Power Transmission System Design

What We have Covered So Far

- Shafts
- Gears
- Power screws
- Bearings
- Flexible Elements

Where Do We Start?

- Given all the requirements: power, reduction ratio, speed ..
- Which component should be designed first?

System design is typically iterative

- Possibly multiple correct solutions
- Start from anywhere with enough information
  - Usually input or output
- Proceed to the rest of the system
- When contradiction arises, correct it
- And redesign other parts to fix that mistake
- Lather, rinse, repeat …

Let's Try with an Example

A motor drive is used to operate a well bucket. The maximum water weight the bucket can hold is 100 N. The minimum required speed of the bucket is 50 cm/s. The bucket is held by an unbreakable rope that loops around a 20-cm-radius pulley that is fitted onto the middle of a 1-m shaft.

The shaft is supported by a pair of bearings, one at each end. The input motor provides 100-W at 1200 rpm. The motor can be engaged/disengaged from the shaft with a disc clutch.

Example

Design:

1. Shaft (N_s = 2, S_y = 300 MPa, E = 210 GPa)
2. Disc Clutch (μ = 0.1)
3. Bearings

Solution

Required power = (100 N)(0.5 m/s) = 50 W

So the given motor works, assuming 100% efficiency

Assuming constant speed operation, required torque = 100(0.2) = 20 N-m = Torque on shaft

Force on shaft = Rope tension = 100 N

Solution

Shaft:

$$N_s = \frac{S_y}{\sigma_e}$$

$$2 = \frac{300 \times 10^6}{\sqrt{\left(\frac{100(1)(r)}{4(\pi/4)r^4}\right)^2 + 3\left(\frac{20(r)}{(\pi/2)r^4}\right)^2}}$$

$$r = 6.36 \times 10^{-3}\ \text{m}$$

Solution

Disc Clutch:

Pick woven material so that $p_{\max}$ = 500 kPa

Take $r_i = 0.6r_o$ and $N = 1$

$$T = \mu\pi p_{\max} r_i \left(r_o^2 - r_i^2\right)$$

$$20 = (0.1)\pi(500 \times 10^3)(0.6r_o)\left(r_o^2 - (0.6r_o)^2\right)$$

$$r_o = 0.069 \text{ m}$$

Solution

Bearings:

Radial force = 100 N

Axial force is calculated from actuating force on clutch

$$
\begin{aligned}
F &= p_{\text{max}}\pi\left(r_o^2 - r_i^2\right) \\
&= 4782N
\end{aligned}
$$

Use angular contact since large axial load.

$$
\begin{aligned}
\frac{F_a}{F_r} &= 47.8 \\
F_e &= 0.911F_a \\
&= 4356\ \text{N}
\end{aligned}
$$

Solution

No other specifications, so assume reliability factor = 1, required life = 9×10^7

Application bearings are Xlt(35 mm), lt(30 mm), med(20 mm)

= L07, 206, 304

Solution

Recalculate shaft to account for axial load

$$N_s = \frac{S_y}{\sigma_e}$$

$$2 = \frac{300 \times 10^6}{\sqrt{\left(\frac{100(1)(r)}{4(\pi/4)r^4} + \frac{4782}{\pi r^2}\right)^2 + 3\left(\frac{20(r)}{(\pi/2)r^4}\right)^2}}$$

$$r = 6.82 \times 10^{-3}\ \mathrm{m}$$

Solution

Check buckling,

$$N_s = \frac{P_{cr}}{F_{comp}}$$

$$P_{cr} = 2(4782) = \frac{\pi^2 EI}{L_e^2}$$

$$I = \frac{\pi r^4}{4} = \frac{2(4782)(1)^2}{\pi^2 (210 \times 10^9)}$$

$$r = 8.76 \times 10^{-3} \text{ m}$$