Simplified experimental technique to extract the acoustic radiation induced static strain in solids

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Simplified experimental technique to extract the acoustic radiation induced static strain in solids

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A simplified experimental technique to measure the acoustic radiation induced static strain during the longitudinal acoustic wave propagation in solids is proposed. Experiments have been carried out to extract the static displacement (dc) component without resorting to electronic filters, as in the case of previously reported experimental measurements. This prevents the influence of the filter time response characteristics on the measurement. The dependence of the static displacement amplitude on the square of the fundamental amplitude of the input wave, its being independent of the burst width of the tone burst, and its abnormal variation at low input amplitudes are reported. © *2007 American Institute of Physics*. [DOI: 10.1063/1.2793181]

The propagation of an ultrasonic wave through a material leads to generation of the harmonics of the original wave due to the nonlinearities in the stress strain relation of the material. Such nonlinearities lead to the generation of a static displacement component in addition to the generation of higher harmonics. Though this was theoretically explored by Thurston and Shapiro,[1] it did not receive much attention until the work of Cantrell[2] and Yost and Cantrell[3] on this topic. Cantrell proposed a theory for the generation of the static displacement component and showed that it depends on the material nonlinearity parameter beta (β).

Yost and Cantrell[3] carried out experiments wherein he used low pass filters on the receiver side to filter out the ac component and extract the dc component. Yost and Cantrell[3] verified the dependence of the static displacement component on the square of the input amplitude and on the burst width of the tone burst. Following Cantrell's work the topic was not studied for two decades until recently when Jacob *et al.*[4] reported interesting experimental results which agreed with most of Cantrell's observations but also contradicted certain aspects. Jacob *et al.* suggested that the filters used in the experiments of Yost and Cantrell interfered with the extraction of the dc component and they carried out systematic experiments to explore the dependence of the extracted dc component on the cutoff frequency of the low pass filter. They verified the dependence of the static displacement on the square of the input amplitude and also concluded that the static displacement component generated depends directly on the distance of propagation and is independent of the burst width of the tone burst, contradicting the previous conclusion of Yost and Cantrell on this aspect.

This paper aims at developing a simplified experimental procedure to extract the static displacement component without using the filters which might interfere with the extraction of the static displacement component. Due to the induced static displacement component, there is an asymmetry induced in the wave and the absolute values of the positive and negative peaks are not the same. One-half of the difference between these absolute values gives the static displacement component. The dependence of the static displacement component on the square of the input amplitude and its being independent of the burst width of the tone burst are verified using the proposed experimental technique, thus supporting the observation of Jacob *et al.* The abnormal behavior of the static displacement component's dependence on the input amplitude is also reported.

The experimental setup is a typical one used for harmonic generation experiment. A computer controlled transmitter-receiver (RITEC Advanced Measurement system (RAM)-5000) is used to transmit a sinusoidal tone burst into the aluminum alloy AA7175-T7351 sample with thickness of 2.5 cm, with planar polished faces using a 5 MHz (Olympus NDT Panametrics V110) ultrasonic lead zirconic titanate (PZT) based transducer with a diameter of 8.8 mm. The RITEC gated rf amplifier module is designed to derive the very high power rf bursts needed for modern transducers. The output from the sample is received using a wide banded (7–20 MHz Olympus NDT Panametrics V113) PZT transducer also with a diameter of 8.8 mm. The signal from the receiver transducer is digitized using a 400 MHz bandwidth Agilent 54621A digital storage oscilloscope.

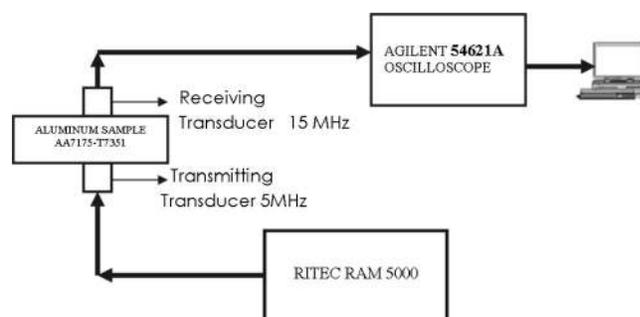The digitized data from the oscilloscope are transferred to a computer through Agilent GPIB 83357A interface cable

FIG. 1. Schematic of the experimental setup.

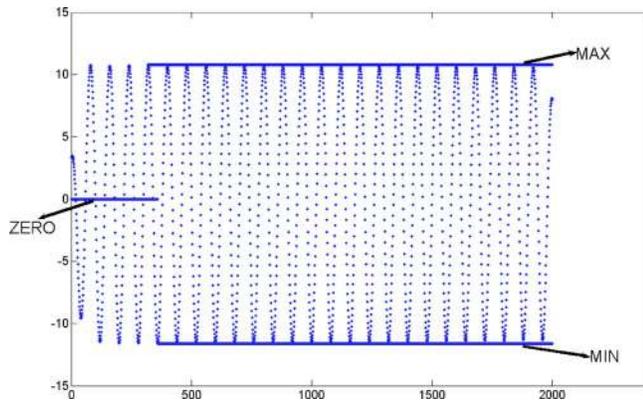a)Author to whom correspondence should be addressed. Electronic mail: balas@iitm.ac.in

FIG. 2. (Color online) A typical signal output from the experiments on the Al alloy sample showing the automated detection of the maximum and minimum values and the zero value of the signal that is automated in MATLAB.

FIG. 4. (Color online) Test for repeatability for multiple trials on the AA7175-T7351 samples showing the variation of A_{dc} with A_1^2 for two typical trials.

with 2000 data points per window. The oscilloscope was set to zero using the ground as reference to ensure that there is no asymmetry introduced from the oscilloscope. This exercise is done every time the power level is changed. A schematic of the experimental set up is shown in Fig. 1.

Figure 2 shows the typical time domain data extracted from the aluminum alloy AA7175 T7351 sample for 100% power level in RAM 5000 with 20 cycles. It can be seen that there is an asymmetry in the wave due to the generated static displacement component. A simple MATLAB code has been written to extract the positive and negative peaks and hence extract the static displacement component. Since all the peaks may not be of equal magnitude, the average value of all the positive and negative peaks over all the cycles has been used in the calculations.

Figure 3 shows a plot of the variation of static displacement component versus the square of the fundamental amplitude. From the straight line fit it can be seen that the static displacement component varies as the square of the fundamental amplitude.

To ensure the reproducibility of the results, the experiment has been conducted twice, dismantling the entire setup each time and reconnecting it again. Figure 4 shows a plot of A_{dc}/A_1^2 versus. input amplitude provided by the power amplifier for the AA7175-T7351 sample for two different trials. The plot suggests that the A_{dc} behavior with amplitude is quite reproducible.

Experiments have been carried out to measure the static displacement component for different pulse widths of the tone burst. Figure 5 shows the variation of the static displacement component with the input amplitude for different
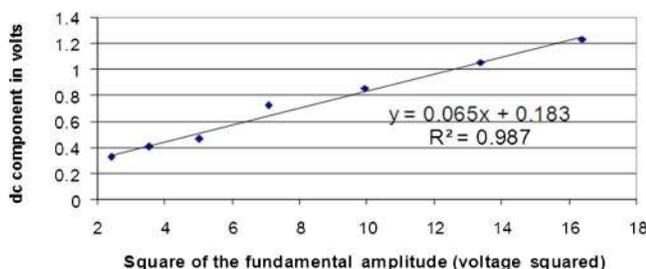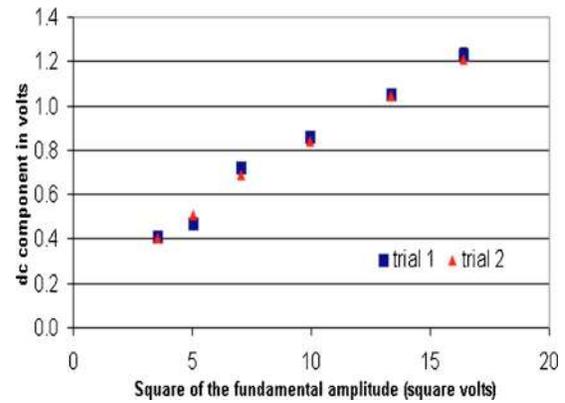
pulse widths of the tone burst. The figure suggests that the static displacement component is independent of the pulse width of the tone burst, which is in agreement with the experimental evidence provided by Jacob et al.[4] The static displacement component is expected to vary as the square of the amplitude of the input wave. However, if A_{dc}/A_1^2 is plotted against the input amplitude provided by RITEC RAM 5000, as shown in Fig. 6 it can be seen that A_{dc}/A_1^2 is not constant at low input amplitudes. This plot suggests that the static displacement generated is proportional to the square of the fundamental amplitude for high power levels. This is similar to the variation of A_2/A_1^2 at low input amplitudes, as reported by Barnard[5] and further experiments need to be carried out to give an explanation to this behavior in line with the explanation suggested by Rajasekhar et al.[6] for the similar behavior of A_2/A_1^2. It should be noted that the static displacement values reported in the previous sections are the ones measured at high input amplitudes so that this abnormal behavior does not interfere with extracting the true value of the static displacement component.

The simplified experimental technique could extract the static displacement component effectively. The present experimental technique does not use low pass filters on the receiver side, as previously used. This prevents the influence of the filter time response characteristics on the measurement. The dependence of the static displacement component on the square of the amplitude of the fundamental and its being independent of the burst width of the tone burst were verified. The abnormal behavior of A_{dc}/A_1^2 at low input

FIG. 3. (Color online) Plot of A_{dc} with A^2 experimentally measured on the AA7175-T7351 sample.
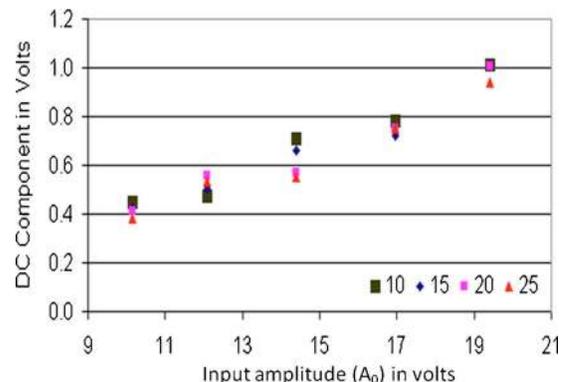

FIG. 5. (Color online) Test the static displacement component's being independent of the width of the tone burst on the AA7175-T7351 sample.
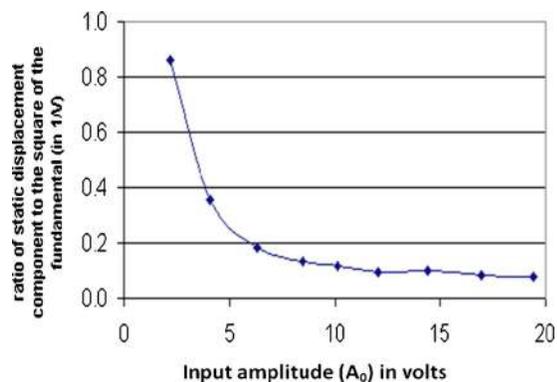
FIG. 6. (Color online) Variation of A_{dc}/A_1^2 with A_1 showing the abnormal behavior at low input amplitudes.

power was observed and it is found to be similar to A_2/A_1^2 behavior at low input power. The present work suggests a simplified experimental approach for measuring the static displacement that can be utilized to quantify acoustic radiation induced static displacement and hence the nonlinearity parameter in material systems.

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