Nonlinear Behavior of Piezoelectric Accelerometers

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Introduction

Piezoelectric accelerometers are widely used for vibration measurements, because of their robustness and reliability, which lead to stable transfer characteristics. Typical piezoelectric accelerometers show good linearity over wide frequency and dynamic ranges. While the linear behavior is understood and documented, specifications of the nonlinear behavior are scarce and, if present, state generally low distortions.

Since the limitations of the transducer have to be considered in the analysis of the measured vibrations, the nonlinear behavior of a typical piezoelectric accelerometer was further investigated. For the measurements a setup for vibration calibration by comparison to a reference transducer, according to ISO 16063, was enhanced by laser vibrometry, to resolve limitations of the vibration exciter. In order to calculate the vibration amplitudes, methods for vibration calibration by comparison to a reference transducer, and primary vibration calibration by laser interferometry, from ISO 16063, were combined. Since current standards for vibration transducers do not regard nonlinear behavior, further analysis has been performed according to IEC 60268 for sound system equipment. In the frequency range, limited by the setup, distortions, added to the measurements by the piezoelectric accelerometer, were typically below 0.5 %, which leads to the conclusion that these can be neglected for typical applications.

Measurement Setup

An existing and accredited system for secondary calibration of accelerometers by comparison to a reference transducer was extended by a laser vibrometer and additional data recording equipment in order to be able to analyse the total harmonic distortions.

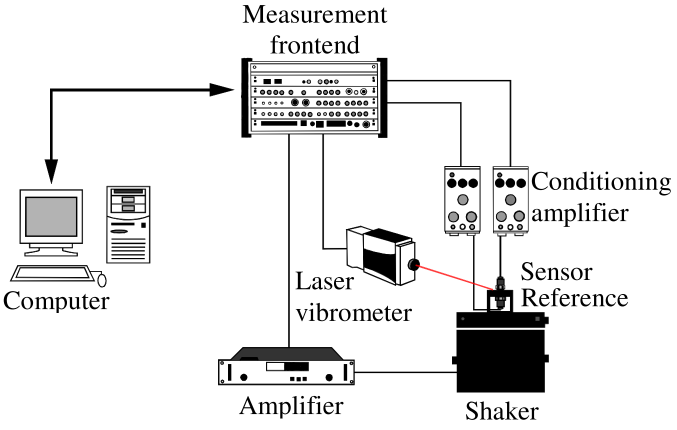

Figure 1: Measurement setup for the true harmonic distortion measurements.

Calibration

In order to calibrate the measurement setup a method according to ISO 16063-21 for vibration calibration by comparison to a reference transducer has been implemented with sine approximation of the magnitude and phase values according to ISO 16063-11. The magnitude of the complex sensitivity was calculated using equation 1 and the phase of the complex sensitivity using equation 2. Input values were calculated using the accurate sine approximation method.

$$S_{Sensor} = \frac{X_{Sensor}}{X_{Reference}} S_{Reference} \tag{1}$$

S_{Sensor} , $S_{Reference}$	Magnitude of the complex sensitivity of the transducer
X_{Sensor} , $X_{Reference}$	Magnitude of the transducer output

$$\varphi_{Sensor} = \varphi_{Sensor-Reference} + \varphi_{Reference} \tag{2}$$

$\varphi_{Sensor\text{-}Reference}$	Phase shift between the sensor to be calibrated and the Reference transducer
φ_{Sensor} , $\varphi_{Reference}$	Phase of the complex sensitivity of the transducer

The results of the sensor calibration illustrated in Figure 2 were validated by comparison to the values of the accredited calibration system which has been extended for the total harmonic distortion measurements. Of course also the laser vibrometer was calibrated accordingly, in order to have reliable measurement values for further analysis.

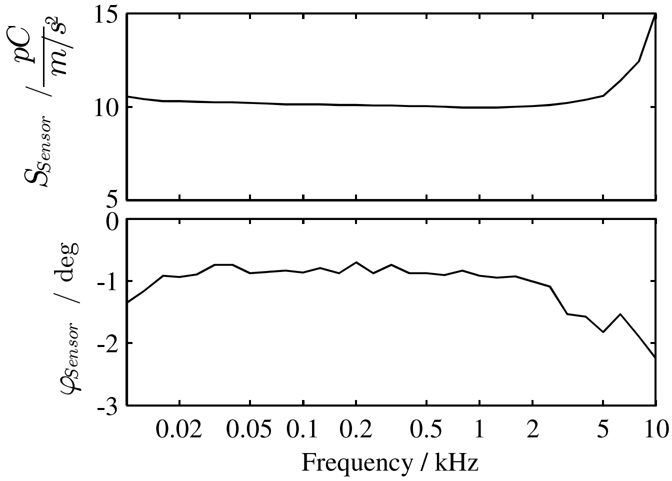

Figure 2: Complex sensitivity of the piezoelectric accelerometer, the magnitude S_{Sensor} shown in the top graph and the phase φ_{Sensor} in the bottom graph.

Excitation

Since it is expected that the piezoelectric accelerometer produces only little harmonic distortions, it cannot be assumed that the distortions of the vibration exciter can be neglected, as it is done in IEC 60268 for the measurement of sound system equipment To correct the influence of the electrodynamic shaker used for the vibration excitation during the measurements, the behavior of the shaker has been measured using a laser vibrometer. The calibrated signal of the laser vibrometer represents the vibration excitation and is used to correct imperfections in the excitation of the piezoelectric accelerometer for which the distortions are calculated. An example of both signals for an excitation frequency of 160 Hz is given in Figure 3.

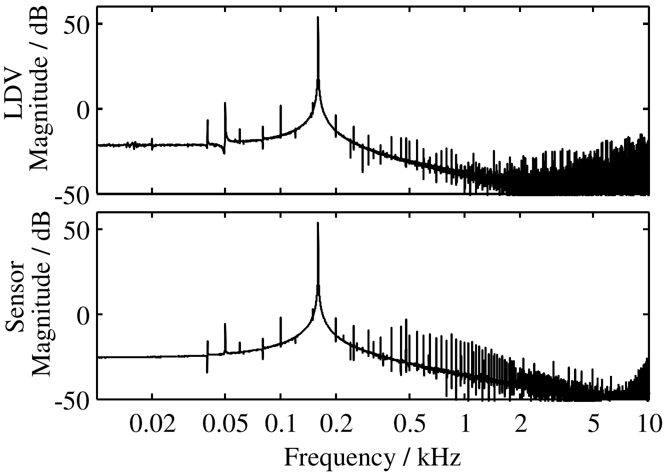

Figure 3: Magnitude of the calibrated laser vibrometer (LDV) output spectrum shown in the top graph and of the calibrated sensor spectrum shown in the bottom graph for an excitation frequency of 160 Hz and an excitation acceleration of 6 m/s^2.

Total Harmonic Distortion

Since the standards for measurements of accelerometers do not include procedures to analyze the total harmonic distortion, the calculation followed IEC 60268 with an extension to correct the influence of the vibration excitation according to equation 3.

$$THD = \frac{\sqrt{\sum_{i=2}^{k}(A_i - L_i)^2}}{\sqrt{(L_1)^2}}\,100\% \qquad (3)$$

A_i	Magnitude of i-th order harmonic of the calibrated sensor output
L_i	Magnitude of i-th order harmonic of the calibrated LDV output

The calculated total harmonic distortions (THD) of the piezoelectric accelerometer are shown in Figure 4 for a constant excitation acceleration of 6 m/s^2. High THD values at fundamental frequencies less than 50 Hz can be explained by rocking motions of the shaker. At low frequencies large displacements of the sensor are necessary to keep the excitation acceleration constant. The electrodynamic shaker of this setup was therfore used slightly out of its specifications at low frequencies. For frequencies greater than 500 Hz the harmonics reach the resonance frequency of the accelerometer, thereby increasing the magnitude of the harmonics. In typical measurement situations this is not a problem, since the resonance frequency is above the specified upper frequency limit of the sensor and is cut off by a low-pass filter. At frequencies greater than 1 kHz, less harmonics are used for the calculation since the Nyquist frequency is reached. In the frequency range between 50 Hz and 500 Hz were the validity of the THD values is not influenced by the measurement setup the THD is below 0.2 %. Higher excitation amplitudes up to 20 m/s^2 were also investigated and a small increase of the THD was found, resulting in THD values typically less than 1 %. Since the basic principle of the piezoelectric accelerometer does not change, it can be assumed that the THD is generally low if the accelerometer is used within its specifications.

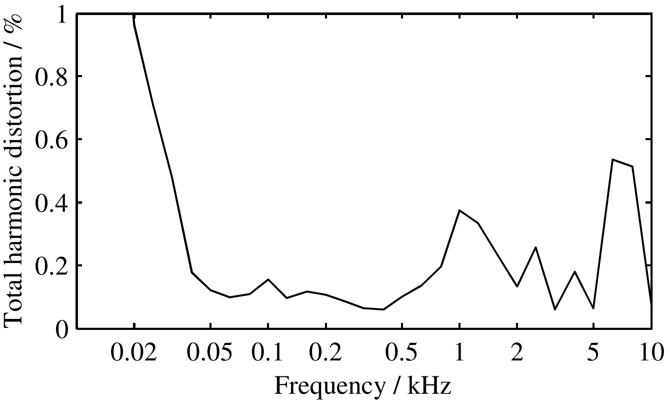

Figure 4: Total harmonic distortions (THD) of the piezoelectric accelerometer for a constant excitation acceleration of 6 m/s^2.

An additional analysis of total, second and third order difference frequency distortions according to IEC 60268 with an extension to correct the influence of the vibration excitation similar to equation 3 showed values that were typically less than 0.5 %.

Acknowledgments

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References

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