Measurement and Analysis of Torsional Vibration

by Adrian Lincoln
Technical Director, Prosig Ltd

Torsional vibration is of key importance in the area of vehicle development and refinement. The main contributory source is the engine where periodically occurring combustion cycles cause variation in the crankshaft rotary vibration. This vibration is transmitted to and modified further by other components in the powertrain such as the gearbox and by other equipment driven off the drive belt or chain. Additional torsional vibrations are also likely to appear downstream at the drive shafts and wheels.

The fundamental approach to analysing torsional vibration is to work in the angle domain rather than the time domain. This requires accurate measurement of the angular positions of shafts and gearwheels, and involves instrumenting these components with tooth sensors, tachometers or laser sensors. Whichever type of instrumentation is used the fundamental output is the angular position of the rotating component as a function of time. In contrast to normal data acquisition applications where vibration signals are recorded at equi-spaced time intervals, for torsional applications the requirement is to measure the times of occurrence.
of equi-spaced angular positions.

Limitations of Conventional Data Acquisition Systems

Conventional data acquisition systems are limited in their precision by their maximum sampling rate – in some situations they simply cannot sample fast enough to quantify an entity that is moving very quickly. The measurement of torsional vibration has two factors to take into consideration: the underlying circular motion and the rotary fluctuation superimposed on the circular motion. In fact it is the fluctuation component that is usually of more importance to the vehicle analyst.

Consider the example of a signal from a shaft encoder that is outputting 1000 pulses per revolution at 6000 rpm. This is equivalent to

\[ 6000 \times 1000 \text{ pulses} / \text{sec} = 100,000 \text{ pulses} / \text{sec} \]

Even with a system sampling at 400k samples/sec this has an inherent positional error of 25% per pulse period. Increasing the sampling rate partially improves the situation but of course this will also result in larger data sizes and unnecessary over-sampling at low pulse rates.

An improved method of Torsional Vibration measurement

A better approach to measuring pulse positions is to use a counter with a high frequency clock to count the intervals between rising pulse edges. The equivalent sampling rate is now increased by approximately two orders of magnitude. The Prosig 4-channel Advanced Tachometer Card (03-33-8420) operates at 60 MHz which gives an effective resolution of 16.67 nanoseconds (1 ns = 10-9 secs). In the context of the example above this now results in a positional error (of pulse duration) of less than 0.17%.

The differences between the Advanced Tacho measurement and a Standard Tacho measurement can be seen in the graph. The blue trace was from a signal sampled using a conventional equal-time based system and the red trace was the same signal sampled using a pulse-edge measurement system based on a high-frequency clock and counter. The input signal was a stepped-sine sweep whose discrete steps can clearly be seen in the red trace. The fluctuating nature of the blue trace indicates the degree of uncertainty and inaccuracy of the conventional method of capturing tacho signals.

Analysis methods for Torsional Vibration

One of the advantages of working in the angle domain is that spectral analysis of the pulse periods produces order waterfalls and order spectra directly without recourse to interpolated resampling.

Adrian Lincoln

Adrian Lincoln is a director of Prosig Ltd and has responsibilities for signal processing applications, training and overseas sales. He was formerly a Research Fellow at the Institute of Sound & Vibration Research (ISVR) at Southampton University. He is a Chartered Engineer and member of the British Computer Society and Institute of Mechanical Engineers.

Prosig provide data acquisition, noise & vibration, acoustic, health & condition monitoring and refinement solutions for the scientific and engineering communities and offer a number of standard hardware and software products. Take a look at www.prosig.com to discover why major automotive, military, aerospace, power and industrial companies rely on Prosig for their complete data acquisition, signal analysis and reporting software & hardware.
The P8012 supports 24 analog inputs plus two dedicated tacho inputs. The P8020 supports up to 40 analog inputs plus two tachos. Units can be stacked to expand the system up to 160 channels. Various input options are available. These include analog, thermocouple, strain gauge, high speed tacho, charge, CAN and GPS. Each option is complete with programmable signal conditioning, that is controlled by the DATS™ software. Each input card can be programmed to sample at its own rate.

The 8420 card is intended as a solution for situations with rotating machines where positional information and time relative to position information are required. This would classically be a very high speed shaft encoder with a fine resolution. This card is used in applications where there is a requirement to accurately measure rotational speed at several points in a drivetrain. The high speed and resolution of this card mean it is suitable for in depth rotational machine analysis such as torsional and angular vibration. The 8420 card measures the time between pulses with a 16ns resolution.

The DATS Rotating Machinery option contains a complete set of tools for analyzing the sources of vibration and noise caused by cyclic forces such as those found in engines, gearboxes and wheel excitation. Prosig acquisition software has additional realtime displays for use with Rotating Machinery Analysis.

Various synchronous analyses can be used to view the data in the order domain. In particular a discrete Fourier transform (DFT) can be used to extract orders directly. Data which has been sampled using a fixed time sample rate can be resampled using the tacho as the synchronous marker, so that the same number of samples are generated for each cycle.

**Analysis functions included**

- Time Sampled Data
  - Average Waterfalls
  - Speed Signal from Tacho
  - Extract Orders & Overall Level
  - Generate Waterfall
  - Generate Waterfall with phase
  - Equilisation Order Filter

- Advanced Tacho Analysis
  - Angular Vibration from Tacho
  - Tacho Crossing times
  - Tacho Ideal Equivalent
  - Tacho to time periods
  - Raw Speeds
  - Average period Speeds
  - Smooth Curve Fitted Speeds
  - Interpolated Speeds
  - Tacho Crossing Checks

- *Synchronously Sampled Data*
  - Angular Vibration of Shaft
  - Asynchronous to Synchronous

**DATS Rotating Machinery Analysis Suite**

- **01-55-802** Rotating Machinery analysis suite (Requires 01-55-622 DATS toolbox)