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SPATIAL AVERAGING ALGORITHMS FOR ULTRASONIC INSPECTION OF AUSTENITIC STAINLESS STEEL WELDS

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ABSTRACT

Interpretation of ultrasonic inspection data from stainless steel welds is difficult because the signal-to-noise ratio is very low. The three main reasons for this are the granular structure of the weld, the high attenuation of stainless steel, and electronic noise. Averaging in time at the same position in space reduces electronic noise, but does not reduce ultrasonic noise from grain boundary scattering. Averaging waveforms from different spatial positions helps reduce grain noise, but desired signals can destructively interfere if they shift in time. If the defect geometry is known, the ultrasonic waveforms can be shifted before averaging, ensuring signal reinforcement.

The simplest geometry results in a linear time shift. An averaging algorithm has been developed which finds the optimum shift. This algorithm computes the averaged, or composite waveform as a function of the time shift. The optimum occurs when signals from a reflector becomes aligned in time, producing a large amplitude composite waveform. This algorithm works very well, but requires significant computer time and storage. This paper discusses this linear shift averaging algorithm, and considers an implementation using frequency domain techniques. Also, data from several weld defects are presented and analyzed.

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I. INTRODUCTION

Interpretation of ultrasonic inspection data from stainless steel welds is difficult because the signal-to-noise ratio is very low. The three main reasons for this are ultrasonic noise due to granular structure of the weld, the high attenuation of ultrasound in stainless steel, and electronic noise. Averaging subsequent waveforms at the same position in space reduces electronic noise, but does not reduce ultrasonic grain noise. Averaging waveforms from different spatial positions helps reduce grain noise, but desired signals can destructively interfere. If defect orientation and inspection geometry are known, the ultrasonic waveforms can be shifted in time before averaging to ensure signal reinforcement. Ultrasonic grain noise and electronic noise will be reduced, increasing the signal-to-noise ratio.

II. EXPERIMENTAL OBSERVATIONS

Ultrasonic signals reflected from weld defects move in time as the transducer is moved closer and farther away from the indication. This phenomenon can be observed in Figure 1. Note how the large signal "walks" from left to right as the distance from the indication is increased. The time shift between subsequent waveforms is proportional to the distance the transducer moved. If all of the waveforms were shifted in time by an appropriate amount, the desired signals would reinforce and the ultrasonic grain noise would be reduced. The difficulty is determining the proper time shift, which is a function of scan geometry, inspection angle, and defect orientation.

III. ALGORITHM DEVELOPMENT

If an ideal geometry is assumed, as shown in Figure 2, the theoretical time shift can be calculated if the velocity of sound in stainless steel is assumed to be constant.

Δx = change in transducer position

Δp = change in path length in stainless steel

φ = refracted angle

v_{ss} = velocity of sound in stainless steel

$$\Delta p = \frac{\Delta x}{\cos \varphi} \tag{1}$$

$$\Delta t = \text{time shift} = \frac{\Delta p}{v_{ss}} = \frac{\Delta x}{v_{ss} \cos \varphi} \tag{2}$$

However, this theoretical time shift calculation is usually not accurate enough. Since the rf waveforms are being averaged, the averaged waveform is very sensitive to time shift errors. The accuracy of the time shift calculation should be approximately the same as the digitizing sampling interval, which is typically 0.02 μsec. The actual inspection geometry deviates from the ideal shown in Figure 2. First, there is usually significant distortion of the parent metal adjacent to the weld caused by the welding process. Second, the plane of the defect is not necessarily normal to the specimen surface. Both of these distortions cause the actual time shift to differ from the theoretical.

One technique for finding the actual shift is to simply search for the shift that yields the largest amplitude resultant waveform. This search can be centered about the theoretical shift, which should be reasonably close. A plot of an amplitude vs. time shift curve is shown in Figure 3. The shape of this curve is typical for the situation in which a fairly prominent signal is present. When no distinct signal is present, the shape is similar but the large peak is greatly reduced. This search method, while effective, takes a great deal of computer time. A faster algorithm is desired that will find the optimum shift.

If the ten waveforms in Figure 1 were averaged with no time shifting, the resultant waveform would contain ten signals separated by the time shift, T. In the frequency domain, a component f = 1/T would be introduced. If this new component could be detected, the time shift T would be known and could be applied to the original waveforms.

Figure 4 shows the averaged waveform and its Fourier Transform. The peak in the spectrum is at 2.95 Mhz, which corresponds to a time shift of 0.34 μsec. This compares to a time shift of 0.33 μsec between waveforms in Figure 1. Figure 5 compares the fourth waveform in Figure 1 to the waveform obtained after time shift averaging all ten waveforms with a shift of 0.34 μsec. Note the improved signal-to-noise ratio.

IV. RESULTS

This time shift averaging algorithm was applied to ultrasonic data from inspection of a pipe weld sample containing fatigue cracks. The pipe was 16 inches in diameter and was 3/8 inch thick. The weld was volumetrically scanned in a grid consisting of 40 circumferential positions at 0.04 inch spacing by 10 axial positions at 0.04 inch spacing. The transducer had two elements in a pitch/catch configuration and had a center frequency of 2.5 Mhz. The inspection mode was 60° longitudinal.

Unprocessed results are shown in Figure 6 for two scans of a fatigue crack approximately 50% through the wall. Only waveforms from the center axial scan positions are plotted. The rf waveform was digitized and stored, and was rectified in software for display purposes.

The time shift averaging algorithm was applied to these data with results shown in Figure 7. Note the improved signal-to-noise ratio. The processing has enhanced the defect signal while suppressing grain noise.

V. SUMMARY AND CONCLUSIONS

There are many possible benefits from this time shift averaging scheme. First, the increased signal-to-noise ratio results in better defect detection. Second, knowledge of the time shift can give important information about the orientation of the defect. If the refracted angle is known, the angle between the defect and the specimen surface can be calculated. Third, the algorithm can be used to reduce large quantities of volumetric inspection data for permanent storage. One waveform can be stored instead of the several that exist before averaging.

However, there are some precautions that must be observed. The scan pattern and defect geometry must be such that a linear time shift is observed. If, for example, the defect is non-planar, some other algorithm must be used to calculate the time shift. For defects examined thus far, the linear time shift has been a good assumption.

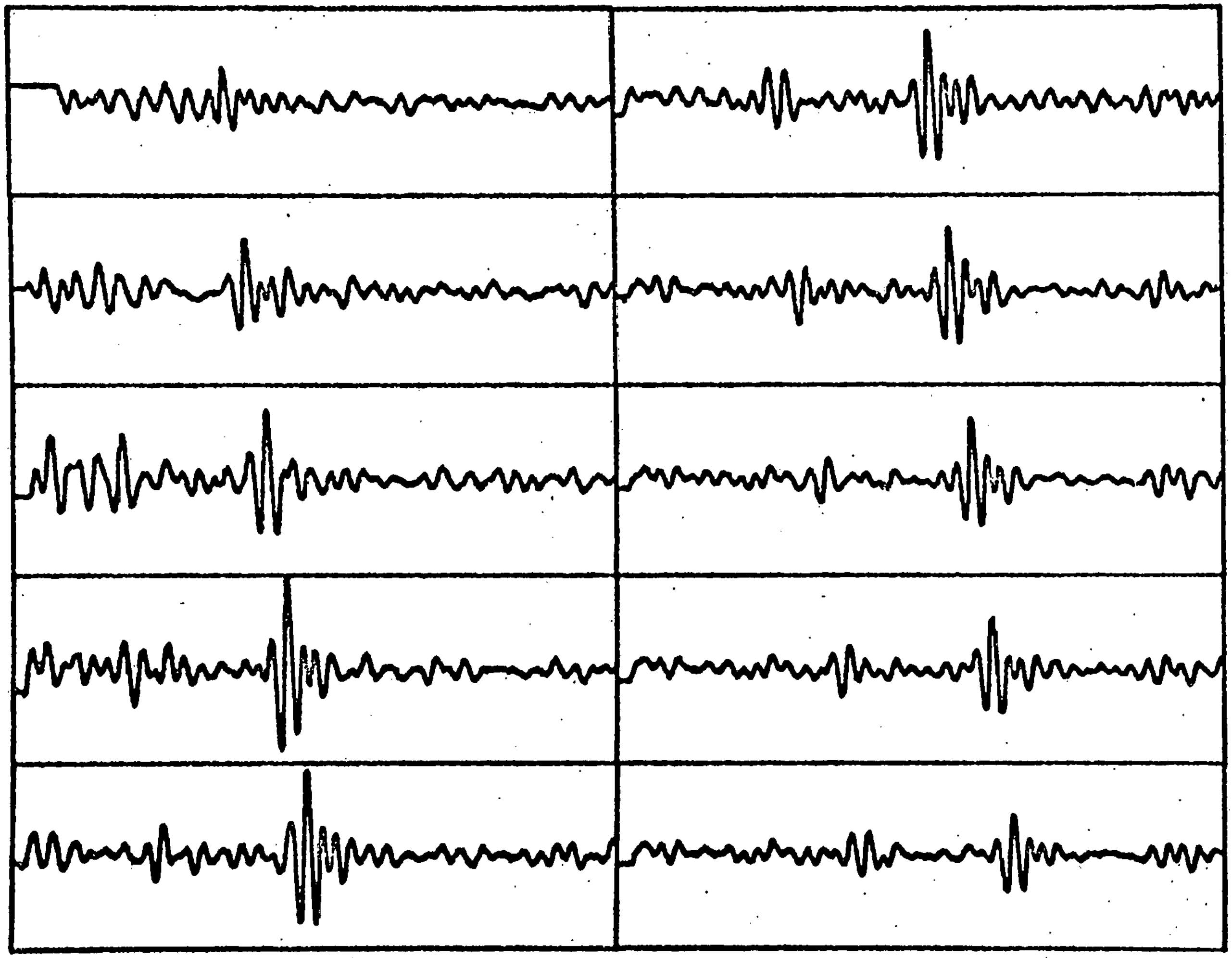


Figure 1. Time Shift of Signal as Transducer is Moved Away From Defect.

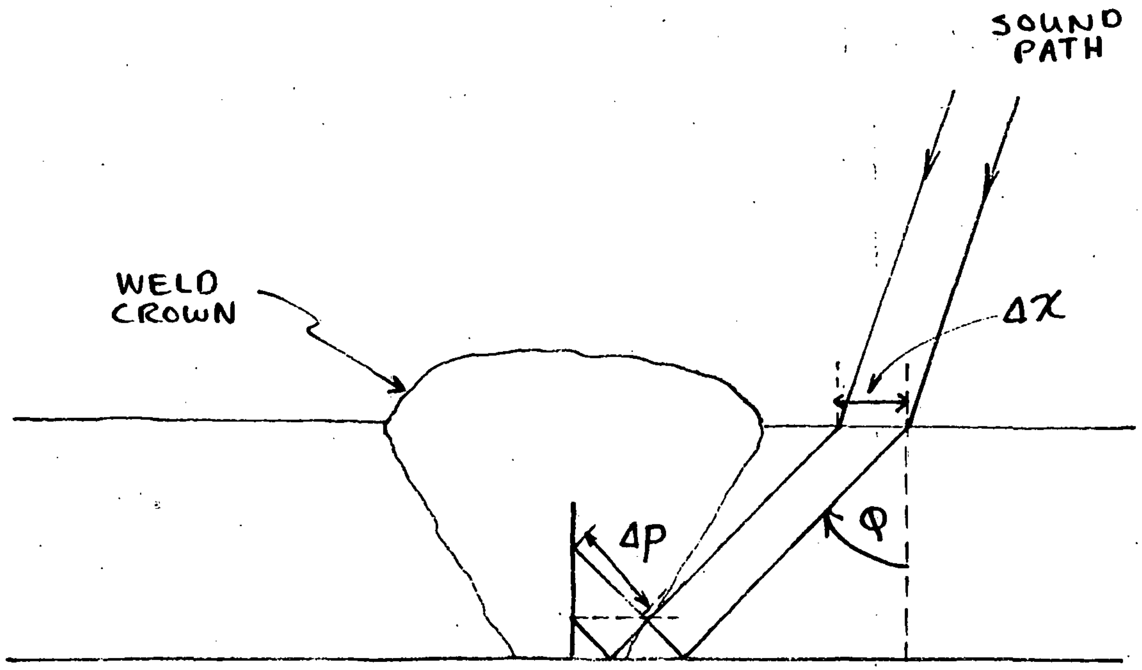


Figure 2. Ideal Inspection Geometry

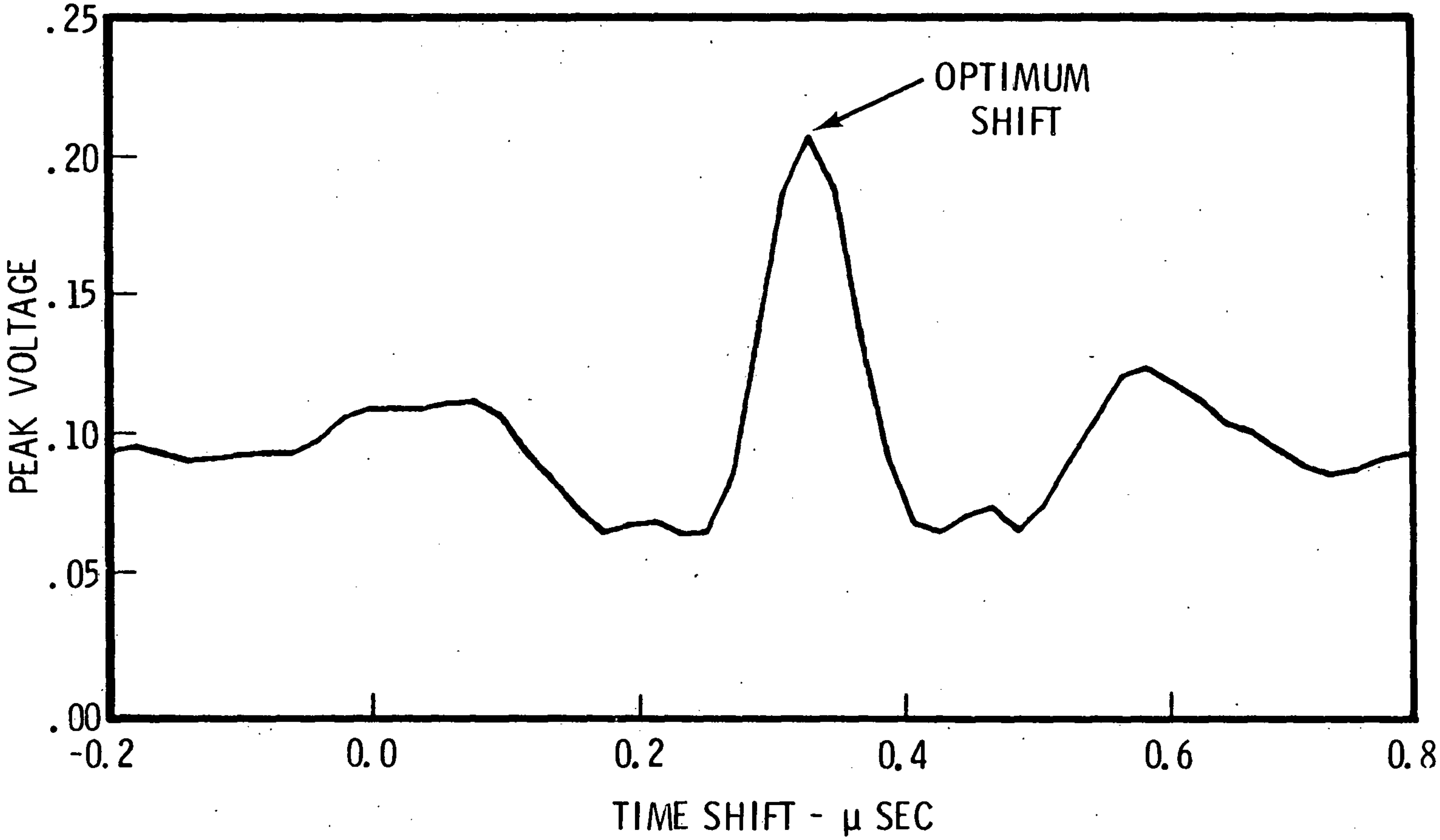
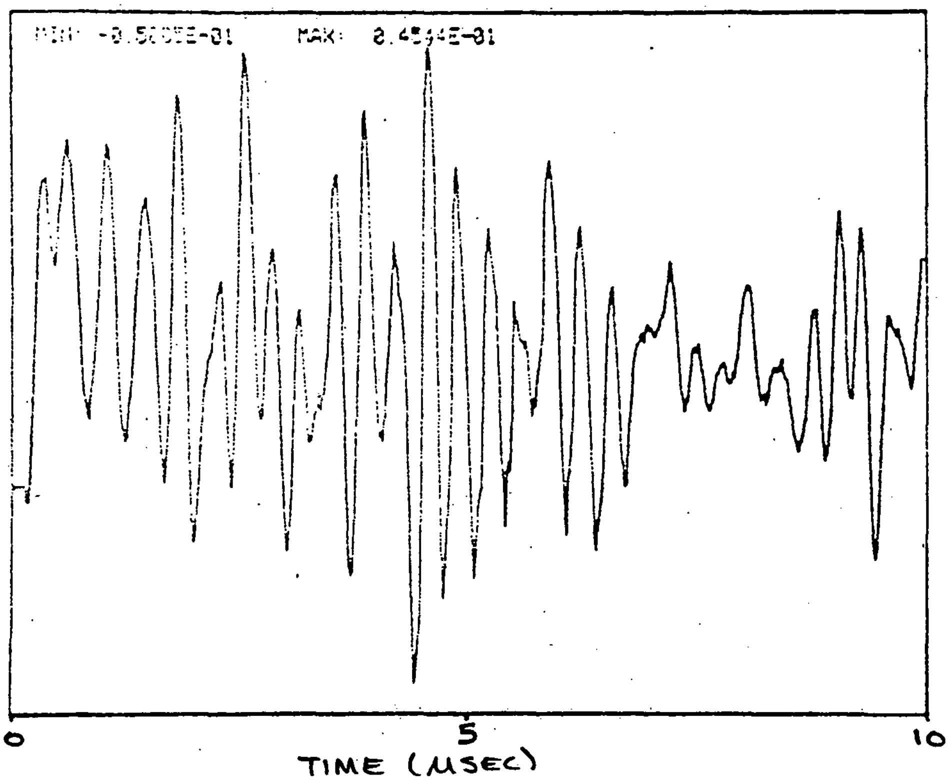


Figure 3. Search For Optimum Time Shift.

AVERAGED WAVEFORM



FOURIER TRANSFORM

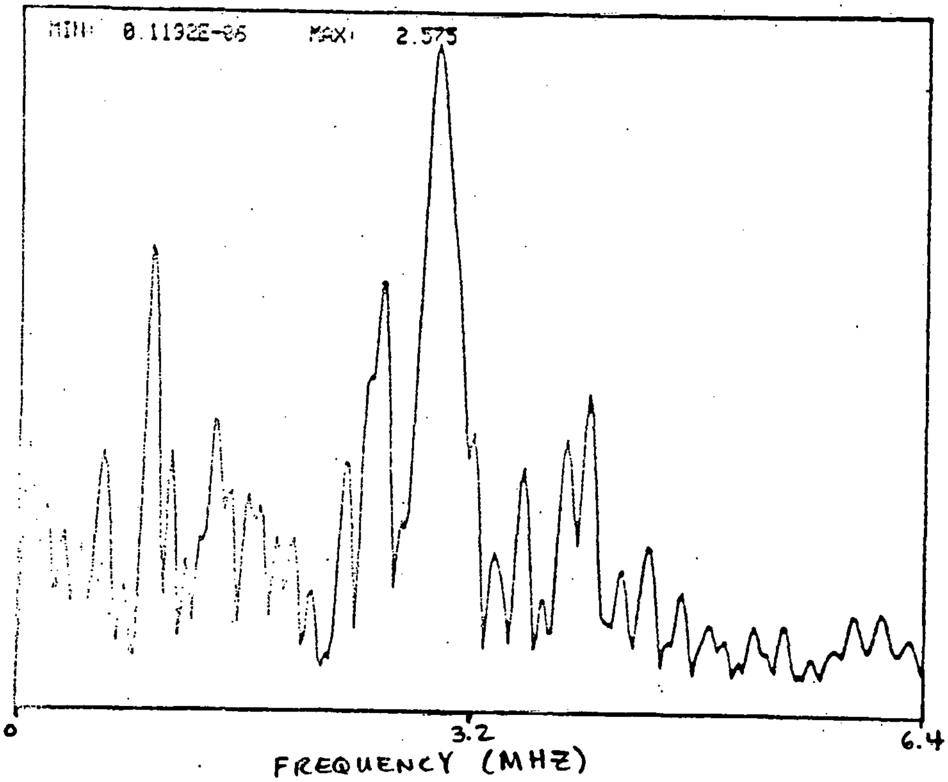


Figure 1. Averaged Waveform and Its Fourier Transform.

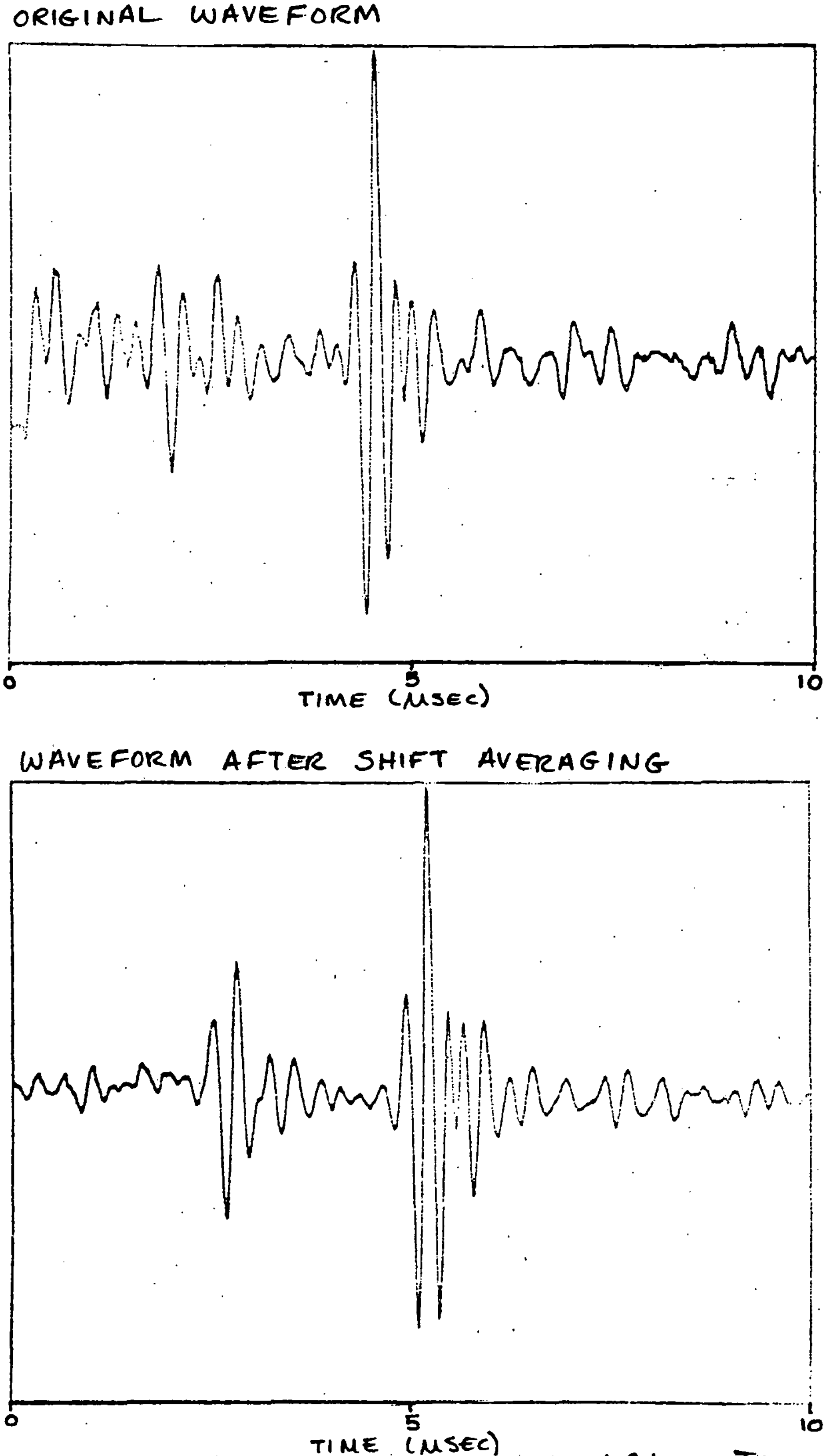
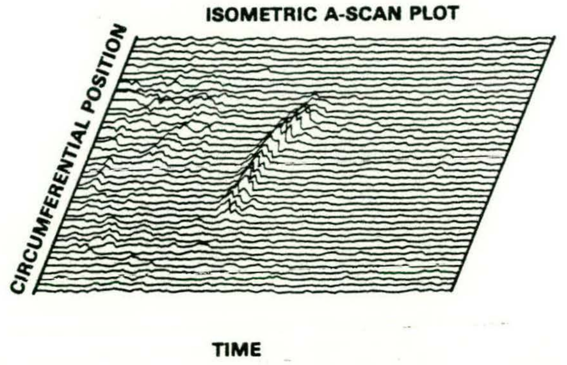


Figure 5. Waveforms Before and After Time Shift Averaging.



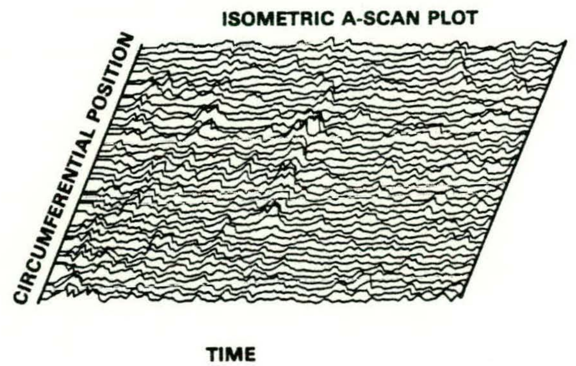
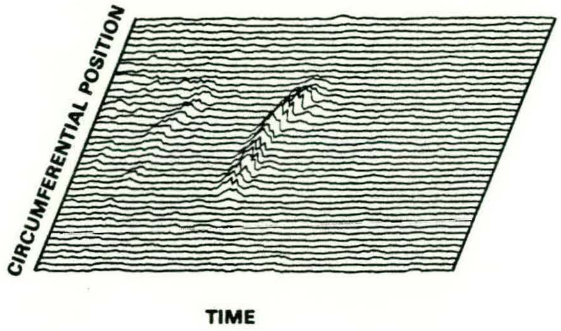


Figure 6. Two Scans of a 50 % Fatigue Crack Before Time Shift Averaging.



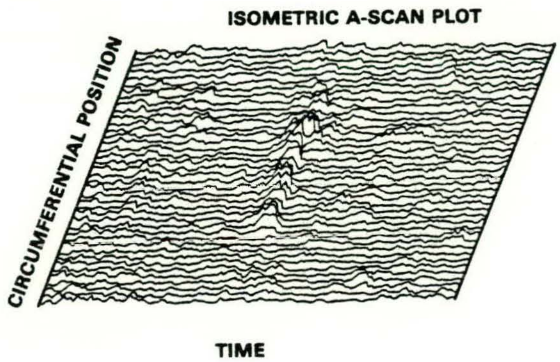


Figure 7. Two Scans of a 50% Fatigue Crack After Time Shift Averaging.