Critical Equipment Measured in the Field

Measuring Torsional Vibration on a Natural Gas Engine/Reciprocating Compressor System

This case history describes how torsional vibration was measured on a natural gas engine driving a reciprocating compressor. It was necessary to check torsional vibration on the front of the engine where the viscous damper was located. Engineering Dynamics Incorporated (EDI) is an industry leader in analyzing and solving vibration problems worldwide. EDI routinely performs torsional vibration analyses of machinery.

Introduction

Torsional vibration involves the twisting of shafts as machinery is rotating. Excessive torsional vibration can lead to failures of crankshaft, couplings, engine dampers, and compressor oil pumps. These failures typically occur at a 45 degree angle to the shaft axis. In many cases, people may not realize there is a torsional vibration problem until a failure occurs because the machine usually does not vibrate (unless it contains a gearbox). Therefore, special equipment is needed to measure torsional vibration.

Reciprocating machinery such as engines and compressors produce harmonics (multiples of running speed). When operated over a wide speed range, it is likely that one of these torque harmonics will excite a torsional natural frequency of the system. At these resonant frequencies, dynamic torque will be amplified and failures can occur. Therefore, it is very important that critical equipment be analyzed in the design stage and tested in the field during startup.

Measurement Devices

EDI used the Polytec laser rotational vibrometer to measure torsional vibration on the front end of a gas engine. The rotational vibrometer replaces older instruments such as a torsiograph (Figure 1), which also measures torsional oscillation, but requires a stub shaft to be attached to the end of a crankshaft.

The damper end of the engine drives a cooling fan through a jack shaft. This makes it impossible to attach a torsiograph.

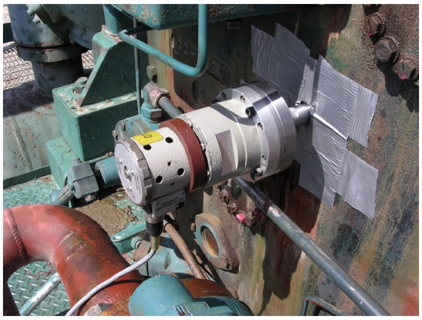


Figure 1: HBM Torsiograph with stub shaft mounted on oil pump, end of compressor (no longer manufactured).

However, the Polytec laser and a shaft encoder with rider wheel could still be used to obtain torsional vibration measurements at this location.

The laser required reflective tape to be wrapped around the jack shaft (Figure 2). The two bright red dots shown are from the laser beams produced by the vibrometer that measure the torsional vibration. Auxiliary piping around the engine did not allow the vibrometer to be mounted within the recommended distance from the rotating shaft (Figure 3). However, the readings were still valid, even at this extended distance.

To obtain the test data, the vibrometer had to be located in adverse conditions outdoors with dust and high temperatures from the nearby turbo charger with an exhaust leak. The vibrometer is powered by a separate computer module, which processes the signal, applies filters, and produces a voltage proportional to torsional oscillation in degrees.

The torsional vibration was also measured with an encoder. Normally an encoder would be mounted at the end of a shaft in a manner similar to the torsiograph shown in Figure 1. However, the jack shaft from the front of the engine drives a cooling fan, which prevented installing an adaptor. Therefore, a rider wheel was used and the measurements were adjusted by the diameter ratio of the jack shaft and wheel.

A special mounting bracket was designed with a spring to apply a constant force to the encoder wheel to prevent slippage relative to the jack shaft. The shaft encoder generates pulses, which must then be processed by a data acquisition system. EDI has developed software that applies the Hilbert transform to measure torsional vibration from the encoder.

Job preparation and installation time was less with the vibrometer, which is mounted on a sturdy tripod and does not require a special adaptor like the encoder. There was some concern that deck vibration could cause erroneous signals from the vibrometer; however, the dual beam system should compensate for this. If needed, foam pads can be placed under the tripod to isolate the laser from excessive vibration.

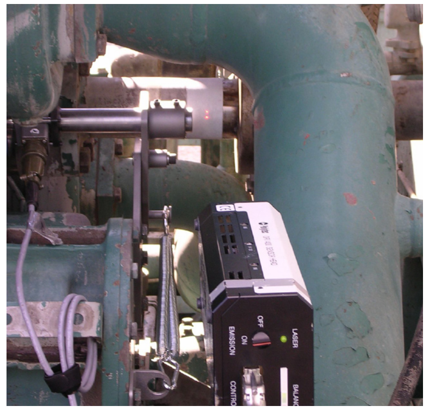


Figure 2: Laser rotational vibrometer aimed at reflective tape on shaft.

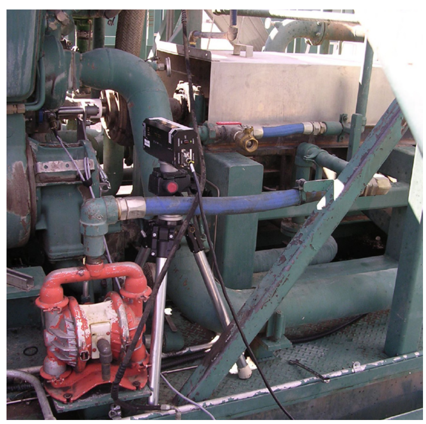


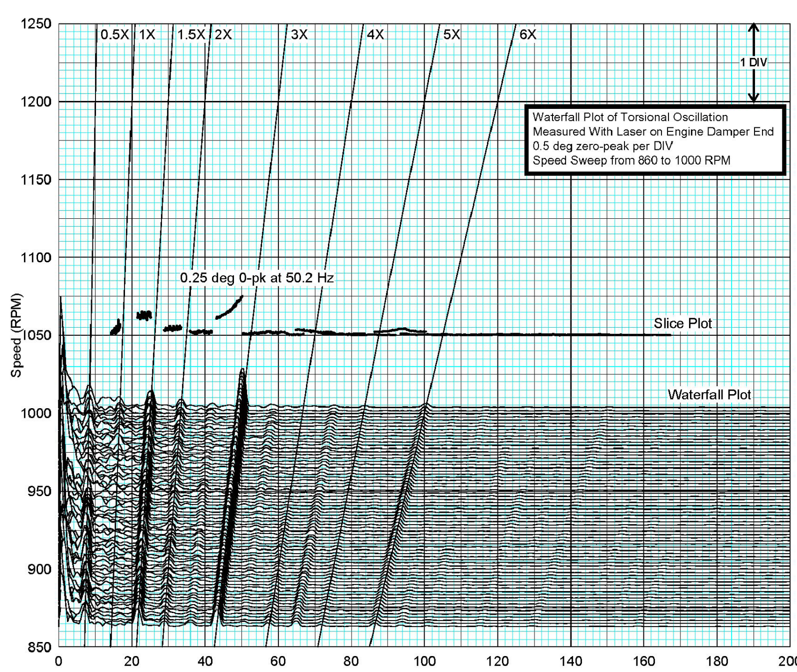
Figure 3: Rotational vibrometer mounted on a tripod.

Test Results

During the test, the engine speed was varied slowly from minimum to maximum operating speed (860 to 1,000 RPM). The torsional oscillation amplitudes (degrees, zero-to-peak) were plotted using a waterfall plot format where frequency spectra are taken every 3 RPM. Diagonal lines superimposed on the plot indicate harmonics or engine orders.
A four-stroke engine will produce energy at half orders in addition to the multiples of running speed due to the firing cycles. Peaks in the waterfall plots can indicate torsional natural frequencies of the system.

In Figure 4, the data obtained using the laser rotational vibrometer is shown. Above the waterfall plot is a slice plot that tracks individual engine orders. The third harmonic was of interest because there was a torsional natural frequency of the system near 58 Hz. This harmonic was approaching the torsional natural frequency, but the engine did not reach a high enough speed to peak through this resonance.

Figure 4: Waterfall plot from data taken with the Polytec Rotational Vibrometer.



Polytec

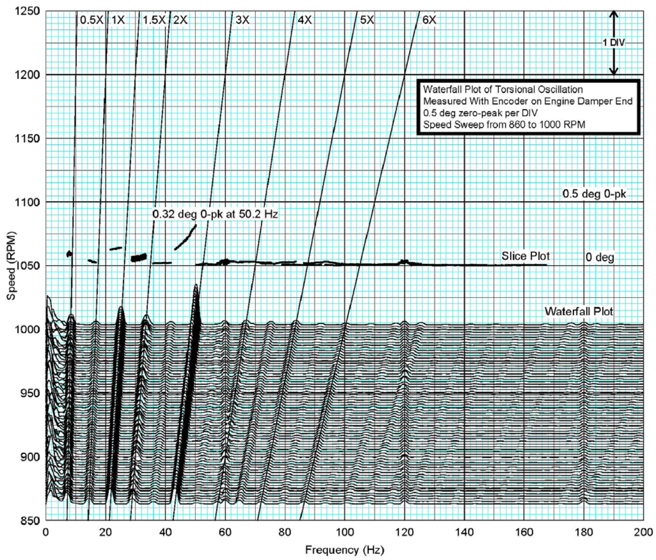


Figure 5: Waterfall plot from data taken with shaft encoder.

For comparison, the data from the shaft encoder that was located near the reflective tape used for the vibrometer measurements is shown in Figure 5. The vibrometer and encoder measurements were taken simultaneously during the test. At the order of concern (3×) the values were very similar, although the measurement techniques were totally different.

There appeared to be less low-frequency, non-synchronous noise (below 5 Hz) from the encoder versus the vibrometer. This may have been due to vibration of the tripod and the fact that the laser was mounted a long distance away. The encoder produced electrical noise at multiples of line frequency (60 Hz, 120 Hz, and 180 Hz), which is not real torsional vibration. This noise may have been due to electrical interference or a ground loop.

It is concluded that the laser rotational vibrometer provided accurate data during the test as compared with the shaft encoder. The vibrometer was easier to setup and did not require a special adaptor to be fabricated.

Torsional Analysis

In addition to acquiring torsional vibration in the field, it is important to perform a full torsional analysis using a computer. A torsional analysis should include several steps:

1. Creating a mass-elastic model of the system
2. Calculating torsional natural frequencies and mode shapes
3. Plotting an interference or Campbell diagram to identify resonances
4. Predicting forced response in terms of alternating shear stress and dynamic torque in the coupling
5. Comparing results of forced analysis to allowable levels.

For example, the American Petroleum Institute (API) recommends separation margins between the operating speed range and any torsional resonances found to be detrimental to the equipment. If torsional vibration levels are found to be high at the front end of the engine, this can be an indicator of a possible problem such as misfire conditions or a failed viscous damper.

The rotational vibrometer was used to verify the torsional modeling of the system by checking the predicted torsional natural frequencies. If discrepancies are found between the field measurements and the torsional analysis, then it may be necessary to normalize the computer model. To determine various parameters such as the crankshaft stresses, damper heat load, and dynamic torque in the coupling, the torsional analysis must be used to infer these values at other locations based upon the measured data from the front end of the engine.

References

Feese, T., 2007, "How to Prevent Torsional Vibration Problems," 2007 NPRA Reliability & Maintenance Conference, George R. Brown Convention Center, Houston, TX.

Hudson, J., Feese, T., 2006, "Torsional Vibration-A Segment of API 684," 35th Turbomachinery Symposium, Texas A&M, pp. 151.

Feese, T., Hill, C., 2002, "Guidelines For Preventing Torsional Vibration Problems In Reciprocating Machinery," 2002 GMRC Gas Machinery Conference, Nashville, TN.

Authors • Contact

Troy Feese, P.E.; Donald Smith

tdf@engdyn.com

Engineering Dynamics Incorporated

San Antonio, Texas

www.engdyn.com

Source: InFocus • Optical Measurement Solutions, Issue 1/2009, ISSN 1864-9203

You will find further information under www.polytec.com/rotvib, or let our product specialists advice you: LM@polytec.de.

Polytec GmbH (Germany)
Polytec-Platz 1-7
76337 Waldbronn
Tel. +49 7243 604-0
Fax +49 7243 69944
info@polytec.de

Polytec France S.A.S.
Bâtiment Orion – 1er étage
39, rue Louveau
92320 Châtillon
Tel. +33 1 496569-00
Fax +33 1 57214068
info@polytec.fr

Polytec Ltd.
(Great Britain)
Lambda House, Batford Mill
Harpenden, Herts AL5 5BZ
Tel. +44 1582 711670
Fax +44 1582 712084
info@polytec-ltd.co.uk

Polytec Japan
Arena Tower, 13th floor
3-1-9, Shinyokohama,
Kohoku-ku, Yokohama-shi,
Kanagawa, 222-0033
Tel. +81 45 478-6980
Fax +81 45 478-6981
info@polytec.co.jp

Polytec, Inc. (USA)
North American Headquarters
16400 Bake Parkway
Suites 150 & 200
Irvine, CA 92618
Tel. +1 949 943-3033
Fax +1 949 679-0463
info@polytec.com

Central Office
1046 Baker Road
Dexter, MI 48130
Tel. +1 734 253-9428
Fax +1 734 424-9304

East Coast Office
25 South Street, Suite A
Hopkinton, MA 01748
Tel. +1 508 417-1040
Fax +1 508 544-1225