Shafting

Mission: Transmit power durably.

Requirements:
1. Convey torque
2. Limit deflections (for gears, bearings, sprockets)
3. Limit stresses

Features:
1. Steps or shoulders to locate bearings, gears, sheaves
2. Keyways or splines to transfer torque
3. Typically steady torque and alternating bending loads

Stress and Deflection:
- Stress analysis is local
  1. Bending moments and torsional shears are loads - independent of geometry
  2. C/I and r/J are local geometries
  3. Stress concentrations are local
- Deflection is a function of geometry everywhere
  1. Deflection and slope are integrated buildup of bending/stiffness

Attachments

§11.6 Keys

Keyways are usually sledrunner (K_t ~ 1.4), end milled (K_t > 1.8), or Woodruff

Key Failure Modes (P. 460):
- Shear on key = Torque / (key width * length * shaft radius) $< S_{sy}$
- Compression = Torque / (0.5 * key height * length * radius) $< 0.9\ S_y = S_{cy}$

Pins are limited by the shear area of the pin

§10.5&6 Press/Shrink Fits (P. 420)

Torque capability = $\text{Pressure}_{interface} \times \text{Area}_{interface} \times \mu_{interface} \times \text{radius}_{interface}$

K_t is up to 2 at entrance and exit.

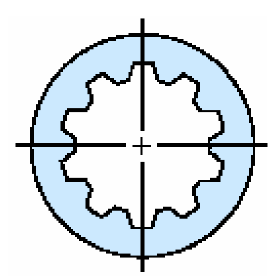
Set Screws (Cup Point; Source: SPS Unbrako)

Tables show holding "power" (force) in LBs vs screw diameter.

Torque capability = holding "power" x radius of contact

Screw Size	Holding Force
#8	385 LB
#10	540 LB
¼	1000 LB
5/16	1500 LB

Splines
- Usually 4 or more splines, so loading is lower than keyways and more uniform
- There are 2 pieces (not 3) so is less relative motion
- Accurate for controlled fit
  1. Side fit 2. Major diameter fit
- Hardened surfaces
- Indexable
- Lengths = 0.75xDia to 1.25xDia
- $$$



Shaft Analysis Procedure §11.2

1. Draw the Free Body Diagram
2. Calculate the reaction loads
3. Draw the Shear, V, and Moment, M, diagrams IN EACH PLANE that loads are in.
4. Draw the Total Moment diagram, vectorially summing the moments in each load plane:

$$M_{tot} = \sqrt{M_x^2 + M_y^2}$$

5. Draw the Torque (Axial Moment) diagram
6. Apply stress concentrations
   - See Figures 6.5 & 6.6 on Pages 231-232
7. Establish the location of the critical cross section where torque and moment are the largest.

Shaft Design

1. Static Loading

If axial loads are small, use this simple equation [Eq. 11.17] to compute the shaft

$$d = \left[\frac{32 n_s}{p S_y} \sqrt{M^2 + T^2} \right]^{\frac{1}{3}}$$

diameter by MSS (Max Shear Stress) given the bending moment, M, the torque, T, the factor of safety, n_s, and the material yield strength, S_y. Can also use this equation to estimate a shaft size early in the design process.

2. Fatigue Loading – General Case, MSS criterion [Eq. 11.35]

$$d = \left[\frac{32 n_s}{p S_y} \sqrt{\left(M_m + \frac{S_y}{S_e} K_f M_a \right)^2 + \left(T_m + \frac{S_y}{S_e} K_{fs} T_a \right)^2} \right]^{1/3}$$

where M_m & M_a are mean and alternating moments, T_m & T_a are mean and alternating torques, and K_f & K_{fs} are bending and shear fatigue stress concentration factors, respectively.

3. Fatigue Loading - Steady Torsion and Reversed Bending

- Use the ANSI/ASME method, shown here:

$$d = \left[\frac{32 n_s}{p} \sqrt{\left(\frac{K_f M_a}{S_e} \right)^2 + \frac{3}{4} \left(\frac{T_m}{S_y} \right)^2} \right]^{1/3}$$

(Ref: ANSI/ASME B106.1M-1985 Standard)

- See §7.7 for the endurance-limit modifying factors, but DON'T include the Stress Concentration factor in S_e - it is booked separately in this equation.
- See Fig. 7.9 on P. 283 for notch sensitivity!