FREQUENCY CONVERTERS are being used.
Transmissions

Basic parameters are:
Gear /transmission ratio – ratio of input rot. speed to output rot. speed
efficiency - ratio of output power to input power (always <1)

Mechanical transmissions are the most important in machine. Most common types are:
• Gear transmissions
• Belt transmissions
• Chain transmissions
• Friction transmissions

3 lectures on this!!!!
Comparison of performance of various transmission types

Rys. 2.96. Porównanie wymiarów przekładni przenoszących to samo obciążenie: a) pasowa z pasem płaskim, b) pasowa z pasem klinowym, c) łańcuchowa, d) zębata
Types of belt transmissions

Main types:
• Flat belt
• Round belt
  • V-belt

multiple V-belt, micro-V®
Types of belt transmissions

- Timing belt – widely used, various teeth profiles, double sided teeth
Timing belt transmissions

• Belt structure

Main feature:
Positive engagement (no slip)

• Belt selection

- No lubrication required
- No stretching due to wear
- Corrosion resistance
- Excellent abrasion resistance
- Reduced noise
- Clean operation
- Long trouble-free service.
Chain transmissions

.... not only in bicycles

.... but also in IC engines
Variable speed transmissions

gear

chain

belt

Podczas zmiany biegu mechanizm przełączający przesuwa łańcuch z jednego koła zębatego na drugie. Mechanizm pozostaje zawsze w położeniu równoległym do koła roweru, niezależnie od wybranego koła zębatego – dzięki temu łańcuch nie zakleszcza się. Para zamocowanych sprężynowo kołek kompensuje poluzowanie łańcucha.
Comparison of performance

### Table 1.1: Comparison of performance characteristics of different types of gear trains

<table>
<thead>
<tr>
<th>Type of Gear Train</th>
<th>Nominal Power kW</th>
<th>Nominal Torque Nm</th>
<th>Efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zebata walcowa u stałych ościach</td>
<td>3000</td>
<td>60000</td>
<td>1.8 ± 0.2</td>
</tr>
<tr>
<td>Zebata walcowa planetarna</td>
<td>2000</td>
<td>30000</td>
<td>0.8 ± 0.15</td>
</tr>
<tr>
<td>Zebata stożkowa u stałych ościach</td>
<td>500</td>
<td>4000</td>
<td>3.0 ± 0.4</td>
</tr>
<tr>
<td>Ślimakowa</td>
<td>200</td>
<td>1000</td>
<td>4.0 ± 0.1</td>
</tr>
<tr>
<td>Łańcuchowa</td>
<td>200</td>
<td>3500</td>
<td>8.0 ± 2.5</td>
</tr>
<tr>
<td>Z pasem płaskim</td>
<td>150</td>
<td>2000</td>
<td>4.0 ± 1.6</td>
</tr>
<tr>
<td>Z pasem klinowym</td>
<td>100</td>
<td>1500</td>
<td>4.0 ± 1.0</td>
</tr>
<tr>
<td>Cierna</td>
<td>25</td>
<td>300</td>
<td>16.0 ± 6.0</td>
</tr>
</tbody>
</table>
Comparison of performance

- zebate
- hydrost
- cierne
- pasy płaskie
- pasy klin
- pasy wieloklin
- pasy zebate
- łańcuchowe
Types of gear transmissions

Main types of gear transmissions:
• gear transmissions with spur gears, helical gears and herringbone gears
Types of gear transmissions

Bevel gears with straight teeth and spiral teeth (hypoid gears sometimes)
Types of gear transmissions

- Worm gears
- Internal gear
- Planetary
Gear transmissions in practical design

Gear transmissions are usually selected from a manufacturers’ catalogue on the basis of:
• configuration – input shaft with respect to the output shaft, distance between the axes
• Required transmission
• Required power

Sometimes whole drive systems are selected composed of a motor, coupling and transmission MOTOREDUKTOR = Silnik (elektryczny) + sprzęgło+ reduktor (przekładnia zwalniająca)
Within the housing there are:
Gears mounted on shafts and supported in the bearings.
Bearings and gears need lubrication – usually with oil splashed by the gears.
Spur gears

In most cases teeth have a profile of an involute
Properties of involute profile

Advantages:
• Constant ratio
• No problem with small errors in center distance (distance between the axes)
• Constant direction of force acting between the teeth
• Various gears can work in pairs (the same pitch!!!!, the same angle)
• Gear can operate with internal, external gear, and rack (toothed bar)
• Manufacturing techniques are relatively simple and efficient
• One tool can be used to cut many different wheels (e.g. various number of teeth, various teeth correction coefficients, helical teeth gears)

Drawbacks:
Convex surface against a convex surface – high surface pressure
Intense sliding – energy losses due to friction
Gear nomenclature

- Tooth
- Dedendum (stopa zęba)
- Addendum (głowa zęba (wierzchołek))
- Module (moduł)
- Circular pitch (podziałka)
- Whole depth (wysokość zęba), grubość zęba (tooth thickness)
- Szerokość wieńca (gear width)
- Pitch circle (koło podziałowe)
- Pitch dia Średnica (walec) podziałowa(y)
- Base wheel (koło zasadnicze)

\[ d = mz \quad \pi d = tz \]
Standarization of gear teeth profiles

Pressure angle - kąt przyporu  \( \alpha = 20^\circ \)
Addendum - wys. głowy zęba \( h_a = m \)
Dedendum - wys. stopy zęba \( h_f = m + cm \)
Clearance - luz \( c = 0.25 \)
Tooth (whole) depth wys. zęba \( h = h_a + h_f = 2.25 \, m \)
Root diameter - średnica stóp
Addendum diameter - średnica głów (wierzch.)
Standarization of gear profiles-tooth system
Two gears in operation
Manufacturing techniques

Machining

Hobbing (za pomocą freza ślimakowego)

Formed disc cutter (frez kształtowy)
Manufacturing techniques

With rack shaped cutter (za pomocą zębatki)

Reciprocating gear shaper (za pomocą dłutaka)
Two gears in mesh - nomenclature

Gear ratio
\[ i = \frac{z_1}{z_2} \]

Center distance (odległość osi)
\[ a_w = 0.5m(z_1 + z_2) \]

Line of action – contact length

Koła toczne
\[ r_{t1} + r_{t2} = a_w \]
\[ r_{t1}/r_{t2} = i \]
Gears – tooth loads

In reality there are no forces but surface pressure acting between teeth and friction (because of sliding)

We neglect friction (it is considered in worm gears only) Surface pressure is replaced with a force $F_n$ perpendicular to contact surface

direction!!!!
It is convenient to resolve it into two components:

**tangential (circumferential):**
\[ P = \frac{2M}{d_t} \]
- \( d_t \) – diameter (equal to pitch dia for uncorrected gears but different for gears with correction)

**and radial:**
\[ P_r = P \tan \alpha_t \]
- \( \alpha_t \) – real pressure angle (standard for uncorrected teeth or teeth corrected with P-0 method) and different for P method of correction

**Normal force (perpendicular to the teeth)**
\[ P_n = \frac{P}{\cos \alpha_t} \]
\[ P_n = \sqrt{P^2 + P_r^2} \]
Gears – contact length and contact ratio

How many teeth are in mesh?
Gears – contact length and contact ratio

How many teeth are in mesh?

Contact ratio:

$$\varepsilon = \frac{AE}{p_b}$$
Teeth correction

Google result for „teeth correction”
Gear- „correction”
Involute gears - problem of cutout of teeth

It is a problem for gears with a small number of teeth
For normal height \( y=1 \) and pressure angle \( \alpha = 20^\circ \)
\( z_{gr} = 17 \)
In practical applications often a small cutout does not have a great influence and \( z_{gr}' = 14 \)

Why do we want to have gears with a small number of teeth?
In order to avoid cutout a different part of involute curve can be used. The effects of such correction are following:

- Thicker root of the tooth
- Increase of diameters (addendum and dedendum circle)
- Decrease of the addendum thickness („acute”)
- Increase of profile radius
- Increase of pressure angle (only in contact with another corrected gear (+))

In manufacturing use of different part of the involute curve is achieved by moving the rack (tool) away from the centre.
Gear- „correction”

Next problem – adjustment of center distance

In multiple stage transmissions – manufacturing, design, cost reasons

Standards of center distance !!!

According to Polish standard center distances are standarized [mm]: 40; 50; 63; 80; 100; 125; 160; 200; 250; 315; 400; 500; 630; 800; 1000
Correction coefficient should be selected from the range between $x_{gr}$ (coeff. to avoid cutout) and value that will cause „sharpening” of the addendum.
Correction – used methods

correction (with no change in center distance) P-0
One gear (which????) is corrected with the use of x coefficient (value????)

The other one  –x
Then no change in: center distance, pressure angle
There are changes in gears diameters (addendum and dedendum))
When such method is used?

Correction P
Both gears are corrected $x_1$ i $x_2$

Changes in center distance, pressure angle and in gears diameters (addendum and dedendum) occur
When such a method is used?
How \( x \) should be selected?

If no other conditions (constraints) then coefficient to avoid cutout and „sharpening” is applied

Often \( x=0.5 \) (DIN)

Sometimes there are constraints (e. g. specified center distance)
And \( (x_1 + x_2) \) is fixed because of center distance
How \( (x_1 + x_2) \) should be distributed to both gears?
Profits of correction

Geometry (profile) modification:
1. Thicker root of the tooth
2. Increase in diameters
3. Decrease of addendum thickness (sharpening)
4. Increase of profile radius
5. Increase of pressure angle (only in contact with another corrected gear (+))

Implications of profile modification:
Ad 1. effect?
Increase of tooth strength (bending section modulus)

Ad 4. effect?
Decrease of surface pressure
Ad 5. effect?
Increase of radial force (bearings load)
# Profits of correction

<table>
<thead>
<tr>
<th>Rodzaj ząbienia</th>
<th>Wytrzymałość zęba na złamanie</th>
<th>Trwałość boku zęba</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$z_2 : z_1$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>27 : 9</td>
<td>54 : 18</td>
</tr>
<tr>
<td></td>
<td>27 : 9</td>
<td>54 : 18</td>
</tr>
</tbody>
</table>

| Zerowe $\alpha_0 = 20^\circ$ (rys. 2.54 A) | 1,00 | 1,00 | 1,00 | 1,00 |
| Korekcja 0,5 (rys. 2.54 B) | 2,03 | 1,26 | 1,60 | 1,33 |
| Ze względu na wytrzymałość na złamanie (sposób c) (rys. 2.54 C) | 2,20 | 1,24 | 1,82 | 1,28 |

![Graphs showing the profits of correction](image1)

![Graphs showing the profits of correction](image2)
Transmissions – helical and bevel gears
Helical gears

Herringbone gears (zęby daszkowe)
Helical gears

Schematic view of involute creation

Manufacturing with the use of rack
Helical gears

In transverse plane profile is different:

- Transverse pitch (podziałka czołowa)
- Transverse module (Moduł czołowy)
- Pitch dia (Średnica podziałowa)
- Transverse pressure angle
Helical gears

Equivalent spur gear

Circle of a radius equal to the radius of an ellipse at pitch point

On such a circle teeth of the same module are distributed

Equivalent number of teeth:

..................
Helical gears

Cutout limit – number of teeth:
Helical gears - loads

Surface pressure is substituted with a force normal to the teeth surface in contact point

It is convenient to resolve it into three components

**tangential:** \( P = \frac{2M}{d_t} \)
\( d_t \) – pitch diameter

**radial:**
\[ P_r = P \tan \alpha_t \tan \alpha_n / \cos \beta \]
\( \alpha_t \) – transverse pressure angle

**Axial (thrust):**
\[ P_w = P \tan \beta = P \tan \alpha_n / \cos \beta \]

**Resultant force (normal):**
\[ P_n = \sqrt{P^2 + P_r^2 + P_w^2} \]
Helical gears – profits and problems

Profits of using helical gears:
• Quiet running, Płynność zazębienia, cichobieżność,
• Compact design due to better load sharing between teeth (lower dynamic load coefficients in calculations)
• Possibility to change center distance without correction
• Possibility to machine gears with smaller number of teeth without cutout

Problems:
• More difficult standardization (helix angles)
• Axial forces – more complex bearing systems
Bevel gears

Straight teeth

Spiral teeth
Bevel gears

Schematic view of creation of involute surface
Bevel gears

Equivalent spur gears

Gear ratio

..................
Transmissions – evaluation of strength, failures
Transmissions

Within the housing there are:
Gears mounted on shafts and supported in the bearings.
Bearings and gears need lubrication – usually with oil splashed by the gears.
Gears – forms of failure

- Break of the tooth - overload
- Pitting - small cavities under pitch circle due to fatigue
- Break of the tooth - fatigue
- Scuffing – welding – close to addendum

Other forms – abrasive wear (slow running wear)
For heat treated steel - pitting is the most important limiting factor
For hardened gears tooth breakage limit is the most important limiting factor
Gears - calculations

Tooth break:
Bending stress
(sometimes also compression and shear stress are considered)

\[ P_c = P_n \sin \alpha_p \]

\[ P_g = P_n \cos \alpha_p \]

Parabola równej wytrzymałości
wg norm ISO

\[ \sigma_g \]

\[ \sigma_c \]

\[ \tau \]
Gears - calculations

Pitting –
Surface stress in pitch center –
Hertzian stresses.
Two cylinders of relevant radi –
such as involute radius
**Influence of manufacturing/material/heat treatment on performance**

Transmission $M_1=21\text{kNm}$, $i=3$, $n_1=500 \text{ rpm}$ (power ca. 100 kW)

<table>
<thead>
<tr>
<th>Material</th>
<th>Pinion and wheel: C 45</th>
<th>Pinion and wheel: 42 Cr Mo 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat treatment</td>
<td>Standardised</td>
<td>Quenched and tempered</td>
</tr>
<tr>
<td>Machining</td>
<td>Hobbed</td>
<td>Hobbed</td>
</tr>
<tr>
<td>Spindle spacing $a$</td>
<td>830 mm</td>
<td>650 mm</td>
</tr>
<tr>
<td>($\text{modulus } m$)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Size (welded housing)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall weight</td>
<td>8505 kg</td>
<td>4860 kg</td>
</tr>
<tr>
<td>Weight of rolling-element bearings</td>
<td>95 kg</td>
<td>95 kg</td>
</tr>
<tr>
<td>Percentage of total weight</td>
<td>174 %</td>
<td>100 %</td>
</tr>
<tr>
<td>Percentage of price</td>
<td>132 %</td>
<td>100 %</td>
</tr>
<tr>
<td>Safety factor $S_1$</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Safety factor $S_2$</td>
<td>6.1</td>
<td>5.7</td>
</tr>
</tbody>
</table>

| Pinion: 20 Mn Cr 5        | Pinion and wheel: 31 Cr Mo V 9 |
| Wheel: 42 Cr Mo 4         | Pinion and wheel: 34 Cr Mo 4    |
| Pinion: case hardened     | Gas nitrided                |
| Wheel: heat treated       | Induction hardened           |
| Pinion: ground            | Finely milled               |
| Wheel: hobbed             | Milled; lapped              |
| 585 mm                    | 490 mm                      |
| 10                        | 10                          |
| 470 mm                    | 350 mm                      |
| 14                        | 10                          |

| Overall weight            | 3465 kg                   |
| Weight of rolling-element bearings | 2620 kg | 2390 kg |
| Percentage of total weight| 95 kg                      |
| Percentage of price       | 2620 kg                   |
| Safety factor $S_1$       | 1.3                       |
| Safety factor $S_2$       | 2.3                       |
| 1.3                       | 1.3                       |
| 6.1                       | 5.7                       |

Graphical representation of the transmission components and their specifications.
Transmissions - lubrication

Failure caused by inadequate lubrication comprises:
Scuffing
Overheating
Abrasive wear

Conditions in gears in mesh relevant to EHL – characteristic features:
• Substantial increase of viscosity at high pressure
• Elastic deformations modify film profile

Oil functions?

Methods of lubrication – bath (1-6 modules)
Transmissions - lubrication

Spray lubrication
Ankieta

Proszę Państwa o uwagi i rady dla wykładowcy na następujące tematy:

Wykład:
- sposób prowadzenia i tłumaczenia,
- tempo,
- materiały ilustracyjne,
- przydatność wykładu do rozwiązywania zadań na ćwiczeniach

Ćwiczenia rachunkowe:
- dobór tematów zadań, poziom ich trudności i złożoności,
- związek ćwiczeń z wykładem
- sposób prowadzenia ćwiczeń: przystępność tłumaczenia, sposób oceniania, podejście do studenta

Projektowanie (jak wyżej)

Inne uwagi