Calibration of Accelerometer Temperature Sensitivity by Laser Interferometer

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Abstract. Piezoelectric accelerometer is widely used in thermal vibration measurement. Temperature sensitivity of accelerometer is usually calibrated by comparison method (ISO 5347-17). Using comparison method, the calibration uncertainty is more than 2% (k=2), and only sensitivity magnitude deviation of the accelerometer can be gotten in a narrow frequency range. In this paper, a new calibration method using laser interferometer is introduced. Complex sensitivity (phase shift and magnitude) of the accelerometer can be gotten directly at fixed temperature with calibration uncertainty less than 0.5% (k=2). This method is applicable for temperature from -190°C to 800°C and frequency range from 10 Hz up to 3 kHz.

1. Introduction

Accelerometer is widely used for the measurement of vibration in very low and high temperature, such as the thermo vibration test and thermo modal analysis. Most accelerometer used for thermo testing is piezoelectric. For this kind of piezoelectric accelerometer, its sensitivity is determined by the material of the crystals, the structure and cable. Usually the accelerometer sensitivity change for more than 15% in its using temperature range. And its available frequency range will be narrow than in the ambient conditions. So the accelerometer should be calibrated in its using temperature range.

Usually the calibration method used is depending on ISO 5347-17 (Methods for the calibration of vibration and shock pick-ups Part 17-Testing of fixed temperature sensitivity), which specifies the instrumentation and procedure to be used for testing fixed temperature sensitivity of vibration accelerometers. The testing system consists of a vibration exciter equipped with a specially designed fixture. The fixture with thermal barrier (connecting ceramics rod) is used for mounting the tested accelerometer inside a temperature chamber and the reference accelerometer outside the chamber at ambient conditions. An example of main parts of testing system is shown in Figure 1.

It is clearly seen that the sensitivity of tested accelerometer can not be gotten exactly because a fixture (ceramics rod) is mounted between the reference and calibrated accelerometer, and fixture’s transfer function error which varies with frequency has not been compensated. The result should be expressed

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as a deviation of the calibration factor at fixed temperature and frequency. The frequency range is from 20 Hz to 1250 Hz.

In this paper, a new calibration method using laser interferometer is introduced, using this method the frequency response (magnitude and phase shift) can be gotten directly and the frequency range expand to 10 Hz to 3000 Hz.

2. Calibration system

This calibration system mainly contains a vibration exciter equipped with a specially designed fixture for mounting accelerometer, a temperature chamber and a laser interferometer, see Figure 2. Using laser interferometer as calibration standard, the fixture’s transfer function error can be ignored, and can determine the frequency response of tested accelerometer’s complex sensitivity for a certain frequency range at fixed temperature.

2.1 Laser interferometer

An interferometer of the modified Michelson type shall be used, with quadrature signal outputs, with two light detectors for sensing the interferometer signal beams. A quarter wavelength retarder converts the incident, linearly polarized light into two measuring beams with perpendicular polarization states and a phase shift of 90°. After interfering with the linearly polarized reference beam, the two components with perpendicular polarization shall be separated in space using appropriate optics (e.g. a Wollaston prism or a polarizing beamsplitter), and detected by two photodiodes. The two outputs of the modified Michelson interferometer shall have offsets of less than 5% in relation to the amplitude, relative amplitude deviations of less than 5% and deviations of less than 5° from the nominal angle of 90°. To keep these tolerances, appropriate means shall be provided for adjusting the offset, the signal level and the angle between the two interferometer signals.

To calculate the acceleration, using sine-approximation method (See ISO 16063-11 method 3), the amplitude and phase shift of the accelerometer can be gotten.

2.2 Vibrator and fixture

The vibrator contains a air bearing vibration with a power amplifier, for low distortion and cross motion. A specially designed fixture is mounted on the vibrator, the fixture is usually made of ceramics for high stiffness, low weight and low thermal conductivity. The tested accelerometer is mounted on the top of the fixture. To reflect laser, the surface for mounting accelerometer should be optically polished, placed mirror, or be plated with chrome etc.
In this system, the mica ceramics is used as the material for the fixture, its thermal conductivity is 1.78 W/mK. The vibration system resonance is 6364Hz (Figure 3), and the max transverse vibration ratio is about 24% in 1850Hz (Figure 4). It should be concerned that the max transverse vibration ratio frequency cannot be used for vibration calibration.

![Figure 3. Vibration system resonance test](image)

2.3 Temperature chamber

A temperature chamber is specially designed for the calibration. At the top of the chamber, a hole should be sealed with glass for the laser passes through. The air temperature in the chamber is measured and controlled by a thermocouple located close to the accelerometer under test. The location of the thermocouple has no influence on mounting and vibrating of the transducer. The temperature in the chamber should be increased or decreased with gradual change of temperature. Once the temperature measured by the thermocouple has reached the setting value and its stability is recommended within ±2°C, maintain this temperature until the transducer under test has achieved temperature stability. Usually the maintain time is 15min, but it differ on the chamber and transducer.

2.4 Determination of the achieving time of setpoint temperature

In the calibration system the control thermocouple is nearby the transducer. It measures not the temperature of transducer but the air temperature. Therefore before calibration, the time should be known when the accelerometer achieves setpoint temperature stability. A dummy transducer with approximately the same size as accelerometer could be used to determine this time. Replace the accelerometer with the dummy transducer, and mount temperature sensor on it by mounting screw or bundling with wire (see Figure 3).

![Figure 5. Test system for the determination of achieving time with a dummy transducer](image)

Set the temperature of the chamber to the preferred value T1. Once the temperature measured by the thermocouple has reached the setting value and its stability is recommended within ±2°C, record this time point as t1. Maintain this temperature and observe the output of temperature sensor until the DUT has achieved temperature stability tolerance, record this time point as t2. The time interval between t2 and t1 can be considered as a achieving time of setpoint temperature for DUT (see Figure 6). This time interval for every preferred temperature could be determined as the above procedures.
3. Calibration result
For reference accelerometer type 8305 made by B&K, the temperature response from -60°C to 200°C at 160Hz and frequency response from 20Hz to 2000Hz at 100°C are measured. In it’s temperature range the phase shift change about 0.2° and magnitude sensitivity change about 1%. For the frequency response it start to turn up at 2000Hz.

Table 1. The temperature response of 8305 at 160Hz

| Temperature/°C | -160 | -140 | -120 | -100 | -80 | -60 | 0 | 40 | 80 | 120 | 160 | 200 |
|----------------|------|------|------|------|-----|-----|---|----|----|-----|-----|-----|
| Sensitivity/pC/m/s² | 0.1238 | 0.1238 | 0.1238 | 0.1238 | 0.1238 | 0.1238 | 0.1238 | 0.1238 | 0.1238 | 0.1238 | 0.1238 | 0.1238 |
| Phase/° | -0.14 | -0.14 | -0.14 | -0.14 | -0.14 | -0.14 | -0.14 | -0.14 | -0.14 | -0.14 | -0.14 | -0.14 |

Table 2. The frequency response of 8305 at 100°C and 10m/s²

| Frequency/Hz | 20 | 40 | 80 | 160 | 320 | 640 | 1280 | 2000 |
|--------------|----|----|----|-----|-----|-----|------|------|
| Sensitivity/pC/m/s² | 0.1234 | 0.1232 | 0.1230 | 0.1231 | 0.1233 | 0.1235 | 0.1237 | 0.1239 |
| Phase/° | -0.28 | -0.28 | -0.28 | -0.28 | -0.28 | -0.28 | -0.28 | -0.28 |

4. Conclusion
This paper use laser interferometer and sin-approximation method as the vibration reference. It can get the phase shift and magnitude sensitivity of the accelerometer directly at fixed temperature. It takes less calibration uncertainty and wider calibration frequency range. Using the primary method to get the temperature response of the reference accelerometer, also make it possible that the so called back to back or shoulder to shoulder calibration at fixed temperature.

References
[1] ISO 5347-17, Methods for the calibration of vibration and shock pick-ups -- Part 17- Testing of fixed temperature sensitivity
[2] ISO 16063-11, Methods for the calibration of vibration and shock transducers -- Part 11- Primary vibration calibration by laser interferometry
[3] ISO 16063-1, Methods for the calibration of vibration and shock transducers — Part 1: Basic concepts.