DETECTION OF SHEAR AND PRESSURE WAVE IN METALS USING DYNAMIC WAVELET FINGERPRINTERING IN LASER ULTRASONIC NDT

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ABSTRACT

The Bulk Ultrasonic wave characterization is attempted by dynamic wavelet fingerprinting and visual pattern recognition method. Laser Based Ultrasonics is used to generate ultrasonic signals in Aluminium, Steel, Inconel and Brass samples. A suitable stepped geometry is selected for samples to assure the same travel distance for all angles of laser incidence. The pulsed wave Nd-YAG laser is used to generate the ultrasonic signal in the material and continuous wave He-Ne laser heterodyne interferometry to record surface(out of plane) waves at the detection end. The coexistence of bulk, surface and Rayleigh wave in the signal makes it little difficult to analyse. Continuous wavelet transform using Morlet wavelet and pattern recognition with moment invariants are used in the analysis. Comparative study of Hu and Zernike moments proved that Zernike moments work better in pattern recognition. The output ultrasonic signals are analysed to identify shear and pressure waves correctly. The pressure and shear velocities calculated are in the theoretical limit. The accurate time of arrival of waves can be used in tomographic inversion techniques to obtain a precise reconstruction of the defects and in-homogeneities in the material. The study shows the utility of wavelet transform based pattern recognition of transient signals.

Keywords: Finger-Printing, Laser Ultrasonics, Shear Waves
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INTRODUCTION

Non destructive Evaluation (NDE) is used for identifying the defects and material properties without damaging the object. Aerospace, automotive and transportation fields are the main areas using NDE techniques widely. The ultrasonic waves for NDE application can be generated by Laser Based Ultrasonics (LBU) technique. In this method of ultrasonic wave generation, pulsed laser is used at the generation end and a continuous wave laser interferometer at the detection face to detect ultrasonic displacements generated by the arrival of elastic wavefronts (longitudinal, shear). The bulk waves generated by LBU are recorded and analyzed to get the exact time arrival location of Pressure and Shear waves. A new algorithm is implemented to find out pattern similarity. On the basis of accurate time of arrival of bulk elastic waves the defects and in-homogeneities in the material can be reconstructed. Dynamic wavelet fingerprinting technique and pattern recognition schemes with continuous wavelet transformation of the ultrasonic signal are discussed.

Scruby and Drain [1] described the mechanism of generation of ultrasonic waves using Laser. Laser irradiation causes the material to heat and set the thermal gradient in the specimen to generate the stress and stain field for the generation of the ultrasonic waves. The generation is divided into two parts as Thermoelastic (preferred in NDE) and Ablation regime. Manu et al [3] used LBU to generate ultrasonic waves in Aluminium and applied continuous wavelet transform for analysis. Hou et al [2] used the dynamic wavelet fingerprinting for time arrival detection of Lamb waves. This paper describes the dynamic wavelet fingerprinting technique for identification of Shear wave.

EXPERIMENTAL DETAILS

The setup figure [1] basically consists of Q-switched Nd-YAG pulsed wave laser and a continuous wave He-Ne (Helium-Neon) laser. Nd-YAG laser generates the ultrasonic signals in the specimen. The transmitted signal through the specimen is detected by He-Ne laser heterodyne probe. The Digital Storage Oscilloscope (DSO) is connected to He-Ne laser probe to amplify and digitize the signals. The oscilloscope is triggered using a synchronization signal from the pockels cell of the pulsed laser. The signals from DSO are transferred by ftp on Ethernet for analysis. The specimen is clamped to the micrometer controlled mount having three degrees of freedom, two translational and one angular. The whole setup is put on the optical bench.
THEORY

Detection of Pressure wave – The Pressure wave in the signal (figure [2]) can be easily identified by its prominent presence as first significant peak. Shear wave being accompanied by the other waveforms, is little difficult to identify. Shear wave identification steps are mentioned below:

1. Denoising of the ultrasonic signal – MATLAB wavelet toolbox is used for denoising operation. The method used to filter signal is called Stationary Wavelet Transform Denoising.

2. Continuous Wavelet Transform – Figure [3] shows the ultrasonic signal in the time domain and its continuous wavelet transform with respect to Morlet wavelet. The transformed image is plotted as scale versus time, scale being inversely proportional to the frequency. It is evident from the figure [3] that continuous wavelet transformation gives good time localization. These continuous wavelet transformed coefficients are used for further analysis of fingerprint matching.

3. Fingerprinting and moment calculation – Hou and Hinders [2] introduced dynamic wavelet fingerprinting, as a tool for pattern recognition. To generate the fingerprints, as a first step, one has to perform the continuous wavelet transform analysis on the ultrasonic signal and then perform the contouring operation on them. For this purpose, a small portion (window in time domain) is considered and the projection of the wavelet coefficients onto the time-scale plane is obtained using MATLAB. Thus a transient ultrasonic signal is transformed into its two dimensional signature (figure [4]), which can then be analyzed as a pattern recognition problem.

As pressure and shear waves get generated from the same laser ablated location, a certain similarity between these two locations can be expected. This conjecture is used for the detection of the shear wave. With the quantitative comparison of the moments, the window showing maximum similarity with that of the pressure wave is taken as the most probable
Hu [4] defined seven functions based on these regular moments which are invariant to translation, scaling and rotation. These moments are the projection of the image function $f(x,y)$ on the $x^p y^q$, which is not an orthogonal basis. Teague [5] proposed the use of orthogonal functions to overcome the drawback of the regular moments. Zernike moments possess the rotation invariance property and with image normalization it provides scale and translation invariance. A comparative study of Zernikes with other five moments [6] showed that Zernike and other orthogonal moments are better in case of information redundancy and image representation. These are found to perform well in the case of image reconstruction

Moments and functions of moments have been used in pattern recognition in most of the applications. These functions encompass the global information about the image. Regular moment $m_{pq}$ is defined as,

$$m_{pq} = \iint_{-\infty}^{\infty} x^p y^q f(x, y) \, dx \, dy$$  \hspace{1cm} (1)

where, $m_{pq}$ is $(p+q)^{th}$ order moment of continuous image function $f(x,y)$.

Fig. 3 : Continuous Wavelet Transformation.

Fig. 4 : Wavelet Fingerprint (1 time step = 0.005 microsecond)

Fig. 5 : Plot of error vs shear wave location for Brass 30p signal.
invariants are calculated for each window. The figure [5] shows the error of window moments versus window location plot for Brass. The error is calculated with reference to the moment values of pressure wave. The bracketed point shows the most probable location of arrival of shear wave. On the basis of this location the wave velocity is calculated (table [1]). The fingerprints are obtained for these locations and a visual match is found (figure [6]).

CONCLUSION
The work proposes a technique to identify the pressure and shear waves accurately. With the accurate detection of time of arrival of the bulk waves, the tomographic reconstruction of the defect in the specimen can be detected. The Continuous wavelet transform is found effective in the analysis of complex ultrasonic signals. Zernike moments are found to perform better than Hu moments in pattern recognition.

REFERENCES

RESULTS
The specimen geometry is made such that the length of flight of wave will remain same for all angles of laser incidence. The centre point of each step lies on a circular arc whose centre will be the point of detection. The Nd-YAG laser is made incident on each step while the ultrasonic signal is recorded at the other face. This ensures direct comparison of the two signals obtained at different angles of incidence.

The steps for shear wave detection are followed. The signals are then discretized in the specified size windows and moment

Table 1 : Comparison of velocities for Brass.

<table>
<thead>
<tr>
<th>Material</th>
<th>Longitudinal Wave velocity( $V_L$) m/s</th>
<th>Shear Wave velocity( $V_s$) m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical</td>
<td>4000-4370</td>
<td>2000-2110</td>
</tr>
<tr>
<td>Experimental (from pattern similarity)</td>
<td>4310.3</td>
<td>2114.2</td>
</tr>
</tbody>
</table>

The same procedure is followed for Aluminium, Steel and Inconel samples and velocities are calculated in the respective materials. The results are tabulated in table [2].

Table 2 : Comparison of velocities for Aluminium, Steel and Inconel

<table>
<thead>
<tr>
<th>Material</th>
<th>Longitudinal Wave velocity( $V_L$) m/s</th>
<th>Shear Wave velocity( $V_s$) m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>Theoretical 5900-6300</td>
<td>2750-3150</td>
</tr>
<tr>
<td></td>
<td>Experimental 5931</td>
<td>2770</td>
</tr>
<tr>
<td>Steel</td>
<td>Theoretical 5900-6100</td>
<td>2800-3200</td>
</tr>
<tr>
<td></td>
<td>Experimental 6097</td>
<td>2875</td>
</tr>
<tr>
<td>Inconel</td>
<td>Theoretical 5700-5900</td>
<td>2800-3200</td>
</tr>
<tr>
<td></td>
<td>Experimental 5862</td>
<td>2881</td>
</tr>
</tbody>
</table>

| Fig. 6 : Fingerprint comparison (a) – Pressure wave window, (b) – Shear wave window. | |