

The Basics of Torque Measurement

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Torques can be divided into two major categories, either static or dynamic. The methods used to measure torque can be further divided into two more categories, either reaction or in-line. Understanding the type of torque to be measured, as well as the different types of torque sensors that are available, will have a profound impact on the accuracy of the resulting data, as well as the cost of the measurement.

STATIC VS DYNAMIC

In a discussion of static vs. dynamic torque, it is often easiest to start with an understanding of the difference between a static and dynamic force. To put it simply, a dynamic force involves acceleration, where a static force does not. The relationship between dynamic force and acceleration is described by Newton's second law; $F=ma$ (force equals mass times acceleration). The force required to stop your car with its substantial mass would be a dynamic force, as the car must be decelerated. The force exerted by the brake caliper in order to stop that car would be a static force because there is no acceleration of the brake pads involved.

Torque is just a rotational force, or a force through a distance. From the previous discussion, it is considered static if it has no angular acceleration. The torque exerted by a clock spring would be a static torque, since there is no rotation and hence no angular acceleration. The torque transmitted through a car's drive axle as it cruises down the highway (at a constant speed) would be an example of a rotating static torque, because even though there is rotation, at a constant speed there is no acceleration. The torque produced by the car's engine will be both static and dynamic, depending on where it is measured. If the torque is measured in the crankshaft, there will be large dynamic torque fluctuations as each cylinder fires and its piston rotates the crankshaft. If the torque is measured

in the drive shaft it will be nearly static because the rotational inertia of the flywheel and transmission will dampen the dynamic torque produced by the engine. The torque required to crank up the windows in a car (everyone remember those?) would be an example of a static torque, even though there is a rotational acceleration involved, because both the acceleration and rotational inertia of the crank are very small and the resulting dynamic torque (Torque = rotational inertia x rotational acceleration) will be negligible when compared to the frictional forces involved in the window movement. This last example illustrates the fact that for most measurement applications, both static and dynamic torques will be involved to some degree. If dynamic torque is a major component of the overall torque or is the torque of interest, special considerations must be made when determining how best to measure it.

REACTION VS IN-LINE

In-line torque measurements are made by inserting a torque sensor between torque carrying components, much like inserting an extension between a socket and a socket wrench (see below).

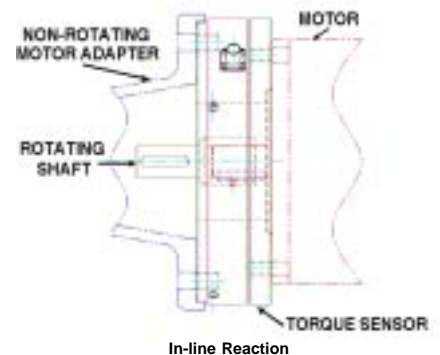


The torque required to turn the socket will be carried directly by the socket extension. This method allows the torque sensor to be placed as close as possible to the torque of interest and avoid possible errors in the

measurement such as parasitic torques (bearings, etc.), extraneous loads, and components that have large rotational inertias that would dampen any dynamic torques.

Just as with the in-line torque example above, the dynamic torque produced by an engine would be measured by placing an inline torque sensor between the crankshaft and the flywheel, avoiding the rotational inertia of the flywheel and any losses from the transmission. To measure the nearly static, steady state torque that drives the wheels, an inline torque sensor could be placed between the rim and the hub of the vehicle, or in the drive shaft. Because of the rotational inertia of a typical torque drive line, and other related components, inline measurements are often the only way to properly measure dynamic torque.

A reaction torque sensor takes advantage of Newton's third law: 'for every action there is an equal and opposite reaction'. To measure the torque produced by a motor, we could measure it inline as described above, or we could measure how much torque is required to prevent the motor from turning, commonly called the reaction torque (see figure below).



Measuring the reaction torque avoids the obvious problem of making the electrical connection to the sensor in a rotating application, but does come with its own set of drawbacks. A reaction

torque sensor is often required to carry significant extraneous loads, such as the weight of a motor, or at least some of the drive line. These loads can lead to crosstalk errors (a sensor's response to loads other than those that are intended to be measured), and may dampen dynamic loads of interest, as the sensor has to be oversized to carry the extraneous loads, thereby reducing sensitivity. Both of these methods, in-line and reaction, will yield identical results for static torque measurements.

Making in-line measurements in a rotating application will nearly always present the user with the challenge of connecting the sensor from the rotating world to the stationary world. There are a number of options available to accomplish this, each with its own advantages and disadvantages.

SLIP RING

The most commonly used method to make this connection between rotating sensors and stationary electronics is the slipring. It consists of a set of conductive rings that rotate with the sensor, and a series of brushes that contact the rings and transmit the sensors' signals.



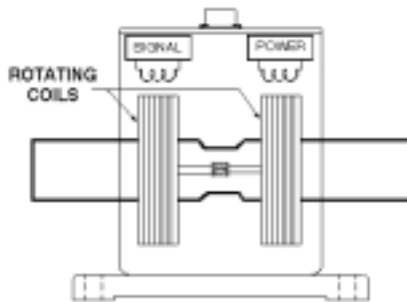
Slip rings and Brushes

Sliprings are an economical solution that perform well in a wide variety of applications. They are a relatively straight forward, time proven solution with only minor drawbacks in most applications. The brushes, and to a lesser extent the rings, are wear items with limited lives that don't lend themselves to long term tests, or to applications that are not easy to service on a regular basis. At low to moderate speeds the electrical connection

between the rings and brushes are relatively noise free, however at higher speeds noise will severely degrade their performance. The maximum rotational speed (rpm) for a slip ring is determined by the surface speed at the brush/ring interface. As a result, the maximum operating speed will be lower for larger, typically higher torque capacity sensors by virtue of the fact that the slip rings will have to be larger in diameter, and will therefore have a higher surface speed at a given rpm. Typical max speeds will be in the 5,000 rpm range for a medium capacity torque sensor. Finally, the brush ring interface is a source of drag torque that can be a problem, especially for very low capacity measurements or applications where the driving torque will have trouble overcoming the brush drag.

ROTARY TRANSFORMER

In an effort to overcome some of the shortcomings of the slip ring, the rotary transformer system was devised. It uses a rotary transformer coupling to transmit power and receive the torque signal from the rotating sensor.

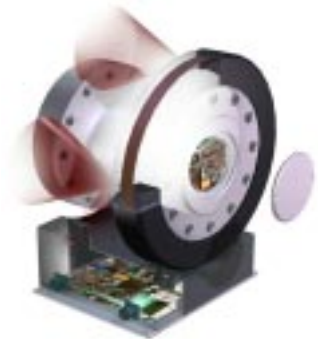


An external instrument provides an AC excitation voltage to the strain gage bridge via the excitation transformer. The sensor's strain gage bridge then drives a second rotary transformer coil in order to get the torque signal off the rotating sensor. By eliminating the brushes and rings of the slip ring, the issue of wear is gone, making the rotary transformer system suitable for long term testing applications. The parasitic drag torque caused by the brushes in a slip ring

assembly is also eliminated. However, the need for bearings and the fragility of the transformer cores still limits the maximum rpm to levels only slightly better than the slip ring. The system is also susceptible to noise and errors induced by the alignment of the transformer primary-to-secondary coils. Because of the special requirements imposed by the rotary transformers, specialized signal conditioning is also required in order to produce a signal acceptable for most data acquisition systems, further adding to the systems cost that is already higher than a typical slip ring assembly.

INFRARED (IR)

Like the rotary transformer, the infrared (IR) torque sensor utilizes a contactless method of getting the torque signal from a rotating sensor back to the stationary world. Similarly using a rotary transformer coupling, power is transmitted to the rotating sensor. However, instead of being used to directly excite the strain gage bridge, it is used to power a circuit on the rotating sensor. The circuit provides excitation voltage to the sensor's strain gage bridge, and digitizes the sensor's output signal. This digital output signal is then transmitted, via infrared light, to stationary receiver diodes, where another circuit checks the digital signal for errors and converts it back to an analog voltage.



IR Transmission

Since the sensor's output signal is digital, it is much less susceptible to noise from such sources as electric motors and magnetic fields. Unlike the rotary transformer system, an infrared transducer can be configured either with or without bearings for a true maintenance free, no wear, no drag sensor.

While more expensive than a simple slip ring, it offers several benefits. When configured without bearings, as a true non-contact measurement system, the wear items are eliminated, making it ideally suited for long term testing rigs. Most importantly, with the elimination of the bearings, operating speeds (rpm's) go up dramatically, to 25,000 rpm and higher, even for high capacity units. For high speed applications this is often the best solution for a rotating torque transmission method.

FM TELEMETRY

Another approach to making the connection between a rotating sensor and the stationary world utilizes an FM transmitter. These transmitters are used to remotely connect any sensor, whether force or torque, to its remote data acquisition system by converting the sensor's signal to a digital form and transmitting it to an FM receiver where it is converted back to an analog voltage. For torque applications they are typically used for specialty, one of a kind sensors, such as when strain gages are applied directly to a component in a drive line. This could be a drive shaft or half shaft from a vehicle for example.

The transmitter offers the benefits of being easy to install on the component as it is typically just clamped to the gaged shaft, and it is re-usable for multiple custom sensors. It does have the drawback of needing a source of power on the rotating sensor, typically a 9V battery which limits the test time, or with an inductive power supply that can be cumbersome to install on a vehicle.

SUMMARY

Understanding the nature of the torque to be measured, as well as what factors can alter that torque in the effort to measure it, will have a profound impact on the reliability of the data collected. In applications that require the measurement of dynamic torque, special care must be taken to measure the torque in the proper location, and to not effect the torque by dampening it with the measurement system. Knowing the options available to make the connection to the rotating torque sensor can greatly affect the price of the sensor package. Sliprings are an economical solution, but have their limitations. More technically advanced solutions are available for more demanding applications, but will generally be more expensive. By thinking through the requirements and conditions of a particular application, the proper torque measurement system can be chosen the first time.

