10.5 SHAFT LOADS

The most general shaft-loading case is that of a fluctuating torque and a fluctuating moment in combination. There can be axial loads as well, if the shaft axis is vertical or is fitted with helical or worm gears having an axial force component. (A shaft should be designed to minimize the portion of its length subjected to axial loads by taking them to ground through suitable thrust bearings as close to the source of the load as possible.) Both torque and moment can be time varying, as shown in Figure 10-1, and can have both mean and alternating components.

The combination of a bending moment and a torque on a rotating shaft creates multiaxial stresses. The issues discussed in Section 6.12 (p. 376) on multiaxial stresses in fatigue are then germane. If the loadings are asynchronous, random, or misphased, then it will be a *complex multiaxial* stress case. But, even if the moment and torque are in phase (or 180° out of phase), it may still be a complex multiaxial stress case. The critical factor in determining whether it has simple or complex multiaxial stresses is the direction of the principal alternating stress on a given shaft element. If its direction is constant with time, then it is considered a simple multiaxial stress case. If it varies with time, then it is a complex multiaxial stress case. Most rotating shafts loaded in both bending and torsion will be in the complex category. While the direction of the alternating bending stress component will tend to be constant, the torsional component's direction varies as the element rotates around the shaft. Combining them on the Mohr's circle will show that the result is an alternating principal stress of varying direction. One exception to this is the case of a constant torque superposed on a time-varying moment. Since the constant torque has no alternating component to change the direction of the principal alternating stress, this becomes a simple multiaxial stress case. However even this exception cannot be taken if there are stress concentrations present, such as holes or keyways in the shaft, since they will introduce local biaxial stresses and require a complex multiaxial fatigue analysis.

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Assume that the bending moment function over the length of the shaft is known or is calculable from the given data and that it has both a mean component M_m and an alternating component M_a. Likewise, assume the torque on the shaft is known or calculable from given data and has both mean and alternating components, T_m and T_a. Then the general approach follows that outlined in the list labeled **Design Steps for Fluctuating Stresses** in Section 6.11 (p. 360) in combination with the multiaxial stress issues addressed in Section 6.12 (p. 376). Any locations along the length of the shaft that appear to have large moments and/or torques (especially if in combination with stress concentrations) need to be examined for possible stress failure and the cross-sectional dimensions or material properties adjusted accordingly.

10.6 SHAFT STRESSES

With the understanding that the following equations will have to be calculated for a multiplicity of points on the shaft and their combined multiaxial effects also considered, we must first find the applied stresses at all points of interest. The largest alternating and mean bending stresses are at the outside surface and are found from