Any method of evaluation (analytical or experimental) which can be substantiated by data from pumps in service, experiencing conditions similar to the specified operating limits, may be used.

**S-2100 CRITICAL SPEEDS**

The evaluation shall address both torsional and lateral, and where applicable, axial critical speeds, shaft deflections, and stresses. Critical speeds and shaft deflections shall be such as to avoid any difficulties for the specified range of the design and operating conditions. The actual percentage difference between critical and operating speeds shall take account of the method of determination of critical speed. The percentage difference between stress allowed and calculated shall also take account of the accuracy of the design and the analysis method.

**S-2200 MAXIMUM TORSIONAL LOAD**

The maximum torsional load shall be defined. The maximum torsional shear stress for this load (stress resulting from this load without application of concentration factors) shall be based on design experience or experimental evidence for the particular class of pump involved. The maximum driver horsepower may determine the maximum torsional loading for units with short shafts (typical of pump types A, B, and C). The motor startup torque may determine the maximum torsional load for pumps with relatively long shafts (typical of type L pumps). Torsional alternating or transient loads shall be considered if applicable.

**S-2300 SHAFT EVALUATION**

The flow chart, Figure S-2300-1, outlines a procedure for evaluation of pump shafts to meet load requirements. This procedure establishes a basic sizing criterion as well as a detailed fatigue evaluation method.

The basic shaft sizing criterion is based on maximum shear stress and conservative cyclic loading factors. These fatigue factors include an evaluation of the endurance limit of the unnotched and polished test specimen reverse bending test data in air ($S_e$), which in the absence of specified data can be approximated as:

$$S_e = 0.5S_u$$

This polished specimen test endurance limit is then factored for the product of reduction factors that account for such items as environment, reliability, size, finish, duty cycles, etc., which is conservatively estimated as one-third. Consequently, this corrected material endurance limit stress can be represented as:

$$S'_e = \frac{1}{K_t} \cdot \frac{S_e}{3}$$

where the terms used on the chart, Figure S-2300-1, are as follows:

- $K_t$ = stress concentration factors. An initial value of 6.0 is suggested where reasonable stress riser control is exercised. Higher values may be required for designs with severe discontinuities (e.g., small fillet radii relative to shaft diameter). Lower values may be used if justified by design methods and/or testing that accounts for the specific shaft discontinuities under consideration. Notch sensitivity values, when available, may be used. For additional information, see ANSI/ASME B106.1M-1985.

- $S_a$ = alternating axial stress
- $S_b$ = alternating component of the shaft bending stress
- $S_c$ = material endurance limit
- $S'_e$ = design endurance limit
- $S_s$ = maximum shear stress
- $S_{ss}$ = material allowable shear stress
- $S_u$ = material ultimate strength at design temperature
- $S_y$ = material yield stress at design temperature
- $U_t$ = summation of usage cycles. Each usage cycle shall be determined as the ratio of the maximum alternating stress in the shaft divided by the design fatigue stress of the material for that number of cycles. $U_t$ will be determined by summing all of the above ratios.

**S-2400 OTHER CONSIDERATIONS**

The fatigue life of a shaft is not always the limiting factor in its design. The effect of misalignment and deflection of a shaft on the performance of support bearings, seals, and couplings as well as on other key power transmission components must also be taken into account. Shafts can be strong enough to meet fatigue life requirements, yet not stiff enough to satisfy natural frequency and operational requirements.
Steps in the Design of a Pump Shaft

1. Establish the maximum operating loads on the shaft
2. Size the pump shaft for maximum torque and axial load
3. Evaluate the deflection and hydraulic shaft requirements necessary for pump operation
4. Break down load component into load cycles and develop load histories
5. Using available material fatigue data, define an S-N curve
6. Determine high stress regions of the shaft and evaluate the required stress concentration factors, $K_t$
7. Determine the values of $S_b, S_t, S_e, S_s, S_{ss}$ for level A + B service loads
8. Calculate the shaft peak stress components and develop a peak stress history
9. Evaluate the cumulative fatigue usage of the shaft
10. Evaluate the stress concentration regions and modify the configuration to reduce $K_t$
11. Determine the values of $S_{ba}, S_b$ and $S_{ae}$

Mathematical expression:

$$\left(\frac{S_b + S_t}{S_e}\right)^2 + \left(\frac{S_s}{S_{ss}}\right)^2 \leq 1.0$$

- Yes:
  - $K_t$ reduced
  - Break down load component into load cycles and develop load histories
  - Yes: $U_t \leq 1.0$
    - Yes: END
    - No: REDESIGN

- No:
  - Yes: $S_{ba}, S_b$
  - No: $S_{ae}$

END