www.ndt.net - 3rd MENDT - Middle East Nondestructive Testing Conference & Exhibition - 27-30 Nov 2005 Bahrain, Manama

USE OF ADVANCED A.E. ANALYSIS for SOURCE DISCRIMINATION USING CAPTURED WAVEFORMS

Phil Cole
Physical Acoustics Limited, Cambridge, CB4 3NZ, UK
Scott Miller
Saudi Aramco, Dhahran, Saudi Arabia

ABSTRACT

Conventional methods of acquiring and using acoustic emission (AE) discard the raw signal waveform after extracting signal features from it. The main reason for this is the number of bytes required to save hundreds of thousands of AE waveforms, using a modern high speed multi-channel system the hard-drive may be quickly filled. One side effect of this "feature extraction" approach is that information is thrown away with the wave-form. The advent of systems capable of acquiring AE waveforms on all channels has opened up the opportunity to use this extra data to get more information about the source and the transmission path. This paper describes the use of acoustic emission waveforms to aid source discrimination, and presents data acquired during pressure testing of a slug-catcher.

AE FROM PRESSURE VESSELS and DATA ACQUISITION

Acoustic emission signals from pressure vessels are typically acquired over a bandwidth of up to 1000 kHz. AE energy is released when a crack propagates, or material yields, but in addition energy in this frequency range is detected from non-AE sources such as surface fretting, corrosion spalling, leaks and impact noise. Information contained in the waveform can theoretically tell you if the source is surface or sub-surface, a result of AE or not, and even the distance over which it has travelled to reach the sensor. As a result of their transient nature it is necessary to sample the waveform at more than ten times the maximum frequency in order to reasonably reproduce the waveform. The large range of amplitudes from AE testing requires at least 16-bit amplitude dynamic range and measurement, the net result requiring 20 MB per second per channel of signal processing. Pressure vessel tests typically use 20-60 sensors (channels) and last a number of hours, so real-time processing is essential to handle the data.

The Physical Acoustics DiSP-56 system used for this work has parallel channels, each with its own analogue filtering, followed by 10 MSPS (mega samples per second) 16-bit A-D (analogue to digital) conversion, with multiple FPGA's (field programmable gate arrays) to extract signal features from signals from one microsecond up to one second in duration, at rates of up to 7000 transients per second. A 32-bit floating point DSP (digital signal processor) carries out the advanced mathematical functions.

Waveforms are captured from the bit-stream by a "piggyback" waveform board with its own 32-bit DSP, this processes waveforms in parallel to the signal feature extraction, the sample rate for waveform storage may be set lower than 10MSPS, and the maximum waveform length may be limited, in order to reduce data storage requirements, and intelligent digital filtering may be used to record only waveforms of interest, all 56 channels can record waveforms. A threshold is used to eliminate noise and small signals, digital filtering may also be used if specific noise sources can be identified and characterised.

All system functions are controlled via Physical Acoustics "AEWIN-PERFPAC" software, this was developed as part of the PERF 95-11 program, an API joint industry development involving all major oil companies and aimed at improving understanding and source discrimination when using AE on-line or during pressure testing. The data is saved to hard-drive, and the operator interface and high level computing runs on Windows 2000 Pro operating system.

PRESSURE VESSEL and SET-UP DETAILS

The vessel, shown in figure 1, is a “slug-catcher”, 10.8 metres tan-tan, 4.5 metres diameter, and 35mm thick carbon steel. In previous service it suffered hydrogen blistering on one side, shown in figure 2.

Prior to defining the test set-up a number of actions are required, these include the analysis of expected wave-modes for the vessel using the “Plot RLQ” module, the result for this vessel is shown in figure 3, it can be seen that the “triple point”, where all wave modes travel at the same velocity, is at about 60 kHz.

Figure 1: Slug-catcher Pressure Vessel ready for Test

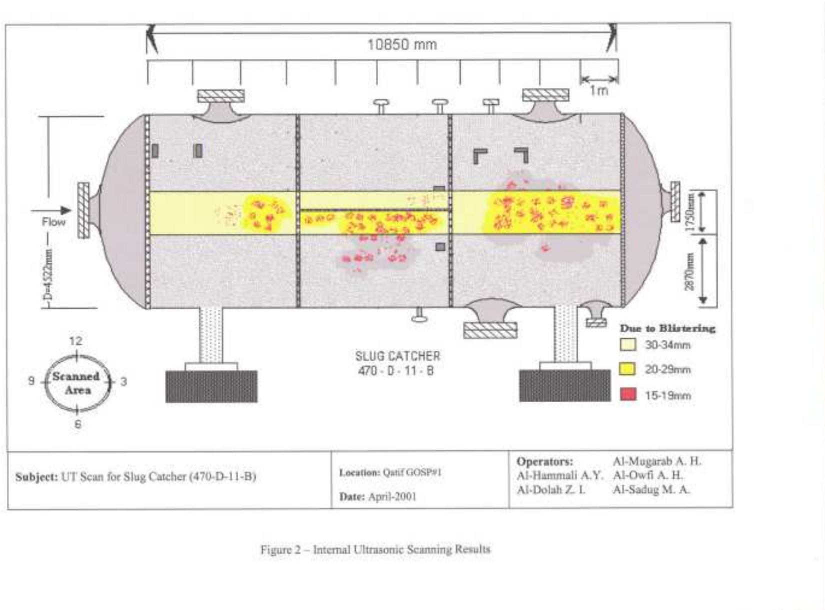

Figure 2: NDT Results showing Areas of Hydrogen Blisters

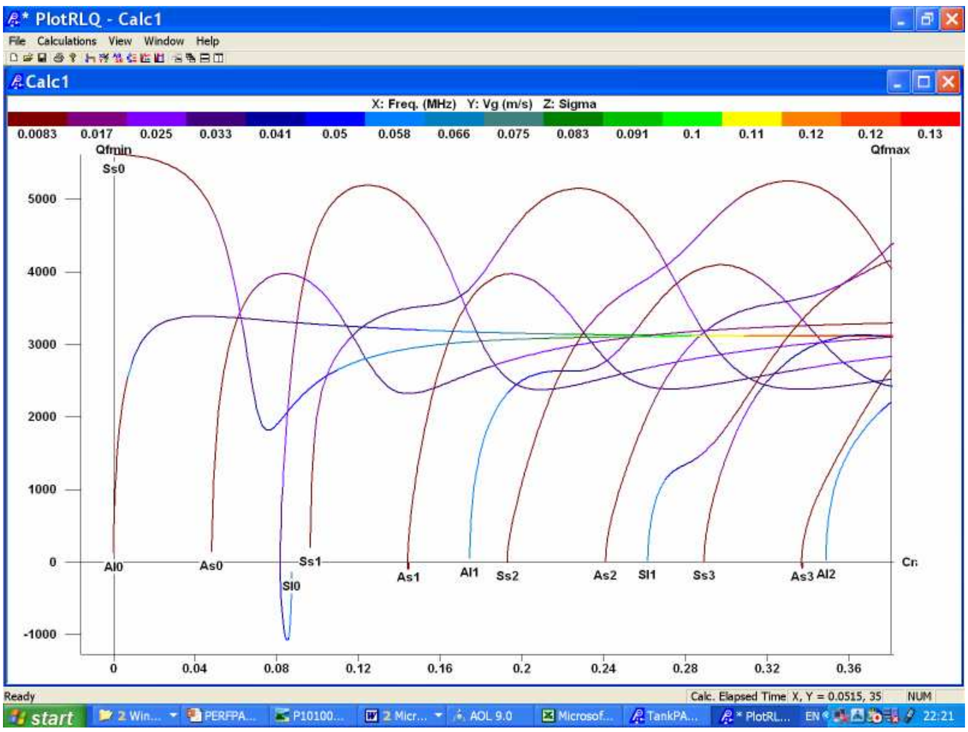

Figure 3: PLOTRLQ shows the wave modes and their attenuation, Y-axis is velocity, X-axis is MHz

One objective of this exercise was to test some of the theory in the field, for this reason three frequencies of sensor were used, thirty eight PAC R15I sensors (the “industry standard” for pressure vessel tests) monitored the entire vessel, and four each PAC R6I (peak response around the triple point), and WDI (wide band 100-1000 KHz) simultaneously monitoring one area of the vessel monitored by four of the R15I's. The area monitored by all three sensor types was 2.2 metres square and encompassed part of the damaged area.

The Hsu-Nielsen pencil-break source was used to verify correct mounting and operation of all sensors, followed by measurement of attenuation. As expected the attenuation measured using the R6I was the lowest, with the source being detectable from almost anywhere on the vessel, as a result of optimised "triple point" transmission. The source was detectable (i.e. dropped to test threshold) at ~6 metres using the R15I and ~4 metres with the WDI. In all cases the processing bandwidth was 20-1000 KHz.

It was found that the attenuation increased when crossing the blistered area, as a result of the inability of the wave modes to travel in the changing thicknesses without repeated conversions.

The Hsu-Nielsen source was then used to test the "source distance" function in PERFPAC for all three sensor types, by capturing waveforms at different distances in the longitudinal direction. In theory, at the triple point, there would be no dispersion, so the arrival of different modes used to calculate source-sensor distance would be impossible to measure using the R6I. In practice the arrivals were clear, probably a result of the relatively broad bandwidth of both the sensor and signal processing, allowing the modes at different frequencies to be seen. The signals and analysis are shown in figures 4 and 5, calculation of source distance from the waveform was quite accurate, with only 5cm error at 2 metres distance. The source distances were calculated accurately for all three sensor types at these distances, however at greater distances, 6 metres the WDI, the extensional wave mode was lost in the noise and so distance measurement from the waveform became impossible, the same would apply to smaller signals at shorter distances.

Measurements were then made across the damaged area, waveform distortion reduced the accuracy, and in the case of the WDI prevented measurement of distance.

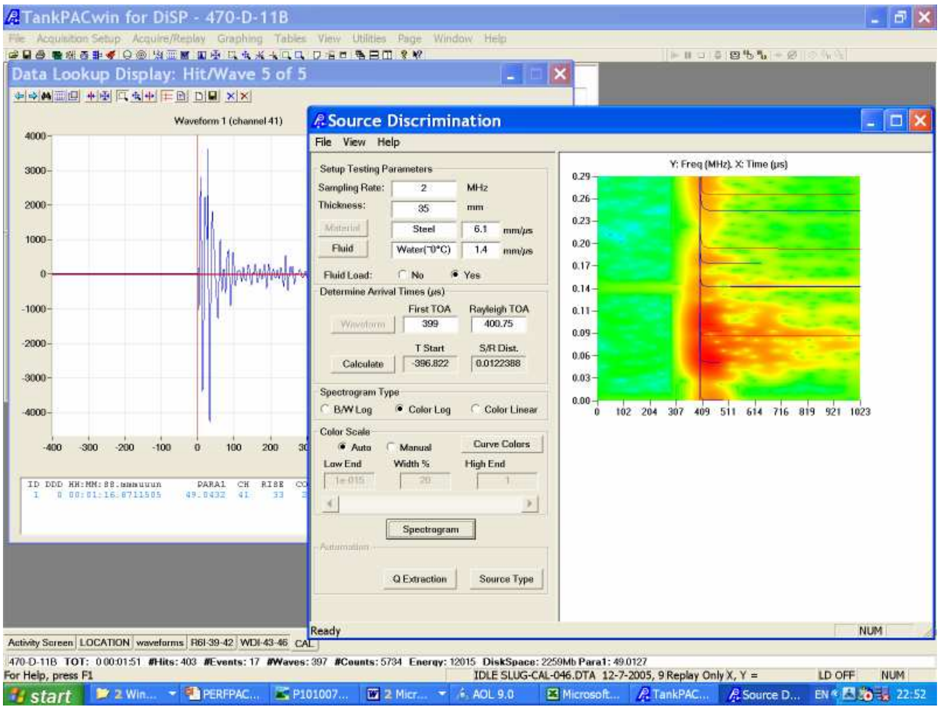

Figure 4: Hsu-Nielsen 100mm from R6I sensor, calculated S/R distance is 0.012 metres

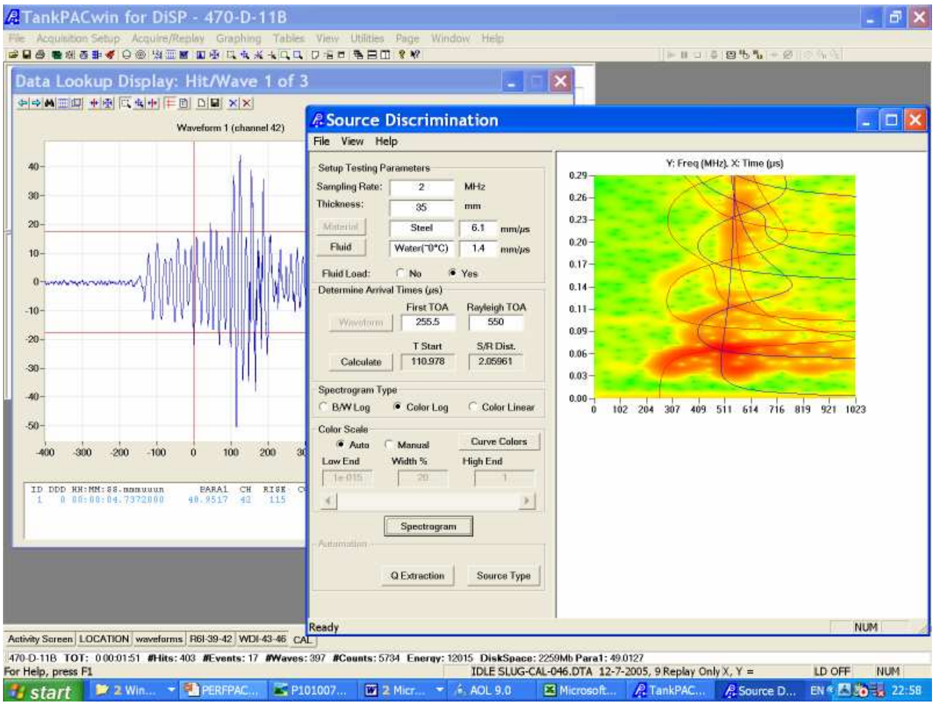

Figure 5: Hsu-Nielsen 2 mm from R6I sensor, calculated S/R distance is 2.05 metres

PRESSURE VESSEL TEST

The vessel was pressurised, recording waveforms in addition to feature and time based data. The feature data is shown in figure 6, at 264 psi pressurisation was stopped to try and stop a small leak at the large man-way, this was not possible, so the test was terminated. At this point thirty three thousand hits had been recorded, twenty thousand waveforms (these were being recorded above a higher threshold), and nearly seven hundred event locations identified, a total of ~1.3 gigabytes of data (98% waveforms).

The recent maximum for the vessel was 130 psi, although in service the vessel usually operated at much lower pressures, even though design pressure was 300 psi. Emissions were located from many areas of the vessel, including the damaged area monitored by the three sets of sensors. In this area the R6I array located the most events, followed by the R15I, the WDI array located no events at all. The most active area on the vessel was near to sensor 10, which became active early on and continued to emit at increasing rates throughout the test. Although there are locations in the area, see figure 7, the source was not concentrated. Analysis of waveforms from channel 10 showed activity characteristic of acoustic emission, originating within 300mm, one of these waveforms is shown in figure 8.

Located signals from the hydrogen blistered area were also examined, figure 9 shows the waveforms received at three R6I sensors from the same emission, their computed source position, the short-time fft, and the source-receiver distance calculated using the waveform received at the nearest sensor. All the data correlated well. The WDI sensors did not locate any emissions, though individual sensors did detect them, insufficient high frequency energy travelled across the damaged area for the WDI to detect, the waveforms received by the R15I were heavily distorted by travelling across the damaged area.

Finally, the PERFPAC source discrimination was applied to find the depth and tensor direction of a source, one result is shown in figure 10, indicating a likely near surface horizontal tensor being the most likely cause. This might be expected in the case of hydrogen blisters, it is of course exceedingly difficult to correlate this information due to the limitations of conventional NDT and the difficulty of making multiple micro-sections from material taken from the area.

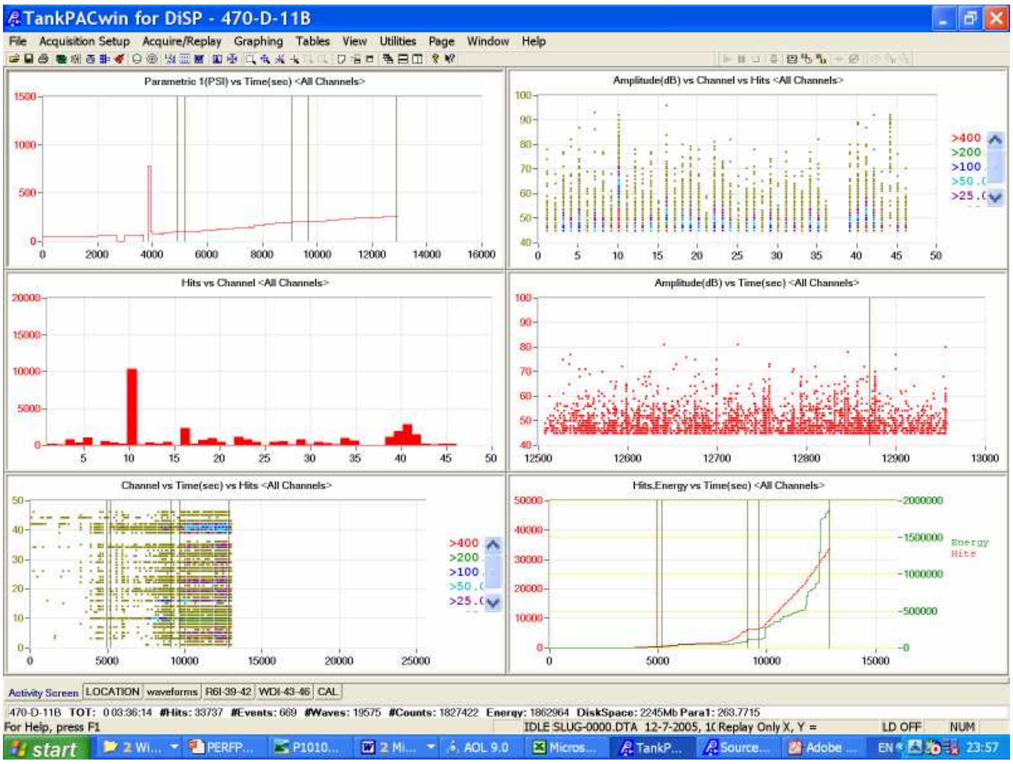

Figure 6: pressure versus time and AE feature data recorded during pressurisation

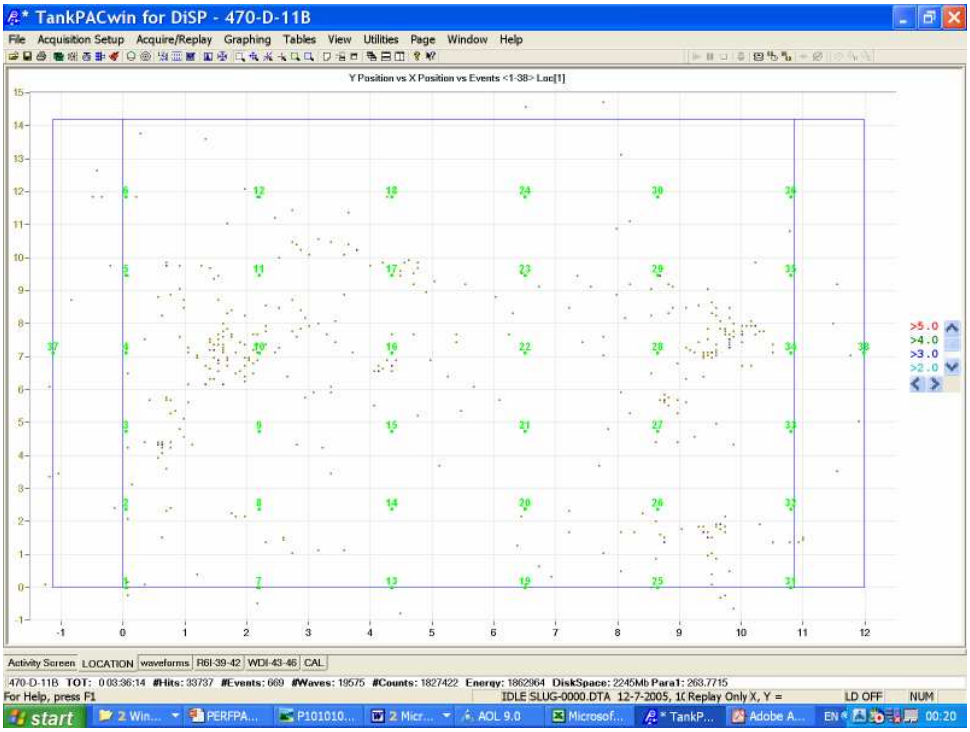

Figure 7: Planar location of vessel sources recorded during pressurisation

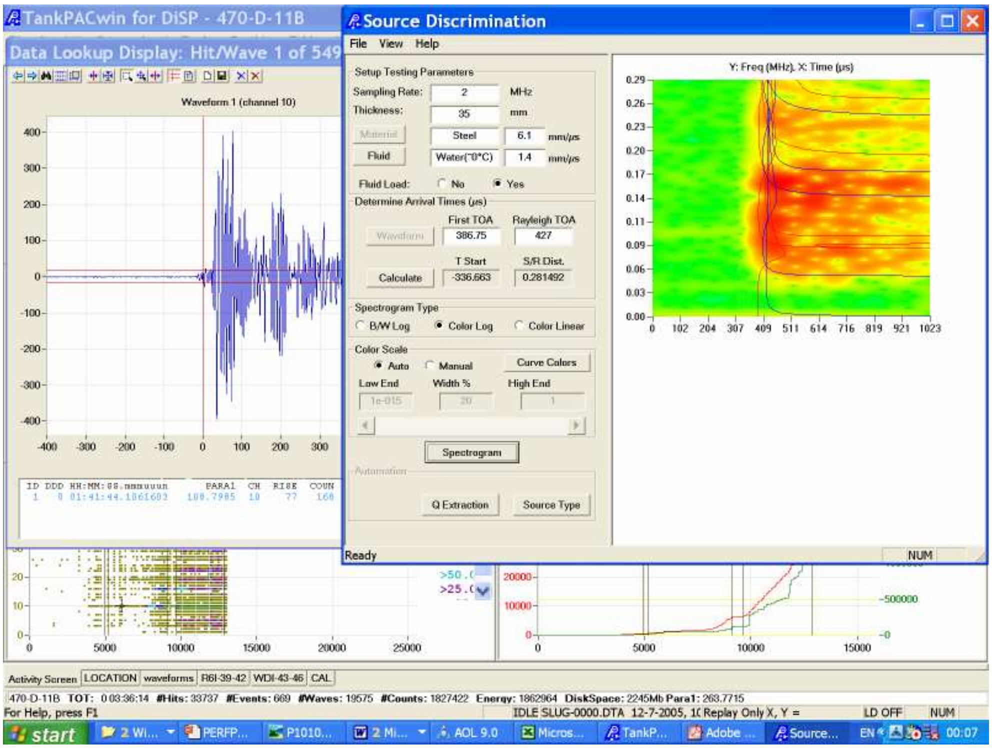

Figure 8: AE Waveform recorded during pressurisation, source-receiver distance calculated at 281 mm

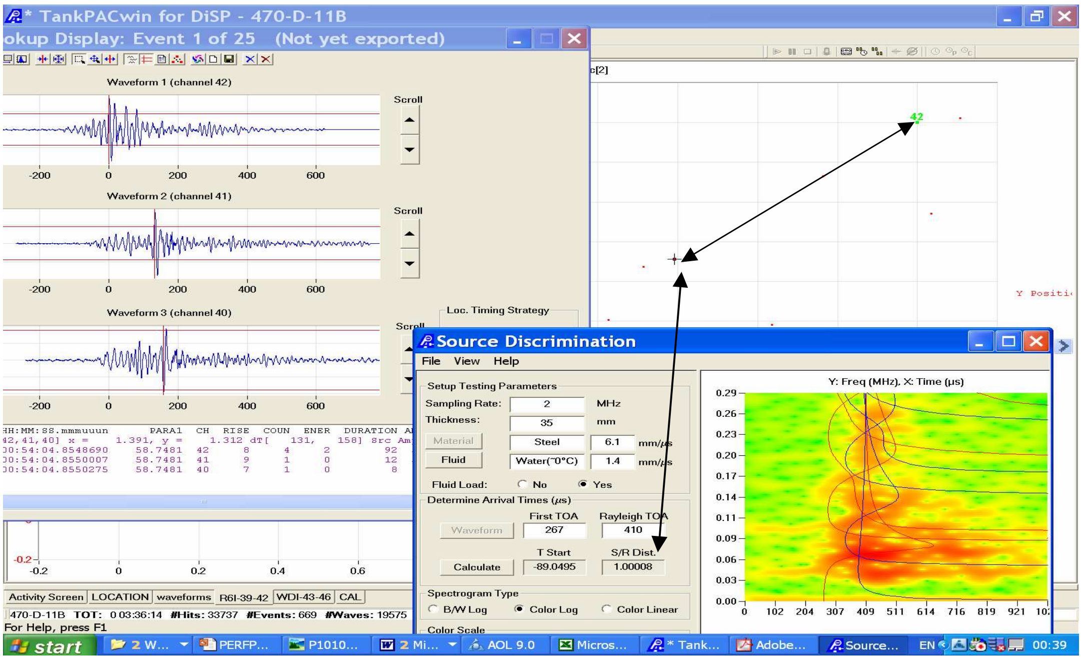

Figure 9: AE Waveforms from located source in damaged area recorded during pressurisation, source-receiver distance calculated at 1m agrees with computed source position

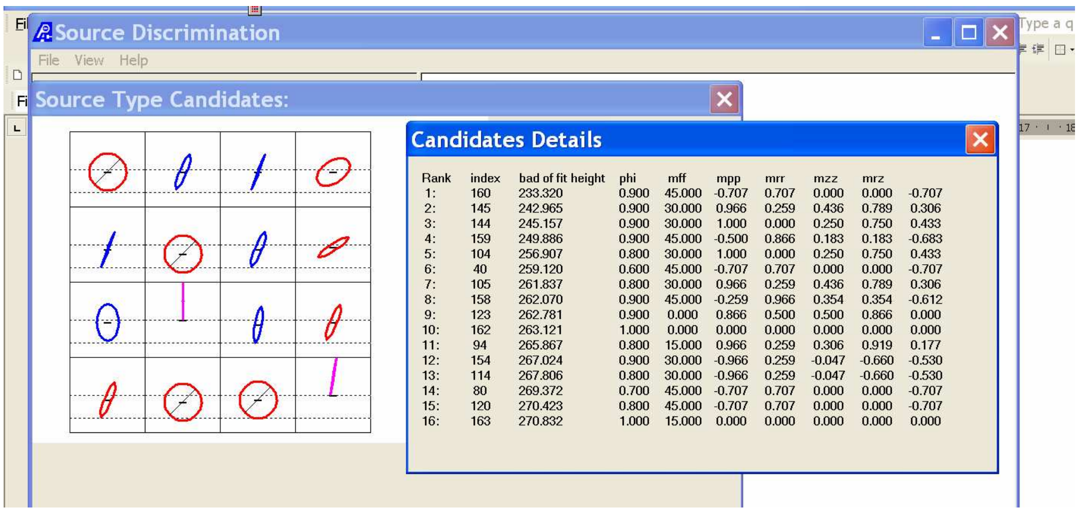

Figure 10: Source characterisation from the above source, indicating a near- external surface source

CONCLUSIONS

The use of waveforms to provide further information about AE sources is now a reality, data acquisition systems are fast enough to record them, and computers are capable of processing them in a reasonable time scale. The data and analysis shown here, which demonstrated the calculation of distance from source to sensor using a single received waveform, is a small part of the potential, which in PERFPAC includes source discrimination (source depth and tensor direction), correction of waveforms using the sensor transfer function and distance to source, and source de-convolution.

As field experience using these new tools increases, analysis of acoustic emission from plated structures both in service and during pressure test will achieve new levels of success, in going from the AE source directly to fitness for service.

ACKNOWLEGEMENTS

The authors would like to acknowledge the PERF 95-11 group for the foresight and development of this technology, and particular thanks to Mark Carlos of Physical Acoustics Corporation for explaining the use of this highly sophisticated software.