Continuous Remote Monitoring Using AE

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Abstract. To ensure safe operation as structures degrade the need for monitoring of integrity increases. The cost of repeat periodic inspection at increasing frequency becomes a significant burden, which in many cases may be relieved by the use of remote continuous monitoring. In some cases specific problems may be identified by periodic inspection, and continuous monitoring is required until repairs can be made. In other cases continuous monitoring enables the inspection frequency to be maintained or even extended, allowing scarce inspection resources to be used elsewhere. The main financial benefit of remote monitoring is that it should remove the need for unnecessary inspection, which is a waste of valuable resources.
This paper looks at the implementation of remote monitoring using acoustic emission as one of the methods, this 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 crack growth on most engineering structures may be only a few microns or several millimetres. The sensor frequency used to detect these signals ranges from typically one thousand, up to a million hertz, compared with less than one hertz for earthquake detection. Like earthquakes, location of emission sources is based on time of arrival, and may be carried out in one dimension for use on pipes, wires, and other “linear” structures, using time of arrival at a minimum of two sensors, or in three dimensions using arrival times at five or more sensors, for use on solid objects such as large concrete structures. For plated steel structures “planar” location is most commonly used, calculating source origin from the time arrivals at three or more sensors. Signals being located from a growing fatigue crack in a plated steel structure are shown in figure 1, the sensor locations are the green squares numbered 1, 2, 3, each dot is at the calculated location of a source of emission, calculated from the arrival time of the signal at the three sensors.

The ability to locate the origin of active sources of acoustic emission on large structures is one of the most powerful aspects of acoustic emission monitoring, since it directs attention to the point at which something is happening, making inspection much more effective. When this location coincides with a possible discontinuity position such as a weld, or area of high stress, then the interpretation of it as a relevant indication becomes more obvious. Signals in the “AE frequency range” also result from particle impact, and objects rubbing together, these need to be identified and eliminated to avoid “false calls”, usually by analysis of the received 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 in a pressurised system is obvious, and leak detection requires only simple low cost instrumentation.

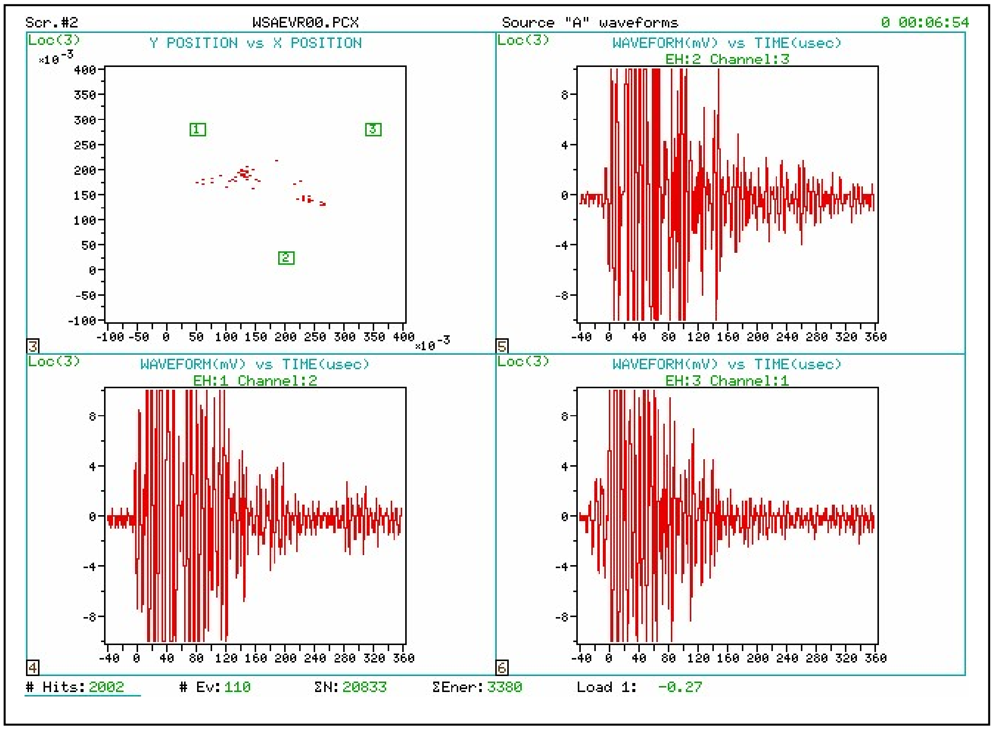

Figure 1: Acoustic Emission event signal detected at three sensors around a growing fatigue crack.

Continuous Monitoring

Continuous monitoring is a significant capital investment, so there is a need for clearly defined reasons to justify it on financial and/or safety grounds. Sometimes the monitoring is planned for the long-term, for example the life of a structure, sometimes it is in response to a known or suspected problem, and may be temporary. The monitoring scope and objectives need to be clearly defined at the outset, in some cases only identified critical areas need to be monitored, in others entire structural members. Usually the engineering company responsible for the structure will define monitoring requirements.

There are a number of reasons why AE has been used to monitor structural integrity, some examples are given below:

- Methanol converter: There is a need to know immediately if a problem develops with the refractory, total refractory failure would result in burn-through of the 100mm steel shell in ~120 seconds, releasing hydrogen at >100 bar pressure. In this situation the decision needs to be automatic, so the burner is turned off automatically, before major damage results.
- Offshore platform: At a number of high stress locations the crack size that could grow to failure between major summer diving inspections is too small to be reliably detected using conventional inspection under operating conditions. To operate safely continuous monitoring for crack initiation is required, a key part of the safety case.
- Pressure vessels: Cracking has been identified, it does not appear to be growing at present, but how do you prove that it will not propagate under different operating conditions. To ensure safety, and possibly to identify conditions under which the crack grows, which should then be avoided, continuous monitoring is needed until the planned shutdown.

- Suspension bridge cables: Wire breakage as a result of corrosion fatigue slowly degrades the integrity of the bridge. Since the wire breakage events are occasional and unpredictable the only way to track the progress of these events is by continuous monitoring.
- Platformer reactor: This vessel was always cracked at a particular location when inspected during shutdown, they did not know why. Continuous monitoring was used to identify the conditions present when cracking occurred, so that the cause could be addressed.
- Heat Exchanger bolts: Following a leak, fire and explosion, the re-built plant was not allowed to start-up without continuous monitoring of bolt integrity.
- Steam header: It was suspected that operations were causing cracking of this vessel by rapid temperature and pressure changes, monitoring was installed to prove this, and the evidence used to force changes to operating procedure to avoid cracking in future.
- Stripper columns: Chloride induced stress corrosion cracking of the shell requires continuous monitoring to direct NDT to the actively cracking areas. This allows inspection and repairs to be targeted, and the vessels kept on-line until replacement vessels are installed.
- Pre-tensioned concrete structures: Continuous monitoring is the only way to know if wires are breaking in the pre-tension cables.
- Primary circuit exchangers: Main identified risk, although very low probability is stress corrosion cracking, by using continuous monitoring the presence and location of possible problems is identified. This results in a significant reduction in radiation exposure to inspection personnel.

The reasons are many and varied, but it is important to define and understand the reason why, and what is expected from the system, and to ensure everyone associated with the project also understands these reasons, the limitations, so they have realistic 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 looks at 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 (sensors certified to 1000 MRAD at 550 deg.C are available).

Figure 2 below shows some “front-end” field instrumentation:

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 pulser and pre-amplifier to drive >500m of cable. 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, 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 typically have 16 channels of processing, since space is needed in the enclosure for the barriers and interface units, and a non I.S. system 16 or 32 channels. Power for these systems is 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 also 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.

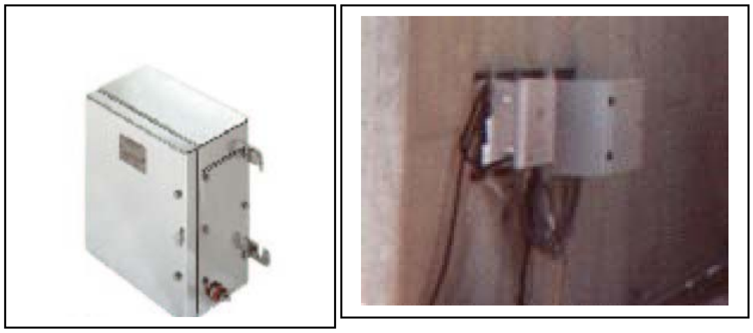

Figure 3: EExe packaging of 16 channel node with barriers for use in hazardous environments with I.S. sensors (left), right is field packaging for non hazardous environment (small box).

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.

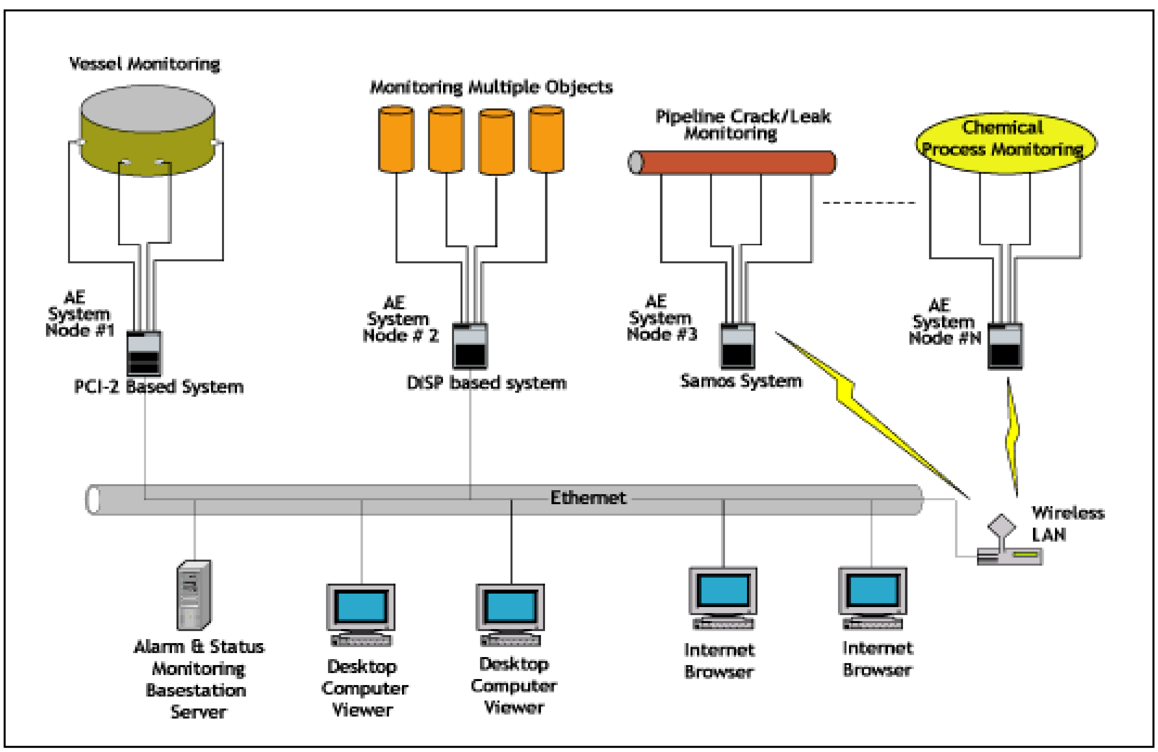

Figure 4: Typical network of multiple networked nodes, base-station web server, expert access “viewers” that can re-configure the nodes, and any browsers which may look at the processed “web” data (with password).

Information Available

The information available is to a large extent configurable and defined by the client in consultation with the contractor and usually 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 neural network and SPR, or 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 usually 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.

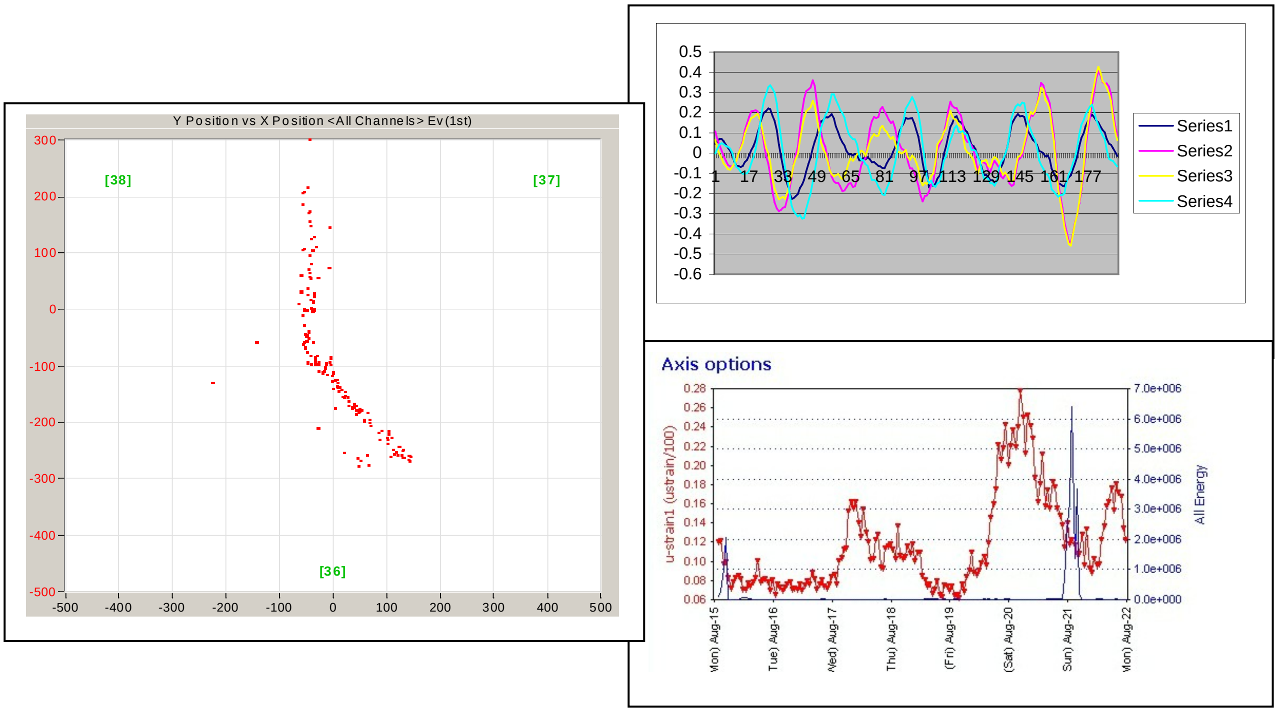

Figure 5: Top left; Acoustic emission locations, the green numbers are sensor positions, red dots are the source positions, X,Y scale in mm. Top right; high speed strain transient at four gauges resulting from wave impact (20 seconds time scale). Bottom right; Peak hourly strain acquired over a seven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

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 operators can see immediately if "closed" valves are passing, the cause of many accidents. In addition they 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, a result of hydrogen being the production bottleneck.

Stripper Columns

Stainless steel equipment, near the sea, if not sufficiently protected from chlorides in the atmosphere, will suffer external stress corrosion cracking. The cracks start off exceedingly tight, and at this stage are not detectable using conventional inspection methods. Usually the first indication of a problem is when the cracks are sufficiently advanced to open at the surface, making them detectable by dye penetrant and advanced ultrasonics, ACFM and eddy-current methods, by this time the damage is already extensive. Stainless plant suffering from stress corrosion cracking is often very difficult to repair as a result of the damage to the material, not yet detectable by inspection, opening up under the thermal stress of welding. Acoustic emission is highly effective at detecting stress corrosion cracking, and is often used during a pressure test to identify damaged areas for careful follow-up inspection, reducing the inspection area from several hundred square metres, to a few square metres. Pressure testing is not always possible however, and then continuous monitoring is the only option.

Conclusions

Monitoring pays, not only in simple economic terms, but also in increased safety, ultimately of course this is also of economic benefit if it can reduce the risk of a plant failure, but this is often quantified in hindsight, when it is too late.

The use of distributed systems and networks makes the task of monitoring and assessment realistic, providing information real-time not only to specialists but also to the plant owner and their engineering consultants, giving the system visibility. Experience operating these systems now extends over more than eight years.

Experience, together with modern electronics and communications, mean that it is possible to have the appropriate information on integrity provided real right time.