INFLUENCE OF PIEZOELECTRIC MATERIAL PROPERTIES ON IMPEDANCE CHARACTERISTIC AND IMPROVEMENTS OF CALIBRATION EQUIPMENT

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Abstract: This paper deals with finite element simulations of impedance characteristics piezoelectric elements utilized in sensors of acoustic emission (AE). Coefficients of piezoelectric material are changed to evaluate the sensitivity to their variation in case they are not known precisely, so to which extent can they influence the sensitivity of the sensor. Result showed sensitivity on coefficient in c-matrix, mainly to coefficients c_{11} and c_{13}. Second investigated topic is issue with test stand for calibration of AE sensors, where output of force sensor was affected by parasite signal. By contactless measurement with laser interferometer was discovered the parasite signal is caused by mechanic of the system and it is no threat for the measuring chain.

Keywords: acoustic emission, simulation, COMSOL, impedance characteristic, laser interferometry

1 PIEZOELECTRIC PARAMETERS

Piezoelectric effect describes transformation of mechanical and electric energy in capable material. Piezoelectric materials are often used in sensors of acoustic emission as a sensing element to transform mechanical wave to electric signal. Key parameters of piezoelectric materials are defined by 4 matrices: [1] [2]

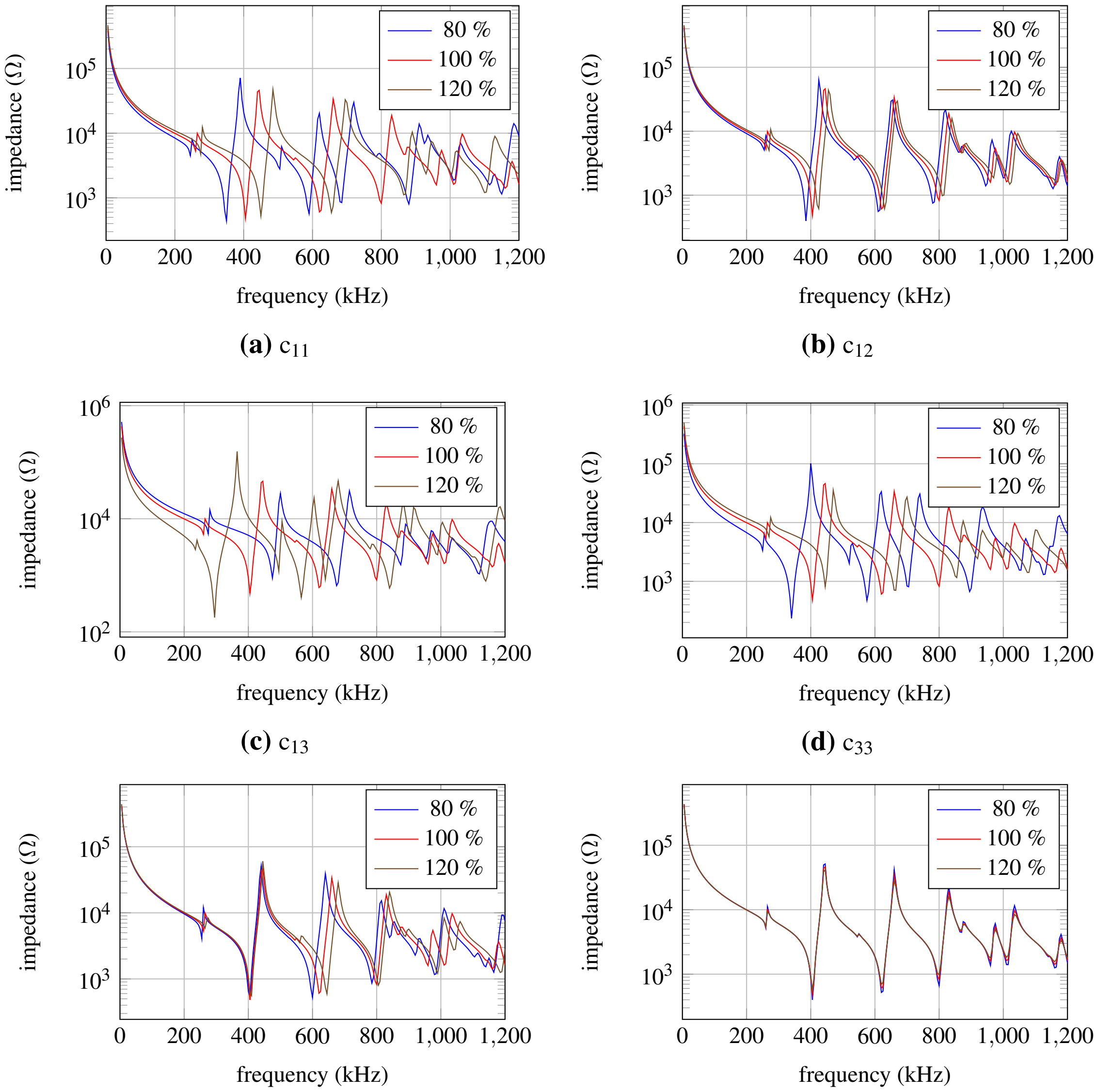
- s - matrix of compliance coefficients, dimension 6x6, m^2/N
- c - matrix of stiffness coefficients, dimension 6x6, N/m^2
- ε - matrix of electric permittivity, dimension 3x3, F/m
- d - matrix of piezoelectric coupling coefficients for Strain-Charge form, dimension 3x6, C/N

These matrices have zeroes at some positions, and some of them are symmetrical, therefore the situation is simplified and for example matrices s and c are each defined by 5 parameters, instead of 36.

2 SIMULATIONS OF IMPEDANCE CHARACTERISTICS

Simulations often use the method that noise is added to the input data to verify the robustness of the whole model. In my procedure I will try to achieve a similar effect, because the piezoelectric material is defined by many inputs and its parameters are not always easily measurable, they may differ from the real values. In simulations, the values of material constants will be changed step by step and it will be possible to quantify which parameter changes the simulation significantly and which has less or none effect. In other words, if any of the material constants are measured incorrectly, then the result may differ from the original state.

I used COMSOL Multiphysics to perform simulations of impedance characteristics of sensing element. Shape of the element is truncated cone with diameters 6.24 and 1.50 mm and height 2.512 mm and I choose typical piezoelectric material from PZT-5H from material library. All material constants were changed to the same extent (original value and values increased or decreased by 20 %) and the resulting change will be evaluated. Results are shown in Fig. 1.



(a) c_{11} **(b)** c_{12} **(c)** c_{13} **(d)** c_{33} **(e)** c_{55} **(f)** damping

Figure 1: Change of different parameters in simulation and their effect on impedance characteristic

As can be seen, impedance characteristic is most sensitive to change of c_{11}, c_{13} and c_{33}. Fluctuations of c_{12} and c_{55} caused only a small difference in comparison with previous ones. Change of damping influences only the amplitude to a small extent. There were no changes in the results when elements of s, ε and d matrix were changed, therefore these are not shown. We currently use the workplace to calibrate AE sensors, but future plans include this process to also simulate and optimize sensor parameters in advance before they are manufactured. The findings from these partial simulations will be used as a basis for which material parameters we must know exactly, or with how much tolerance, and how they may possibly affect the results.

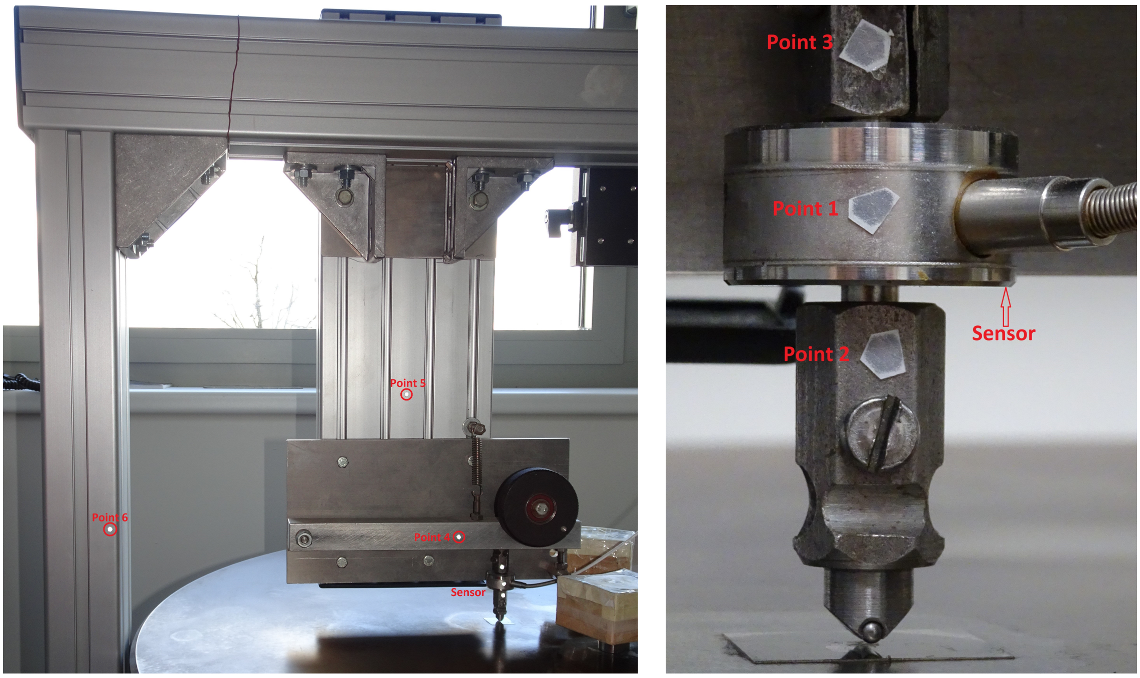
3 ISSUES WITH AE SENSOR CALIBRATION APARATURE

One of issues we encountered in the calibration using a step function - capillary break [3] (test equipment [4] is shown in Fig. 2) - was that the output signal from the force transducer had a superimposed harmonic component with a frequency of approximately 2 kHz after capillary refraction (Fig. 3). It is not a parameter that significantly affects the measurement of the output signal from the sensor, but it was an interesting topic for diagnosing the cause. One possible reason can be the signal is crosstalk on the measurement path or on the sampling card. However, since it is a frequency that is not usual and, moreover, it appears in the signal only after the refraction, it seems to be false option.

Another possible and very probable source of this signal may be the mechanical side of the whole structure, ie how the force sensor is mounted. After the capillary break, the structure can oscillate and the inertial mass can additionally affect on the force transducer, which would not only be statically relieved, but alternately stressed by periodic resonances. An experiment was performed to verify this possible source. One of the main problems is that it is not possible to perform the measurement typically with accelerometers, because the mounting of the sensor would dampen the possible resonance of the whole system with its inertial mass. Thus, the measurement was performed contactlessly using a laser interferometer Polytec OFV 5000 and the only effect was the adhesion of the reflector tape attached to the measured object, which is negligible.

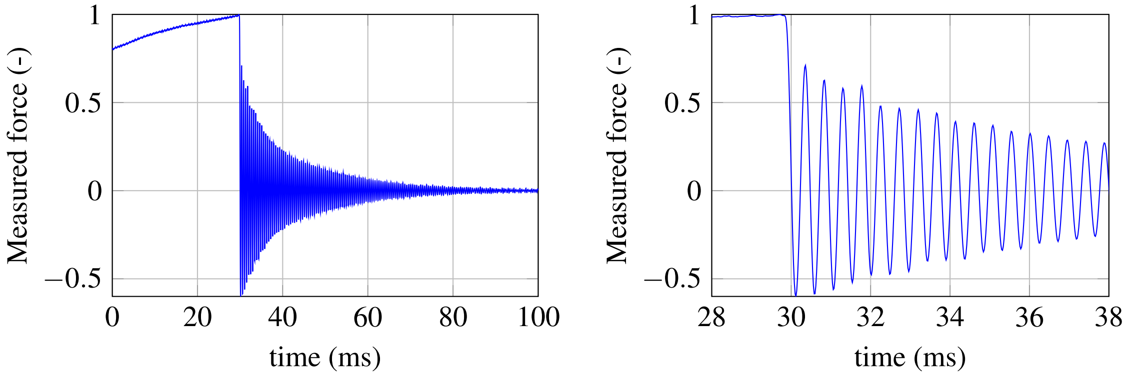
The measurements were performed in several places, first on the surface of the force transducer, then below and above it. To verify the possible clogging of the mechanical influence, the measurement was performed even at greater distances from the sensor (measurement points are shown in Fig. 2a). Result of one measurement (performed at the location of sensor, which is crucial), is shown in Fig. 4, where the parasite signal is also noticeable. The vibration velocity was also integrated to calculate a maximal unexpected displacement during the process. Results of all measurements are summed up in Table 1.

Results of the measurements show that this is not a crosstalk signal that would be difficult to diagnose,



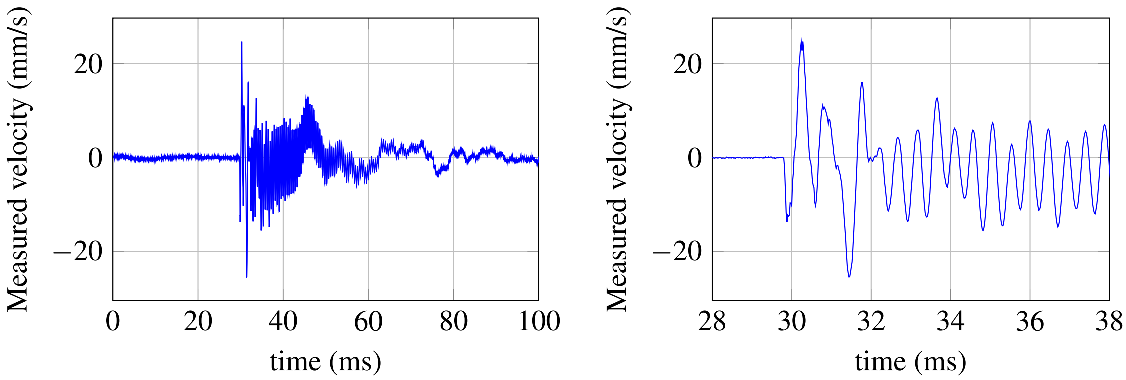
(a) Calibration stand **(b)** Force sensor

Figure 2: Measured equipent with reflector tapes



(a) Whole waveform **(b)** Detail

Figure 3: Typical waveform of measured force



(a) Whole waveform **(b)** Detail

Figure 4: Velocity measured at the sensor body

but it deals with a mechanical resonance of the system. It is evident the amplitude of examined frequency is decreasing with increasing distance from the sensor. Although the measurement was performed only in 1 axis, the trend is noticeable. There mechanic oscillations could be suppressed by adjusting the mounting of the force transducer, but since the measurement only evaluates the maximum amplitude of the force during capillary break, this is not necessary. Alternatively, it is possible to use a narrowband filter to smooth the signal, as the cause of this issue is known and it is static. Smoothing of the measured characteristic by Butterworth filter, 3rd order with boundary frequencies 1 000 to 3 000 kHz is shown in Fig. 5.

point n.	description	vibration velocity of 2140 Hz (mm/s)	maximal amplitude (μm)
1	sensor body	3.2	20
2	spike below sensor	3.61	20
3	attachment above sensor	0.38	20
4	place near to sensor	0.74	15
5	place farther from the sensor	0.16	6
6	external structure	0.065	2

Table 1: Comparison of measured results

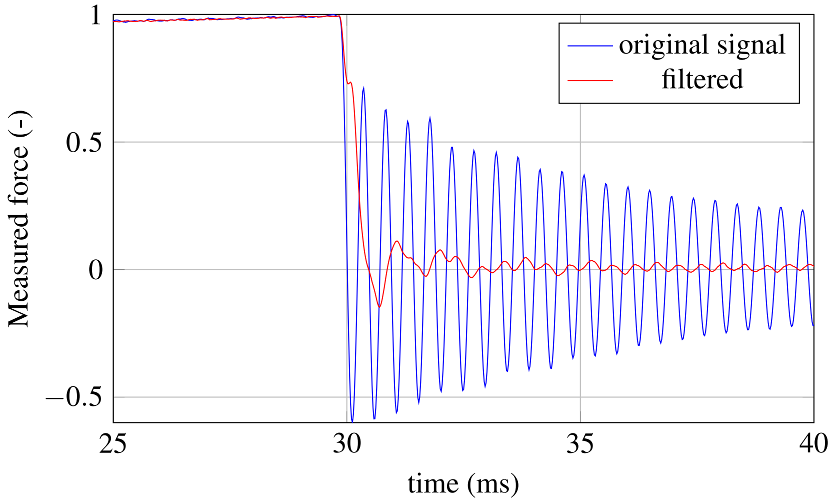


Figure 5: Comparison of original and filtered signal measured by force sensor

4 CONCLUSION

This paper studied finite element simulations of impedance characteristics of piezoelectric elements utilized in sensors of AE. Results showed biggest influence, when elements c_{11}, c_{13} and c_{33} of c matrix are changed. When characterizing these materials, it is necessary to pay increased attention to these parameters. The other elements of the matrix caused less modification of the impedance characteristics and as expected change in amplitude, when damping is varied. Based on the simulations, result were the same for changes of elements in matrices s, ε and d, they probably do not have link to impedance characteristic, or some features were omitted, which will be a topic of my next studies. Secondly, in issue with test stand for calibration of AE sensors was investigated, where output of force sensor was affected by parasite signal. Contactless measurement with laser interferometer allowed to discover the parasite signal is caused by resonance of the fixture and it means no threat for the measuring chain concerning previous measurements or measurements performed in the future.

ACKNOWLEDGEMENT

The completion of this paper was made possible by the grant No. FEKT-S-20-6205 - “Research in Automation, Cybernetics and Artificial Intelligence within Industry 4.0” financially supported by the Internal science fund of Brno University of Technology.

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