Torsional Vibration

A. **Natural (Torsional) Frequency of a Mass-Elastic System**—Torsional vibration occurs in any rotating mass-elastic system where periodic forces are present. A mass-elastic system consists basically of two or more masses connected by an elastic shaft. If one end of this system is held rigid, and the other end twisted about its axis and then released, the free mass or masses will oscillate about the axis at a certain frequency called the natural frequency of torsional vibration. The natural frequency of torsional vibration is determined by the mass distribution and the torsional elasticity between masses. These vibrations may cause dangerous stresses in the system if the frequency of the periodic forces which excite these vibrations occurs in, or near, resonance with the natural frequency of the system.

B. **Torsional Critical Speed**—The mass-elastic system described in the previous paragraph involves a nonrotating situation but, if the system were free and rotating, the natural frequency would be the same. In actual shaft systems, the situation is considerably more complicated. Periodic impulses are applied to the engine crankshaft at each of the cranks. When the frequency of these impulses, or some harmonic thereof, equals the natural frequency of the system, resonance occurs. At resonance, the amplitude increases with corresponding increase of shaft stresses. The rotative speeds of the engine at which resonance occurs are known as torsional critical speeds.

C. **Torsional Vibratory System Characteristics**—A critical speed may, or may not, be dangerous, depending upon the forces involved and the arrangement of the vibratory system. Some of the excitation forces which cause vibrations may come from the engine, but others may come from the driven equipment. Although it is not possible, within the scope of this book, to undertake a treatise on methods of torsional analysis, it is important that every installation be analyzed during the design stages to determine critical speeds and torsional stresses on components at these speeds. This can be done readily by established calculation procedures. Such calculations must be based on complete design data covering the mass-elastic system.

These data include:

1. All shafting information, such as physical characteristics of materials, lengths, diameters, etc.

2. Location of rotating masses along the shaft length.
3. WK^2 values of rotating masses (and P^2 values fo generators).
4. Method of securing masses to shafting, tightness o fits, length of fit, keyways, bolt and dowel sizes, etc
5. Arrangement, type, location, and torsional stiffnes factors of clutches and couplings.
6. Nature of the load.
7. Speed and load ranges required.

Such analysis makes possible the prediction of operation that is free of harmful torsional criticals or indicates a need to make design changes that will alleviate a torsional stress problem. The mass-elastic system mus be considered as a whole and, therefore, the effect of al elements, such as gears, couplings, pumps, generator rotors, and connecting shafting, must be taken into ac count.

Gears introduce a factor in the torsional vibration problem because of the vibratory tooth loading. Gear chatter or tooth separation will occur if the superimposed vibrating torque exceeds the transmitted torque A vibratory torque of a system, which may not be g enough to cause shaft damage or tooth separation, m still cause considerable torque variation on the gear tooth, and such cases should be specifically approved by the gear manufacturer.

Couplings may have considerable effect on the torsional natural frequencies of a mass-elastic system. For instance, couplings of the same torque rating may have a wide range of mass and torsional stiffness values. For this reason, couplings are further selected to provide the most satisfactory torsional mass-elastic characteristics. In fact, some electric or hydraulic couplings, because of their inherent slip features, isolate the machinery elements on either side of the slip coupling from each other, and separate the entire system into two independent torsional systems.

D. **Design Objectives and Criteria**—In variable-speed installations the objective is generally to provide an operating speed range as free as possible from harmful torsional vibratory stresses in the range from 10 per cent below minimum operating speed to 10 per cent above the maximum rated operating speed. In the case of constant speed units, such as generator sets, the objective is to insure that no harmful torsional vibratory stresses occur within five per cent above and below the rated speed.

For crankshafts, connecting shafts, flange or coupling components, etc., made of conventional materials, torsional vibratory conditions shall generally be considered safe when they induce a superimposed stress of less than 5000 psi, created by a single order of vibration, or a superimposed stress of less than 7000 psi, created by the summation of the major orders of vibration which might come into phase periodically.

For the case of shaft elements variously known as "quill shafts," "tuning shafts," or "torsionally resilient torque shafts," and other elements which are specifically designed for the application, and manufactured from material of adequate physical properties, with careful attention to design and machining of keyways, fillets, etc., superimposed vibratory stresses at much higher levels may be acceptable. The design of such elements is always correlated in the torsional analysis. In the case of vibratory torque across gears, the gear manufacturer shall review the torsional analysis and his full acceptance thereof is the purchaser's best guide to the adequacy of the gear design for the service intended.

E. Modification of the Mass-Elastic System—It is usually impractical to obtain all the required data to make a complete torsional analysis before a proposal becomes a contract. However, when the complete analysis is finally made, the existence of any harmful torsional vibration will become apparent. The solution leading to the necessary alterations in the system can then be worked out. At this time, negotiations may be necessary to amend the contract.

F. Calculations and Responsibility—The responsibility for the preparation of a torsional analysis usually devolves upon the engine manufacturer, even if he does not furnish some, or any, of the driven equipment. The accuracy of the results of the engine manufacturer's calculations depends upon the accuracy of the information supplied to him and obviously his respons[illegible] limited accordingly. If inaccurate or incomplete informa[illegible]tion is furnished to the engine manufacturer, changes may be necessary to make a satisfactory installation and added expense and delay may result. When the engine manufacturer furnishes the driven equipment, he assumes responsibility for its performance with respect to torsional vibration. If he does not furnish the driven equipment, he should be responsible only for the accuracy of the calculations and for the engine, but not for the performance of the driven equipment. The engine manufacturer should not be responsible for vibrations that are excited by sources external to the engine. Alterations, additions to, or removal of equipment from an approved torsional system should not be made without first consulting the engine manufacturer as to the effect the change would have on critical speeds. It is, likewise, evident that the operating speed range of a unit should not be changed without consulting the engine manufacturer, as the modified speed range may include critical speeds or come close enough to one or more of them to be dangerous.

Axial Shaft Vibration—Crankshafts have a natural axial frequency. When torques are applied to a crankshaft, it is alternately shortened and lengthened. Experience has shown that these motions become troublesome only when an axial natural frequency is close to a torsional frequency. When this happens, large axial shaft vibrations, sometimes called longitudinal vibrations, are possible. Failures from this condition are rare, though the force from the axially vibrating shaft may cause vibration and noise at other points in the installation. Axial shaft vibration of a troublesome nature is sufficiently rare to make calculation unwarranted in most cases and is mentioned here to complete the subject of vibration possibilities.