The scientific application of acoustic emission (AE) technology first emerged in the 1950's*, but appeared to fall out of fashion from the late 1970's onwards. However with the focus now on cost-effective ways of optimising machine and equipment reliability & availability, AE is experiencing a renaissance as a valuable condition-based monitoring (CBM) and predictive maintenance tool. David Green of AV Technology looks at new ways of applying this versatile technology.

Machines talk **and it pays to listen**

Gottwald Cranes

Modern acoustic emission technology is a very versatile, non-invasive way to gather information about a material or structure and was originally developed as a means of non-destructive testing and quality control. Examples in these areas include detecting and locating faults in pressure vessels, damage assessment in fibre-reinforced polymer-matrix composites, monitoring welding applications and corrosion processes, various process monitoring applications and long-term monitoring of civil-engineering structures such as bridges, pipelines and offshore platforms.

The past five years have seen an increase in the use of AE as a powerful and flexible condition monitoring/predictive maintenance tool, especially when used in conjunction with other recognised CBM disciplines such as lubrication management, vibration analysis and thermography. Applications can be as diverse as providing early warning systems for misalignments in bucket elevator drive mechanisms to predicting failure modes of bearings in rotary filling machines, anode formers or offshore cranes. AE technology can be used for short term one-off monitoring projects, longer term monitoring or permanent installations typically involving some form of failure warning system.

The cost of plant downtime for unscheduled repairs or maintenance can be significant, running into thousands or even tens of thousands of pounds per hour. Unnecessary additional costs are also incurred if a 'belt and braces' approach is adopted whereby critical components such as bearings are replaced ahead of time. The use of AE technology for CBM is a qualitative rather than a quantative technique. For example it can be used very effectively to monitor and trend the condition of bearings in large rotating or reciprocating equipment and be set up to give early warning of impending failure.

AE Technology

Acoustic Emission is a naturally occurring phenomenon, whereby external stimuli such as mechanical loading generate sources of elastic waves. Acoustic emission waves are generated through changing load patterns above discrete thresholds, producing a rapid release of energy within a material. These manifest themselves as high frequency waves on its surface, which can then be detected using surface mounted AE sensors.

AE is related to an irreversible release of energy and can be generated from sources not involving material failure, including friction, abrasion, cavitation and impact. This makes AE particularly suited to predictive maintenance projects involving slow moving bearings, gears and sprockets and is often more effective than conventional vibration monitoring.

AE sensors are passive high frequency piezo-electric transducers, which detect structural borne noise transmitted through structures. The sensors, which typically cover a frequency range of 20 kHz to 1MHz, are not sensitive to ambient air-borne noises and can be selected to 'listen' to sounds within very localised regions of interest and within optimised frequency bands, selected to maximise the 'signal to noise' properties. This makes AE very effective in harsh operating environments, where high ambient background audible noise usually masks any audible noise caused by damaged or worn components.

Sensors can be installed directly onto equipment or via attached waveguides. Epoxy adhesives or silicon rubber is usually placed between the sensor base and the structure to ensure optimum acoustic coupling. Magnetic clamps are an effective way of mounting sensors onto round pipes and steel structures. An array of strategically placed sensors is typically used to gain a 2D or even 3D overview of the acoustic wave patterns so that differentiation can be made between normal and abnormal operational conditions. However, in flow applications, a single sensor may be sufficient.

There are a number of ways of managing the raw signals produced by the sensor when it detects AE waves although, sadly, these are not detailed in the *BS ISO 22096:2007 'Condition Monitoring and Diagnostics of Machines – Acoustic Emission'*.

Commonly, after amplification by an integral or external pre-amplifier, these high frequency signals are then demodulated by the signal-conditioning unit to provide a logarithmic output within an audible frequency range of 0 to 20 kHz.

At this stage there are options for a single system whereby, for example, the signals are converted into low frequency RMS trends. The RMS-SE signals can then be monitored continuously by a multi-channel data logger.

For more complex applications, the conditioned AE data can be captured and post-processed to perform more complex analysis and diagnostics. For example, trend additional statistical values, including Kurtosis and Crest Factor (ratio of maximum to RMS levels) or powerful auto-correlation techniques to identify periodicities in slow moving bearings.

For defect location applications, the data from multiple sensors can be processed to identify AE source locations.

The availability of ATEX certified sensors and instrumentation for use in hazardous areas makes AE technology ideal for petrochemical and offshore monitoring applications. In a typical application, certified sensors and pre-amplifiers are installed in the area, connected via certified interface units and line drivers in the safe area subsequently connected through to the analysis instrumentation.

AE in practice

Deciding where and how many sensors to use, together with the correct response frequency, is a critical part of an AE monitoring project, with projects investigating equipment faults and abnormalities usually carried out in two phases. Firstly an evaluation is set up with the initial objectives designed to:

- *Confirm that the process produces measurable AE signals, which vary with operational conditions.*
- *Quantify typical background noise levels.*
- *Define a meaningful AE 'fingerprint' identifying the AE activity associated with each fault condition.*
- *Determine which of several sensor frequencies produces the largest 'signal to noise' ratio*
- *Confirm that the equipment under test produces repeatable AE 'fingerprints' signals during normal operation*

The second phase involves optimising sensor positioning and establishing signal threshold levels to trigger alarms.

Bearing fault detection

AE techniques are ideal for assessing and monitoring both periodic and non-periodic problems with large slow moving bearings such as slew bearings. In many applications, direct access to the bearings is very limited making it expensive if premature failure occurs. The AE sensors can usually be installed at some distance from the bearing itself provided suitable signal strength can be detected.

Any periodic bearing mechanical damage faults should manifest themselves as periodic 'clusters' of spikes in the angular rotation acoustic emission 'history'. Given a bearing with 'n' rolling elements, a rolling element radius of 'r' and a mean race radius of 'R', the angular period for the three common modes of failure would be:

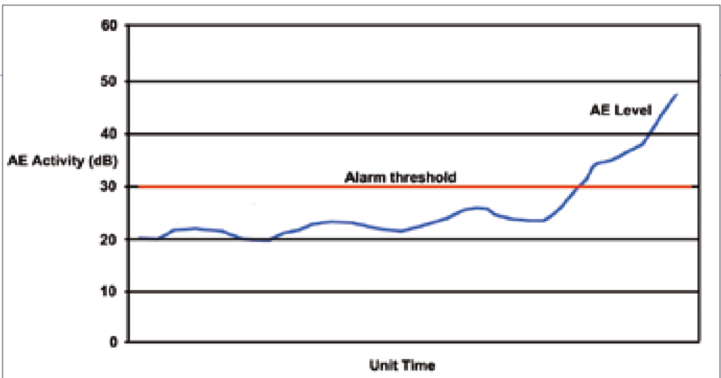
(1) $\theta_{\text{outer or inner}} = \frac{720}{n}$ (Degrees) (2) $0_{\text{element}} = 720.\frac{r}{R}$ (Degrees)

The period between peaks will give an insight to the nature of the bearing fault and thus by identifying a periodicity in the AE signature, it should be possible to attribute it to a specific bearing fault such as inner or outer race damage, rolling element damage, lubrication problems or trapped debris.

To assess other non-periodic bearing faults, statistical parameters can be trended to provide a general indication of the bearing and lubrication condition. (Max, min, mean, root mean square, standard deviation, skewness and Kurtosis)

Lubrication Monitoring

As mechanical friction is one of the most effective sources of AE, it follows that AE is one of the most effective methods of monitoring effectiveness of lubrication. In most cases, machinery and bearing problems are due primarily to lubrication problems and consequently, a well implemented lubrication management regime that ensures machines are lubricated correctly will help to prevent costly premature failures and bearing damage. In parallel with their AE expertise.



The graph shows typical application where AE activity slowly changes with time as wear/problem increases.

Flow Characteristics

AE technology can be used to detect flow related maintenance issues such as blocked filters by listening to changing patterns within pipe work. Particulate flow under normal conditions will have a clear AE fingerprint but this pattern will change if contaminant levels, such as sand content of crude oil, increase or filters start to become clogged.

Leak Detection

AE monitoring has proven to be an extremely powerful method of leak detection, for example, for gas or fluid leakage across leaking valves or in pipe work. Whilst a fully open or fully closed valve generally produces very low levels of AE activity, smaller leaks tend to produce larger AE signals and can be easily detected using portable or permanently installed equipment.

Valve Operation

AE techniques are very effective in monitoring the operation of many types of valves including those in reciprocating machinery and process control valves. Valves in reciprocating machinery give a clear AE spectrum which changes when wear or damage occurs to either the valve heads or the seats.

Assessing the data

As with all CBM techniques, analysing and presenting collated data to clients in a clear and concise way is a crucial part of any project. AVT, for example, have developed proprietary data logging and analysis techniques to assess large quantities of AE data. AVT engineers can access data remotely and systems can be set up so that SMS text messages are sent in the event of a problem.

Conclusion

Traditionally AE instrumentation is very different from conventional instrumentation such as temperature and vibration sensors, needing special power supplies and signal conditioning. It produces very high frequency data, normally scaled in units of dB and can be affected by local background emissions from parts of the machinery not being specifically monitored. It is also very important to recognise that AE sensors have no meaningful physical calibration. All of this has helped to earn AE the reputation of being a highly sophisticated and somewhat difficult technique for use by 'boffins' only. However, in response to the demands for practical AE systems, modern AE instrumentation is becoming much more user-friendly and can be easily interfaced with both data loggers and PC systems to produce extremely powerful and versatile systems for many industrial applications.

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**The true origins of AE are hard to pinpoint. As early as 6,500 BC, potters were known to listen for audible sounds during the cooling of their ceramics, understanding that such noises signified impending structural failure. In metal working, the term "tin cry" (audible emissions produced by the mechanical twinning of pure tin during plastic deformation) was coined around 3,700 BC by tin smelters in Asia Minor, whilst the first documented observations of AE appear to have been made in the 8th century by Arabian alchemist Jabir ibn Hayyan.*