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CHARACTERIZATION OF THE TEMPERATURE BEHAVIOR OF A PIEZORESISTIVE ACCELEROMETER

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1. Introduction

Piezoresistive accelerometers use a strain-sensing element, generally made of semiconductor material, e.g., silicon to convert the mechanical motion into an electrical signal. This element is usually designed in form of a cantilever beam loaded with a mass. Acceleration causes bending of the beam, which produces a change of electrical resistance proportional to the applied acceleration. Main advantages of piezoresistive accelerometers in comparison to other types, e.g., piezoelectric and capacitive, is their robust and highly dynamic behavior, which qualifies them for application in high impact shock applications. Mechanical damping is typically implemented with silicon oil in a way that the output signal is undistorted over a wide frequency range. These characteristics principally qualify them for the application in drop tests carried out at BAM [1], for which they are calibrated over the frequency range from 1 to 4 kHz. However, using silicon oil for damping, has the drawback of temperature dependent change of its viscosity, leading to temperature dependent deviation of the accelerometer's sensitivity.

This study presents experimental results of the temperature behavior of a piezoresistive accelerometer with a dynamic range up to ±5000 g. This type of accelerometer is applied for drop tests which are partially performed at temperatures of -40 or +100 °C.

2. Experimental method and setup

BAM uses a Hopkinson Bar to characterize accelerometers for their application in drop tests corresponding to ISO 16063-13:2001 [2]. Its mode of operation is based on the propagation of an elastic shock wave in a long and thin bar. An independent measuring reference is given through a laser vibrometer. By combining a Hopkinson Bar with a temperature chamber [3], a method was implemented to test and characterize accelerometers at conditions corresponding accurately to drop test scenarios (Fig. 1).

Fig. 1. Hopkinson Bar with its front end integrated in a temperature chamber.

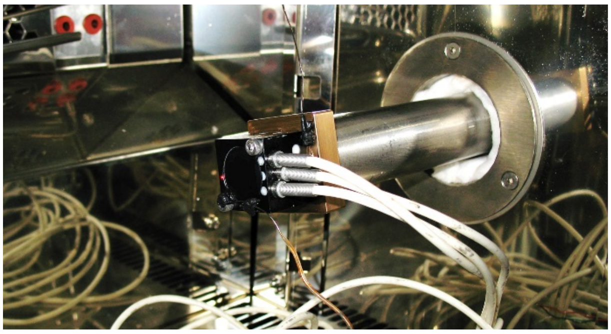

Fig. 2. Front end of the bar with an attached three-axial piezoresistive accelerometer.

Fig. 2 shows the piezoresistive accelerometer attached to the front end of the bar inside the temperature chamber. To characterize its temperature behavior Hopkinson Bar tests were performed between temperatures of -55 and 102 °C, starting at room temperature of 25 °C, going stepwise down to -55 °C with exposure times of minimum 1 h. Correspondingly to drop tests, the exposure at -55 °C was kept for about 48 h. This time is required to assure the temperature adaption of the whole drop object. Subsequently, temperature increase was applied stepwise up to 102 °C, again with exposure times of minimum 1 h. At each temperature step a Hopkinson Bar test was performed with dynamic impact of ca. 1000 g.

3. Results

Fig. 3 displays the temperature dependent deviation of sensitivity of the accelerometer, normalized to the sensitivity at 25 °C. The sensitivity is averaged over excited frequencies from 1 to 4 kHz.

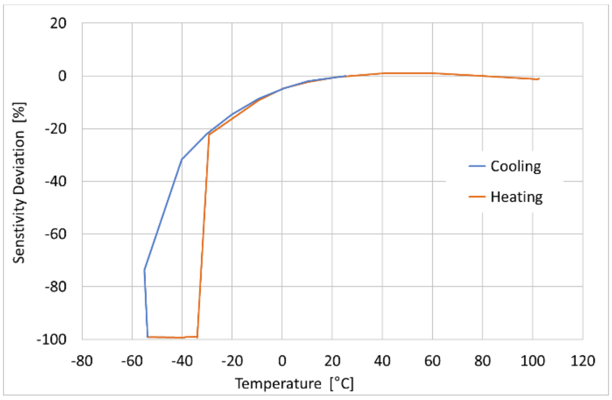

Fig. 3. Temperature dependent sensitivity deviation from 1 to 4 kHz.

By manufacturer's data the sensor's storage and operating temperature reaches from -40 to 120 °C with temperature compensation from 20 to 80 °C. The test results clearly confirm the temperature compensated range with sensitivity deviations in the range ±1.5 %. However, for operation at temperatures below 20 °C a considerably lower sensitivity must be respected, with a deviation of -22 % at -30 °C. While the sensor was basically functioning at -40 °C during the stepwise cooling process, it failed after 48 h exposure at -55 °C, what is the usual cooling procedure for drop test at -40 °C. During stepwise heating and testing, the accelerometer only showed functioning at -30 °C, again. The following sensitivity results were approximately the same as before cooling.

Another interesting aspect is the frequency response of sensitivity at different temperatures. Fig. 4 shows the results during the cooling process, while Fig. 5 displays the results for the subsequent heating process, each normalized to 25 °C and 1000 Hz. For temperatures above 20 °C the typically stable output signal can be found over the frequency range up to 6000 Hz. In contrast, at lower temperatures the sensitivity decreases, particularly with increasing frequency. This behavior clearly illustrates the temperature characteristics caused by using silicon oil for the damping mechanism. The increase of viscosity limits the dynamic of the sensor at low temperatures, resulting in clearly reduced average sensitivity and dramatically reduced sensitivity at high frequencies.

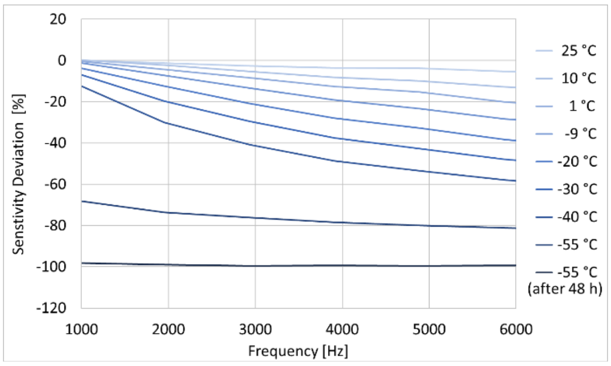

Fig. 4. Frequency response of sensitivity at different temperatures during the cooling process.

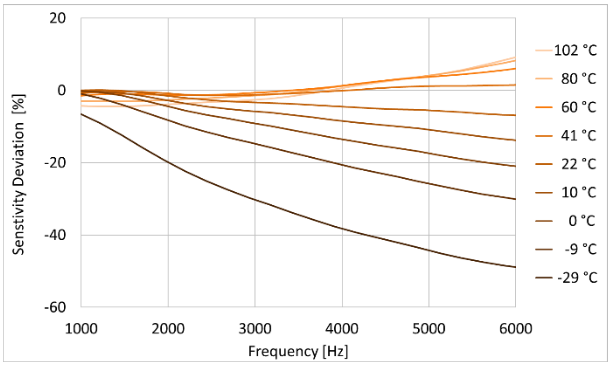

Fig. 5. Frequency response of sensitivity at different temperatures during the heating process.

4. Remarks

- Conclusively, it is important to consider the reduced sensitivity of piezoresistive accelerometers at temperatures below 20 °C and possible failure at temperatures below -30 °C.
- Additionally, the dynamic of the application has to be respected, since measurements with frequencies above 1000 Hz are mostly affected.
- However, for application at temperatures close to their operation limits, it is reasonable to calibrate any accelerometers in good accordance with application conditions.

References

[1] Musolff, A., et al., Impact Analysis of RAM Packages under Kinematic Aspects, Proceedings 18th PATRAM 2016, pp. 1030 ff.

[2] ISO 16063-13:2001: Methods for the calibration of vibration and shock transducers.

[3] Bartholmai, M., et al., Hopkinson bar method for temperature dependent testing and calibration of accelerometers, Proceedings 31st Danubia Adria Syposium 2014, pp. 244-245.