Reliability of Detection of Small Defects in Noisy Weldments By Advanced Signal Processing And Pattern Recognition Techniques

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SYNOPSIS

Load bearing capacity of any structure for a given dimension can be increased by improving the reliability of detection of smaller defects in weldments. This is highly desirable in aeronautical and space industries where the overall weight of the structure is a major constraint as it decides the pay load capacity.

Maraging steels are widely used in space industries for fabrication of rocket motor casings. Conventional ultrasonic pulse echo technique is applied for defect detection in weldments. However, inspection by ultrasonic testing of top midsection of maraging steel weldments, which is acoustically noisy, poses problems for reliable detection of defects of size 3 mm long x 1 mm deep or less (a design requirement). This is because of small amplitude difference of echo signal (2dB) between the noise and defect signals. Reliability of detection of such defects is improved by adopting advanced signal processing and pattern recognition techniques, which in turn increases the load bearing capacity of the structures.

A developmental work was undertaken for reliable detection of small defects in maraging steel weldments. For this purpose, a fatigue crack of 3 mm x 1 mm size was created in top midsection of the maraging steel weldments representing expected weld defects formed during fabrication. This paper discusses the application of advanced techniques like, autocorrelation, cross power spectral analysis, demodulation and clustr analysis for detection of the simulated fatigue crack. By adopting these techniques 95% reliability has been achieved for the detection of the fatigue crack. The approach has been assessed for shop floor adaptability. The approach would yield considerable enhancement in the pay load of space vehicle thus resulting in enhanced capability and effective utilization.

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1.0 Introduction

Load bearing capacity of any welded structure having given dimensions is dependent on the fracture toughness properties of material and weldment. Fracture toughness considerations also impose reliable detection of allowable defect size in the material and weldments for avoiding failure under given service conditions. In high strength weldments of maraging steel grade M250, it is essential to detect 3 mm x 1 mm fatigue type cracks for achieving desired payload capacity of satellite vehicles.

Maraging steels are widely used in space industries for fabrication of rocket motor casings. Though conventional ultrasonic pulse echo technique is applied successfully for defect detection in wrought material, the weldments (6 mm thickness) pose problems to achieve inspection specifications. Top midsection of the maraging steel weldment is acoustically noisy as this region has coarse and more textured microstructure (fiq 1). This is primarily because of small

Fig.1 : Microstructure of Maraging Steel Weldment.

amplitude difference of echo signal between the noise and defect. Developmental work was undertaken for reliable detection of 3 mm long x 1 mm deep simulated fatigue crack representing the types of defects normally encountered during the fabrication of rocket motor welded casings using advanced signal processing and pattern recognition techniques.

This paper discusses the application of advanced signal analysis techniques like autocorrelation, crosspower spectral analysis, demodulation and cluster analysis for detection of the simulated fatigue crack.

2.0 Experimental

Fig.(2) shows the block diagram of the experimental set up. The experimental set up consists of ultrasonic transducer analyser (UTA) and signal analyser (SA) with high speed data acquision subsystem (DAS). The ultrasonic probe used for testing the weld was a 4 MHz 45° shear angle beam probe. The probe was moved along the weld keeping it at one skip distance from the top midsection of the weld. The probe was excited by the UTA with the maximum repetition rate. The reflected echo from top midsection of weld received by UTA. The time domain echo signal was fed to the DAS after selecting delay and gate width. This is required to eliminate the backscattered signal from the noisy weldments. The signal was sampled by the DAS at the rate of 100 Mega samples per second. The digitised signal was stored in the floppy for post analysis by the SA.

The following signal analysis techniques were applied for defect detection : shape of time domain signal, time delay required for doublet formation in power spectrum, autocorrelation of time domain signal, demodulation of autocorrelated time signal and cluster analysis of cross power data.

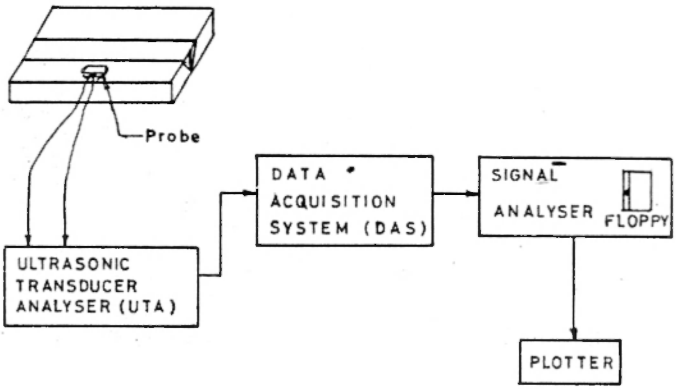

Fig.2 : Block Diagram of the Experimental Set Up.

Procedure adopted for the above technique and the results obtained are discussed in the following sections.

3.0 Analysis and Results

3.1 Shape of Time Signal

For the defect signals the fall time is shorter compared to that of noise signals. Using this criterion, a confidence level of 60% for detection was obtained. Fig.3 shows the typical shapes of defect and noise signals.

3.2 Time Delay Required for Doublet Formation in Power Spectrum

The time signal for fixed duration from different portions of overall time signal has been analysed in frequency domain for both defect and noise signals. The time domain signal taken from a particular location on either side of the peak of the overall time signal resulted in doublet formation in power spectrum. It was found that the delays required (i.e. location of time signal) on either side of the peak is nearly equal in the case of noise whereas it is unequal in the case of defect signal. Based on this technique, a confidence level of 65% on the defect discrimination was obtained.

3.3 Autocorrelation of Time Domain Signals

Correlation of any two signals brings out the common frequency components present in both the signals. In case of autocorrelation, correlation of a signals is done with the same signal. Conjugate multiplication of autocorrelated time signal, $Z(\tau)$, has been obtained and two features, namely, exponential decay (ED) and central valley (V) formation have been used for discrimination of noise and defect signals.

$$A(\tau) = E \sum_{-T}^{+T} f(t) \times f(t-\tau)$$

Where $A(\tau)$ is the autocorrelated time signal.

$$Z(\tau) = A(\tau) \times A^{*}(\tau)$$

For defect signals, it has been found that either exponential decay or central valley or both have been observed in majority of the trials, whereas for most of the noise signals, the two features were absent. Figs. 4(a) to 4(d) typically show the features described above. One of the signals which does not satisfy the above criteria is shown in fig.4(c). The confidence level achieved by this technique for discrimination of defect signal is 65%.

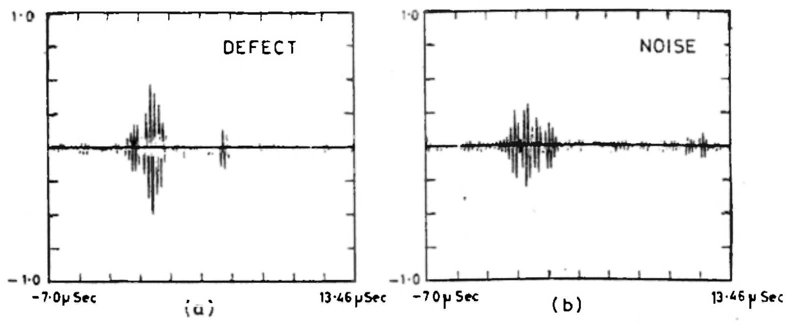

Fig.3 : Waveform of Time Domain Signal.

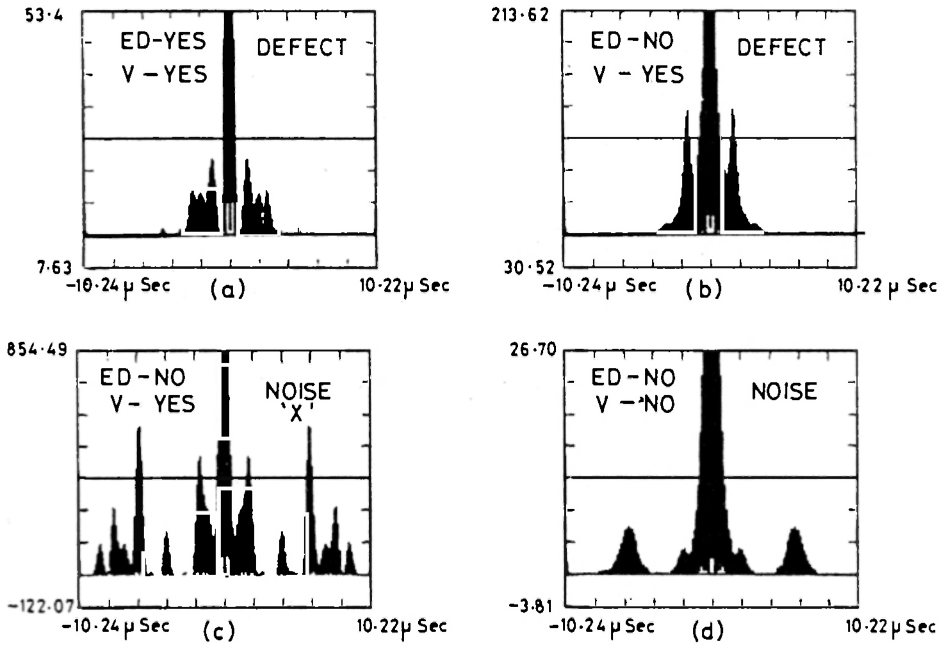

Fig.4 : Autocorrelation Technique

3.4 Demodulation of Autocorrelated Time Signal.

Demodulated signal by log operation, P(t), has been carried out on the above processed signal (Section 3.3) and looked for number of distinct lobes and width of the lobes, particularly for the end lobes on both sides.

$$P(t) = \log Z(t)$$

For defect signals, it has been observed that there are more number of distinct lobes having less width, whereas for noise signals, there are few distinct lobes but they have higher width. Figs. 5(a) and 5(b) typically show the features described above. The confidence level achieved for defect discrimination by this technique is around 85%.

3.5 Cluster Analysis of Cross Power Data (CACPD)

Cross power data has been obtained by conjugate multiplication of the respective FFT(Fast Fourier Transform) of two different time signals [F1 (w) and F2 (w)].

$$\text{CACPD, } Q(w) = F1\,(w) \times F2\,(w)$$

Cross power spectrum consists of real and imaginary components. The analysis has been done for a number of noise-noise and noise-defect combinations. From these spectra, the total positive and negative powers were computed for the real and imaginary components. This power data has been plotted and the same is shown in figs. 6(a) and 6(b) for one set each

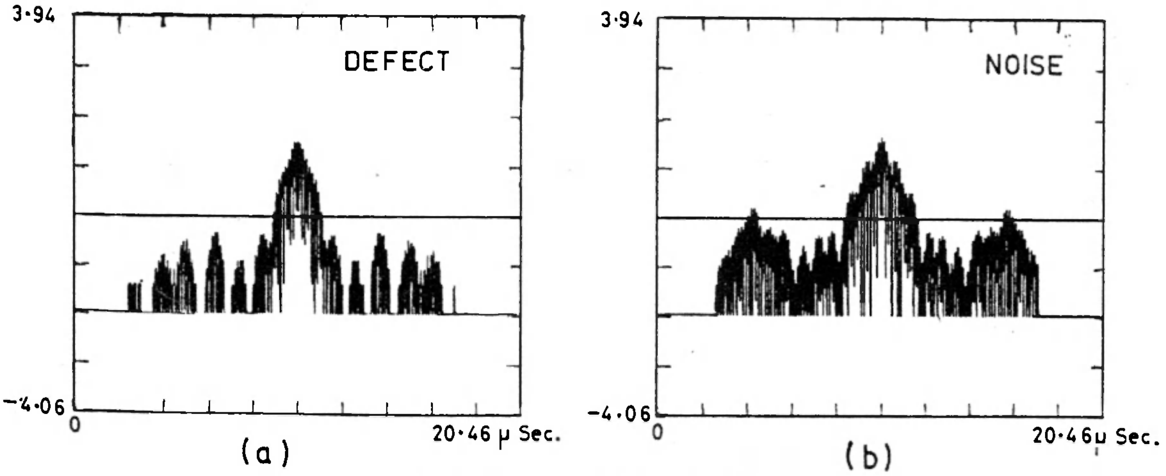

Fig.5 : Demodulation Technique

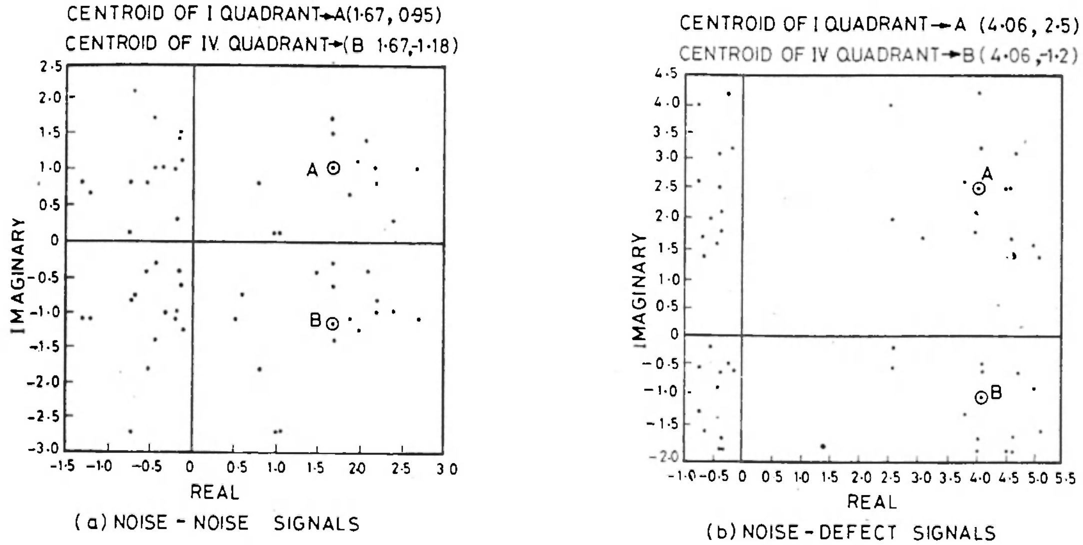

Fig.6 : Clusters for Cross Power Data

of noise-noise and noise-defect signals. It is evident from the plots that the real positive powers (R +) form different clusters for noise-noise and noise-defect signals. The clusters were analysed statistically for finding the centroid and standard deviation. It is found that the centroid of noise-defect cluster is widely separated from that of noise-noise cluster. By adopting Gaussian probability distribution, the probability of the centroid of R + of defect-noise cluster being an element of noise-noise cluster has been computed and found to be less than 5%. The confidence level achieved by adopting this technique is 95%.

4.0 Conclusions

Advanced signal analysis techniques can be applied realiably for detection of small defects which cannot be detected by conventional ultrasonic pulse echo technique. In this paper, it has been shown that CACPD technique can be applied for detection of small simulated fatigue crack in a maraging steel weldment. By applying this technique, it is possible to detect defects (similar to the fatigue crack) which get introduced during the fabrication of the weldments.

The technique can also be extended for early detection of similar defects during inservice inspection of critical components.

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