REMOTE STRUCTURAL MONITORING USING ACOUSTIC EMISSION

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ABSTRACT

As structures age and degrade the need for monitoring integrity to ensure safe operation increases. At some point the cost of the repeat visits at ever increasing frequency to carry out a periodic inspection becomes a significant burden, that in many cases may be relieved by the use of remote continuous monitoring. In some cases a problem is identified by periodic inspection that cannot be immediately repaired and continuous monitoring is the only option. In other cases continuous monitoring enables the inspection frequency to be maintained or extended, sparing inspection resources for use elsewhere. The main point about remote monitoring is that is should remove the need for unnecessary inspections, which are a waste of valuable resources.

This paper looks at the implementation of remote monitoring using acoustic emission, which is able to detect cracking, and in many cases active corrosion, in both metals and concrete.

ACOUSTIC EMISSION

Acoustic emission is the energy released when a crack propagates, or its faces rub together, this is like an earthquake but on a totally different scale, since the crack growth may be only a few microns or several millimetres. The sensor frequency needed to detect these signals ranges from several thousand to a million hertz, compared with less than one hertz for earthquake detection. Signals being located from a growing fatigue crack are shown in figure 1 below, the sensor locations are the green squares numbered 1,2,3, each dot is at the estimated location of a source of emission, calculated from the arrival time of the signal at the three sensors, called “planar location”. Location may also be carried out in two dimensions, for use on pipes, and in three dimensions, for use on solid objects.

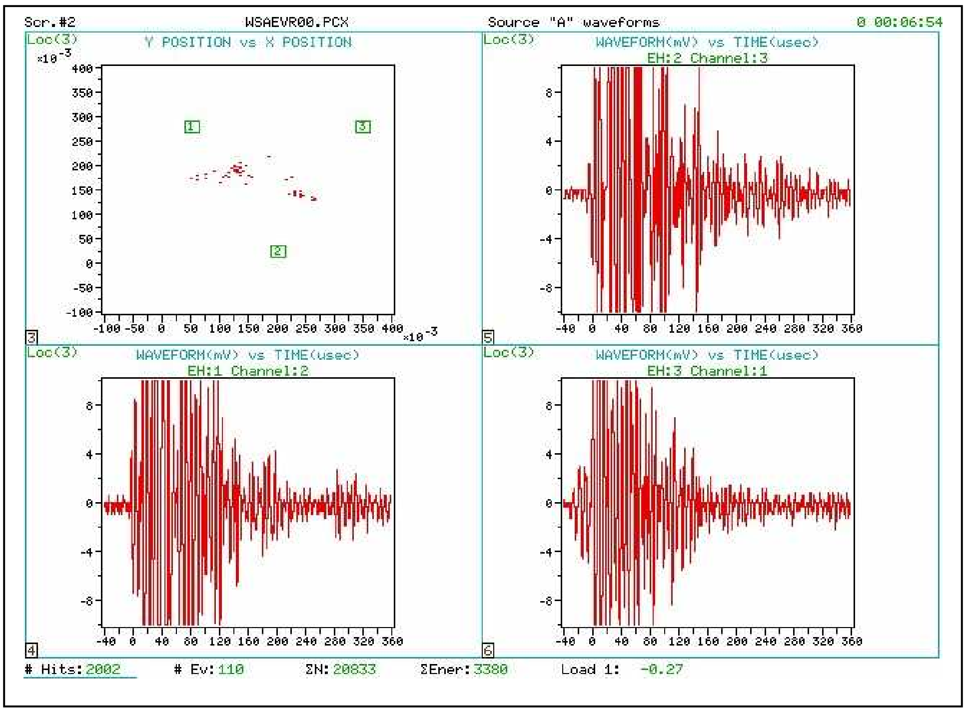

Figure 1: Acoustic Emission event signal detected at three sensors around a growing fatigue crack.

The ability to locate is one of the most powerful aspects of acoustic emission monitoring, a picture speaks a thousand words, and if the location co-incides with a possible discontinuity position such as a weld, or area of high stress, then the interpretation of it as a relevant indication is far more obvious. Signals in the “AE frequency range” also result from particle impact, and objects rubbing together, these need to be identified to avoid false calls, usually by analysis of the waveform. Leaks also cause energy in this frequency range, though because they result in a “continuous” increasing signal rather than a transient the presence of a leak is obvious, and leak detection requires only simple low cost instrumentation.

WHY CONSIDER REMOTE CONTINUOUS MONITORING?

The set up of continuous monitoring is an investment, and like any other there should be clearly defined reasons and financial or safety justifications. Sometimes the monitoring is planned long-term, but often it is in response to a known problem. It is best to define clearly at the outset what the scope of the monitoring actually is, there are an enormous number of reasons why AE has been used in the past, some examples from current installations are:

- We need to know immediately if a problem develops here as we need to turn the burner off before major damage results.
- The critical crack size at that location, which could grow to failure between major shutdowns, is too small to reliably detect using other methods under operating conditions; it is not economically viable to keep shutting down for inspection, to run safely we therefore need acoustic emission continuous monitoring.
- We know the defect is there, it does not appear to be growing at present, but we don’t know if it will grow under other conditions. We cannot repair without shut down, so we need monitoring for safety until the planned shutdown.
- The defect is there, we cannot get a replacement for six months, we need to control the operating conditions so we do no get further crack growth, which means we need real-time crack growth monitoring.
- This vessel is always cracked when we inspect it during shutdown, we do not know what conditions result in the cracking, we need acoustic emission to tell us under what conditions the vessel is damaged, so we may avoid them in future.
- The authorities and insurers will not allow us to start up without an effective monitoring system.
- We suspect operations crack this vessel by rapid temperature and pressure changes, if we monitor and can prove it then we have the evidence to get changes to procedure and avoid it in future.
- Conventional inspection detects SCC too late in this stainless tank, AE is a better method giving earlier detection.
- Conventional inspection during shutdown is too difficult and time consuming; by using AE we take the inspection outside the shutdown and get advanced warning of problems so that we can be ready with a replacement.
- There is no other way to know if we have wires breaking in the pre-tension wires of this concrete structure.
- This is the only practical way to know if we have wires breaking in these suspension bridge cables.
- The only risk to this vessel is cracking during cool-down as a result of thermal stress, by using AE on-line we usually avoid the enormous costs of entry, and if there is cracking then being directed to the exact spot on a 45 metre vessel saves a LOT of time….
- The consequences of failure are so high we cannot afford not to monitor integrity continuously.

So the reasons are many and varied, but you should always understand the reason why, and what you expect to get out of the system, and ensure everyone associated with the project understands these reasons and expectations.

SYSTEM DESIGN

There are a number of key considerations when planning a system installation, is it temporary or permanent, what type of sensors, intrinsic safety, communications etc, this section plans to take you through these decisions.

Sensors

Sensors need to be chosen based upon a number of parameters:

- Temperature, will they be directly mounted, or mounted on waveguides (metal rods welded to the structure).
- Do they need to be intrinsically safe (I.S.)?
- Frequency range, high noise environments need more sensors of a higher frequency, concrete structures use lower frequency sensors.
- Can we use integral pre-amplifier sensors (low cost, convenient, but not I.S., and limited upper temperature).
- Is there a high radiation environment (sensor certified to 1000 MRAD at 550 deg.C are available).

Figure 2 shows sensors and pre-amplifiers used in the field, the pre-amplifier is used with the small sensor, the large sensor has its own pre-amplifier built inside, but is not intrinsically safe.

Figure 2: Acoustic Emission sensors, I.S unit top right is used with the I.S. pre-amplifier (left), the larger sensor has a built in pre-amplifier and will drive 500m of cable, but is not I.S. certified. All are IP66 rated.

Data Acquisition

Modern digital systems can be configured in almost any form, but historically have needed a safe environment, a rack with air conditioning, and mains power. The latest continuous monitoring systems are ultra low power, ~15 watts, and are designed for distributed networking environments. The big advantage of low power is that they may be installed in EExe enclosures containing the barriers, distributed around the plant, and networked. This significantly reduces cabling requirements, in addition the use of special processors and flash memory gives them an operating temperature range of -30 to +70 deg.C. An I.S. system would have 16 channels of processing, since space is needed in the enclosure for the barriers, and a non I.S. system 16 or 32 channels. Power for these systems may be low voltage DC, 9-28 volt, or mains 110/230 volt. The ultra low power consumption means that for DC battery operation solar power is an option, a single small panel providing sufficient power in most situations. Despite the size and low power consumption the systems have full DSP capability with 960 MIPS processing power and a 16-bit ADC and software controlled filtering for each channel, with feature extraction and waveforms, all software controlled. Though usually operated connected to a host computer, the systems will work independently when the host is not available, and can be run as independent data acquisition systems, saving data internally or being accessed by a notebook computer. Figure 3 shows the EExe and non EExe field packaging of the PAC SH2.

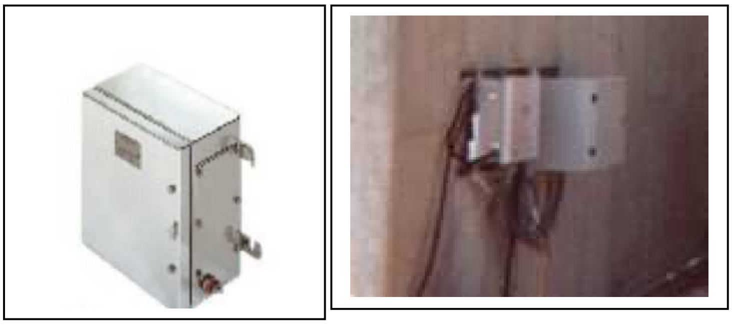

Figure 3: EExe packaging of 16 channel node with barriers for use in hazardous environments with I.S. sensors (left), right is field packaging for non hazardous environment (small box).

Networking

Figure 4 illustrates a typical network configuration, the base-station server collects data from all the nodes, processes it, and automatically updates a website that is accessible from any browser using the correct password. The operation and configuration of the nodes may be changed by an "expert" using a special program which is resident on another networked computer "viewer". The network may be an intranet or the internet, or a combination of both over several networks. The system also works with any of the older PCI card based data acquisition systems.

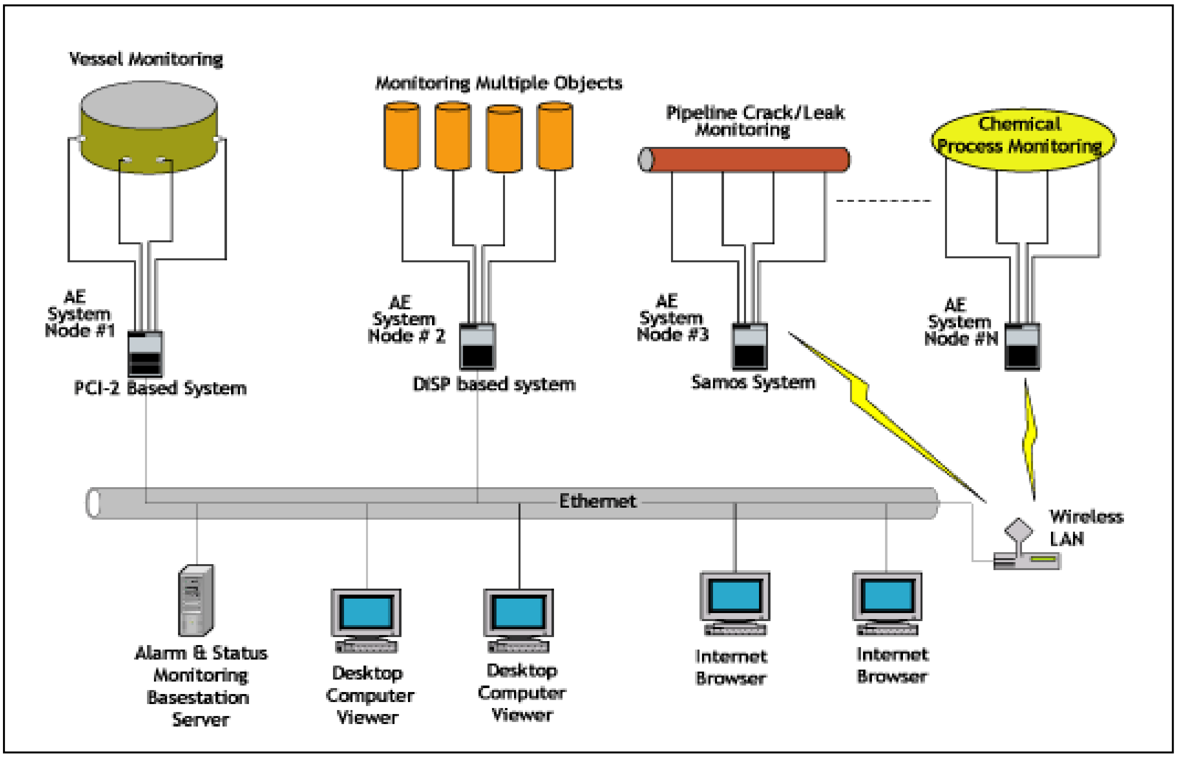

Figure 4: Typical network of multiple networked nodes, base-station web server, expert access "viewers" that can re-configure the nodes, and any browsers which may look at the processed "web" data (with password).

INFORMATION AVAILABLE

The information available is to a large extent configurable and defined by the client in consultation with Physical Acoustics and often their structural engineering consultant, typically it is split into several levels:

- Web information; this is processed to be simple to view and interpret, for the end-user who does not want to be a “specialist” but wants to know if the system is operating and if the activity is normal or abnormal, in which case the “specialist” may be called to carry out further evaluation.
- Viewer information; this is far more detailed; the “viewer” user has access to a lot more analytical information, the level of which is dependent upon the original system set-up.
- Expert information; Specialists may use analytical tools on the raw data such as Noesis, (neural network and SPR), or PERF (wave mode analysis) in order to get as much information as is possible from the stored data.

In addition to the acoustic emission data from cracking or corrosion, information on other parameters is often collected and processed at the same time, for example strain, vibration, or displacement (on structures), or pressure and temperature on process equipment. Figure 5 is an example of information from remote monitoring of an offshore structure, showing the peak hourly strain at a certain brace, emission located from a critical weld (during system verification checks !!), and the dynamic strain transients from four strain gauges on the same brace, (resulting from wave action and impacts), from which the bending and dynamic stresses at critical are calculated.

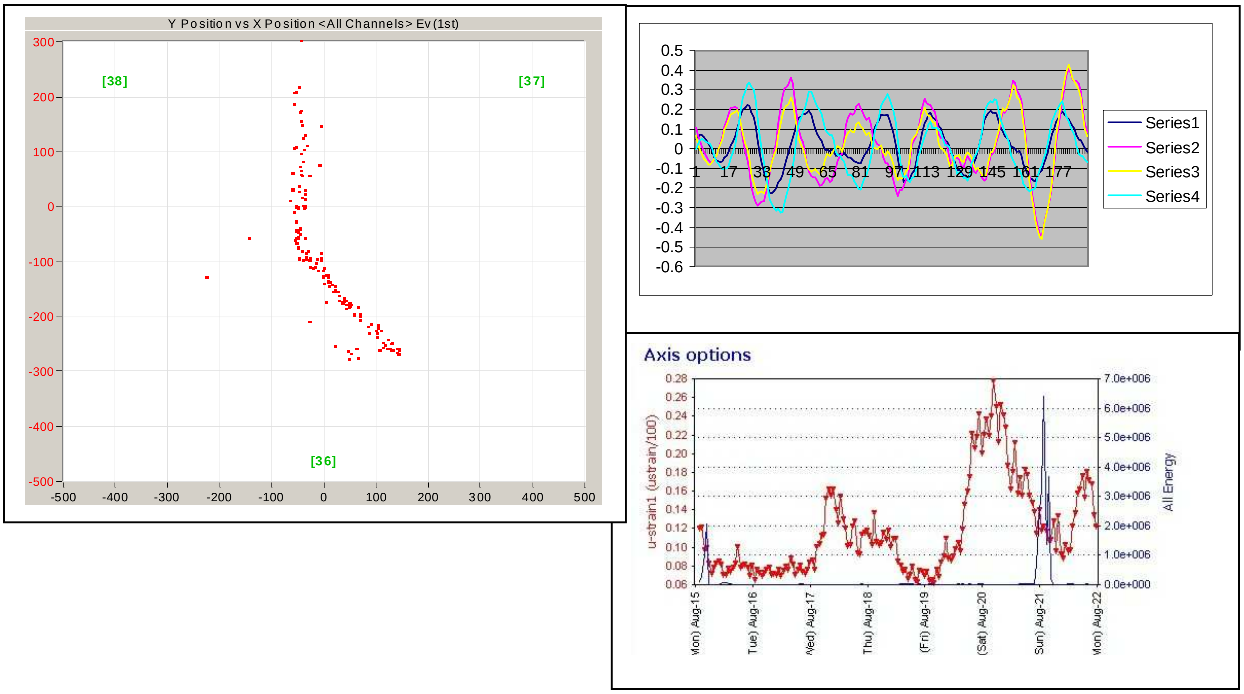

Figure 5: Top left; Acoustic emission locations, the green numbers are sensor positions, red dots are the source positions, X,Y scale in mm. Top right; high speed strain transient at four gauges resulting from wave impact (20 seconds time scale). Bottom right; Peak hourly strain acquired over a seven day period.

GLOBAL NETWORKING

Remote continuous monitoring is widespread now that the global communications infrastructures are built, from a wireless notebook PC, it is possible to view data from sensors installed in a process plant or on a bridge the other side of the world, or even thousands of metres sub-sea. The network connection is transparent to the user, since it is just an IP address (the necessary permissions and passwords are of course required from the various network

administrators), and a connection may use any combination of transmission systems including ISDN, satellite, internet, private LAN and wireless.
Typically the only systems to which it is not technically possible to connect away from the local area are the nuclear automation networks which have no physical or network connection with the outside world; in this case the information is restricted to the network on which the system operates.
Many systems operate on private networks that have no "browsing" access from outside, in this case if the user wants "browser" access to the data the data is compressed and sent to an external web server. One such server is the Physical Acoustics "Remote Monitoring Applications" server, which hosts web-based information for private clients that has originated from their networks, this ensures that those given browser access to the data do not actually have access to the secure private network from which the data has originated itself.

SOME PRACTICAL EXAMPLES of REMOTE CONTINUOUS INTEGRITY MONITORING

Offshore Structures

The loading on offshore structures is a result of wave and wind action, detection of fatigue damage at critical areas therefore requires continuous monitoring. An FPSO was identified by its consulting structural engineers as having eight critical areas that could not reliably be inspected conventionally without a costly diving operation, and in a location where diving is only possible during summer months. In order to ensure the highest levels of safety each of these areas is monitored using five acoustic emission sensors which surround the area concerned. Any emission from these areas is located using triangulation, should there be any concentration of emission indicating the presence of fatigue cracking then the platform knows immediately and can take the appropriate action, depending upon the severity of emission. The system also records strain information simultaneously on four sets of four gauges, at a slow rate when the conditions are mild, and at a high rate when strains exceed a set threshold. This strain information is used to refine the fatigue model, and develop a dynamic model of platform behaviour in different sea conditions. The system front-end processes the input signals at 800 MB/second, this is reduced using ten digital signal processors (DSP), field programmable gate arrays (FPGA), and high end software to approximately 2MB per month of AE data (with no active cracking), and 200-300MB per month of strain data. The "live" website, served by the PAC RMA server in New Jersey, is updated hourly using compressed statistical data that requires only a 2KB data packet to be sent over the limited bandwidth satellite link. Remote network control is used to manage the system, so the absolute minimum offshore intervention is required.

Pressure Vessels in Nuclear Power Plant

High radiation means expose to inspection personnel, plant operators have a duty to reduce this as much as possible. In this case the installation of continuous monitoring on four stainless steel heat exchangers means that unnecessary inspection and exposure of personnel is avoided. Due to the high temperature the sensors are installed on waveguides welded to the vessel shell in the primary containment, and the signals travel by co-axial cable to the system nodes located in the secondary containment, which are connected to the automation network. In this case because there is no connection to the outside world the "simple" "web" display is provided by a base-station server located on the same network, and an analysis and control computer with a viewer gives control of the nodes to an "expert".

Refinery Reactor Vessels

Thick walled reactor vessels often suffer cracking as a result of thermal stress during cool down. Cool down may be planned, such as a shutdown, but may also be accidental, for example during plant "trips". The cost of inspection, and the risks involved in not identifying serious cracks should they occur, means that continuous monitoring is the ideal approach, since "trips" are not planned events. Waveguides are used to keep the sensors in a cool environment, since the plant surface may be at >500 deg.C, and the plant may have anywhere from 20 to 70 sensors per vessel, depending upon its size. Monitoring provides the location of any areas that were overstressed during cool-down, so that inspection may be sent directly to the damaged area. This approach means that safety is maintained and inspection is restricted to small areas, giving major cost reductions. One side benefit is that by knowing the conditions that result in cracking, such as too rapid cool down for an outage, these conditions may be avoided in future, preventing damage to the plant.

Critical Safety Valves

Acoustic leak detection is widely used for detecting and quantifying leakage through valves, the BP and PAC jointly developed "VPAC" technology is in use at >500 sites worldwide, both on and offshore. Most widely known is the portable instrument for this application, but on-line systems have benefits, especially for critical and emergency valves. Emergency shutdown valves (ESDV's) are normally open, so the portable unit is of no use to check their integrity during normal operation. When the plant shuts down however (intentionally or otherwise) many ESDV's typically close, and it is not practical to have lots of engineers with portable units to go and check them, they are too busy dealing with the emergency!! The "on-line" VPAC is a simple unit with a 4-20ma interface that connects directly to the DCS or other plant integrity monitoring system. The operator can see immediately if "closed" valves are passing, the cause of many accidents. In addition he can see how much a valve is passing. The on-line VPAC system has sufficient dynamic range to estimate leakage levels, depending upon pressure and valve size, from less than 0.1 litre per minute to >30,000 litres per minute.
In some cases the cause of a passing valve is debris on the seat which can be cleared with a partial stroking. A further development are systems that records the behaviour of the valve during shutdown, using torque, actuator pressures, and the acoustic signal, to provide condition assessment without the need to remove the valve and take to the workshop. Valves that are normally closed may be checked with portable systems, the reduction in manning though means it often pays to continuously monitor valves that are likely to leak, or those that block valuable products and hydrogen. The cost of one leaking hydrogen blow-down valve on a UK refinery was estimated at >$250,000 per annum, and contributed to 30,000 tons consequential loss of production, as a result of hydrogen being the production bottleneck.

CONCLUSIONS

Monitoring pays, not only in simple economic terms, but also in increased safety, ultimately of course this is also of economic benefit, but often quantified in hindsight, when it is too late. Modern electronics and communications means that there is no longer an excuse for not having the right information on integrity provided at the right time.