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THE USE OF PLATE WAVE ANALYSIS IN ACOUSTIC EMISSION TESTING TO DETECT AND MEASURE CRACK GROWTH IN NOISY ENVIRONMENTS

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ABSTRACT

One of the major problems encountered in using Acoustic Emission(AE) techniques to monitor structures in the field is the difficulty in separating AE signals from crack growth, from signals due to extraneous noise sources. These extraneous noise sources can be created by frictional rubbing, impact of particles on the structure being monitored and leaks by pressurized components. Most extraneous noise sources of this type are out-of-plane (OOP sources) and although they can have very high frequency components in an undamped structure, most of the energy in the stress waves created in most structures constructed from plates, can be found at frequencies below 100KHz. This energy is carried by a low frequency flexure wave in the plate. Since most field tests in the past have been conducted with high pass filters at 100KHz and above using resonant transducers, few practitioners were even aware that these waves were present prior to recent work by (Gorman and Prosser 1990). AE signals generated by crack growth are in-plane sources(IP sources) and most of the energy in the stress wave is carried by high frequency extensional and shear waves. This report shows how special transducer and instrumentation techniques can be used to recognize the type of wave predominate in a plate to allow filters to be constructed in the instrumentation to not only eliminate extraneous noise sources from the AE data, but also have the potential of measuring the depth of a growing crack in a plate.

INTRODUCTION

Acoustic Emission techniques have used in the field for over 25 years for the testing of metal and composite pressure vessels and piping. It has also found wide application in the testing of composite man lift booms. It is used primarily for locating cracks and potential problem areas in metal pressure boundary applications while other types of Nondestructive techniques are used to provide acceptance or rejection criteria. The technology has not achieved the acceptance of other Nondestructive techniques for the testing of bridges, and other components of the infrastructure for two primary reasons: One, the difficulty in separating valid signals from extraneous noise and two, the inability of the AE technique to determine the size of the crack.

BACKGROUND

We have recently reported results (Dunegan 1995) of an experimental program conducted to study and analyze the types of wave modes present in plates. Our results have shown that a small aperture mass loaded transducer is the best type of transducer to use for accurately defining the displacement and frequency content of OOP sources. This type of transducer was found to be very insensitive to IP sources which one associates with crack growth. On the other hand, it was found that a large aperture transducer without mass loading was very sensitive to IP signals and less sensitive to OOP signals. These results lead to the design of a "false" aperture transducer which comprises a piezoelectric crystal that is mass loaded over a small area of the crystal in the center. We have found that by adjusting the size of the mass and the relative area of the crystal covered by the mass that its sensitivity to OOP and IP sources of AE signals can be adjusted so that it has equal sensitivity for both types of signals. Examples will be given for two types of transducers, one for the testing of small specimens and the other for the testing of larger components.

PROCEDURE

Published literature to date dealing with plate wave analysis of AE signals has been on thin metal and composite plates. We were interested in applying the technique to bridges and other thicker plate structures and therefore starting our experiments on steel bars of 1/4 and 1/2 inch thickness. Experiments were also conducted on a 3/4 inch thick compact tension fracture toughness specimen (CT). Figure 1 shows the experimental setup on the CT specimen. The larger transducer on the edge of the plate was used to provide a trigger signal for the digital oscilloscope when 0.3mm Pentil pencil lead breaks were made at different depths in the specimen shown by the parallel bars on the edge of the specimen. The pencil lead breaks were made at each level on the vertical line drawn through the different levels. The small transducer shown was used to detect the AE data from the specimen for each lead break. The trigger transducer was used so that velocity of sound for the different waves could be measured and phase shift of the signals could be observed.

Figure 1

The small data transducer was designed with a 1/8 inch aperture and the piezoelectric crystal was mass loaded. The aperture and size of the mass was adjusted so that the transducer was equally sensitive to OOP and IP signals in the specimen. The out-of-plane (OOP) signal was generated by breaking the pencil lead on the top or bottom surface in the vicinity of the vertical line on the specimen. The transducers were attached to the CT specimen with hot glue.

The standard method used for years to calibrate an AE system in the field has been to place a pulser on the

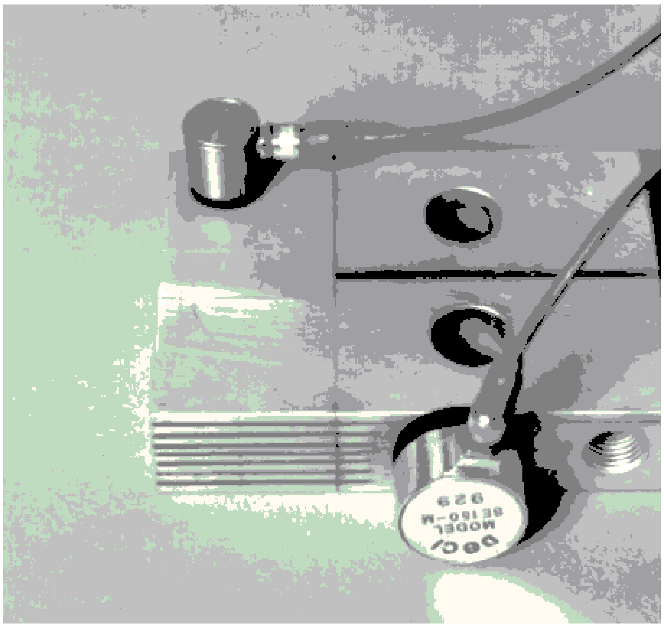

Figure 1- CT specimen with data and trigger transducer attached.

structure or break pencil leads to provide a calibration signal. We have found that both of these methods act as out-of-plane (OOP) sources, resulting in most of the energy being dispersed in the form of a flexure wave, with very little of the energy propagating in the extensional and shear modes associated with crack growth. (Prosser and Gorman) found that breaking a pencil lead on the edge of a small plate coupled to a structure provided a source of extensional waves in the structure. We were interested in finding a method of field calibration, and therefore experimented with coupling the CT specimen shown in figure 1 to a steel bar to see how effective the specimen would "clone" itself to the bar. Figure 2 is a photograph showing this experimental setup.

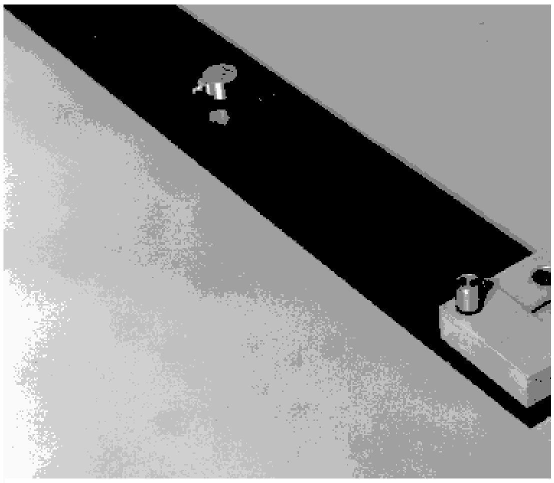

Figure 2- CT specimen coupled to bar, data transducer at

bar. The "false aperture" transducer described previously was then coupled to the bar with Vaseline at a distance of 24 inches from the end of the bar. 0.3mm pencil leads were broken on the CT specimen at different depths signified by the horizontal bars on the specimen as in the previous experiment (figure 1).

In order to provide a calibration of a structure in this manner, one needs to be assured that the data recorded is representative of what one would obtain on the structure alone. With this in mind, we then removed the CT specimen, coupled our trigger transducer to the end of the bar with hot glue and broke pencil leads at the same percentage depth in the bar as was used for the CT specimen with the data transducer remaining at 24 inches from the end of the bar.

Figure 3 is a block diagram of the instrumentation used to detect and record the signals from each setup. The trigger transducer starts the sweep of the digital oscilloscope. The signal from the data transducer is split and passed through a 100KHz hipass filter and a 20-80 KHz bandpass filter. The digital oscilloscope captures the transient signals and passes them to the computer through a fiber optic cable. The waveforms are then printed. When a pencil lead is broken at a given depth, both the high frequency and low frequency waveforms are captured and printed.

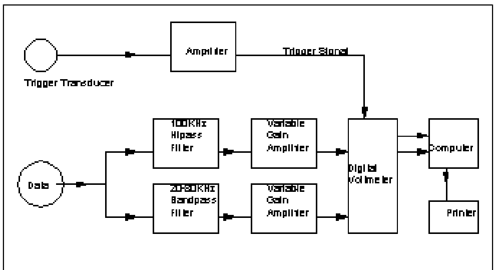

Figure 3- Block diagram of instrumentation.

Figure 3

EXPERIMENTAL RESULTS

Figure 4 shows the low frequency data from the compact tension (CT) specimen for an OOP signal(4a),

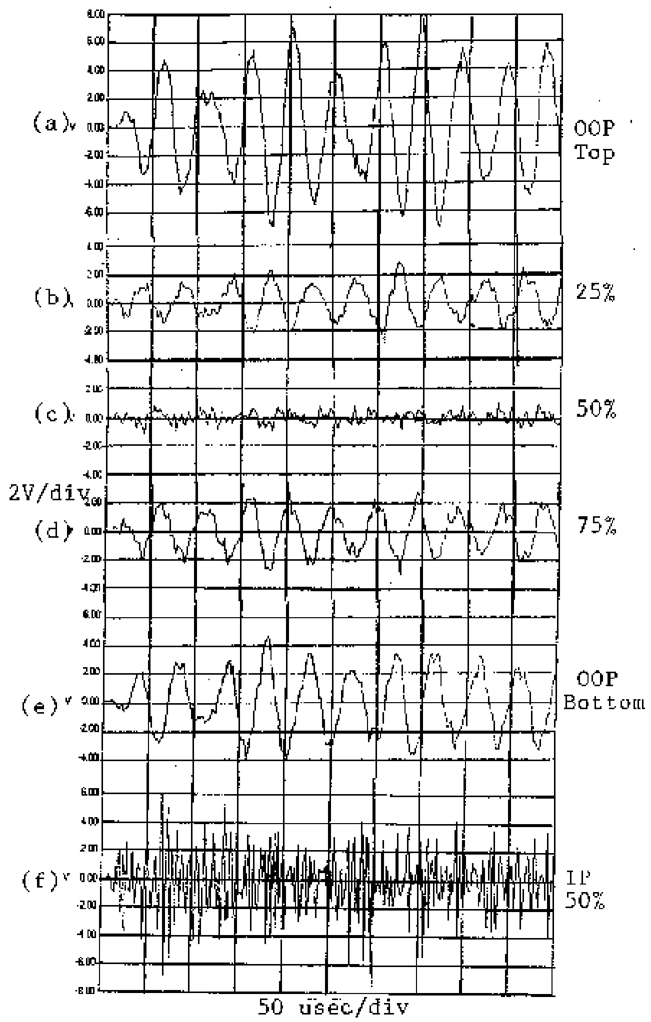

Figure 4- Showing response of low frequency chanel(a,b,c,d,e,), and high frequency channel(f) for lead breaks at different depths in CT specimen.

Figure 4

Figure 5

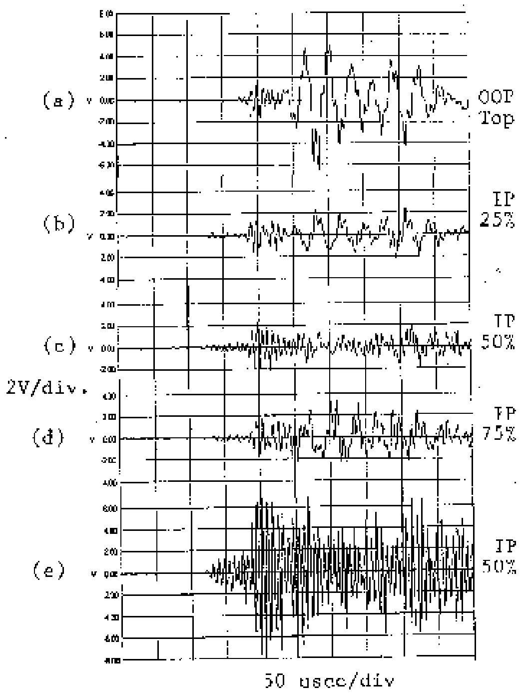

Figure 5- Response from transducer located 24 inches from end of 1/2X3X42 inch steel bar, to pencil lead breaks made at different depths in CT specimen coupled to end of bar.

and IP signals from 25%(4b), 50%(4c) and 75%(4d) depth in the specimen. An OOP signal from the bottom surface of the specimen is also shown(4e) The high frequency signals change very little as a function of depth, so only the signal from the 50% (4f) depth is shown.

Figure 5 shows the data obtained from the transducer located at 24 inches on the steel bar when the CT specimen is coupled to the end of the bar and the same procedure used for figure 4 is repeated. The high frequency signal shown was for the 50% depth(5e). The gain of the amplifiers was increased approximately 6 dB in order to obtain signals of approximately the same voltage level as figure 4. It was surprising how well the specimen "cloned" its response to the bar, with only 6dB of signal attenuation.

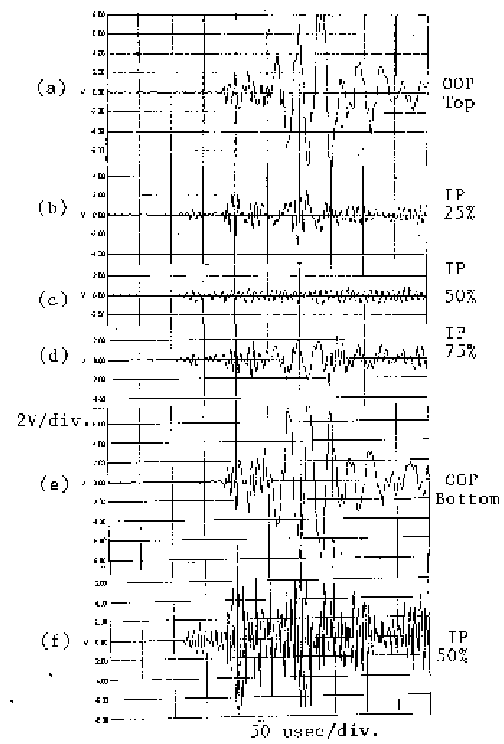

Figure 6-Response from transducer located at 24 inches from the end of a 1/2X3X42 inch steel bar. Lead breaks were made at the end edge of the bar at different depths, and on the top and bottom surface. (a-e low frequency channel). (f- high frequency channel)

Figure 6

Figure 6 shows the data from the bar alone for lead breaks at the same percentage depth used in the CT specimen. The gain increase was reduced to the same level used in the CT experiments in order to keep the signal levels at approximately the same as shown in figure 4 for the CT specimen. The vertical scale on each of these figures is 2V/division. Approximately 70dB of total gain was used for figures 4 and 6, and 76dB of gain was used for figure 5.

ANALYSIS AND DISCUSSION OF RESULTS

The breaking of pencil leads at different depths in the CT specimen (Figure 4) produce dramatic changes in signal level of the low frequency channel. This is an expected result in thin plates, but was not expected in such a thick un-plate like structure. As can be seen in 4a and 4e, an OOP source results in a large low frequency flexure type wave being set up in the specimen. Lead breaks at different depths on the edge of the specimen result in very little low frequency signal at the point of symmetry at the center of the specimen (4c) with increasing amounts of low frequency signal at 25%(4b) and 75%(4d) for unsymetrical input of the lead break. Note the phase shift in the signals between 4a and 4e, also between 4b and 4d.

The data in figure 5 demonstrates that the response of the CT specimen to lead breaks at different depths can be "cloned" into the bar. This is illustrated by the large flexure wave signal generated by the lead break on the top surface, compared to the very small signal observed from the lead break made at the center of the CT specimen. Note that the signals arriving at approximately 120 microseconds correlate well with the extensional wave velocity of 200,000 in/sec(5,000M/sec) in steel. The first large signal seen in 5d has an arrival time corresponding to the shear velocity of approximately 130,000 in/sec(3,300M/sec).

The data were analyzed from each of the three combinations by dividing the peak amplitude of the high frequency signal by the peak amplitude of the low frequency signal. The results of this analysis is shown in Figure 7. Each data point represents an average of 5 pencil lead breaks. It is very difficult to always put the same signal into the bar with a pencil lead break. Also one must be very careful to hold the pencil parallel to the plane of the bar when breaking the leads. Any force perpendicular to the plane of the bar will tend to induce flexure waves in the bar. Since we are taking a ratio of two components of the same signal, the ratio is not highly dependent on the absolute amplitude of the signal. It is very dependent on the location where the lead is broken and the pencil orientation in respect to the plane of the bar.

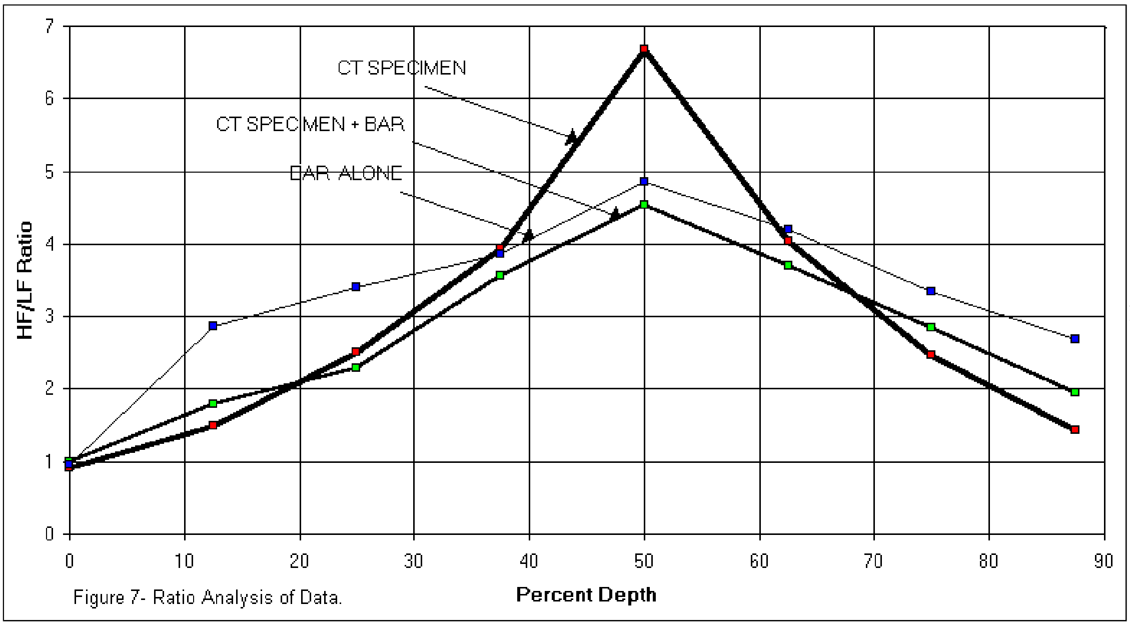

Figure 7- Ratio Analysis of Data.

Figure 7

One can observe from the data in Figure 7 that out-of-plane (OOP) sources for all three situations represented by figure 7 have ratios of less than one. A filter can therefore be constructed for data of this type by setting up the instrumentation and software to only accept as valid signals those signals having a high frequency to low frequency ratio greater than 1. Since extraneous noise sources are primarily OOP sources, they can be eliminated from the data set early by simple analog front end filtering as used in these experiments coupled with a simple software calculation and algorithm.

The excellent correlation of the data between the CT specimen coupled to the bar and a data from the bar alone suggest that structural calibration in the field can be accomplished using this technique in order to measure crack depth. A hypothetical example is given to show how this might be accomplished:

Assume that a crack is present in a bridge structure and one wishes to monitor the crack to see if it is growing, and if growing at what depth the crack is in the bridge plate structure.

In this example, one would couple the CT specimen to the plate in the vicinity of the crack and place a trigger transducer on the CT specimen and a data transducer, say at 24 inches away. Pencil leads are broken at different depths in the CT specimen and signals are recorded by the data transducer. A calibration curve similar to figure 7 is constructed in order to correlate frequency ratios to crack depth, and separate OOP from IP sources. Once calibrated, the CT specimen is removed and a trigger transducer put in its place. Continuous monitoring of the crack proceeds and ratios are calculated for all received signals, as well as time of flight between the trigger transducer and data transducer (this time is used to construct a time related filter). The ratio of each signal is calculated and signals rejected that come from OOP sources. If a signal passes the ratio test the time of flight between trigger and data transducer is observed. If the time does not fall within a predetermined window the data is rejected. If the signal passes the time test its ratio is compared to the calibration curve to estimate the depth of the crack responsible for the signal. As the crack continues to grow, it is observed whether or not the ratio is increasing or decreasing. If increasing the crack is less than half way through the plate, if decreasing the crack has passed the mid point of the plate (Figure 7). The trigger transducer will allow the change in phase of the low frequency signal to be observed. This information can also be used to determine crack depth information.

CONCLUSIONS

The data in this report presents a new technique for using Acoustic Emission data to eliminate extraneous noise sources from a data base, and measure the depth of a growing crack in metallic structures. This can have tremendous impact on use of the technology for monitoring of structures in the field. Only crack depth information can be measured, but this is the most important parameter effecting structural integrity for surface cracks. Some assumptions concerning the crack shape and physical measurement of the crack length at the surface, might allow one to determine the profile of the crack tip for a crack that has not penetrated through the thickness. The CT specimen used in these experiments has the capability of being bolt loaded. Future studies will involve loading the specimen after hydrogen charging to create crack growth, and attempting to correlate the AE data with actual crack growth with a more automated computer based system.

REFERENCES

M.R. Gorman and W.H. Prosser, *Journal of Acoustic Emission 9(4), 283-288 (1990)*

H.L. Dunegan, "The Effects of Aperture Size and Mass Loading on the Response of AE Transducers to Plate Waves," *38th AEWG conference, NASA, Langley VA 1995.*

W.H. Prosser and M.R. Gorman, "Accurate Simulation of Acoustic Emission Sources in Composite Plates," *Proceedings of the 1994 ASNT*

Spring Conference, New Orleans, March 1994, pp. 152-154.