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Immersion Measurment of Laser-Induced Ultrasound in Plastics

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Abstract.
The paper considers measurement of laser-induced ultrasound in plastic plate immersed in water by piezoelectric thin film transducer based on polyvinilidenfluoride. The electrical signal induced on the electrodes of the detector is amplified by means of two types of amplifiers. The first amplifier operates in «voltage» detection mode, where the signal is proportional to the time profile of pressure pulse, while the second type of amplifier operates in «current» detection mode, where the signal is proportional to the time derivative of the pressure pulse. The comparisons of time profiles and spectra of signals are presented.

Keywords: Laser-Induced Ultrasound; Polyvinilidenfluoride

Introduction

The applications of ultrasonic technique for evaluation of elastic properties of the materials are topical issue. The broader spectrum and shorter pressure pulses possess some advantages for diagnostics. Optoacoustic conversion implies an excitation of the ultrasound by nanosecond laser pulses [1]. The laser-induced probe acoustic pulse demonstrates expressed compression phase while duration is comparable with the duration of the laser pulse. The spot of the laser radiation on the absorbing material defines the efficiency of excitation of different elastic modes such as longitudinal, shear and surface acoustic waves. The excitation of longitudinal pulses by wide laser spot in the plate is the simplest case, which can be considered in one-dimensional approach for evaluation of elastic modulus by primary waves. The probe pulse arrives to the opposite side of the plate and can be detected by variety of methods, which demonstrate some advantages and disadvantages [2]. The following echoes of the primary pulse can be detected for the estimation of velocity and attenuation of the longitudinal waves in broadband. The spectra of sequences of the pulses are getting narrower during the propagation these changes contain the information about microstructure and inhomogeneities such as, for instance, length of dislocations, their density and mean values grain size in metals. The absorption of the ultrasound in plastics are mainly due to the viscoelastic phenomenon.
Piezoelectric detection is the most widely used in ultrasonic diagnostics. It is assumed that the excitation of ultrasound is carried out by laser pulse that simplifies general task and requires only the proper detection of the probe ultrasonic pulse. In general case the circuits of preamplifiers are used to increase the electrical signal. The circuit of the preamplifier defines the operating mode. There are two established approaches for the sensors the first scheme is 'short circuit' or 'current' detection mode, where the low impedance resistor of about 50 Ohms is in parallel to the capacitance of the sensor and condition $R < 1/\omega C_s$ is fulfilled. The 'short circuit' mode allows detection of high frequency part of the induced pulse spectrum while 'voltage' mode is working in the narrower band because of the slower charge flow. The high frequency limit of the operating bandwidth should satisfy the condition $f < 1/T$ in the 'short

circuits'. A calculated time constant of ~3.8 ns allows the detection of the frequencies up to 200 MHz. The current across the resistor according to the Ohm's law is as:

$$\frac{dq(t)}{dt} = \frac{U}{R}. \tag{1}$$

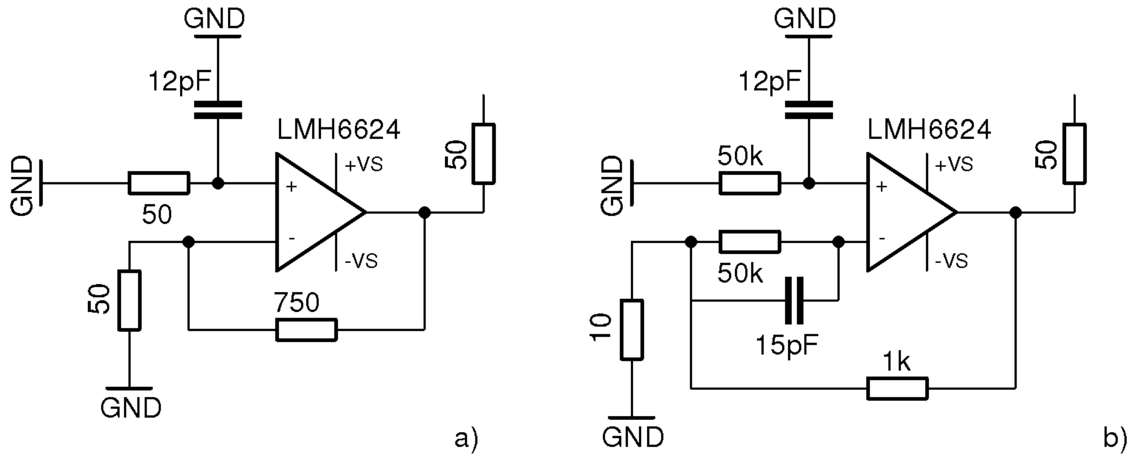

Fig. 1 Preamplifiers' circuits
(a) relates to the 'short circuits' or 'current' detection
and (b) corresponds to 'voltage' detection modes

The displaced charge is proportional to the instantaneous mean stress inside the film that can be written as follows [3]:

$$q(t) = A\frac{d_{33}}{h}\int_0^h P(x,t)dx, \tag{2}$$

where d_{33} is the piezoelectric charge constant, A is the area of the sensor, h is the thickness of the foil, $P(x, t)$ is the pressure field including counter propagating waves reflected by backing material. This pressure field depends on the thickness of the covering protective aluminum foil and the acoustical impedances of all materials.
The calculation of the voltage yields the following expression:

$$U(t) = R\frac{dq}{dt} = R\frac{d_{33}A}{h}\int_0^h \frac{d}{dt}P(x,t)\,dx. \tag{3}$$

The expression shows that the voltage drop signal is proportional to the area of the sensor that is true if the pressure pulse with the plane wavefront covers the larger area of piezoelectric film then the stronger current flows through the resistor. The proportionality to the value of the resistor increases the sensitivity with the decreasing of the bandwidth. It is noteworthy that measured signal is proportional to the derivative of the pressure profile over time that highlights the inefficiency of the 'short circuit' or 'current' mode for the measurement of the slow variations or the signals composed by low frequencies. The opposite situation is in the case of voltage detection mode where the low frequencies are conserved but high frequencies fast decay [4].
The high impedance resistor placed in parallel to the capacitor of the sensor increases the sensitivity in the low frequency range and omits the high frequencies. The simplest and limit case of infinite impedance of sensor leads to the following expression:

$$U(t) = \frac{q(t)}{C_s} = g_{33}\int_0^h P(x,t)\,dx \qquad (4)$$

As the charge and capacity are proportional to the area the expression (4) shows that voltage dependence mainly proportional to the integral value of the pressure over the thickness. The time dependence gives also some integrated pressure value in comparison with 'current' detection mode.

Results

The experimental setup employs laser LOTIS Tii model LS-2131M-10 operating on the wavelength of 532 nm in Q-switch mode with pulse energy about 10 mJ and duration of pulse about 10 ns. The size of the laser spot on the plastic surface was about 5 mm diameter. The plate of black ABS plastic with the thickness of 3.8 mm was illuminated by laser radiation. The detection of the ultrasound was carried out from the opposite side of the specimen by piezoelectric transducer based on 25 µm thick polarized PVDF film. The diameter of the sensitive element is 2 mm. The preamplifiers were connected to the transducer via coaxial cable. The electrical signals were measured by digital oscilloscope with bandwidth of 200 MHz and 1 GHz sampling rate. The moment of laser pulse excitation was detected by PIN photodiode Hamamatsu S5971-1.

The free side of the specimen was illuminated by laser pulse, while the opposite side was in contact with 2 mm thick water layer which provided acoustical contact between specimen and transducer. The transducer was connected to one of the preamplifiers. The signals separately obtained by two preamplifiers are presented in the Fig.2. The peak-to-peak amplitude of amplifier operating in 'Voltage' detection mode is at least 3.5 times higher in comparison with the signal obtained in 'Current' detection mode. The laser power density was kept for both measurements. The spectra of the signals are in the Fig.3. The dynamic range is about 40 dB for each case but the sensitivity to the low frequencies is higher in the case of 'Voltage' detection mode that is in agreement with calculations.

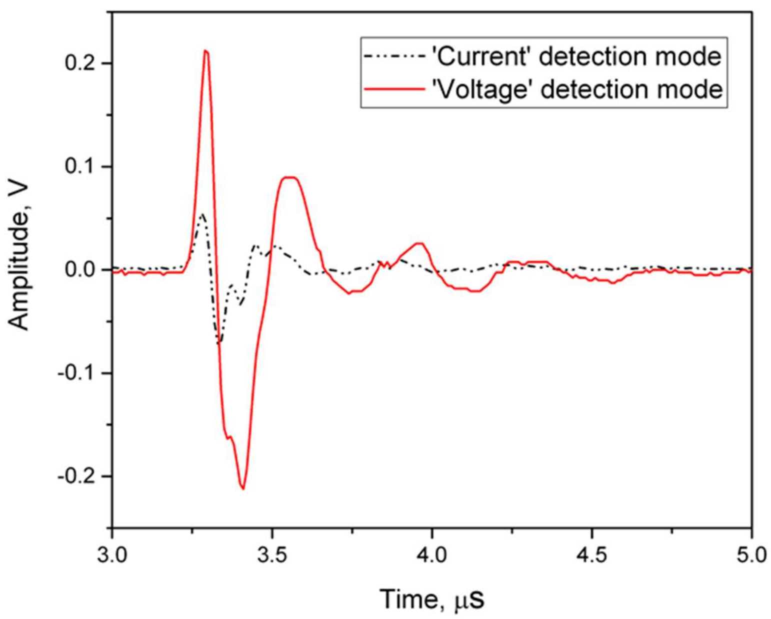

Fig.2. Signals detected by transducer with preamplifiers operating in voltage and current detection modes

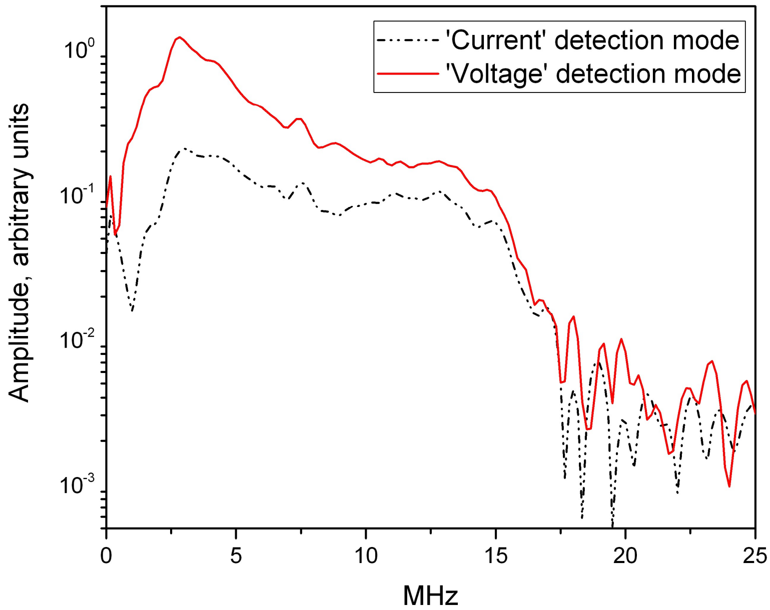

Fig. 3. Spectra of the signals detected by transducer with preamplifiers operating in 'voltage' and 'current' detection modes.

Conclusions

The features of piezoelectric detection of laser-induced ultrasonic pulses are considered. Sensors can measure longitudinal ultrasonic pulses by immersion technique both in the metals and in the polymer composites. There are two types of preamplifiers' circuits for broadband piezoelectric sensors based on 25 μm thick PVDF film. The broadband detection of the frequencies in the range from 2 to 15 MHz requires low value resistor in parallel to the capacity of the sensor that is called 'short circuit' or 'current' detection mode where the measured signal is proportional to the time derivative of the mean pressure field in PVDF film. The 'voltage' mode allows to increase sensitivity in the low frequency bandwidth up to 15 MHz.

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