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Transmission of Larger Amplitude Ultrasound with SiC Transistor Pulser for Subharmonic Signal Measurements at Closed Cracks

Ren Koda[a]*, Tsuyoshi Mihara[a], Katsuhiro Inoue[b], Goki Konishi[b], Yoshio Udagawa[c]

[a]Grad. School of Eng., Tohoku University, Aoba 6-6-02, Aoba-ku, Sendai 980-8579 Japan
[b]Grad. School Sci. Eng., Univ. of Toyama, 3190 Gofuku,Toyama 930-8555, Japan.
[c] Imaging Supersonic Laboratories Co.,Ltd., 12-7 Tezukayamanaka-machi, Nara 631-0063, Japan

Abstract

With measurements using the Subharmonic Phased Array for Crack Evaluation system, transmission of large-amplitude ultrasound is required to generate subharmonics near closed cracks. We designed a new pulser using a SiC transistor making larger currents available with low output impedance to generate large-amplitude signals. We report on the efficacies of the pulser in comparison with a conventional pulser. We investigated combinations of excitations from several transducers and the two pulsers by measuring signal amplitude, effective voltage, and electric current for each transducer. By applying larger electric currents, larger excitation amplitudes were produced, even when the capacitance of transducer was larger.

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Keywords: Subharmonic signal; Large amplitude ultrasound; SiC transistor pulser; Cracks evaluation

1. Introduction

Since the basic study reported by Buck et al. three decades ago [1], nonlinear ultrasound signals are promising to detect and assess closed cracks. The measurements of signals are based on the detection of their nonlinear components, i.e., superharmonics reported by Okada et al. [2] or subharmonics by Solodov et al. [3] generated by the interaction of large-amplitude ultrasonic signals with closed cracks. Measurements using the Subharmonic Phased

* Corresponding author. Tel.: +81-22-795-7359; fax: +81-22-795-4298
E-mail address: ren.koda.a4@tohoku.ac.jp

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Array for Crack Evaluation (SPACE) system, which is an imaging system that exploits the features of subharmonics in ultrasound signals generated at closed cracks, have been reported by Ohara et al. [4]. Although SPACE measurements enable better selectivity for closed cracks than that of any other nonlinear ultrasound system, Mihara and Ishida reported that the subharmonics appear only when the amplitude of the incident wave is larger than a certain threshold [5].

Mihara et al. have reported on a laminated transducer [6] that generates a larger signal amplitude. Moreover, higher voltage excitations were needed to produce these larger amplitudes.

However, conventional pulsers have limitations in generating larger signal amplitudes at the higher voltage excitations for two reasons: 1) an impedance mismatch between transducer and pulser, and 2) an unsustainable electric current at high voltage because of the powerless in the pulser. To overcome these limitations, we designed a new pulser using a SiC transistor to have a large current available.

In this study, we developed the SiC transistor pulser with low output impedance to generate high amplitude ultrasound signals. Here we report on the efficacies of the novel pulser excitation by comparing several transducers with different impedance.

2. Experimental methods

2.1. Impedance variations of transducers

To evaluate the drivability of the pulser, we prepared several transducers. Each transducer has an impedance that depend on the materials of the elements. Three commercially available piezoelectric materials were investigated, M6, C6, and C9, (Fuji Ceramics Corp., Fujinomiya, Japan). These are piezoceramics based on PZT, which is commonly used in typical piezo-actuators. Table I lists the piezoelectric properties of the constituent materials used in this study. Among these PZT piezoceramics, C9 exhibits the highest value for the piezoelectric charge constant d_{33} whereas M6 exhibits the lowest value. However, in terms of dielectric constants, $\varepsilon_{33}^T/\varepsilon_0$, which is a coefficient relevant to the capacitance of the transducer, M6 has the lowest value and C9 has the highest. These elements of the transducers have the same properties in terms of shape (square), physical size (20 × 20 mm^2), and central frequency (4 MHz). The thicknesses of the elements, which depend on the central frequency and material, are about 0.54 mm (M6), 0.51 mm (C6), and 0.51 mm (C9). The components of the transducers are a face plate, an element, an outer case, and a coaxial cable connected using solder. The case was packed with sealing plastic.

Table II lists transducer properties that depend on each element. The impedance and capacitance of each transducer were measured using an impedance analyzer (IM 3570, Hioki E.E. Corp., Nagano, Japan).

Table 1. Piezoelectric properties of the ceramic materials.

Materials	d_{33} [$\times 10^{-12}$ m/V]	$\varepsilon_{33}^T/\varepsilon_0$
M6	71	215
C6	472	2130
C9	718	6640

Table 2. Properties of the transducer elements.

Materials	Area [mm^2]	Impedance [Ω]*	Capacitance [nF]*
M6	400 (20 × 20)	39.1	1.4
C6	400 (20 × 20)	6.4	11.9
C9	400 (20 × 20)	3.5	35.3

*measured by impedance analyzer

2.2. Experimental setup

We prepared two pulsers. One is a conventional pulser (Pulser I), which has a highest voltage setting of 600 V and an output impedance of 50 Ω. The other is the new SiC transistor pulser (Pulser II), which has a highest voltage setting of 1200 V and an output impedance of 0.5 Ω. We designed for the lowest possible output impedance because higher output impedances are easy to achieve by inserting load resistors in series whereas setting lower impedances is difficult.

To measure the displacement waveform of the transducers accurately in the evaluation of the generated signals for each pulser, we constructed an experimental set up (Fig. 1) to record basic measurements such as the excitation voltage and applied electric current of the transducers. Displacements of the face plate of each transducer were measured using a laser vibrometer (OFV-505, Polytec, Waldbronn, Germany). A 1000:1 probe (HVP-39pro, Pintek, New Taipei, Taiwan) was connected to an oscilloscope from the pulser to measure the excitation voltage at the transducer. A small resistor of 0.05 Ω was connected between transducer and pulser to measure the electric current applied to the transducer. By observing differences in voltage in the small resistor and calibrating for 1 V : 20 A, the electric current is obtained.

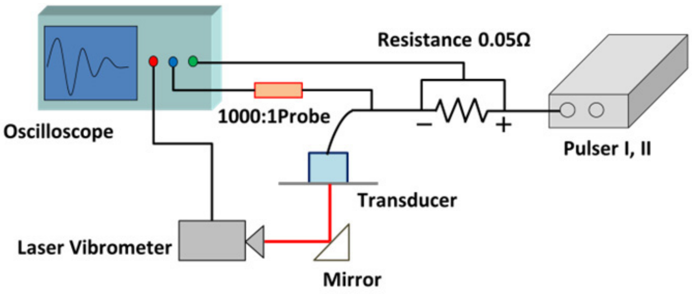

Fig. 1. Schematic of the experimental setup for measurements of amplitude, voltage, and current of ultrasound signals.

3. Results and Discussion

Figure 2 shows the displacement waveforms of ultrasound signals, and the voltage and current for the C9 transducer when driven with a 5-cycle tone burst of 4-MHz longitudinal waves by (a) Pulser I and (b) Pulser II. The voltage was set to 100 V and 125 V for Pulsers I and II, respectively. Crossed horizontal lines and arrows, which are drawn on the voltage and current graphs, indicate actual measuring range. In Fig. 2(a), the electric current was insufficient and hence the effective voltage was measured at only 30 V. In consequence, the displacement amplitude was not large enough. In Fig. 2(b), a large electrical current is observed particularly the first two cycles and an excitation of about 60 V was produced. The voltage was maintained and a larger amplitude was observed.

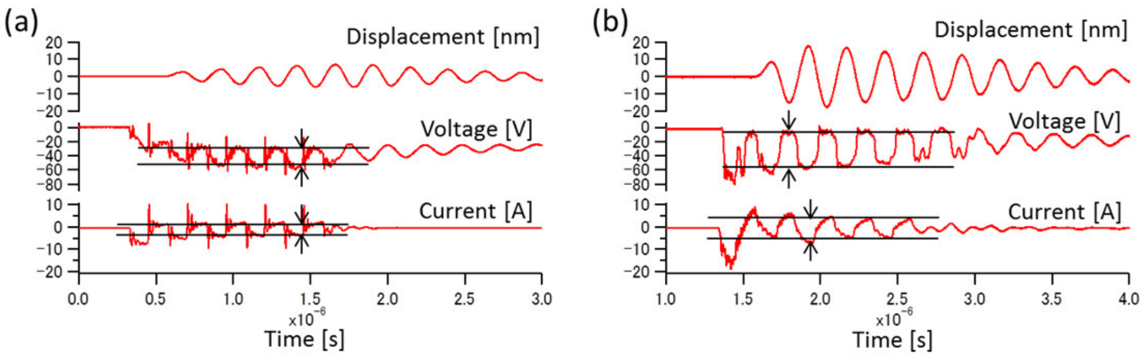

Fig. 2. Waveforms of ultrasound signal, voltage and current driven by (a) Pulser I and (b) Pulser II.

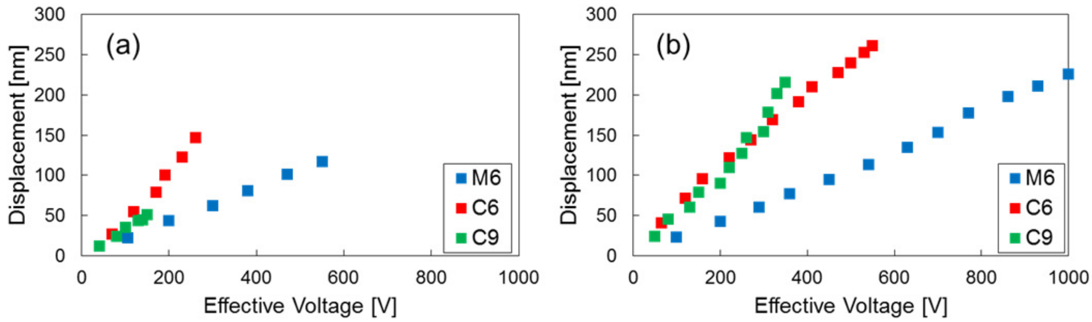

Fig. 3. Amplitude of ultrasound signal vs. excitation voltage for the transducers driven by (a) Pulser I and (b) Pulser II.

Figures 3(a) and (b) show the effective voltage dependence of the displacement amplitude of an ultrasound signal for the transducers driven by Pulsers I and II, respectively. In Fig. 3(a), the setting voltages were set from 100 to 600 V with Pulser I. In particular, the C9 transducer shows a larger voltage drop, which was defined as the setting voltage – the effective voltage at the transducer. In terms of the effective voltage range, C9 was affected only a quarter relative to M6. The gradient of the plots for C9 is insufficient whereas magnitude of d_{33} is the highest. In Fig. 3(b), the transducers were driven with the new pulser, Pulser II. The setting voltages were set from 125 to 1200 V. The voltage drop for C9 improves compared with that in Fig. 3(a). The gradients of the graphs for the C6 and C9 transducers are about two times larger than that for M6. In Figs. 3(a)(b), when the setting voltage was 600 V with both pulser, each the effective voltage actually measured at the C6, C9 transducer was about 260 V(C6), 150 V(C9) with Pulser I, 320 V(C6), 220 V(C9) with Pulser II, respectively. Under Pulser II excitation, larger effective voltages could be applied because of the effect of low output impedance of pulser (0.5 Ω); i.e. reduced the voltage dividing between pulser and transducer. However, the voltage drop for the C9 transducers remains still large because C9 transducers have large capacitance of about 35 nF. In this instance, a pulser producing higher currents is required.

4. Conclusions

We developed a new pulser using a SiC transistor that produced larger currents to enable large amplitude ultrasound signals to be generated. Such excitations can even be produced when the capacitance of the transducer is larger. Additionally, with the matched pulser in impedance, voltage drop, which depend on the transducer impedance, decreased compared with conventional pulser excitations.

In the future, we will be improving our pulser using a new SiC transistor that responds to higher frequencies and provides additional current available.

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