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# Improved determination of viscoelastic material parameters using a pulse-echo measurement setup

Dmitrij Dreiling [1], Dominik Itner [2], Tim Hetkämper [1], Carolin Birk [2], Hauke Gravenkamp [3], Bernd Henning [1]
[1] Measurement Engineering Group, Paderborn University, 33098 Paderborn, Germany
[2] Institute of Structural Analysis, University of Duisburg-Essen, 45141 Essen, Germany
[3] International Centre for Numerical Methods in Engineering (CIMNE), 08034 Barcelona, Spain
dreiling@emt.upb.de

**Abstract:**

Transmission measurements can be used to determine the frequency-dependent material parameters of polymers for simulative purposes. To achieve this goal, a hollow cylindrical sample is placed between two ultrasonic transducers. Hereafter, the material parameters are determined by ultrasound excitation in the MHz range and an inverse approach. However, the coupling conditions between the transducers and the sample is prone to uncertainties. Therefore, modeling of the setup for the inverse approach proves to be difficult. To reduce the uncertainties, this paper presents a measurement setup using a pulse-echo method in order to obtain frequency-dependent material parameters.

**Keywords: ultrasonic transducer, pulse-echo method, material characterisation, polymers, scaled boundary finite element method.**

### Motivation

In order to keep production costs low, typical design processes rely on simulation-based approaches. For the simulations, the knowledge of the material behaviour is a central issue. Especially for polymers, reliable material parameters are only measured quasi-statically by the manufacturers. However, there is a demand for frequency dependent parameters for simulation purposes. In order to determine material parameters of polymers up to 2.5 MHz, a transmission measurement setup was introduced in [1].

### Transmission measurement setup

The setup depicted in Fig. 1 consists of two transducers for transmitting and receiving acoustic waves through a hollow cylindrical polymer sample. Moreover, voltage gain amplifiers are used to amplify the electrical input and output signal. Otherwise, the received signals would be too small to evaluate, especially when investigating polymers with greater attenuation. By knowing both, the input and output, material parameters of a sample can be determined in an inverse approach by modelling the sample as a hollow cylindrical waveguide via an SBFE method [1, 2]. Previous studies of the measurement setup show a low sensitivity of the mechanical shear parameter $\mu_{\mathrm{L}}$ due to the uniform full surface excitation of the transducers [1]. In order to increase the sensitivity of the measurement setup, a non-uniform, segmented excitation was investigated by means of numerical simulations in [3]. The simulation results show that the sensitivity can be increased by a segmented excitation. For this purpose, new ultrasonic transducers with 1-3 piezoelectric composites but structured electrodes were designed [4]. To apply these in the measurement setup and increase sensitivity and reproducibility, further modifications to the measurement setup are presented in this work.

*Fig. 1. Two ultrasonic transducers (white) with a polymer sample in between.*

### Pulse-echo measurement setup

In the case of a full-surface excitation of a sample as in Fig. 1, results are insensitive to the exact position of the sample on the transducer's contact surface. Whereas a non-uniform excitation requires a perfect alignment of both transducers in order to match the waveguide simulations in the inverse approach. For example, if a transducer with two sector-segments (half-half) is used for transmitting and another for receiving, it is difficult to place them on the sample and align the facing sectors of both transducers perfectly. Because of this difficult alignment, the uncertainty increases, and the reproducibility of a measurement decreases. One way to solve this problem is to use solely one transducer to transmit and receive the signal. The ultrasound transducers are developed for broadband use and are therefore suitable for transmitting and receiving. Due to the transition from polymer to air, the transmitted wave is reflected at the end face of the sample. The reflection occurs because of a large acoustic impedance difference. In addition, the forward model becomes simpler because only one transducer needs to be characterised and modeled.

Fig. 2 shows the concept for the new measurement setup. As already mentioned, voltage gain amplifiers are used to amplify the electrical signals. Due to the amplifiers, a direct connection between the transmit and receive path would lead to hardware damage. Therefore, a switch circuit is designed to prevent a short circuit between the transmitting amplifier $A_1$ and the receiving amplifier $A_2$. Due to a low contact resistance of $3.6\,\Omega$, the high symmetrical input voltage range of $\pm 15\,\mathrm{V}$ and the sufficient maximum current, the DG470 from Vishey is well suited for the presented switch-circuit.

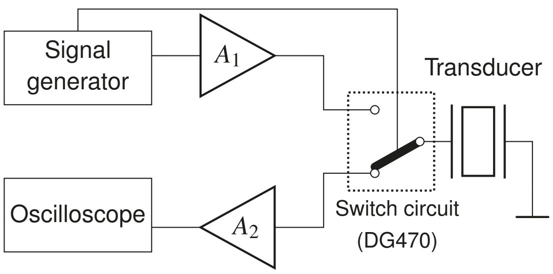


*Fig. 2. The realised concept of the pulse-echo measurement setup.*

## Measurement results

Fig. 3 shows a result achieved with the pulse-echo measurement setup in comparison to a simulation via the SBFE method. In this measurement, a polyether ether ketone (PEEK) sample of $17\,\mathrm{mm}$ length and $18\,\mathrm{mm}$ outer diameter is investigated. Fig. 3 shows the typical three wave packets, resulting from mode conversion of the transmitted wave packet. While the time of arrival of the first packet mainly depends on the longitudinal velocity, the time of arrivals of the other wave packets are additionally depend on the transverse velocity. The simulation shows good agreement with the measurement. While the first wave packet is already in good agreement, the second and third wave packets show clearer differences. This is because the inverse method has not yet been tuned for the pulse-echo setup. The switch is not yet sufficiently represented in the model and the selected damping model has not been finally validated. This is particularly noticeable in the pulse-echo measurement method, where the sound wave has to travel twice the distance.

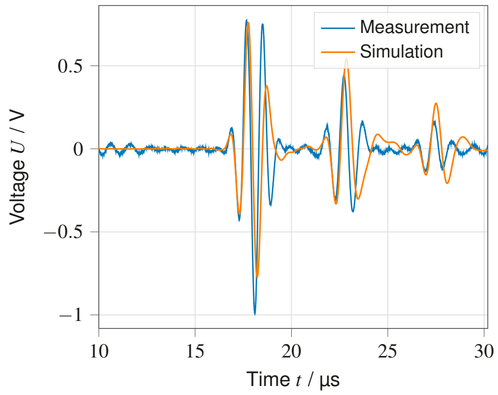


*Fig. 3. Measurement result and simulation of a polyether ether ketone (PEEK) sample.*

## Conclusion

The modification of a transmission measurement setup to a pulse-echo setup is possible. By using a switching circuit, it is feasible to make comparable measurements, which can be used in an inverse approach to determine material parameters of polymer samples. Further investigations with regard to the chosen damping model and the reproducibility of the results have to be carried out.

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