PROBLEM 6-19

Statement: **Determine the size of the clevis pin shown in Figure P6-8 needed to withstand an applied repeated force of 0 to 130000 lb for infinite life. Also determine the required outside radius of the clevis end to not fail in either tearout or bearing if the clevis flanges are each 2.5 in thick. Use a safety factor of 3. Assume S_{ut} = 140 ksi for the pin and S_{ut} = 80 ksi for the clevis.**

Units: $kip := 10^3 \cdot lbf$ $\quad ksi := 10^3 \cdot psi$

Given:

Minimum force $P_{min} := 0 \cdot lbf$

Maximum force $P_{max} := 130 \cdot kip$

Flange thickness $t := 2.5 \cdot in$

Material strength

Pin $S_{utp} := 140 \cdot ksi$

Clevis $S_{utc} := 80 \cdot ksi$

Factor of safety against fatigue failure $N_f := 3$

Assumptions: The parts are machined. Use 90% reliability and room temperature.

Solution: See Figure 6-19 and Mathcad file P0619.

1. Calculate the alternating and mean components of the forces on the clevis and link.

$$P_a := \frac{P_{max} - P_{min}}{2} \qquad P_a = 65\,kip$$

$$P_m := \frac{P_{max} + P_{min}}{2} \qquad P_m = 65\,kip$$

Stress in Pin

2. The pin is in double shear and there is no stress-concentration. The alternating and mean loads at one section on the pin are

$$\tau_a = \frac{1}{2} \cdot \frac{P_a}{A_{pin}} \qquad \tau_m = \frac{1}{2} \cdot \frac{P_m}{A_{pin}} \qquad (1)$$

3. The cross-section area of the pin is $A_{pin}(d) := \dfrac{\pi \cdot d^2}{4}$ (2)

4. The alternating and mean shear stresses and von Mises stresses are

$$\tau_a(d) := \frac{P_a}{2 \cdot A_{pin}(d)} \qquad \tau_m(d) := \frac{P_m}{2 \cdot A_{pin}(d)} \qquad (3)$$

$$\sigma'_a(d) := \sqrt{3} \cdot \tau_a(d) \qquad \sigma'_m(d) := \sqrt{3} \cdot \tau_m(d) \qquad (4)$$

Pin Strength

5. Calculate the unmodified endurance limit. $S'_{ep} := 0.5 \cdot S_{utp}$ $\quad S'_{ep} = 70\,ksi$

6. Calculate the endurance limit modification factors for a nonrotating round pin in bending.

Load $C_{load} := 1$

Size $A_{95}(d) := 0.010462 \cdot d^2$ $\quad d_{equiv}(d) := \sqrt{\dfrac{A_{95}(d)}{0.0766}}$

$$C_{size}(d) := 0.869 \cdot \left(\frac{d_{equiv}(d)}{in}\right)^{-0.097}$$

Surface $A := 2.70$ $b := -0.265$ (machined)

$$C_{surf} := A \cdot \left(\frac{S_{utp}}{ksi}\right)^b \qquad C_{surf} = 0.729$$

Temperature $C_{temp} := 1$

Reliability $C_{reliab} := 0.897$ (R = 90%)

7. Calculate the modified endurance limit.

$$S_{ep}(d) := C_{load} \cdot C_{size}(d) \cdot C_{surf} \cdot C_{temp} \cdot C_{reliab} \cdot S'_{ep} \qquad (5)$$

Design Equation

8. Using the modified-Goodman failure criterion and a case 3 load line, the factor of safety is given by equation 6-18*e* as

$$N_f = \frac{S_e \cdot S_{ut}}{\sigma'_a \cdot S_{ut} + \sigma'_m \cdot S_e} \qquad (6)$$

9. Substituting equations 4 and 5 into 6 and solving for *d* yields Guess $d := 2.0 \cdot in$

Given

$$N_f = \frac{S_{ep}(d) \cdot S_{utp}}{\sigma'_a(d) \cdot S_{utp} + \sigma'_m(d) \cdot S_{ep}(d)}$$

$d := Find(d)$ $d = 2.632\, in$

Rounding to the next higher eighth of an inch, let $d := 2.750 \cdot in$

With this value of *d*, we have

$\sigma'_a(d) = 9.5\, ksi$ $\sigma'_m(d) = 9.5\, ksi$ $S_{ep}(d) = 39.71\, ksi$

and the realized factor of safety against fatigue failure in the pin is

$$N_f := \frac{S_{ep}(d) \cdot S_{utp}}{\sigma'_a(d) \cdot S_{utp} + \sigma'_m(d) \cdot S_{ep}(d)} \qquad N_f = 3.3$$

Clevis Tearout (See Figure 6-19)

10. Let the outside radius of the clevis be R. Then the tearout area is

$$A_{tear}(R) := t \cdot \sqrt{R^2 - (0.5 \cdot d)^2}$$

11. The alternating and mean shear stresses and von Mises stresses are

$$\tau_a(R) := \frac{P_a}{4 \cdot A_{tear}(R)} \qquad \tau_m(R) := \frac{P_m}{4 \cdot A_{tear}(R)} \qquad (7)$$

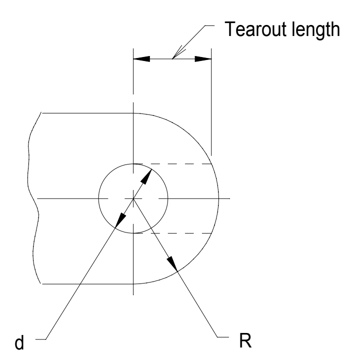

FIGURE 6-19
Tearout Diagram for Problem 6-19

$\sigma'_a(R) := \sqrt{3}\cdot\tau_a(R) \qquad \sigma'_m(R) := \sqrt{3}\cdot\tau_m(R)$ (8)

Clevis Strength

12. Calculate the unmodified endurance limit. $S'_{ec} := 0.5\cdot S_{utc}$ $\quad S'_{ec} = 40\,ksi$

13. Calculate the endurance limit modification factors for a nonrotating rectangular shear area (uniformly stressed).

Load $\quad C_{load} := 1$

Size $\quad A_{95}(R) := A_{tear}(R) \qquad d_{equiv}(R) := \sqrt{\dfrac{A_{95}(R)}{0.0766}}$

$$C_{size}(R) := 0.869\cdot\left(\frac{d_{equiv}(R)}{in}\right)^{-0.097}$$

Surface $\quad A := 2.70 \qquad b := -0.265$ (machined)

$$C_{surf} := A\cdot\left(\frac{S_{utc}}{ksi}\right)^{b} \qquad C_{surf} = 0.845$$

Temperature $\quad C_{temp} := 1$

Reliability $\quad C_{reliab} := 0.897$ (R = 90%)

14. Calculate the modified endurance limit.

$$S_{ec}(R) := C_{load}\cdot C_{size}(R)\cdot C_{surf}\cdot C_{temp}\cdot C_{reliab}\cdot S'_{ec} \tag{9}$$

Design Equation

15. Using the modified-Goodman failure criterion and a case 3 load line, the factor of safety is given by equation 6-18e as

$$N_f = \frac{S_e\cdot S_{ut}}{\sigma'_a\cdot S_{ut} + \sigma'_m\cdot S_e} \tag{10}$$

16. Substituting equations 8 and 9 into 10 and solving for R yields Guess $R := 2\cdot in$

Given

$$N_f = \frac{S_{ec}(R)\cdot S_{utc}}{\sigma'_a(R)\cdot S_{utc} + \sigma'_m(R)\cdot S_{ec}(R)}$$

$R := Find(R) \qquad R = 2.572\,in \qquad R := 2.625\cdot in$

Bearing Stress

The maximum bearing stress in the hole in each flange is

$$\sigma_{maxbear} := \frac{(P_a + P_m)}{2\cdot d\cdot t} \qquad \sigma_{maxbear} = 9.5\,ksi$$

This is small compared to the ultimate strength of the clevis.