LOCATION OF LEAKS IN PIPES BY USE OF ACOUSTIC EMISSION MODAL RATIO TECHNIQUES

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INTRODUCTION

Acoustic techniques have been in use for decades for the detection of leaks in pressurized piping. If the surface of the pipe is exposed, the location of the leak can sometimes be determined by visual methods. If the pipe is coated or buried or otherwise concealed, one can sometimes estimate the approximate location by measuring the amplitude of the acoustic emission signals produced by the leak. If a leak occurs due to the growth of a fatigue crack at high pressures, it has a tendency (for liquids) to "weep" one drop at a time and does not leave much visual evidence of its presence. In this situation the leak is easily detected by acoustic emission techniques but not so easily located based on the amplitude of the acoustic emission signal or visual methods.

This report describes experiments conducted on a 500 ft. section of coiled tubing used for applications down hole in providing pressurized liquids as well as directional drilling in the oil and gas industry. The tubing used in these experiments had an outside diameter of 45.4mm with a wall thickness of 2.77mm.

THEORY: There are several stress wave modes generated in a pipe full of water due to the growth of a crack or a high pressure leak. There are three primary waves generated in the pipe wall:

1. An extensional wave, (longitudinal) with high velocity.
2. A shear wave with intermediate velocity..
3. A low frequency dispersive pipe wave. (similar to the anti-symetrical lamb wave in plates) with the lowest velocity.

A dilatational (longitudinal) wave is also produced in the water in the pipe with a velocity of approximately ½ the velocity of the shear wave in the pipe. The three waves in the pipe generated by the leak itself will be attenuated fairly rapidly but will be regenerated by expansion of the pipe due to the passage of the slower water wave. Therefore the water wave becomes the most important wave for detection and location of the leak. High frequency components of the water wave will be attenuated more rapidly than low frequency components. Therefore the ratio of the amplitude of the high frequency (HF) components divided by the amplitude of the low frequency (LF) components should be proportional to the distance between the leak source and the sensor detecting the signals from the leak. The HF/LF ratio will be referred to in this report as the modal ratio. The AESMART 2000 multiple channel acoustic emission instrument utilizing DECI-24ASL software and SE40-QI sensors were used for recording and analyzing the data in this report. The instrument and software measures high frequency (HF 100-700Khz) and low frequency (LF 20-70KHz) components of the signals detected by the sensors , computes the HF/LF modal ratio and displays the data in an excel spread sheet.

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EXPERIMENTAL PROCEDURE

The 500 feet of tubing was put in a big loop and the two ends were brought into close proximity to each other. A pump for providing pressurized water was hooked up to one end of the pipe and our experimental measurements were made near the other end. Figure 1 shows the two ends of the pipe. A 2 meter section of pipe containing a fatigue crack was welded on to the experimental end and a pressure gage installed. This is shown in the figure 1.

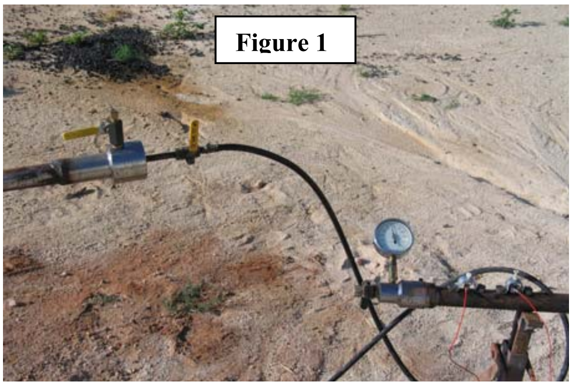


Figure 1

We were interested in measuring the velocity of the stress waves generated in the pipe. This was accomplished by mounting a small aperture SE25-P sensor near the end of the pipe and also placing a SE375-M sensor near it to act as a trigger sensor for a digital oscilloscope. The model 600 pulser was connected to the SE25-P in order to transmit a transient stress wave into the pipe that had been purged of air and pressurized to 800psi. The pulser is designed to pulse approximately 1 pulse per second continuously. The cylinder like object in figure 2 is the pulser set in the 150V output position. The white dot observed near the connector is the SE25-P sensor turned over to show the 3.3mm aperture of the sensor. The box near the pressure gage is the battery pack for the pulser. Figure 3 shows a magnetic hold-down containing an SE40-QI sensor. This sensor contains a 20dB internal preamplifier and is connected to the data port of a Mux-Module.

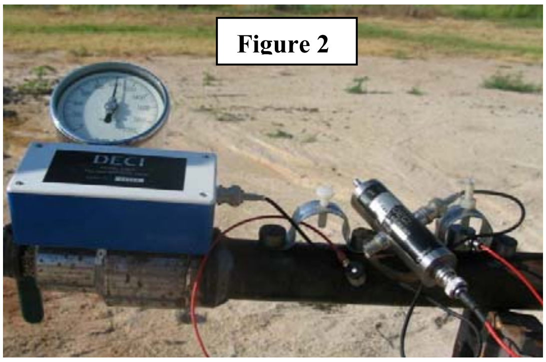


Figure 2

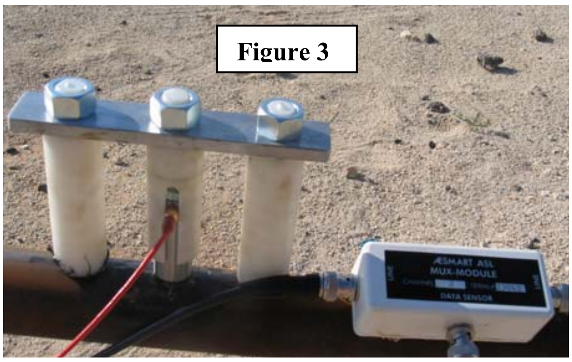


Figure 3

We used four channels of the AESMART 2000 for gathering the data. Each channel comprised a sensor and Mux-Module as shown in figure 3 and all channels were daisy chained on one cable which was connected to the AESMART 2000 approximately 100 feet away in the shop.

EXPERIMENTAL RESULTS TRANSIENT SIGNALS

The oscilloscope traces below (Figure 4) show the results from each channel due to the signals produced by the pulser. The distance each sensor is from the pulser is shown and the estimated velocity to the peak of the signal is shown. The velocity measurements were calculated using the time base of the oscilloscope and therefore are not precision measurements. The velocity of sound in water is approximately 1,500 m/sec. The correlation of the data below is close enough to this value to give convincing evidence that most of the energy of the stress wave is carried by the water. Note that the amplitude of the signals in both the high frequency and low frequency channel in the channel 1 data nearest to the pulser are approximately the same, giving a modal ratio of approximately 1. Channels 2,3,and 4 show that the modal ratio decreases as the distance from the pulser to the sensors in each channel increases. This is due to the higher rate of attenuation for the high frequency components of the signal.

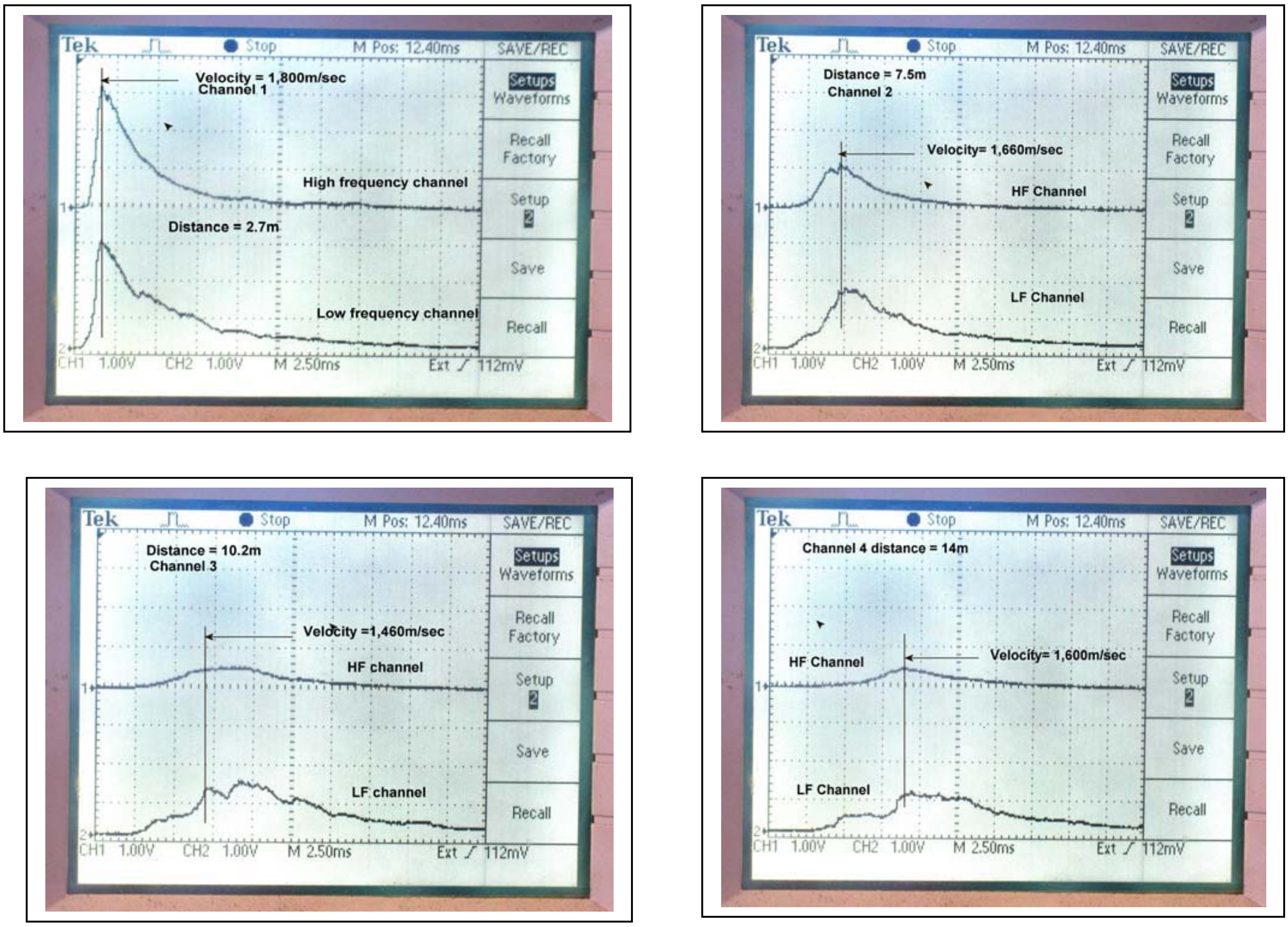


Figure 4- Showing the high frequency (HF) and low frequency (LF) signals received from the pulser sensor at different distances from the pulser for each of the 4 channels..

EXPERIMENTAL RESULTS LEAK TESTING

The planning stage for this experimental program included pressurization of the pipe to 10,000 psi. We hoped that the situation would present itself that a "weeping" leak at the fatigue crack under very high pressure would materialize From this we could see the advantage of using acoustic emission monitoring in situations where detection of the leak by visual methods would be impossible. We also had in the plan to bury a section of the pipe to determine the results of attaching metal wave-guides with a pointed end to the transducers. In this manner the wave-guide would be driven into the ground until the point of the waveguide touched the buried pipe. We are confident based on our experiments with pointed waveguides that the idea would work and in doing so provide an easy method for detecting leakage in underground pipelines. Unfortunately we spent most of the week allocated for this testing in an attempt to rent a high pressure pump for the experiments. The experiments were conducted in Midland Texas which is "oil patch" country and therefore the assumption was made that finding a high pressure pump in this region would be easy. On the last day scheduled for testing we were able to find a pump that would go to 800 psi maximum pressure.

Figure 5

Figure 5 shows a picture of the pump and some of the surrounding area where the pipe was placed.

We discovered that when the pump was used to pressurize the pipe full of water, 800 psi was insufficient pressure to cause a leak at the fatigue crack in the pipe. The fatigue crack was created by three point bending of a 2 meter section of pipe in a special fatigue machine that was capable of stressing the pipe while it was under pressure. The displacement of the pipe during this test was high enough to plastically deform the pipe. When the leak occurred the test was stopped at a position that placed the fatigue crack in compression. The pipe set around after the test for some time which resulted in rust forming on the crack surfaces. Had we had a pump capable of 10,000 psi it probably would have leaked at these higher pressures.

We improvised a clamping arrangement which could be used to put the pipe in reverse bending to open up the crack enough so that a leak would occur at the 800 psi pressure from the pump we were using. In one instance we pressurized the pipe to 800 psi and used a shut off valve to take the pump out of the system. Under this situation the

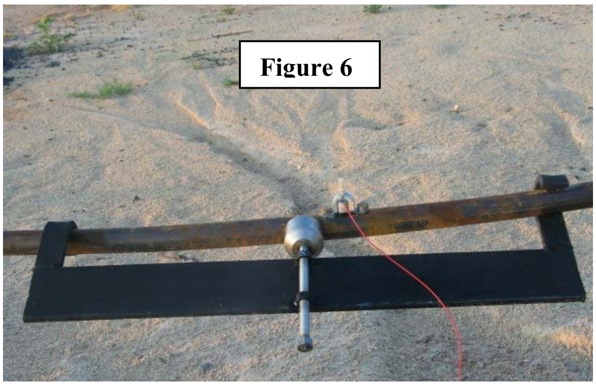


Figure 6

pressure gradually decreased due to the leak until 200psi was shown by the pressure gage, at which time the leak stopped. A photo of the fixture designed to put reverse bending on the pipe is shown in figure 6. The fixture is clamped to the pipe and a wrench is used to tighten the long screw. This action tends to straighten the pipe and open up the fatigue crack that is 180 degrees opposite the center portion of the clamp.

The sensor placement was the same used for the transient measurements reported in the first part of this report. A high pressure leak produces continuous acoustic emission signals. The average signal level (ASL) of these signals results in a DC shift of the signals on the oscilloscope. Figure 7 shows the trace for the HF and LF ASL signals observed on the oscilloscope with no leak present.

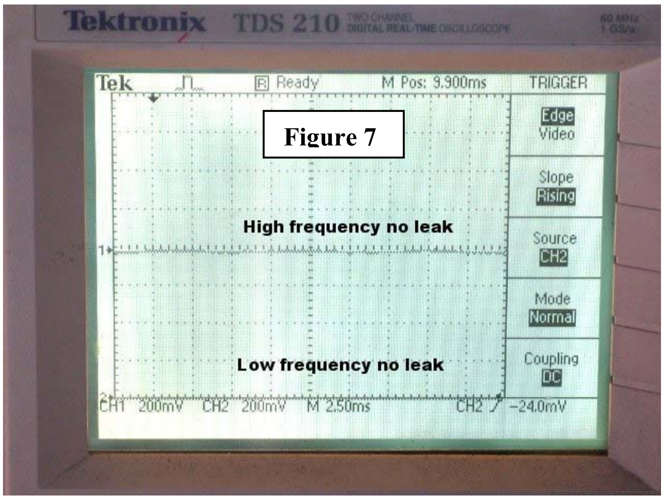


Figure 7

Figure 8 shows the signal shift produced by a leak in the pipe. A sine wave input into the ASL circuit would produce a pure DC shift. The varying amplitude of the signals in figure 8 are due to the variation in amplitudes of the acoustic emission signals produced by a leak. Since our goal is to measure the ratio of HF/LF amplitudes it is obvious that averaging of these ratios must be done in order to get an accurate correlation between the modal ratio and distance from the leak.

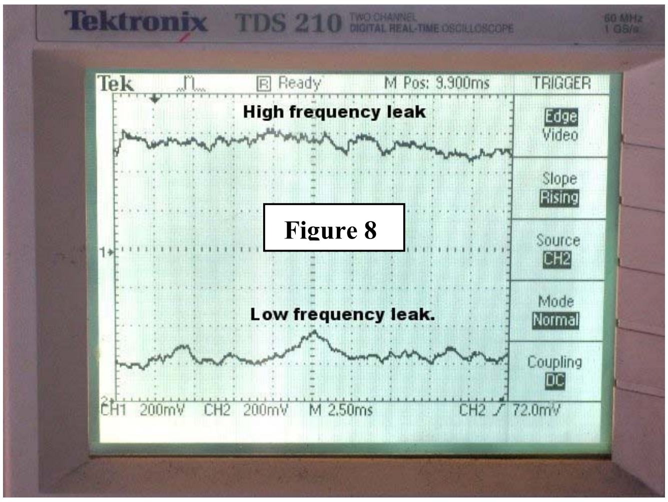
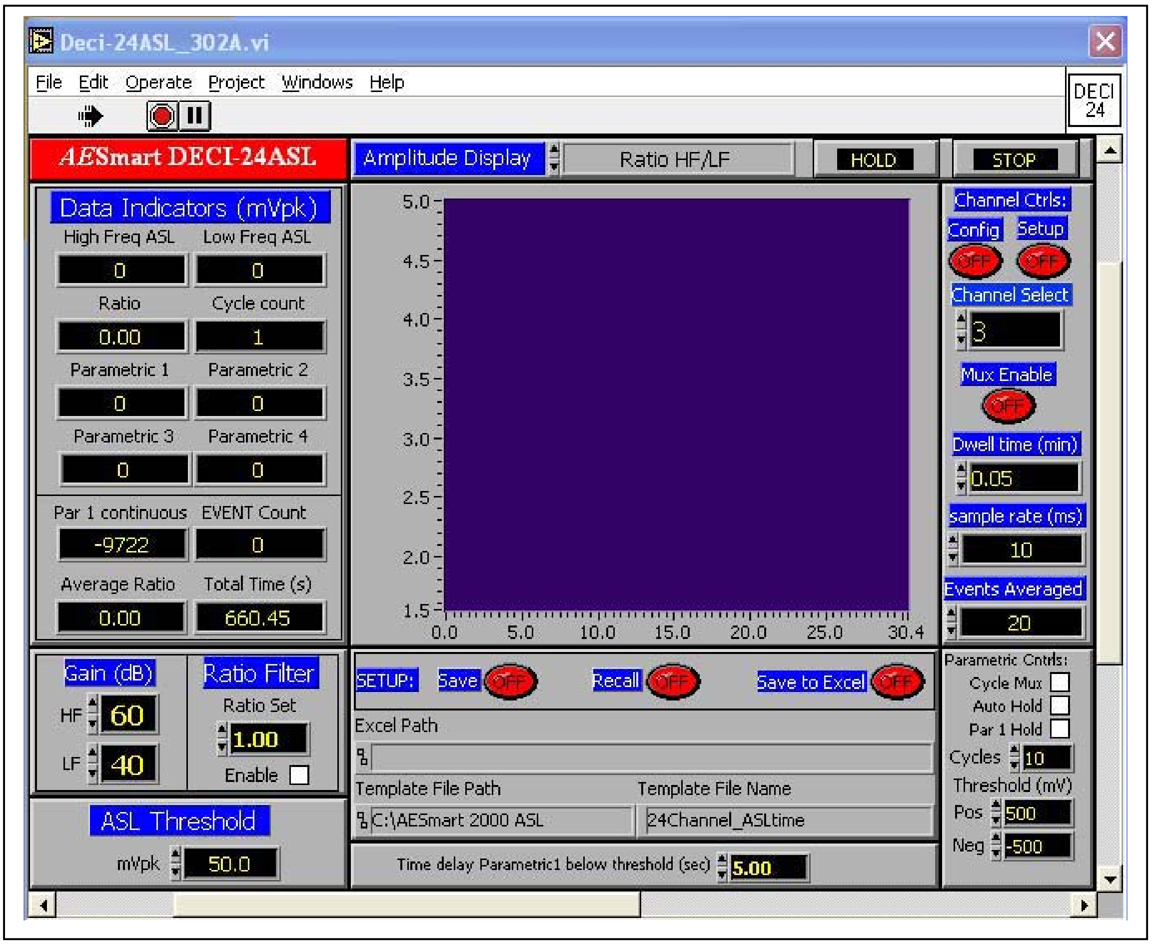


Figure 8

The software of the AESMART 2000 is designed to average over as many samples as the user chooses. Figure 9 shows the virtual screen of the AESMART 2000 using DECI-24ASL software. Note that the gain settings of the high frequency (HF) channel is set at

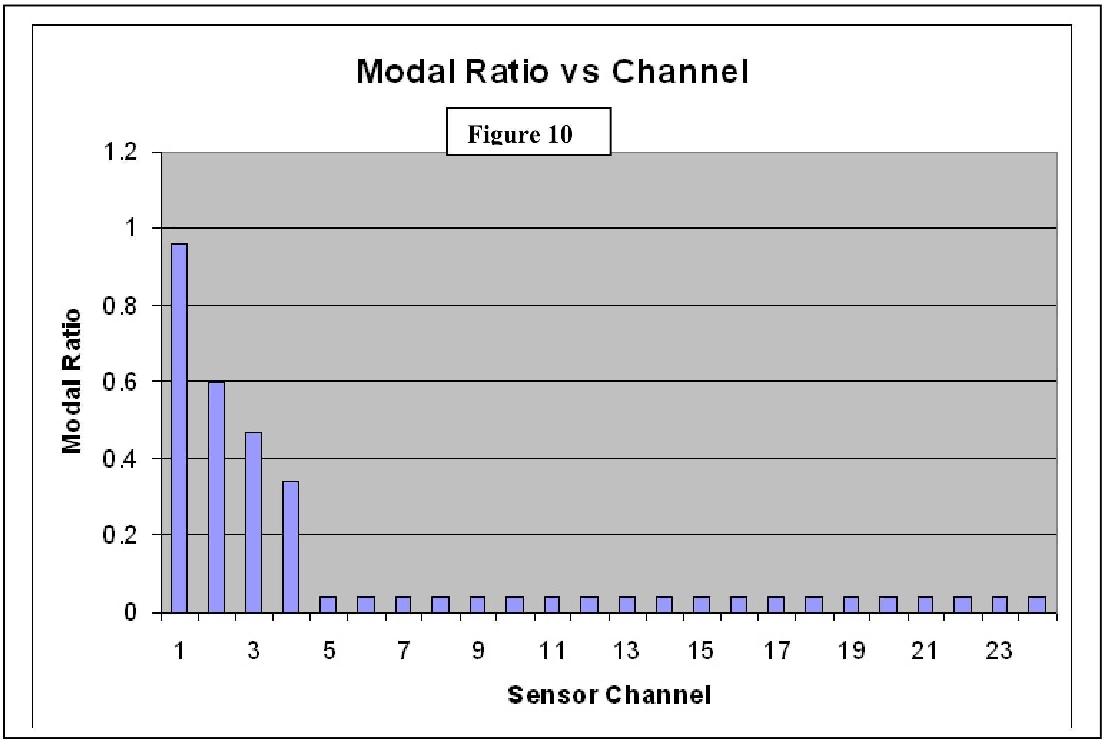


20 dB more gain than the low frequency (LF) channel. This is due to the fact that the SE40-QI sensor used in these tests has its maximum displacement sensitivity of 1volt/nanometer at 40KHz, which is in the bandpass of the LF channel. It is much less sensitive in the bandpass of the HF channel. This difference in gain was selected so that when one of the sensors is near the leak site the modal ratio is approximately 1.

The dwell time for muxing through the 4 channels used was set at 0.05 minutes. The sample rate for the A/D converter was set at 10 milliseconds. Note immediately below the sample rate box is events averaged. The parameter averaged is the HF/LF modal ratio. We found that averaging 20 samples of the modal ratio was adequate to provide correlation with distance from the leak. As the system muxes to another channel the previous averaged modal ratio is transferred to an excel spreadsheet. A 24 channel histogram graphic is automatically generated for the average modal ratio of each channel.

The software used will handle up to 24 channels but can be expanded to 100 channels . It was configured for only four channels for this test.

Figure 10 shows the histogram graphic of the modal ratio from each channel. The highest value of the modal ratio occurs for the sensor nearest to the leak, and the lowest value of the modal ratio occurs for the sensor that is the greatest distance from the leak.



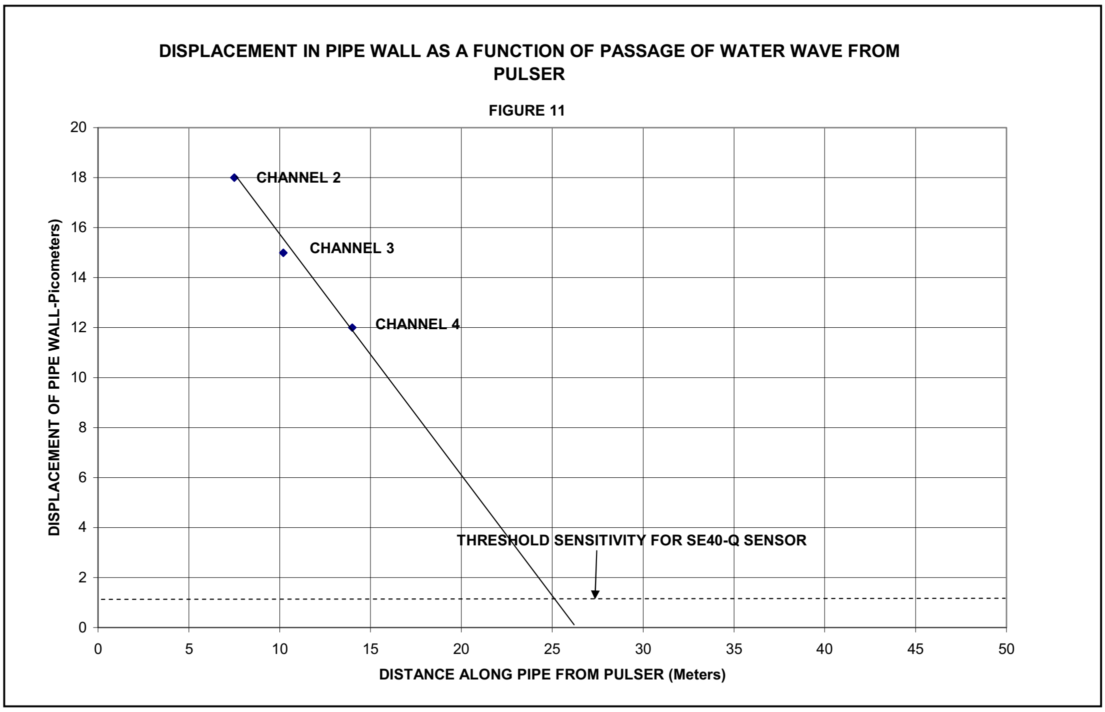
DISCUSSION AND CONCLUSIONS

The primary reason for using 500 feet of the coiled tubing was to prevent standing waves due to reflection of signals from the opposite end of the pipe from influencing the AE data. The original plan was to use spacing between the sensors of 7.63 meters but we had problems with the Beta version of the DECI-24ASL software and ended up using only 3.8 meters spacing between channels 2,3 and 4. Channel 1 was only 2.7 meters from the leak source in both the transient and leak testing portion of the test. Note that both the data from the transient source from channel 1 in figure 4, and the leak source in figure 10 show a modal ratio near a value of 1. In figure 10 we observe a close correlation between the modal ratio and the distance between the equally spaced sensors of channel 2,3 and 4. The problem we encountered with the beta software during these tests has now been corrected.

Due to scheduling problems, there was not time enough to complete the tests we wished to conduct with the sensors mounted on pointed waveguides. We were fortunate that we took with us to Texas one of our portable Termite Tracker instruments. The probe on this instrument has an SE40-Q sensor mounted to a wave guide with a point that is inserted into a drill hole in wood to detect termite activity. We found that when placing the point of the waveguide against the coiled tubing during the transient tests, that the signal from the pulser could be detected at a distance of 91 meters (300 feet) from the pulser. The 800psi leak signal could be detected over the total length of the pipe 152 meters(500feet).

We found from further analysis of the data in the LF channel of figure 4 that extrapolation of the signals to the maximum sensitivity of the SE40-Q to displacement with 40dB of gain (100 mv/picometer), that the signals from the pulser would only be detected at a maximum distance of 25 meters. Based on the information gained from the portable instrument it is anticipated that a high pressure leak could be detected over a much longer distance.

Figure 11 shows a graphic of the displacement of the pipe wall for channels 2,3, and 4 as



a function of distance along the pipe from the pulser. We believe that this shorter distance for detection of the pulser signal (25 meters as opposed to 91 meters for the portable unit) is due to the design of the electronics in the portable unit. It is designed such that any signal above threshold will cause the output to go to the rail of 15 volts regardless of its amplitude. Therefore it is always operating at maximum sensitivity. The signals from channel 1 were not included in the above graphic due to its nearness to the pulser. Signals from the pipe as well as from the water wave resulted in a much higher amplitude signal for channel 1.

We believe that these results show great promise for the use of modal ratios for locating leaks in long pipelines. If one attempted to locate a leak from the amplitudes alone in

figure 4 the accuracy of location would not be very good. Since the modal ratio is measuring two components of the same signal, the modal ratio is independent of the absolute amplitude of the signal
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Further studies on pipes of different diameters and wall thickness containing fluids of different viscosity will determine how these variables affect the modal ratios of the acoustic emission signals. Another variable that could affect the data is whither or not the pipe is coated or buried in the ground. Since the wave in the fluid appears to dominate the results and will not be affected by this variable, it is anticipated that coating or burial of the pipe will not affect the results providing that the sensor or point of a waveguide is in direct contact with the pipe surface..