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CALIBRATION OF FIBER OPTIC ACCELEROMETERS BY SHAKER BASED VIBRATION TEST SYSTEM

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Abstract: A unique type of fiber optic accelerometer based on wavelength modulation by the Bragg grating principle has been developed.
Testing, characterization and calibration of such transducers represent a challenge since they are not readily compatible with conventional data acquisition platforms.
To overcome this technical challenge a system based on a precision vibration exciter driven by a newly released vibration controller has been configured.
With this system the optical transducer system can be tested and the frequency response determined.
This shaker based vibration test system represents a very useful solution for testing any new accelerometer technology that is not directly compatible with conventional data acquisition platforms.

Keywords: Vibration, accelerometer, calibration, optical.

1. INTRODUCTION

Fibre Bragg grating (FBG) based sensing has moved from a purely academic research area to find industrial applications within monitoring of both static loads (temperature, strain pressure etc.) and lately also within dynamic monitoring (e.g. for sound and vibration measurement). Over the last few years, FBG based accelerometers have become commercially available and have found use in applications within power generation, oil and gas exploitation, aeronautics, structural monitoring etc. Brüel & Kjaer S&V developed such a sensor technology as part of a Danish government funded project.[1] A part of the work to refine the methods for characterising these vibration sensors is reported in this paper.

To our knowledge, there has been a lack of standardised methods for characterisation of Bragg grating based vibration sensors. For electrical vibration transducers, there is a long history of standards for test and calibration that has been set out by the ANSI S2.11 and ISO 5347/16063. To some extent, the methods defined in these standards could be applied, although there are certain technical aspects and terminologies that are unique for optical transducer systems. Some efforts have gone into defining these special issues, e.g. within IEC 61757 and the COST Action 299 “FIDES” that was reported on the 20th OFS conference.[2] These standard methods and terminologies have been taken into account for the testing and characterisation reported here.

2. ACCELEROMETER CALIBRATION METHODS

For electrical vibration transducers, the characterisation in terms of sensitivity and frequency response may be performed as either; (1) A primary calibration, e.g. with respect to a laser interferometric reference; (2) A secondary calibration via substitution by a traceable reference transducer. Running a primary laboratory is a rather costly and demanding task, so most measurements are done at the secondary level. The metrological precision of these secondary calibrations relies on a traceable calibration of the reference transducer, e.g. as a primary calibration carried out at an accredited laboratory.

2.1 Single-frequency sinusoidal response calibration

The simplest way to characterise the sensitivity of an accelerometer is to subject it to a sinusoidal excitation and perform a comparative measurement between the signal generated by the device under test (DUT) and a reference signal (REF). Here, the REF signal may be taken as either a primary source (laser interferometers etc.) or a secondary source (such as a reference accelerometer with traceable calibration). The comparison of the DUT and REF signals may be carried out as either a phase sensitive detection or via a simple magnitude comparison. In order to reproduce a full frequency response, the sinusoidal measurements has to be repeated or swept over an extended range of frequencies. As such, the sinusoidal calibration method is a rather time consuming technique.

2.2 Broad-band measurements via frequency response functions

The time used for characterising the frequency response of a vibration transducer may be reduced significantly by using broad-band excitation and performing the correlation of DUT and REF signals in the frequency domain. Such a broad-band calibration relies on a cross-correlated digital frequency analysis that calculates the response function given by

$$H(f) = \frac{S_{\mathrm{DUT}}(f)}{S_{\mathrm{REF}}(f)} \quad (1)$$

where $S_{\mathrm{DUT}}(f)$ and $S_{\mathrm{REF}}(f)$ denote the complex frequency spectra of the DUT and REF signals respectively. In practice, the response function is expressed and evaluated in terms of the ratio between the cross-spectrum and auto-spectrum as

$$H_1(f) = \frac{S_{\mathrm{DUT}}(f) S^*_{\mathrm{REF}}(f)}{S_{\mathrm{REF}}(f) S^*_{\mathrm{REF}}(f)} \quad (2)$$

Most characterisations of sensitivity and frequency response on electrical vibration transducers are carried out by means of broad-band excitation and frequency response functions. It does not only benefit from reduced measurement times, but as a full complex analysis, it gives both magnitude and phase information and offers very good noise rejection. The only major drawback is that it requires synchronous digital data sampling of both the DUT and REF signals.

3. IMPLICATIONS FOR OPTICAL TRANSDUCER CALIBRATION

For FBG based optical sensing systems, most interrogators do not allow for easy synchronisation with conventional data acquisition platforms. In practical terms, that excludes the use of broad-band frequency response measurements. Most tests and calibrations are therefore carried out with sinusoidal excitation, either point-by-point or by means of frequency sweeping. Furthermore, most fibre optic sensing systems are stand-alone platforms that are not readily compatible with conventional acquisition systems. Therefore, the most convenient implementation of a measurement system for test and calibration is to use a separate feed-back loop to control the reference level while sweeping over a range of frequencies.

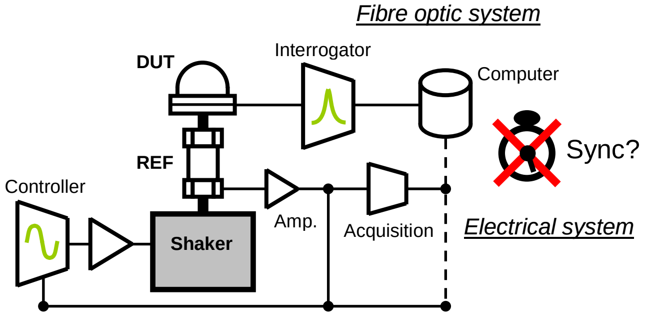

Figure 1. Schematic layout of a measurement system for test and calibration of Bragg grating based vibration sensors. The device under test (DUT) and reference transducer (REF) are mounted back-to-back on a shaker that is driven by a feed-back loop controller. The fibre optic system used to track the wavelength modulation of the DUT signal consists of an interrogator connected to a PC. At the same time, data may be acquired from the REF signal, but in most cases, there is no easy way to obtain accurate synchronisation between the fibre optic and electrical systems.

3.1 System implementation and performance tests

For the implementation of an actual measurement system, it was natural to rely on the long heritage of Brüel & Kjær precision measurement shakers (Types 4808, 4809 and 4810). These shakers are optimised for test and calibration up to frequencies of 10–20 kHz for which there exists a number of purpose built reference fixtures. Such reference fixtures are designed to ensure a rigid transfer of vibration from the shaker armature to the reference plane where the DUT and REF transducers are mounted back-to-back. The control loop was implemented with a newly released range of vibration controllers under the VC-LAN trademark. These are mostly intended for industrial vibration tests but are also well suited for test and calibration with their high precision (Absolute Amplitude Precision (1 kHz, 1 Vinput) 0.5% FS) input channels ranging up to 46 kHz.[3]

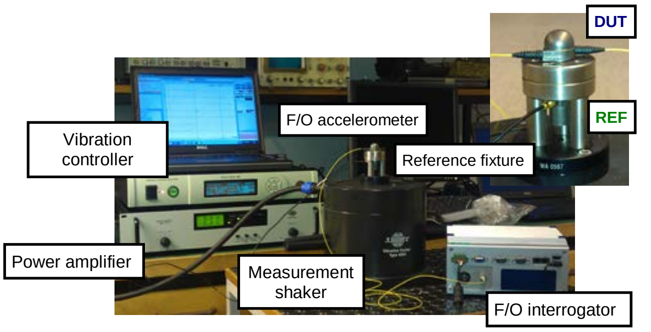

Figure 2. System for test and calibration of Bragg grating based vibration sensors based on a measurement shaker (Type 4808) with a reference fixture that contains a well-calibrated reference transducer (Type 4371). The shaker is driven by a VC-LAN vibration controller (Type 7542) that uses the reference signal (REF) for an amplitude controlling feed-back loop. The device under test (DUT) is mounted on the reference fixture and monitored by a fibre optic interrogator.

The performance of such a measurement system is best characterised via a calibration by substitution with a well-known reference accelerometer in place of the DUT transducer. In that way, the estimated precision may be directly compared with a traceable calibration of the reference transducer. Such a system calibration is shown in Figure 3, which confirms that the measurement system has an amplitude precision of about 1% up to 3 kHz and 3% up to 7 kHz (including the 0.5% accuracy for the input channels of the vibration controller).

This performance is obtained using standard equipment with no corrections for the known measurable performance.

If corrections are made the uncertainties could be reduced to about 0.7-0.8% up to 3 kHz and 1.5% up to 6 kHz. This makes it comparable to conventional comparison calibration systems.

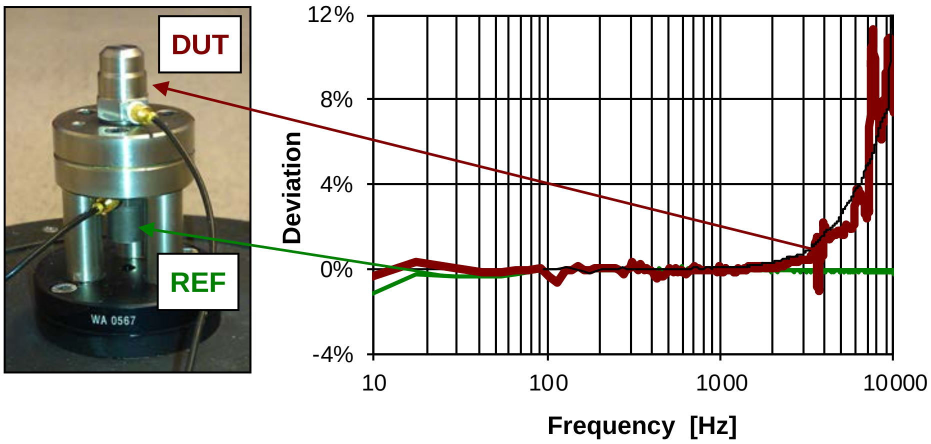

Figure 3. System calibration by substitution with a well-known reference transducer (Type 8305) obtained from a sinusoidal sweep at 5 Hz/s with an amplitude of 10 ms^{-2}. The REF signal (green trace) has been corrected for the natural slope of –1.8% per decade and the DUT signal (red trace) has been overlaid with a reference curve measured on a conventional test system at the Brüel & Kjær accredited calibration laboratory.

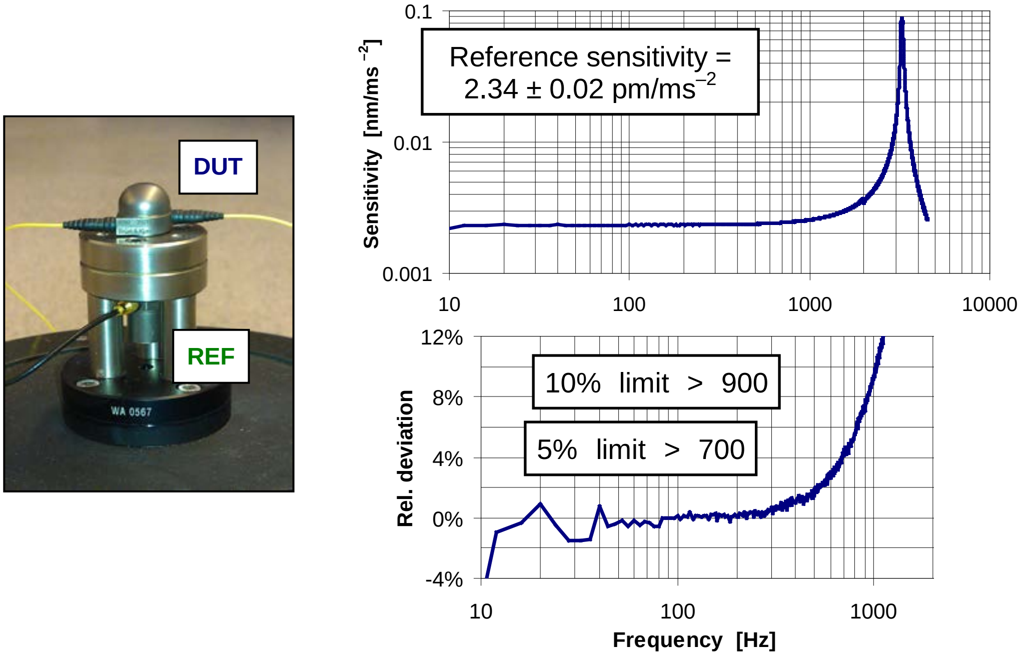

Figure 4. Calibration of a Bragg grating based vibration sensor performed with a sweep rate of 10 Hz/s and amplitude level of 10 ms^{-2}. The reference sensitivity at 160 Hz ($\omega = 1000\ s^{-1}$) is given with an accuracy of 1% (as estimated from the system calibration). Below 40 Hz, the accuracy is degraded to about 2% as a consequence of the increased sweep rate (compared to the system calibration at 5 Hz/s).

3.2 Bragg grating based vibration sensor calibration

To calibrate an actual Bragg grating based transducer, it simply needs to be mounted in place of the DUT transducer. Our particular FBG accelerometer has a dynamic range of about 0.01–1000 ms^{-2} (depending on measurement bandwidth) and a resonance frequency of about 3 kHz.[1] These parameters suit the amplitude and useable frequency range of the actual calibration system quite well. As shown in Figure 4, the result of such a calibration is a frequency response measurement with an amplitude precision of about 1% from 50 Hz up to the resonance frequency of just above 3 kHz.

4. CONCLUSIONS

We have presented a measurement system dedicated to test and calibration of Bragg grating based vibration sensors. The challenges with synchronisation between the fibre optic sensing system and an electrical reference measurement has been overcome by using a separate control loop to maintain a well-defined reference level. The amplitude precision of such a system has been demonstrated to be within 1% up to 3 kHz and 3% up to 7 kHz with a potential to be reduced to 0.7 and 1.5%.

5. ACKNOWLEDGMENTS

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