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# Frequency Analysis of Laser-generated Pressure Waves using Wavelet Transforms

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***Abstract** -This paper deals with the analysis of the pressure wave signals generated in an aluminium-stepped sample. The ultrasonic signals are generated using pulsed Nd-YAG laser and detected using a He-Ne Heterodyne interferometer. The pressure wave signals at constant laser power are recorded at various directions with respect to source laser direction and the intensity of various frequency components present in these pressure wave signals are estimated with the help of coefficient lines in theirs wavelet transforms. The variation of the intensity of individual frequency components with detection direction and the intensity variation with signal frequency at a given detection direction are studied and the results are presented.*

**Key words: Laser generation, pressure waves, frequency spectrum.**

## 1 Introduction

LBU (laser based ultrasonic) has been proved to be one of the powerful tools used in the field of non-destructive evaluation techniques (NDE). LBU generation affords an opportunity to make truly non- contact studies in materials, in materials at elevated temperatures, in corrosive and other hostile environments. Lasers are able to produce various types of ultrasonic waves like pressure waves, shear waves, Rayleigh waves etc. in bulk materials. Our present work is focused on generation, characterization and signal analysis of bulk waves generated in thick stepped sample of Aluminum.

Scrubby and Drain [1] discussed the mechanisms of generating various ultrasonic waves with lasers and detection by using variety of laser interferometers. Laser irradiation of bulk sample leads to the generation of pressure and shear waves while it leads to the generation of lamb waves in thin plates. Hoffmen and Arnold [2] have modeled the ablation source in ultrasonics. Rose [3] discussed the increasing Ultrasonic wave techniques in areas ranging from non-destructive inspection of materials to medical diagnosis. Grossmann [4] first proposed the concept of wavelets in its present theoretical form. Wavelet analysis and the properties of different wavelets are explained by Daubechies [5]. Legendre et al [6] have proposed a wavelet-based method to perform the NDE ultrasonic signal. By combining the time domain and the classical Fourier analysis, the wavelet transform provides simultaneous spectral representation and temporal order of the signal decomposition components. Monchalin [7] have given a good presentation about laser ultrasonic instrumentation. .Shull [8] discussed NDE theory, techniques and applications in elaborated manner. Krautkramer and Krautkramer [9] discussed the techniques of measuring the wave speeds of different waves in conventional mode, and hence characterizing flaws in materials. More recently, Manu Singhal et al [10] discussed the results of studies using LBU generation of bulk wave signals, which were analyzed using wavelet transforms.

## 2 Experimental details

Nd:YAG pulsed laser is used to generate ultrasonic waves in aluminium stepped sample and an optical heterodyne laser interferometer is used to detect the transmitted acoustic signals through the material. The signals are then amplified and digitized using aYokogava DL170 digital storage oscilloscope (DSO). The oscilloscope is triggered using a synchronization signal from the Pockels cell of the pulsed laser. The recorded waveforms through DSO are transferred over an Ethernet interface for subsequent storage and analysis. The scanning is done manually using to single axis micrometer controlled XYZ translator mounted on the optical test bench. The schematic layout of experimental set-up is shown in Fig. 1.

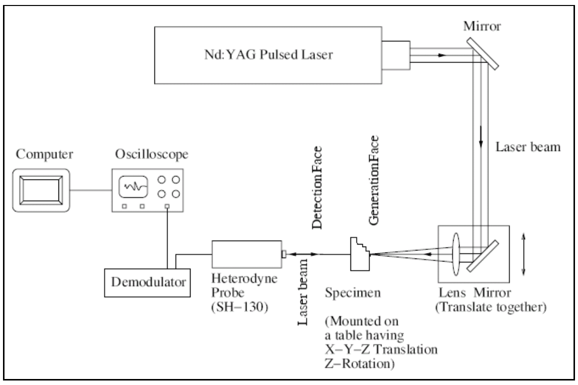



Figure 1 :Schematic of the experimental setup

The schematic representation of stepped sample is shown in Fig 2. The geometry of the sample is such that the center point of each step lies on an arc of a circle. This is to ensure that time of flight of the bulk waves is constant for all angles of detection.

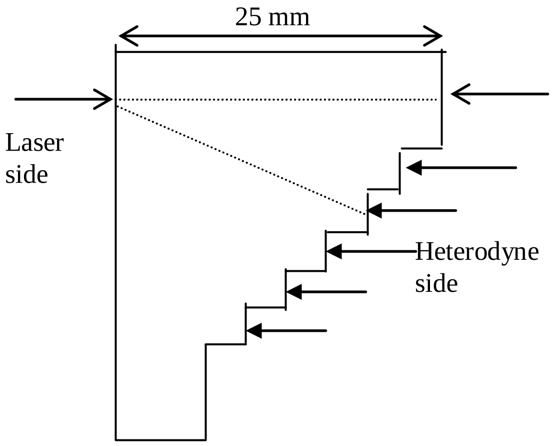



Figure 2 : Stepped sample

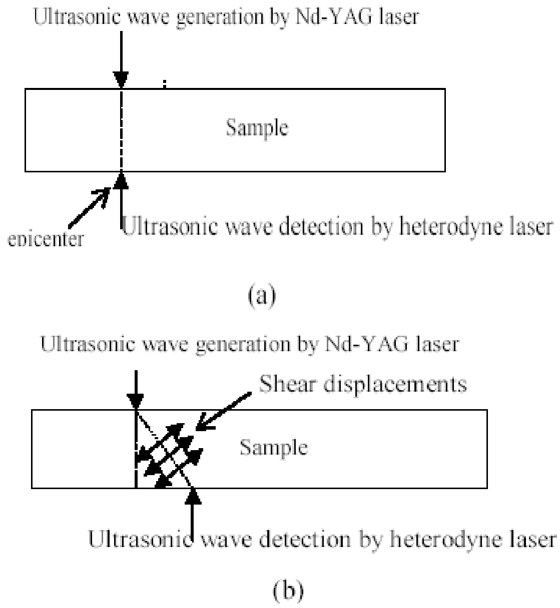
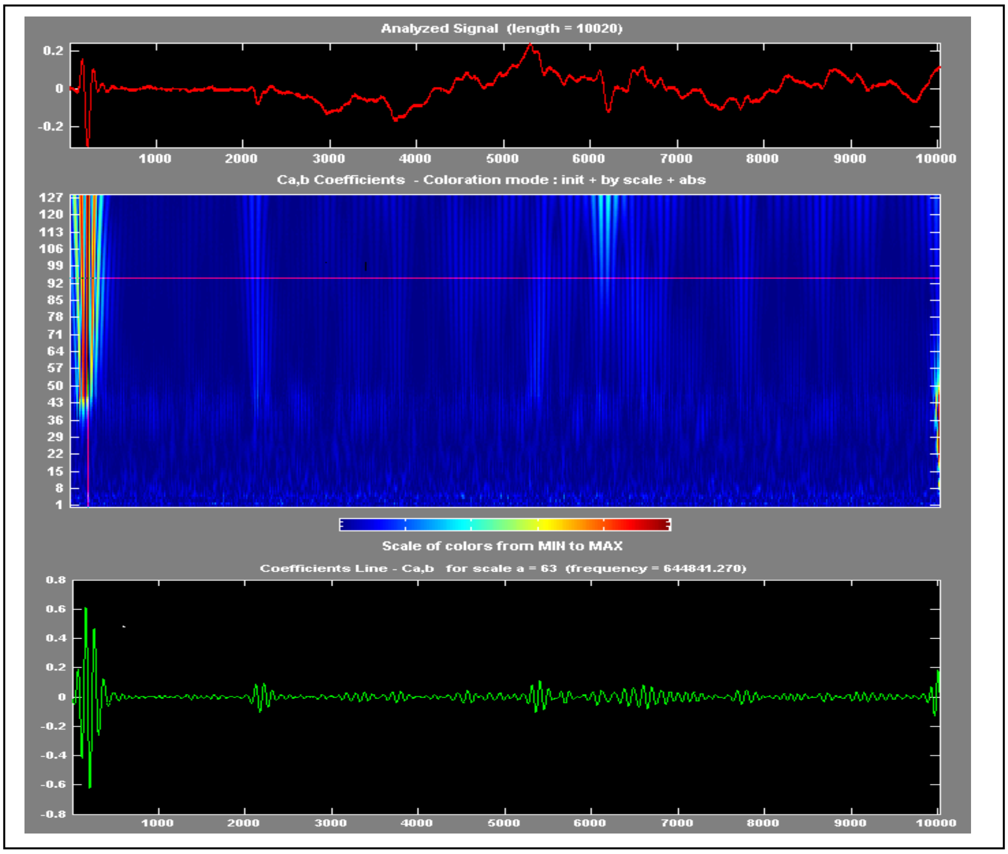


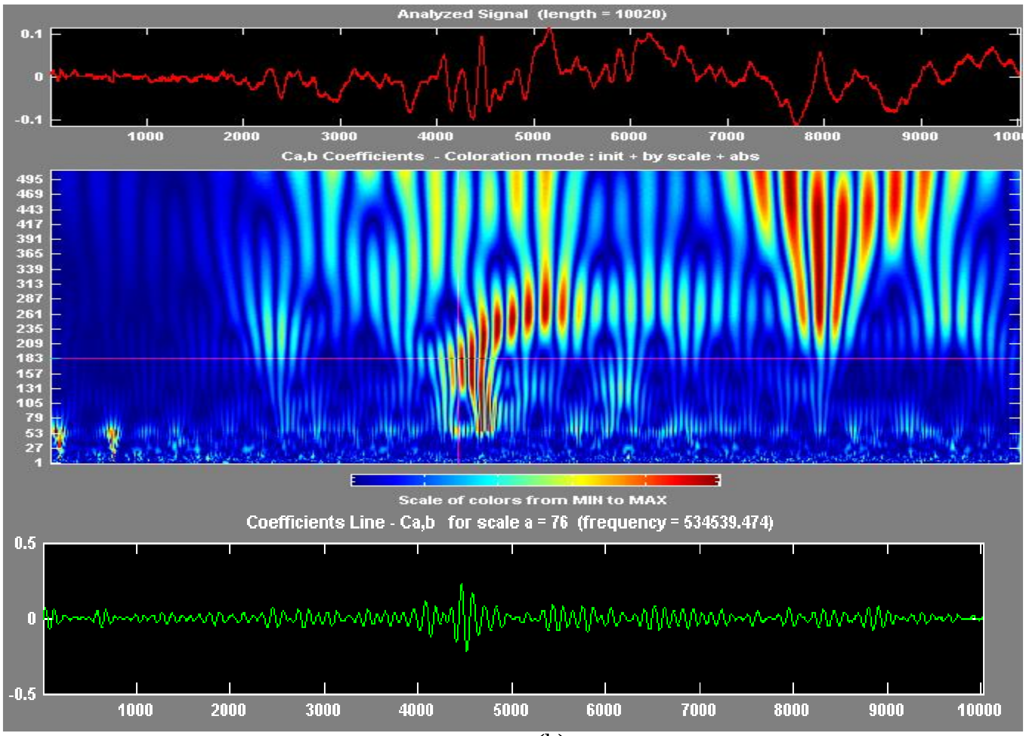

Figure 3 : Ultrasonic wave detection (a) at epicenter (b) at off epicenter

If the ultrasonic waves generated in material are detected at 'epicenter', then the heterodyne probe laser will detect the longitudinal (pressure) waves as well as their back-reflections from the surface under investigation as shown in Fig.3 (a). However, it will be unable to detect the transverse (shear) waves due to the fact that their displacements lie in the plane of the sample surface and hence cannot modulate the probe beam.

If the detection is made at an off epicenteral location with the probe beam normal to the surface, the heterodyne will be able to pick up the components of vibration amplitudes of both pressure wave and shear wave as shown in Fig.3 (b). Actual amplitudes of vibration can be obtained from knowledge of the values of measured amplitudes and the angles of detection




(a)




(b)

Figure 4 : LBU signal at (a) $0^o$ , (b) $40^o$ alongwith its wave-let transform and a coefficient line

## 3 Results and discussion

The LBU signals are detected in aluminium-stepped sample in eight detection directions in the range of $0^0$ to $70^o$. The recorded signals at epicenter ($0^o$) and $40^o$ are shown in Fig. 4 along with their wavelet transforms and coefficient lines. A comparison of the recorded signals in these two directions reveals the complexity of the off-epicentral ultrasonic signals. The frequency band that arrives first corresponds to the pressure wave signal. To carry out the frequency analysis of *the pressure wave*, the wavelet transform of the signal until after the pressure wave arrival is taken and the amplitudes of various frequency components present in the pressure wave are measured. These amplitudes are then normalized by dividing them with the cosine value of the angle of detection. The variation of the intensity (amplitude) of two different frequency components at 132 and 260 KHz with the angle of detection is plotted in Figures 5 and 6 respectively.

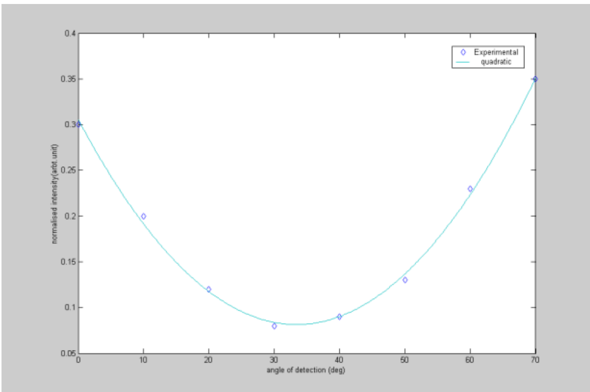



Figure 6 : Variation of intensity with angle at f =260KHz

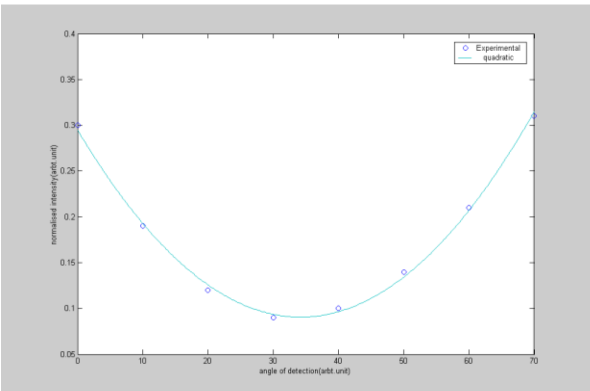



Figure 5 : Variation of intensity with angle at f =132KHz

Both the plots show the signal intensity to be going through a minimum around 30-$40^o$ regions. $30^o$ is known to be the *critical angle* for aluminium. It seems that one can determine the critical angles of any material by studying the frequency behavior of bulk waves generated in a stepped sample. In figures 7, 8 and 9 the behavior of the signal intensity with frequency for a particular angle of detection is shown. The plots show the signal intensity to be decreasing with increasing frequency. This is as expected as higher frequency vibrations require more energy input.

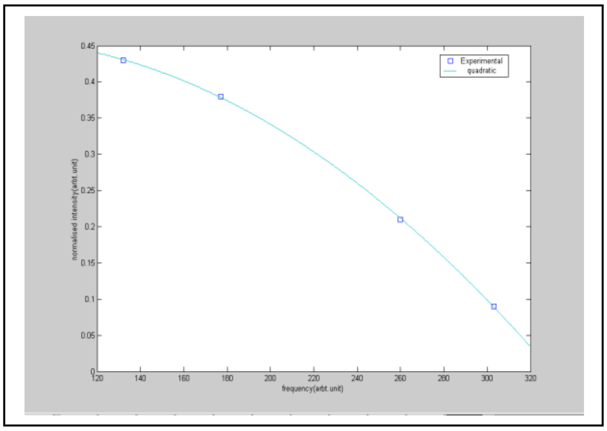


Figure 7 : Variation of intensity with frequency at $0^{o}$ angle of detection

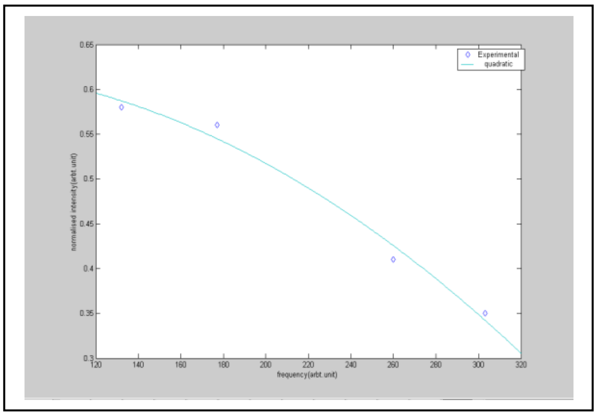


Figure 8 : Variation of intensity with frequency at $40^{0}$ angle of detection

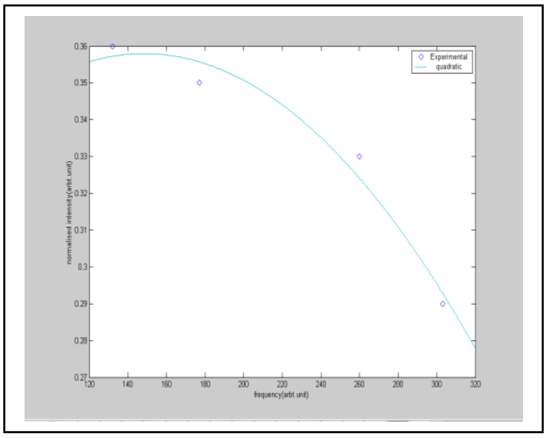


Figure 9: Variation of intensity with Frequency at $70^{0}$ angle of detection

## 4 Conclusions

The results of the analysis of the pressure wave signals generated in an aluminium-stepped sample are presented in this paper. The ultrasonic signals are generated using Pulsed Nd-YAG laser and are detected using a He-Ne Heterodyne interferometer.. From a study of variation of the intensity of individual frequency components with detection direction, one can determine the critical angle of the material under study.

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