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Selecting the elastic coupling and lubrication system to a single speed reducer to a mathcad computer-assisted

Mihaela TUROF
Department of General Engineering Sciences, Naval Electromechanics Faculty, Constanta Maritime University
mihaela_turof@yahoo.com

Abstract. The Mathcad interface allows users to combine a variety of different elements (math, descriptive text, and support images) in the form of a natural-readable worksheet. Since mathematics is essential for the program, mathematics is inherently alive, dynamically recalculating, as upstream values change. This allows easy manipulation of input variables, hypotheses and expressions, which in turn are updated in real time. The following example serves to highlight Mathcad's capabilities rather than to provide specific details about the functionality of the individual product.

This paper aims to make selection of the elastic coupling and lubrication system for the design of a single stage speed reducer using MathCad program.

1. Introduction
Couplings make a permanent or intermittent connection between two consecutive elements of a transmission for the purpose of transmitting the rotation motion and torque moment, without modifying the motion law.

From the coupling definition mode, the main function of these couplings is: transmission of the movement and the torque moment.

The wide range of coupling applications has required attachment and other additional functions:

- compensation of position deviations of coupled elements (axial, radial, angled or combined) due to execution and / or assembly errors;
- protection against shocks and vibrations;
- interruption of the link between the two elements;
- limitation of the transmitted task;
- speed limitation;
- the limitation of the transmission of the load.

The conditions that the couplings have to fulfill are:

- safety in operation;
- reduced gauge dimensions;
- easy assembly and dismantling;
- to be statically and dynamically balanced;
- to ensure high durability.

Transmission of motion and torque through the gears is achieved by contacting the flanges of the gear wheels that are engaged. In the tooth interaction area there is a relative movement accompanied by friction, which leads to various forms of wear. To alleviate this phenomenon, a lubricating environment is introduced between the friction surfaces, which aims at avoiding the direct contact of the flanks, which
would lead to their grip, as well as to increase the efficiency and cooling the gear. In certain special situations, the lubricant (liquid) is also used in the hydraulic control circuit of the transmission.

2. Elasting coupling selection
The elastic coupling is both transmitting the moment from the reducer to the next working machine but is dumping vibrations and shock in some degree.

The moment for calculation is the one from shaft II

\[ M_{tc} = C_s M_{tII} = 1 \cdot 1.606 \cdot 10^5 = 1.606 \cdot 10^5 \text{Nmm} \]  

where

\( M_{tc} \) is the moment to be used in calculation, \( M_{tII} \) – is the moment coming from the shaft II, C\(_s\) = 1 is the service coefficient.

The flange elastic coupling is given in two versions, but we’ll consider the normal version N.

![Figure 1](image)

3. Lubricating system selection
The lubricating system will be selected as function of the kinematic and loading parameters of the reducer, the type of gears and their materials. For us are important the speed of the shaft with the biggest moment to transmit.

The speed of gears at their pitch diameters are:

\[ v_1 = \frac{\pi d_{w1} n_1}{60.000} = \frac{\pi \cdot 77.830 \cdot 2.464}{60.000} = 10.041 \text{[m/s]} \]  

\[ v_2 = \frac{\pi d_{w2} n_2}{60.000} = \frac{\pi \cdot 172.170 \cdot 1.100}{60.000} = 9.916 \text{[m/s]} \]
Where $d_{w1}$ is the pitch diameter for the pinion and $n_1$ is its speed, rot/min.

Some recommendations are made for lubricants:

- If $v = (0...0,4)m/ s$ one may use graphite as lubricant
- If $v = (0...0,8)m/ s$ grease
- If $v = (0,8...4)m/ s$ grease or oil
- $v > 4m/ s$ only oil (our case)

In order to select the viscosity of the oil the above chart is to be used where on Ox axis is the Ratio \( ks/v \) where $ks$ is the Striubeck pressure:

Already calculated:

- **Tangential force**
  \[
  F_{t1} = F_{t2} = \frac{M_{pinion}}{d_1} = 932,785N
  \]  \( (4) \)

- **Pinion width**
  \[
  b_1 = 65mm
  \]  \( (5) \)

- **Transmission ratio**
  \[
  u = 2.24
  \]  \( (6) \)

- **Diameter $d_1$**
  \[
  d_1 = m_z z_1 = \frac{z_1 m_n}{\cos(\beta)} = 76,869mm
  \]  \( (7) \)

- **The rolling factor**
  \[
  \left( \frac{x_1 + x_2}{z_1 + z_2} = \frac{0,6931}{106} = 0,0065 \right)
  
  Z_H = \sqrt{\frac{\cos\beta_b}{\cos^2\alpha tg\omega t}} = 2,34
  \]  \( (8) \)
• the contact length factor

\[ \varepsilon_\alpha = 1.55 \]
\[ \varepsilon_\beta = 2.288 \]
\[ \Rightarrow Z_\varepsilon = 0.81 \] (9)

\[ \therefore \text{Striebeck pressure} \]

\[ k_s = \frac{F_{t1}}{b_1 d_1} \cdot \frac{u+1}{u} \cdot Z_H^2 Z_\varepsilon^2 = \]
\[ = \frac{932.785}{65 \cdot 76.869} \cdot \frac{2.24+1}{2.24} (2.34)^2 \cdot (0.81)^2 = 0.97 \] (10)

\[ \therefore \text{Ratio} \]

\[ \frac{k_s}{v_1} = \frac{0.97}{10.041} = 0.097 \] (11)

From the diagram in fig. 2 and with regard to the ratio ks/v for the 50 degree Celsius we’ll have the viscosity

30[mm2/sec] =30 [centistoccs].

From the below table we’ll take the oil type TIN 25 EP

<table>
<thead>
<tr>
<th>Oil symbol</th>
<th>Kinematic viscosity [50^\circ\text{C} \text{ mm2/sec}]</th>
<th>Viscosity index IV</th>
<th>Freezing point [\circ\text{C}]</th>
<th>Fire point [\circ\text{C}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIN 42 EP</td>
<td>37.45</td>
<td>60</td>
<td>-25</td>
<td>210</td>
</tr>
<tr>
<td>TIN 55 EP</td>
<td>50.57</td>
<td>60</td>
<td>-20</td>
<td>220</td>
</tr>
<tr>
<td>TIN 81 EP</td>
<td>82.80</td>
<td>60</td>
<td>-20</td>
<td>230</td>
</tr>
<tr>
<td>TIN 125 EP</td>
<td>130.14</td>
<td>60</td>
<td>-15</td>
<td>235</td>
</tr>
<tr>
<td>TIN 300 EP</td>
<td>200.220</td>
<td>70</td>
<td>-10</td>
<td>240</td>
</tr>
<tr>
<td>TIN 300 EP</td>
<td>230.300</td>
<td>70</td>
<td>0</td>
<td>255</td>
</tr>
</tbody>
</table>

Figure 3
The oil type

The lubricating system may be:

► Immersed lubrication is used for speeds below 12 m/s and each gear has to be immersed inside the oil bath (our case).

► With forced oil circulation is for speeds above 20 m/s is using a pumping system with pipes, heat exchangers, filters etc. This is not our case.
4. Reducer thermal calculation

When in service the gears flanks are in friction on to another and the oil inside the oil bath where the gears are immersed is agitated and so heat is developing. The power leaving the reducer $P_{II}$ is smaller than the incoming one $P_I$, the difference is lost by heating $P_p$:

$$P_p = P_1 - P_{II} = P_a + P_l + P_u$$ (12)

Where:
- $P_a$ – the power lost due to gear friction;
- $P_l$ – lost in bearings;
- $P_u$ – lost by agitating the oil.

The total efficiency for the reducer is:

$$\eta_R = \frac{P_{II}}{P_I} = \eta_{a12} \eta_l^2 \eta_{u1} \eta_{u2} =$$

$$= 0,996 \cdot (0,99)^2 \cdot 1 \cdot 0,877 = 0,855$$ (13)

$$\Rightarrow P_{II} = P_I \eta_R = 15,826$$ (14)

For the gearing the power lost due friction is:

$$\eta_{a12} = 1 - \frac{\pi \mu \varepsilon \alpha}{f \cos \beta} \left( \frac{1}{z_1} + \frac{1}{z_2} \right) =$$

$$= 1 - \frac{\pi \cdot 0,1 \cdot 1,56}{5 \cos(15^\circ)} \left( \frac{1}{33} + \frac{1}{73} \right) = 0,996$$ (15)

Where:
- $\mu = 0,1$ – friction coefficient
- $\varepsilon \alpha = 1,56$ – engagement factor;
- $\beta = 150$ – flank inclination angle
- $f = 5$ – it’s a factor which is 2 for straight teeth gears, (5 for helical gears and 2…3 for high speed gearing).

$\eta_{12}$ – the efficiency of the gearing,

$\eta_{12} = 0,996$

$\eta_l$ – the efficiency of a bearing pair and

$\eta_l = 0,99$

As for the power lost due oil agitation:

$$\eta_{u1} = 1 - \frac{P_u}{P_1} = 1 - \frac{1}{P} \left( \frac{b_1 h_1 v_1^2}{1,3 \cdot 10^4} \right) =$$

$$= 1 - \frac{1}{30} \left( \frac{65 \cdot 10^{0,041 \cdot 3/2}}{1,3 \cdot 10^4} \right) = 1$$ (16)
\[ \eta_{u2} = 1 - \frac{P_u}{P_{II}} = 1 - \frac{1}{P} \left( \frac{b_2 h_2 v_2^2}{1.3 \cdot 10^4} \right) = \]
\[ = 1 - \frac{1}{30} \left( \frac{62.5\cdot15\cdot9.916^2}{1.3\cdot10^4} \right) = 0.877 \]

\( \eta_{u1}; \eta_{u2} \) – the efficiency lost due to oil agitation.

\[ \eta_{u1} = 1 \]
\[ \eta_{u2} = 0.877 \]

Where:
- \( b \) – is the gear width,
- \( h \) – the immersion depth of the gear (is 3xtooth height for driven gear ),
- \( v \) – gear speed,
- \( P = 18.5 \, kW \) – the transmitted power.

Taking into account the thermal equilibrium equation the heat produced during service is dissipated during service in environment through the reducer housing by convection of the surrounding air and radiation.

The equation is:

\[ P_p = P_c \]

Where:
- \( P_p \) – lost power,
- \( P_c \) – power dissipated via housing to the environment.

So that:

\[ t = \frac{(P_I - P_{II}) + K S t_0}{K S} = \frac{[3 + 0.18 \cdot 0.29 \cdot 20]}{0.18 \cdot 0.29} = 68.7^\circ C < 90^\circ C \]

Where:
- \( P_I = 15.826 \, kW \) – is the reducer power;
- \( K \) – global heat exchange between housing-environment, \( (K = 0.12...0.18 \, kW/(m^2 \, grd) \) for normal service reducers).
- \( S = 0.29 \, m^2 \) - the reducer housing surface.
- \( t_0 = 20 \, C \) the environment temperature

Having the preliminary sketch of the housing we have:
- Length = 0.348 m,
- Width = 0.135 m and
- Height = 0.181 m
we’ll have the surface

\[ S = 2(0.384 \times 0.135 + 0.384 \times 0.181 + 0.135 \times 0.181) = 0.29 \, m^2 \]

The allowable reducer temperature is 80\(^\circ\)C - 90\(^\circ\)C. Above that the oil properties are worsening.
5. MathCad software application for designing
The calculation program MATHCAD initial design data is entered. Enter formulas and standards chosen
dates thereafter. The program calculates and generates results.
MATHCAD application program looks like this:

Introduce your data in the yellow fields

**Lubricant selection**

**VARIABLE**

\[
\begin{align*}
dw1 & := 82.53 \\
dw2 & := 167 \\
b1 & := 2464 \\
b2 & := 1100
\end{align*}
\]

**FORMULAS**

\[
\begin{align*}
v1 & = \frac{\pi \cdot dw1 \cdot n1}{60000} \\
v2 & = \frac{\pi \cdot dw2 \cdot n2}{60000}
\end{align*}
\]

**RESULTS**

\[
\begin{align*}
v1 & = 10.041 \\
v2 & = 9.916
\end{align*}
\]

\[
\begin{align*}
Ft1 & = 932.785 \\
b1 & = 65 \\
b2 & = 62.5 \\
u & = 2.24 \\
ZH & = 2.34 \\
Ze & = 0.81 \\
d1 & = 76.869
\end{align*}
\]

\[
\begin{align*}
ks & = \frac{Ft1}{b1 \cdot d1} \left( \frac{u + 1}{u} \cdot ZH^2 \cdot Zε^2 \right)
\end{align*}
\]

\[
\begin{align*}
s1 & := 0.97
\end{align*}
\]
\[ \eta_1 = 1 - \frac{1}{P_I} \left( b_1 \cdot h_1 \cdot (v_1)^3 \right) \]

\[ \eta_2 = 1 - \frac{1}{P_I} \left( b_2 \cdot h_2 \cdot (v_2)^3 \right) \]

\[ P_I = P_I \cdot \eta_R \]

\[ \eta_R = 0.855 \]

\[ P_{II} = 15.826 \]

\[ S := 0.29 \]

\[ K_{kw} := 0.18 \]

\[ t_0 := 20 \]

\[ \eta = \eta_{12} \cdot (\eta_l)^2 \cdot \eta_1 \cdot \eta_2 \]

\[ t_{\text{reductor}} := \frac{(P_I - P_{II}) + K_{kw} \cdot S \cdot t_0}{K_{kw} \cdot S} \]

\[ t_{\text{reductor}} = 68.756 \]

6. Conclusions
Designing and making a machine is an extremely complex process that builds on the accumulation of knowledge and requires great experience gained from previous achievements.

In order to achieve the final product, a series of intermediate steps are required that are closely related to each other.

By introducing the Mathcad software in design of machine is made interactive and easier data processing. In application created can be modified easily input data to obtain more rapid project results. The program calculates and generates results.

References