ACOUSTIC EMISSION EXPERIENCE WITH AE MONITORING OF NEW VESSELS DURING INITIAL PROOF TEST

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Keywords: **Acoustic emission, proof test.**

ABSTRACT

This paper looks retrospectively at experiences with the AE monitoring of new vessels during initial proof-test and discusses the implications for applying the proposed European Standard for AE monitoring of proof tests.
Case histories discussed in detail are a new reactor and a storage sphere, both intended for refinery service.
Comparison between first and second loading and the practical implications for running tests according to the code are discussed.

BACKGROUND

The initial proof test of equipment serves two purposes, the first is to mechanically stress relieve the vessel by loading well above the intended service stress, typically x1.45, this yields high stress areas and blunts crack tips, retarding subsequent fatigue crack initiation, and ensuring that local microstructure is operating well below yield. For vessels that do not have post-weld heat treatment, typically those <30mm thick, this is very important as the local welding residual stress will be up to yield in many areas. The second purpose is to demonstrate that the vessel does not leak under pressure.
The design codes specify inspection requirements prior to the test to ensure significant defects are not present, but they do not specify inspection following the proof test. This means that any defects which grow during the proof test will be put into service with the vessel.
Acoustic emission monitoring during the first loading at initial proof test can help to identify growing defects or problems with material and heat treatment but interpretation is complicated by the emission that occurs as a result of normal stress relief, so care must be exercised. ASME defines criteria for AE monitoring of proof tests, and in the event that these are exceeded during the first application of load, as is always the case for vessels that have not been heat treated, allows a second cycle to be applied. If the second cycle is “quiet” then any defects present are considered stable and the vessel “passes” the test. It may however still have large but “stable” defects present, so careful analysis of the initial loading to try and identify these is important if you wish to minimise the defects that find their way into subsequent service.

VERTICAL REACTOR SHOP HYDROTEST

Material: A516-70
Size: 2.74 metres diameter, 13.9 metres high (tested horizontally)
Thickness: 25mm
Design pressure: 25.2 bar (403 psi), at 94 degrees C
Hydrotest pressure: 38.75 bar (620 psi) at ambient, ~10 degrees C (January 1993)

Intended service: Refinery, hydrogen.
Special features: Catalyst loading man-way in top head, ~half diameter of vessel.

Seventeen integral pre-amplifier sensors were used to monitor this vessel, from the signal attenuation measurement (see figure 1) this was far more than required according to ASME, however, planar location was used to aid interpretation of the emission, particularly useful for the first loading of a new vessel, and this requires many more sensors as each emission must reach three sensors to be located. Planar location highlights specific areas, comparison of relative emission density from welds over the entire vessel gives an indication of which areas might be growing defects or have material problems, allowing follow-up NDT to check these out efficiently.

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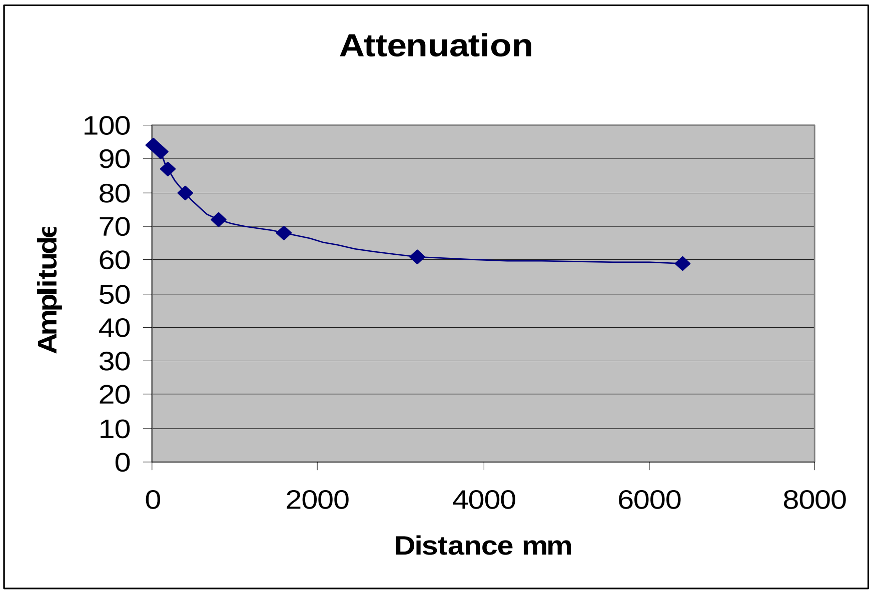

Figure 1 Attenuation of the Hsu-Nielsen source on vessel

The first pressurisation initially appeared quite normal, with emission starting from low loads as expected as a result of stress relief (figure 2 shows the history of hits, energy and amplitude for the entire vessel, the vertical black line is the start of the final hold period), it became clear that a large amount of emission was from a single weld, the one around the catalyst loading man-way, sensor 13 was adjacent to this weld where it was close to the top head circumferential weld. This emission was so pronounced that the weld drew itself out on the location plot (figure 3a, 3b), the first cluster appeared at a small % of test pressure, and had a total of >200 events by the end of the first loading, (figure 4) by which time clusters had appeared around that entire weld circumference. At the time this test was carried out there was no official CEN location code, had the test stop criteria from the code been applied the test would have been repeatedly stopped for NDT of these and other cluster locations (>26 in total). Emission continued to the end of the final hold period, predominantly from the top man-way area.
The second loading was totally quiet, until at ~70% of the previous maximum pressure emission suddenly started, once again predominantly from the top man-way weld near sensor 13 (figure 5).

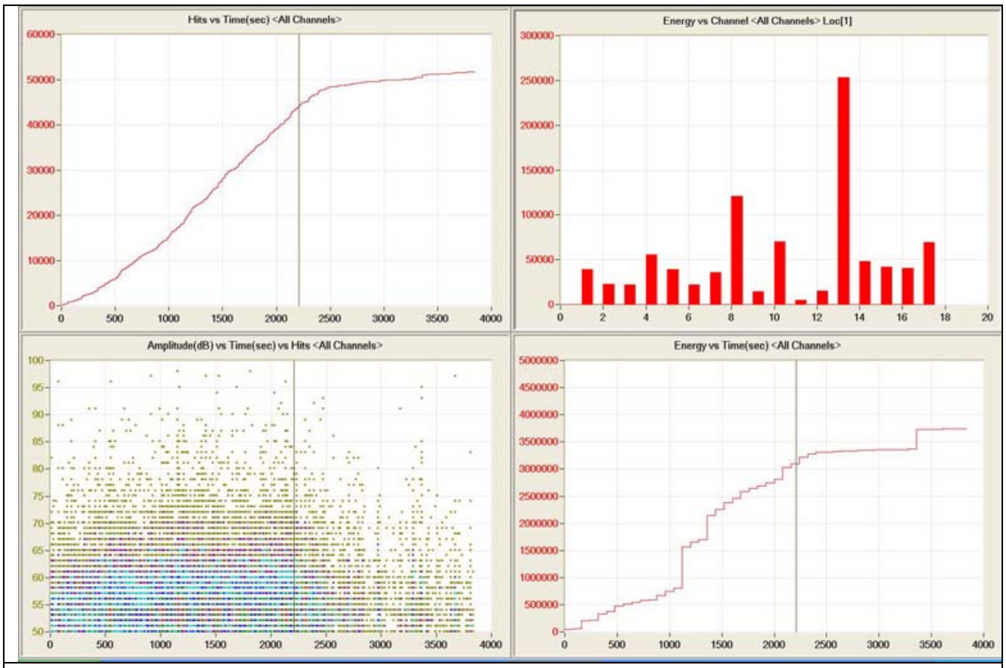

Figure 2 History of hits, energy and amplitudes for the first loading (vertical black line is start of final hold period)

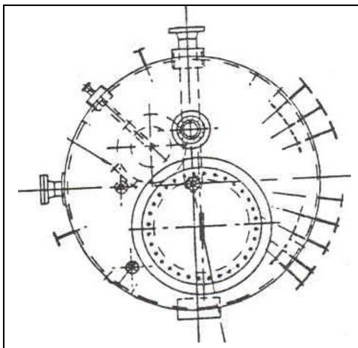

Figure 3a Top head of vessel showing large catalyst loading man-way.

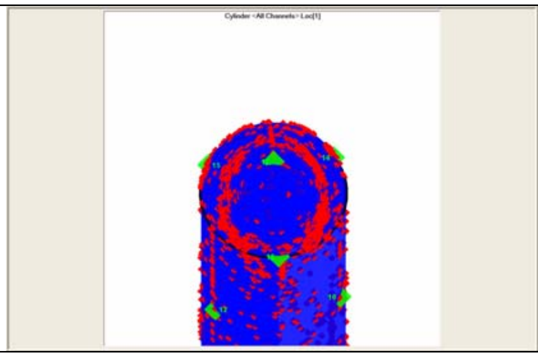

Figure 3b Location of emissions around top man-way weld during first loading.

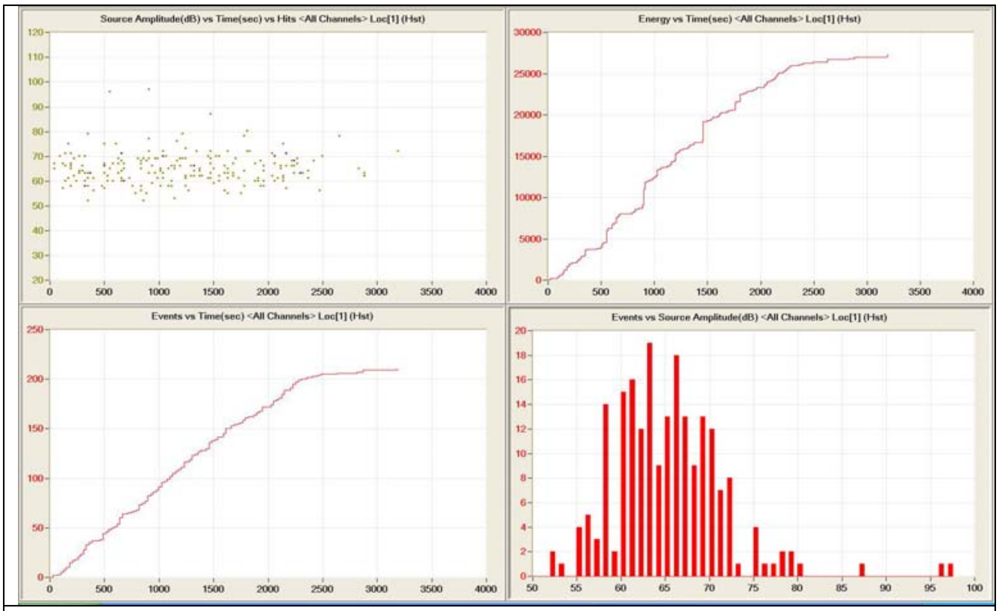

Figure 4 Cluster history from small section of the man-way weld.

MONPAC™ analysis of the first pressurisation produced grade “E” for the sensors around the man-way area, this activity reduced to “C” on the second loading resulting in a recommendation for further evaluation and possible follow-up NDT.

Post test, extensive NDT was carried out to the man-way weld area, both from inside and outside, no reportable indications were found. Since 90% of the emission from the vessel had come from the one weld there were still questions and an investigation into the manufacturing process ensued. The outcome of this was the discovery that a much lower weld pre-heat had been used on the man-way weld than on any other weld on the vessel, resulting in higher residual stresses, clearly not fully relieved after even two cycles to proof pressure. The reason given for the lower pre-heat was that from a design standpoint the man-way had been treated as a pipe, allowable under the codes, despite this clearly being the most highly stressed part of the vessel.

The end-users concern was the high risk of hydrogen damage to the area once the vessel went into service, and the risk of cracks developing from the still present high local stresses from manufacturing.

It is interesting that despite emissions with source amplitudes well in excess of 80dB (usually associated with cracking) no reportable indications were found by NDT. One possibility is that micro-cracking was distributed around the weld and there was as a result no individual “big crack” for NDT to find. Localised inspection may not be sensitive to micro-cracking distributed around a large area; however this can still be a threat to integrity.

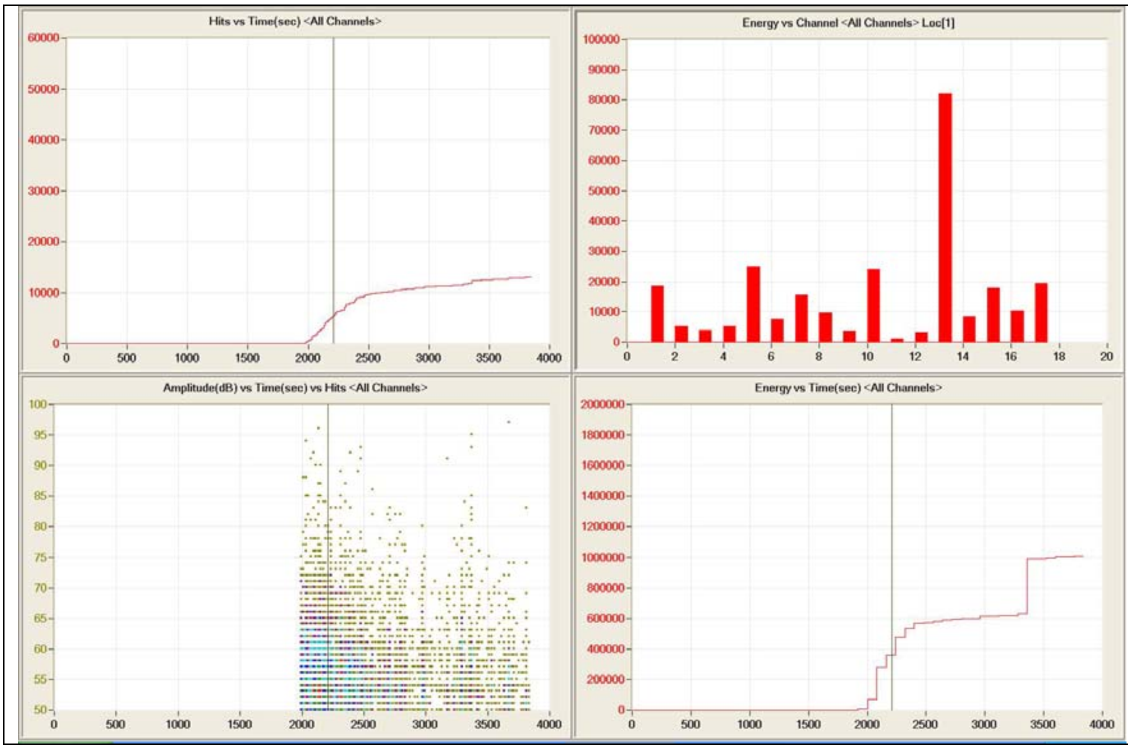

Figure 5 History of emission during second loading (vertical black line is start of final hold period)

STORAGE SPHERE INITIAL HYDROTEST

Diameter:	21.3 metres
Legs:	10
Material:	BS5500 carbon steel
Thickness:	~18mm
Design pressure:	4.83 bar
First Hydro pressure:	6.79 bar
Subsequent hydro pressure:	6.1 bar

Forty six sensors were used to monitor this vessel, due to the thin wall (~ one wavelength) the attenuation was relatively high, since energy rapidly transferred into the liquid. This made planar location of smaller signals impractical as the test threshold would have needed to be so low that channels would be continuously active from emission resulting from normal stress relief, the alternative was many hundreds of sensors, again impractical and too costly.
The first loading produced high levels of activity from all areas of the sphere, (figure 6) suggesting extensive yielding, and high amplitudes indicated possible micro-cracking, activity exceeded the evaluation criteria many times over.

Figure 6 Activity from first proof test and repeat loading of a 21m sphere

Zone intensity location analysis of the initial loading produced nothing less than a “C” grade, with eighteen “D” zones, and five “E” zones (figure 7). Planar location was carried out but the located data represents only 3.7 % of the total emission, and did not identify active clusters (figure 8).

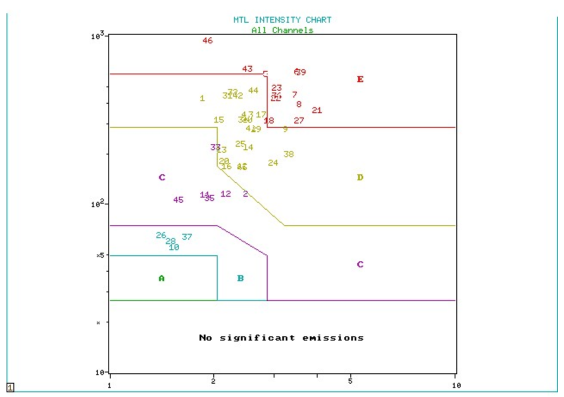

Figure 7 1st Load Zone intensity analysis

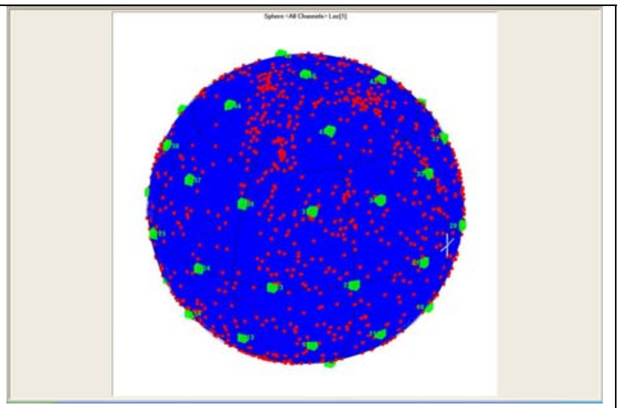

Figure 8 Planar location, typical view.

The second loading was relatively inactive; however there was still one “D” grade near the top head pressure relief valve stack, (fig 9,10), follow-up NDT found no indications.

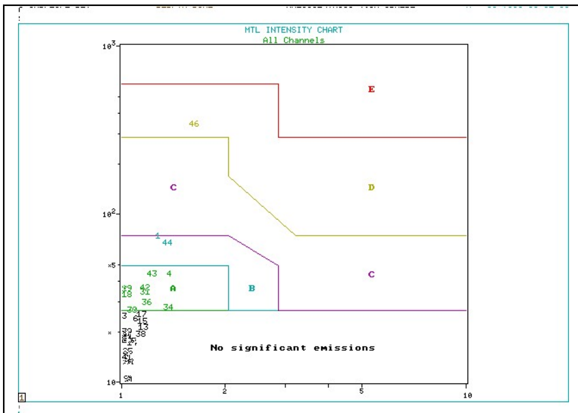

Figure 9 2nd Load Zone intensity analysis

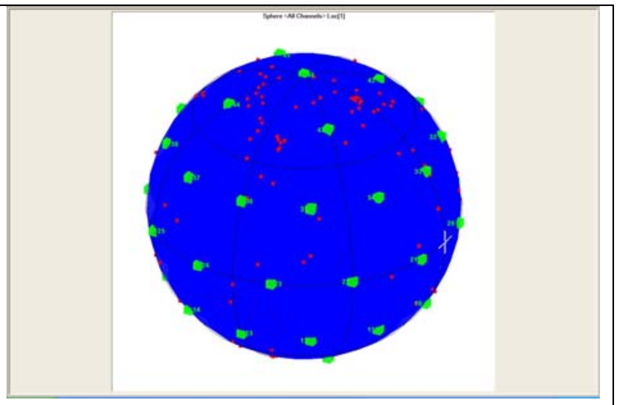

Figure 10 2nd Load planar location.

A few years after putting the sphere into service it was taken out for inspection, and MPI carried out internally, thousands of HAZ cracks were found, present in most of the welds. These were ground out together with one crack that was quite deep, approaching 50% through wall. Metallurgical analysis showed all the cracks to be of manufacturing origin, with no evidence of in-service growth. The implication, since the vessel was inspected prior to its initial hydro-test, was that the cracks opened up during the first loading.

DISCUSSION

It is clear that AE gives useful information during initial proof testing; there are cautions when using the method however:

- Emission resulting from crack growth during the first loading can be difficult to identify amongst “normal” emission from expected stress relief. Intensity analysis

identifies the higher levels of activity, and where it is practical and cost effective to use planar location this can be enormously useful to identify “hot spots”.
-The second loading is relatively easy to interpret, no emission means no propagating defects or continuing stress relief, this should be the case.
-“Abnormal” levels of emission from stress relief may be the result of inadequate weld pre-heat or other manufacturing problems that leave high residual stresses in the welds, not necessarily defects that can be found by NDT. It is also common to see abnormal levels of activity from stress relieved vessels, where the manufacturer has welded attachments after the stress relief has been carried out!!!
-Perhaps the most controversial issue is vessels that “pass” on the second loading, what this means is that any defects present are stable under these stress conditions, it does not mean the vessel is defect free, defects may have grown or yielded during the first proof and become stable. The question is whether you want even these defects to go in to service, if not then inspection after the hydro-test is necessary if there is any significant emission, even on the first loading.
-Where “test stop” criteria are used for the initial loading, it is important to realise and plan for the eventuality that multiple clusters may mean multiple test interruptions for NDT, especially if the activity is the result of excessive weld stress relief. The practicality of this may often be questionable.