The objective for the first part of the design project is the static design of the three shafts that transmit power in the system in figure 1. The following design information is given:

1. The 2 kN load due to mud should be lifted 80 meters within 90 seconds.
2. Power is input through the motor attached to shaft $S_1$.
3. The extra power spins a 1.5 kW generator by shaft $S_3$.
4. The tension ratio for pulley III is 8:1. Also, assume angle of wrap of the belts on the pulleys is 180°.

Figure 1: Deep water well mud extractor

![Diagram of the deep water well mud extractor with dimensions and gear properties](image)

Sketch b, for Project 19.2

<table>
<thead>
<tr>
<th>$\phi$</th>
<th>$\psi$</th>
<th>$N_{G_1}$</th>
<th>$N_{G_2}$</th>
<th>$N_{G_3}$</th>
<th>$N_{G_4}$</th>
<th>$d_{G_1}$</th>
<th>$d_{G_2}$</th>
<th>$d_{G_3}$</th>
<th>$d_{G_4}$</th>
<th>$d_{P_{III}}$</th>
<th>$d_{P_V}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>20°</td>
<td>25°</td>
<td>32</td>
<td>32</td>
<td>80</td>
<td>64</td>
<td>100 mm</td>
<td>100 mm</td>
<td>250 mm</td>
<td>200 mm</td>
<td>500 mm</td>
<td>500 mm</td>
</tr>
</tbody>
</table>

Table 1: Gear properties

The properties and dimensions of the gears are given in table 1. Even though the gears drawn in figure 1 are spur gears, for the sake of this project, assume that they are **helical** gears, which operate more...
smoothly than spur gears. Helical gears have teeth that are not straight across the width, but have an angle $\psi$. The pitch angle is represented by $\phi$. Since gears have not yet been discussed in class, some useful formulas used for determining forces caused by gears are given below.

When two gears mesh with each other, the ratio of rotational speeds ($n$) is related to the number of teeth ($N$) in the gear and the diameter of the gear ($d$). For gears 1 and 2, the speeds and sizes are related as follows:

$$\frac{N_1}{N_2} = \frac{n_2}{n_1} = \frac{d_1}{d_2}$$  

(1)

In order to relate the power ($H$) to the torque ($T$) in the shaft, the following formula can be used:

$$H = \frac{Tn}{9549}$$  

(2)

where $H$ is in kilowatts, $T$ is in $N \cdot m$ and $n$ is rpm. The other important values to be able to calculate are the torque and forces in a gear. The normal force ($F_n$) transmitted between two gears can be broken into a tangential ($F_t$), radial ($F_r$) and axial ($F_a$) component. The normal force acts equal and opposite on two gears in contact. The following relationships are useful:

$$T = F_t \frac{d}{2}$$  

(3)

$$F_t = F_n \cos \phi_n \cos \psi$$  

(4)

$$F_r = F_n \sin \phi$$  

(5)

$$F_a = F_n \cos \phi_n \sin \psi$$  

(6)

$$\phi_n = \tan^{-1} \left( \tan \phi \cos \psi \right)$$  

(7)

Using the above equations, the forces and torques from the gears can be computed. These are necessary to determine the stresses in the shafts.

The supports (A-F) are bearings that allow rotation, but prevent translation in the transverse directions. In order to resist axial forces, bearings B, C and E are thrust bearings, which also resist axial forces. Another support consideration is that pulley II is prevented from translating in the transverse directions, therefore making shaft $S_2$ statically indeterminate.

Based on the above information, perform the following tasks.

→ Choose a material from Chapter 3 in the text, from which the shafts will be made

→ Design the required diameter of the shafts $S_1, S_2$ and $S_3$ to prevent yielding

→ Consider that the machine is misused and overloaded. The input motor has a shut-off mechanism that kicks in when the “mud load” reaches 4 kN. Design your shafts so that this maximum load can be withstood.

→ Consider the factors of safety in table 2

<table>
<thead>
<tr>
<th>Static loading (forces, torques)</th>
<th>$n_L$</th>
<th>1.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress analysis (bending, axial, torsion)</td>
<td>$n_S$</td>
<td>1.03</td>
</tr>
<tr>
<td>Failure analysis (static yield)</td>
<td>$n_{Fy}$</td>
<td>1.15</td>
</tr>
<tr>
<td>Yield strength</td>
<td>$n_y$</td>
<td>1.05</td>
</tr>
</tbody>
</table>

Table 2: Design factors of safety