MASS MOMENT OF INERTIA, TORSIONAL STIFFNESS, AND SHAFT CRITICALS

Torque measurement in rotating machinery has always presented a unique set of problems for the test engineer. Ideally, the user will want a sensor that is infinitely stiff, infinitely small, and preferably of minimal cost. In reality, the user will probably be more concerned with specific performance specifications of the torque sensor, i.e. 1) mass moment of inertia, 2) torsional stiffness and 3) shaft criticals.

Mass Moment of Inertia

Inertia, as defined by Newton's Laws of Motion, is a body's (mass) resistance to a change in momentum, whether in motion or at rest. The intrusion of a torque-sensing device into the testing driveline, therefore, adds an element of mass to the test system. This changes the dynamic characteristics of the drive system under test. In the static state, this intrusion is effectively nulled out by virtue of the relationship:

$$T_{input} = T_{output} +/- I \cdot \alpha$$

where,

T_{input} = Input Torque to the system under test

T_{output} = Output Torque of the system under test

I = Mass Moment of Inertia for all rotating elements

α = Angular acceleration/deceleration

When a system is rotating at a constant velocity, or when at rest, its angular acceleration is zero, thus making the torque input equal to the torque output. However, most rotating systems require accurate measurement during the important power up and power down phases of the test, i.e. when acceleration is not zero. It is during these measurement phases of the test when the inertial effects of the rotating torque sensor must come under close scrutiny.

For purpose of discussion, Mass Moment of Inertia (**I**) for rotating torque sensors is defined by the relationship:

$$\frac{m \cdot r^2}{2}$$

where,

m = Mass of Rotating Component of the Sensor

r = Radius of Rotating Component of the Sensor

The reduction of radius (**r**) of the rotating member of the torque sensor is of greater significance than the reduction of mass (**m**) in minimizing the inertial component error. In some cases the $I \cdot \alpha$ error can be eliminated altogether by use of a non-rotating reaction torque sensor, but again, other system dynamics must be considered such as frequency response.

Torsional Stiffness

Strain gage torque sensors deform linearly under load. This deformation, called strain (ε), is important to the successful measurement of torque. In a dynamic rotating system, the stiffer the rotating member is, the more faithful the measurement of torque will be. This characteristic is referred to as torsional stiffness (**k**). The higher the value the better. The dimension of torsional stiffness is:

lb-in/radian

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Shaft Criticals

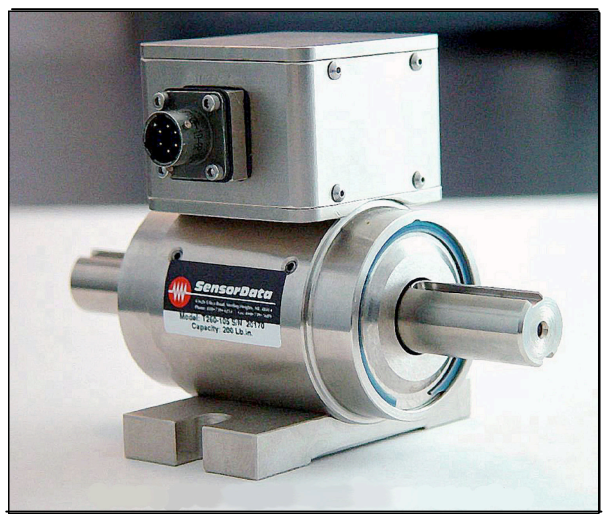
At specific rotational speeds of the shaft of a rotating torque sensor will, under certain conditions of loading and support, become dynamically unstable due to shaft resonance. If the condition of instability is maintained, mechanical failure can occur. Shaft criticals will occur at more than one speed, but generally the first order harmonic, or the lowest speed at which resonance occurs, is the one most engineers are interested in. A good general rule to follow is that the rotating speed of the system should always be at least ten percent above or below the rotating torque sensor's shaft critical. When passing through a shaft critical, time of passage is recommended to be as short as possible to prevent potential system damage. Techniques for minimizing shaft critical speed problems involve foot mounting the torque sensor, thus shortening the drive system and increasing

Shaft Criticals (continued)

the shaft critical upwards beyond the test requirement region, or, more simply, using a torque sensor that is physically as short in length as possible. Typically, foot mounting is a costly operation involving a more elaborate mechanical set-up, and additional mechanical couplings. Ideally, a torque sensor with a very short length and low mass can be directly installed without a foot mount.

Conclusion

SensorData Rotating Transformer Coupled Torque Sensors are designed with all the previous considerations in mind. Low mass, short length, and minimal outside diameter directly translate to greatly reduced mass moment of inertia, enhanced torsional stiffness, and higher shaft criticals.



Above - SensorData T261 Rotary Transformer Torque Sensor with i200 Signal Cond/Amp.
Left - SensorData T231 Rotary Transformer Torque Sensor.

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