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Evaluation of material nonlinearities using rectangular pulse trains for excitation

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Abstract

Aim of the presented investigation was to evaluate the suitability of the rectangular pulse trains for nonlinear material parameters study. It was assumed that if duty cycle of the excitation is 50% then second harmonic is significantly reduced. Excitation signal frequency was fixed to the A/D sampling frequency and signal carefully gated to reduce the signal leak into neighbouring frequency bins. Sine wave correlation was used to extract the harmonics content. Results of nonlinear parameters measurement for several materials are given as performance comparison.

Keywords: Nonlinear ultrasound; rectangular pulse trains; transducer excitation; ultrasonic pulser.

1. Introduction

Nonlinear acoustic parameters of the material carry additional information on material properties see Bjørnø (2010) or Goursolle (2005). Nonlinearity parameters application for materials fatigue has been suggested by Bruno et al. (2009). Solodov (1998) suggested exploring nonlinear ultrasound for nondestructive testing.

High power linear power amplifiers are required which are bulky, expensive and suffer low electronics efficiency. Conventional ultrasonic inspection equipment is using the rectangular pulses for excitation. Such equipment is relatively simple and small. Aim of the presented research was to evaluate whether rectangular excitation signals can

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be used for nonlinearity study. Two assumptions were used: i) if duty cycle of the excitation is 50 % then second harmonic is significantly reduced; ii) if excitation signal frequency is tightly fixed to the A/D converter sampling frequency, then there is no signal leak into neighbouring frequency bins. Performance comparison of linear and rectangular excitation equipment is presented and experimental results for several materials are given.

2. Experiment techniques

Three experiment setups were used: i) excitation using linear output stage and sinusoidal toneburst excitation; ii) excitation using fixed voltage rectangular wave toneburst pulser with succeeding attenuation of the output signal and iii) variable voltage rectangular wave toneburst pulser with direct drive of the ultrasonic transducer. Linear output stage excitation experiment (further labeled as *Sin*) setup is presented in Fig.1.

Direct digital synthesis (DDS) generator was used to produce the continuous wave (CW) signal. CW signal was gated to produce the sinewave toneburst. DDS was synchronized to the gating pulse in order to produce fixed phase CW toneburst. Output of DDS generator was regulated using programmable (0-63) dB attenuator. Attenuator output was used to drive linear 40 dB gain power amplifier. Two ADA4870 amplifiers were driving the output transformer in full bridge configuration. Transformer used binocular ferrite bead BN-43-7051 with 2 turns primary and 8 turns secondary. Amplifier output (240 Vpp max) was measured using 100:1 voltage divider and 10 dB attenuator. Signal was sampled using 10 bit 100 Ms/s A/D converter. Sample was inserted between two transducers using clamp presented in Fig. 1a. Wideband composite 2 MHz transducer TF2C6N was used for excitation and 5 MHz transducer TF5C6L was used for reception. Setup follows presented in Ren (2015). Signal received by transducer was fed into programmable (0-63) dB attenuator, amplified by 10 dB and sampled by another A/D converter channel. Both A/D converter channels and DDS share the same clock frequency. Therefore harmonic amplitudes of the received and transmitted signal can be easily estimated using sine–wave correlation (SWC see Svilainis et al. (2015)).

Second setup (further labeled as *RectAtt*) used rectangular wave toneburst, produced by high voltage pulser, capable of arbitrary position and width pulse (APWP) trains. Setup configuration is presented in Fig.2a. Pulser description can be found in Svilainis et al. (2015). Two power MOSFETs were driving the output transformer in push-pull configuration. Pulser was set to provide 200 Vpp output. In order to keep pulser signal parameters stable pulser output was fed to transducer via programmable (0-63) dB high power attenuator. This signal was routed for ADC measurements using 100:1 divider and 10 dB fixed attenuator. Signal received on the opposite side of the sample was fed into programmable (0-63) dB attenuator, amplified 10 dB and sampled by same A/D converter. Pulser was synchronized with A/D converter in order to allow harmonics amplitudes estimation using SWC.

Third setup (labeled as *RectHV*) used rectangular wave toneburst, produced by the same high voltage pulser, which was directly fed into transmitting transducer. Setup configuration is presented in Fig.2b. Pulser output voltage swing was varied by programming its high voltage power supply. Signal on transmitting transducer contacts was routed for ADC measurements using 20:1 divider and variable (0-63) dB attenuator.

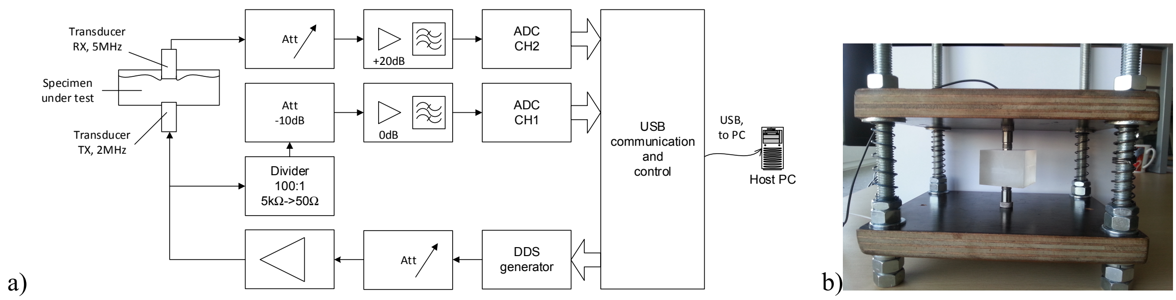

Fig. 1. Setup (a) used for linear output sinewave toneburst excitation (*Sin*) and test fixture (b) used for sample and transducers alignment.

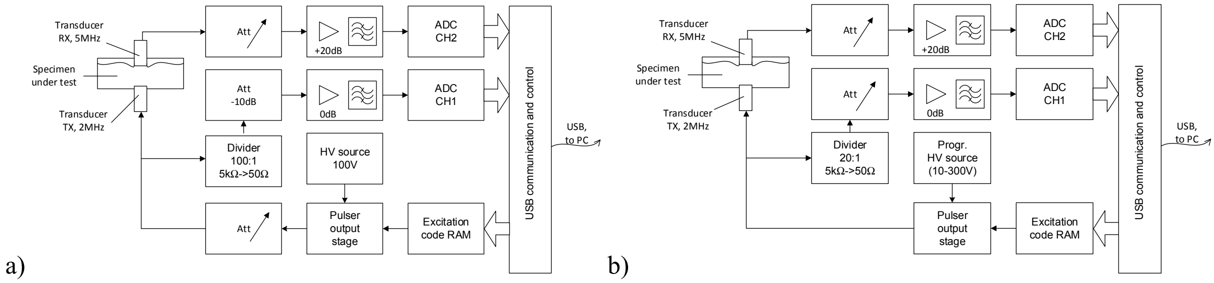

Fig. 2. Setup used for rectangular wave toneburst excitation using high voltage signal attenuation (a, *RectAtt*). Setup used for rectangular wave toneburst excitation using direct high voltage transducer drive (b *RectHV*).

The rest of setup and transducers were the same. Excitation toneburst was 2 MHz 9 µs duration (18 periods). Received signals were carefully gated to produce perfect cyclic signal. Amplitude of the excitation signal was varied from 1.2Vpp to 250Vpp for *Sin* setup, from 1Vpp to 200Vpp for *RectAtt* setup and from 20Vpp to 600Vpp for *RectHV* setup. First test used transducers coupled face to face in order to investigate the nonlinearities (see Jiang (2000)) of the system (labeled as *F2F*). Water was selected for performance investigation because of high nonlinearity and easy coupling (55 mm transducers spacing; further labeled as *H2O*). Lead was used because of low nonlinearity (14.81 mm thick; further labeled as *Pb*). Plexiglas was included into investigation because of intermediate nonlinearity (30.66 mm thick; further labeled as *PMMA*). Polyurethane potting compound PPC180 was expected to exhibit some nonlinearity because of trapped air bubbles (7.5 mm thick; further labeled as *PC180*). Because of the same reason (trapped air) sputtered glass fiber composite was used in investigations (6.95 mm thick; further labeled as *GFRP*).

3. Results and discussion

Fundamental (2 MHz) and second (4 MHz) harmonics magnitudes, U_{RX1} and U_{RX2} correspondingly, were extracted from properly gated output signal. Result plots for second harmonic vs. fundamental are presented in Fig.3.

Investigation indicates that results for same results are obtained for pure sinusoidal toneburst using linear drive and rectangular wave toneburst. Zoomed-in version of the plot reveals minor discrepancies. Harmonics were analyzed for quadratic behavior, by approximating the Fig. 3 results by power function:

$$U_{RX2} = aU_{RX1}^{b} \tag{2}$$

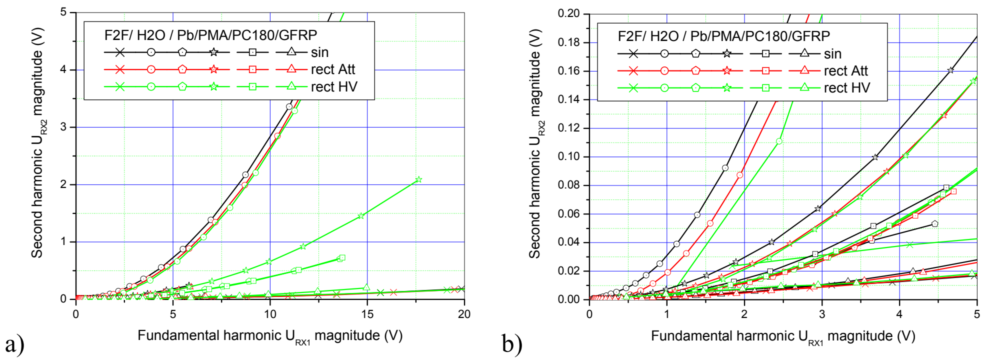

Fig. 3. Nonlinearity measurement results: (a) full scale and (b) zoom-in plots for all tested setups and materials.

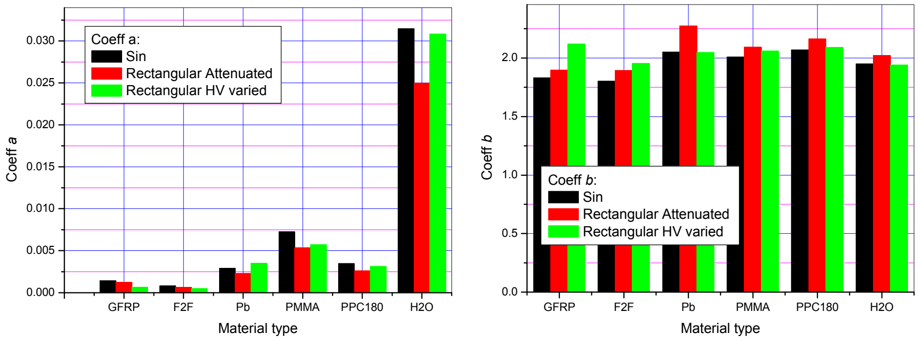

Fig. 4. Nonlinearity approximation by power law coefficients (a) and (b).

Resulting interpolation coefficients *a* and *b* are presented in Fig.4. It can be seen that coefficient b is 2. According to Bruno et al. (2009) for a completely hysteretic system *b* should be equal to 2 for second harmonic dependence. Very small coefficients *a* were found for direct transducers contact arrangement. Despite higher excitation amplitudes *a* were smallest for rectangular toneburst excitation. Coefficients established using purely harmonic and rectangular weave excitation match. Therefore we draw conclusion that rectangular wave signals can be used for materials acoustic nonlinearity studies.

4. Conclusion

It was demonstrated that rectangular signal can be used for materials acoustic nonlinearity studies. Sine wave correlation greatly simplifies harmonics extraction. For that purpose excitation and acquisition channels have to be synchronized. Because of binary nature of rectangular wave such synchronization is much easier established. Binary excitation simplifies also the excitation equipment and increases generator efficiency. Much higher voltages can be achieved with less stress on excitation electronics.

Acknowledgements

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