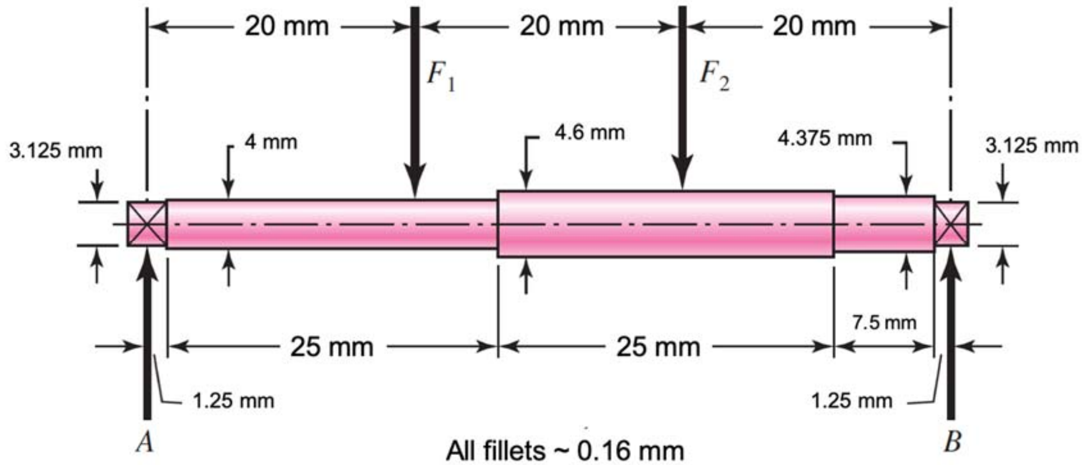
## Machine Design - 1

The shaft shown in the figure is machined from AISI 1040 CD (cold-drawn) steel. The shaft rotates at 1600 rpm and is supported in rolling bearings at A and B. The applied forces are $F_1$ = 120 N and $F_2$ = 60 N.




Assume the following:

- The Neuber constant is given: $\sqrt{a} = 0.1263$
- Yield strength: $S_y = 450$ MPa
- Ultimate tensile strength: $S_{ut} = 586$ MPa

Only consider the surface factor ($k_a$) and size factor ($k_b$) for endurance limit.

(a) Plot shear stress and bending moment diagrams **(20 pts)**
(b) Predict whether yielding occurs or not **(20 pts)**
(c) What is the minimum critical shaft diameter that causes yielding? **(20 pts)**
(d) Estimate the number of cycles to failure (fatigue strength fraction is given as $f = 0.9$) **(40 pts)**

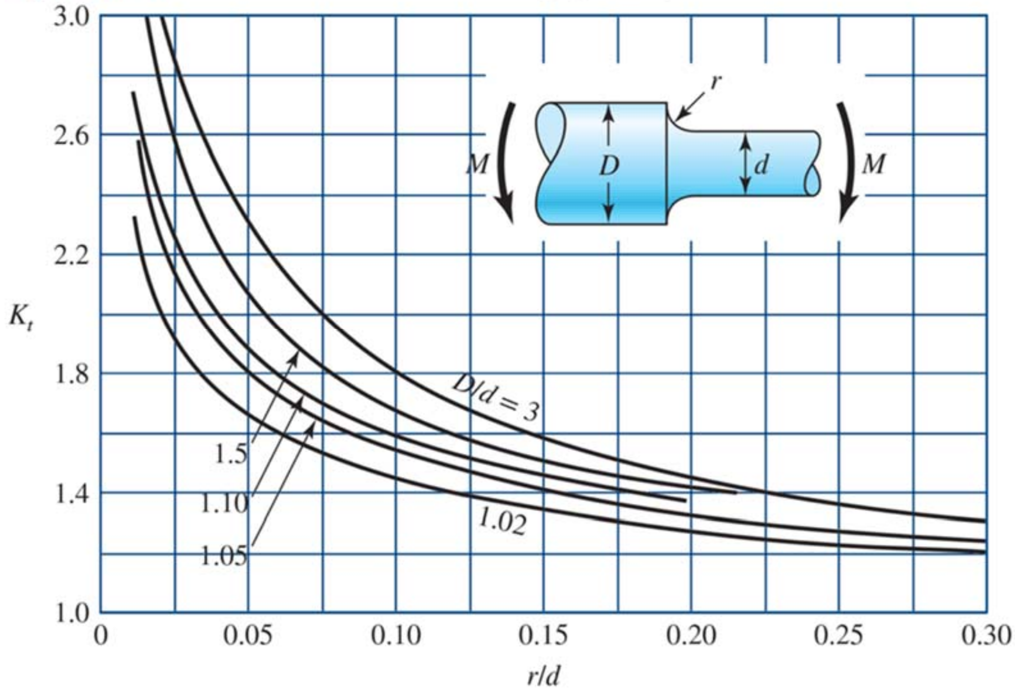
### Helpful Equations/Information

- *Moment of Inertia (Circle):* $I_{xx} = I_{yy} = \pi d^4/64$
- Axial Stress: $\sigma = F/A$ ; *- Bending Stress:* $\sigma = Mc/I$
- Stress Concentration and Notch Sensitivity:

$$\mathbf{q} = \frac{\mathbf{K}_f - 1}{K_t - 1} \quad ; \quad K_f = 1 + \frac{K_t - 1}{1 + \sqrt{a/r}} \quad ; \quad q = \frac{1}{1 + \frac{\sqrt{a}}{\sqrt{r}}}$$

Problems

Figure A–15–9 Round shaft with shoulder fillet in bending. $\sigma_0 = Mc/I$, where $c = d/2$ and $I = \pi d^4/64$.




- Endurance Limit:

  Marin equation:

  $S_e = k_a k_b k_c k_d k_e k_f S'_e$

- (reminder: only consider $k_a$ and $k_b$)
  where:

$$S'_e = \begin{cases} 0.5S_{ut} & S_{ut} \le 200 \text{ kpsi } (1400 \text{ MPa}) \\ 100 \text{ kpsi} & S_{ut} > 200 \text{ kpsi} \\ 700 \text{ MPa} & S_{ut} > 1400 \text{ MPa} \end{cases}$$

Surface Factor ($k_a$)

| Surface Finish | Factor $a$ $S_{ut}$, kpsi | Factor $a$ $S_{ut}$, MPa | Exponent $b$ |
|---|---|---|---|
| Ground | 1.34 | 1.58 | −0.085 |
| Machined or cold-drawn | 2.70 | 4.51 | −0.265 |
| Hot-rolled | 14.4 | 57.7 | −0.718 |
| As-forged | 39.9 | 272. | −0.995 |

From C.J. Noll and C. Lipson, "Allowable Working Stresses," *Society for Experimental Stress Analysis,* vol. 3, no. 2, 1946 p. 29. Reproduced by O.J. Horger (ed.) *Metals Engineering Design ASME Handbook,* McGraw-Hill, New York. Copyright © 1953 by The McGraw-Hill Companies, Inc. Reprinted by permission.

Problems

Size Factor ($k_b$)

$$k_b = \begin{cases} (d/0.3)^{-0.107} = 0.879d^{-0.107} & 0.11 \le d \le 2 \text{ in} \\ 0.91d^{-0.157} & 2 < d \le 10 \text{ in} \\ (d/7.62)^{-0.107} = 1.24d^{-0.107} & 2.79 \le d \le 51 \text{ mm} \\ 1.51d^{-0.157} & 51 < d \le 254 \text{ mm} \end{cases}$$

- Fatigue Strength

$$S_f = a\,N^b \qquad a = \frac{(f\,S_{ut})^2}{S_e} \qquad b = -\frac{1}{3}\log\left(\frac{f\,S_{ut}}{S_e}\right)$$

If a completely reversed stress is given, then:

$$S_f = \sigma_{\text{rev}}$$