THE DEVELOPMENT OF CONDITION MONITORING TOOLS FOR THE POWER GENERATION INDUSTRY

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Abstract: The UK power industry is going through a difficult period, trying to balance the demand for electricity with conforming to the new environmental regulations. Because of overcapacity, it is no longer an attractive proposition to build new power stations but instead, it makes economic sense to keep older power stations running beyond their design life.
The objective of this work was to ascertain whether we could apply certain condition monitoring techniques, to complex geometries, novel materials and extreme environments within the power industry; success would enhance safe working conditions and compliment conventional NDT applications.
A Power Station contains a multiplicity of complex materials and geometries; some plant items are subjected to extreme environmental conditions, whilst others rotate at high speed. Of the various condition monitoring methods, Thermography and Acoustic Emission were considered most likely to succeed.
An analysis was conducted on conventional materials, such as ferritic steel and aluminium based claddings, together with new materials, such as Glass Re-enforced Polymers. Trials were conducted under normal running conditions; pressure 2000psi; temperature 500°C; structures were acoustically noisy.
The principle findings of this work were that: Thermography was instantly successful, relying on the difference in temperature between the live steam and the outside surface of the boiler or pipework, whereas Acoustic Emission struggled with operating conditions and extreme structural noise.
On the basis of these findings we consider that both Thermography and Acoustic Emission are worth further investment and if successful would provide major advances in Structural Integrity Assessments.

Introduction: During the past 20 years, the Electrical Supply Industry in the United Kingdom has gone through considerable change; before 1989 there was one publicly owned company called the CEGB which served the country's electricity power generation needs, facilitated by over 70 power stations, predominantly coal, oil and nuclear powered; currently, following privatisation and having to conform to regulatory requirements, there are now over 30 independent power generating companies competing against each other to provide the UK's electricity requirements.
In the current economical climate, it would be most unlikely that companies would consider building new power stations, other than the modern Combined Cycle Gas Turbine (CCGT) power stations (see Fig. 1), or others powered on renewables, therefore, there is considerable demand for keeping existing plant running past its original design life.

Fig. 1 - Didcot B Power Station (CCGT)

Historically, plant diagnostic requirements were satisfied by an extensive use of conventional non-destructive methods, such as ultrasonic, magnetic particle, dye penetrant, visual and radiographic inspections; later in the cycle, other methods such as eddycurrent and thermography emerged. Some of the non-destructive methods cut across the boundaries into Condition Monitoring, such as thermography, so you could make use of thermographic inspection as an NDT method or thermographic condition monitoring.
In the early days, the success of condition monitoring on power generation plant was varied, the use of thermography relied on cumbersome equipment requiring liquid nitrogen to cool the detector and acoustic emission had no chance in the harsh acousitic environment of a power station, although later in the time cycle, some systems were successfully installed on boiler plant.
Over the past few years, Condition Monitoring has gained momentum, many applications involving Vibration Monitoring, Oil Analysis, Thermography and Acoustic Emission have been successfully employed in the power generation industry. PCN, the UK's EN473 compliant National Certification scheme is developing certification for all these Condition Monitoring methods and in some cases, certification is already available from PCN Authorised Qualifying Bodies (AQBs).
This paper talks about the Condition Monitoring advances within RWE Innogy, concentrating on thermography and acoustic emission and offers a vision for the future.

RWE Diagnostics: Improvement of power plants commercial, engineering and environmental performance is the key objective to ensure the longevity of our ageing power stations. RWE Diagnostics serves all our plant performance, analysis and diagnostic requirements; it includes services, such as benchmarking assessment monitoring and expert advice. A key feature of RWE Diagnostics is to be able to gather data remotely and to carry out the analysis in Swindon, thus avoiding the need to travel to site. Our wide range of diagnostic services is underpinned by "Power Plant Vibration Diagnostics" and "Transformer Oil Dissolved Gas Analysis".

Power Plant Vibration Diagnostics: The Plant Vibration Diagnostics product is market driven, that is to say, it is designed to monitor running plant, to identify signs of impending failure and to offer commercial solutions. For example it may be beneficial to continue running with a known defect until it is financially advantageous to effect a repair or alternatively, to take the plant off line immediately to avoid a costly failure; the installation of remote diagnostics allows us to react quickly to potential problems, to identify causes and to offer solutions. Power Plant Vibration Diagnostics is mainly applied to Turbine Generator Rotating plant (see Fig. 2) and currently we are monitoring 62 machines at 17 different locations world wide.

Fig. 2 - Tilbury Power Station Turbine Rotor Plant – Monitored by Power Plant Vibration Diagnostics

Following failures on similar machines, it was identified that a generator rotor could be suffering from fatigue cracks but due to commercial constraints continued operation was required until an outage could be properly planned. Successful implementation of vibration plant diagnostics allowed the machine to run safely for a number of months until a convenient outage.

Transformer Oil Dissolved Gas Analyses: RWE's Transformer Oil Dissolved Gas Analyses (DGA) identifies faults within transformers and enables repairs to be carried out at an early stage, before the fault becomes critical (see Fig. 3). Our unique multi parameter approach is essential in transformer fault diagnosis, as no single parameter is capable of giving comprehensive information. We can also perform fault interpretation using oil analysis results. An unexpected failure of a transformer results in significant downtime, loss of generation and income. In extreme circumstances there can be explosion followed by fire.

Fig. 3 - What we are trying to avoid

RWE's routine DGA enables us to identify transformers in distress, to save time and money, to identify a fault at an early stage before it becomes critical, prevent extended outages and avoid long transformer replacement and commissioning periods. RWE identified that a serious thermal fault on the transformer was most likely to have been caused by a bolted connection under oil that had become loose and developed high resistance. An immediate outage of the transformer was required; inspection of all internal connections identified an HV bushing connection with higher than normal resistance. The fault was successfully repaired and with regular DGA, it was confirmed that the fault had been correctly identified and repaired.

Thermography: Thermographic inspection has been carried out in RWE and its preceding companies since the early 70s but in the latter years we have attempted to maximise the potential of thermograhy by applying it as a condition monitoring tool. Our initial involvement with thermographic condition monitoring did have some success but we were confident that it was capable of better added value applications. Developers of new applications, whether it is non-destructive evaluation or condition monitoring, rely on access to both samples and running plant and to that end, RWE have had an advantage in its attempts to develop new technology. One of the early applications was on COGEN plant; part of the generation mechanism required the used steam to be recycled back through the system but this could only be achieved if the steam was recondensated back in to hot water. The process is accomplished via a series of fan cooled tube banks and headers but it was essential that we were able to confirm the precise time and location of the transition. The top left picture below shows the condition monitoring results of a successful transition (see Fig. 4); similarly, the top right picture shows a successful transition but it also identifies a defect, highlighted in the bottom left picture; the finger of heat should not be there. On investigation, it transpired that the tubes were set 10mm apart so that the cooled air generated by the fan could pass through and assist the cooling mechanism. However, the first tube in the bank was sited hard up against the superstructure which diminished the cooling effect and facilitated overheating. The cooling fan, bottom right picture was also monitored for successful operation.

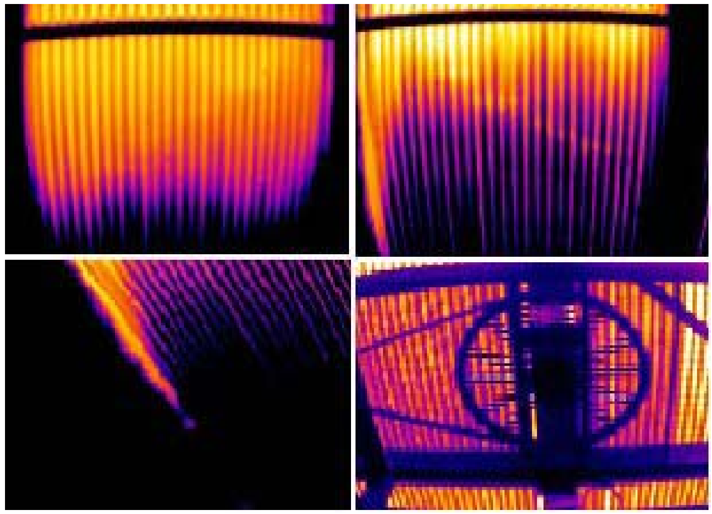


Fig. 4 – Thermographic Condition Monitoring of COGEN plant

Another application was required by a Power Plant Operator; at the bottom of the HRSG at Didcot B Power Station, the external cladding is not light corrugated aluminium as with normal boilers but instead it is constructed from ¾” steel plate, this makes it difficult to detect lagging deficiencies and remedy lagging defects. Following the successful thermographic survey which identified numerous areas of lagging deficiencies, the Power Plant Operator identified a novel method of carrying out a repair by injecting a semi-soluble solution through tapping points but he needed to be sure that it would work, especially as the fairly new plant was still under guarantee. You will see from the top left picture (see Fig. 5) the extent of the problem; if this was consistent throughout the HRSG, it would result in considerable heat loss and inefficiency of the system. The top right picture shows one of the tapping point where the semi-soluble solution was injected into the deficient area; the lagging injection was repeated several times until, as shown in the bottom right picture, the defect was remedied.

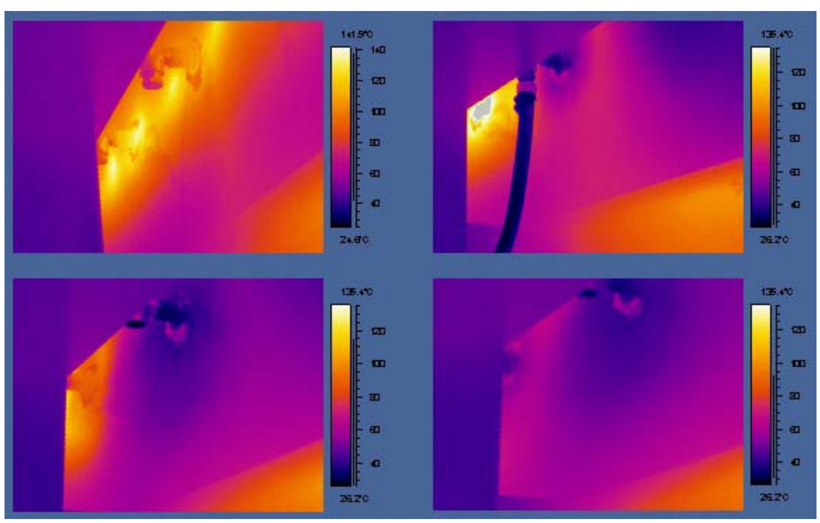


Fig. 5 – Thermographic Condition Monitoring of an HRSG

We have also experimented with periscopic applications (looking round corners or in areas you don’t normally have visual access to); failures have occurred in Secondary Superheater Boiler Feed Pump (SSBFP) rotors where overheating of the end-winding bars has caused the soldered joints to fail through the poor creep properties of the solder when exposed to a conductor temperature in excess of 85ºC.

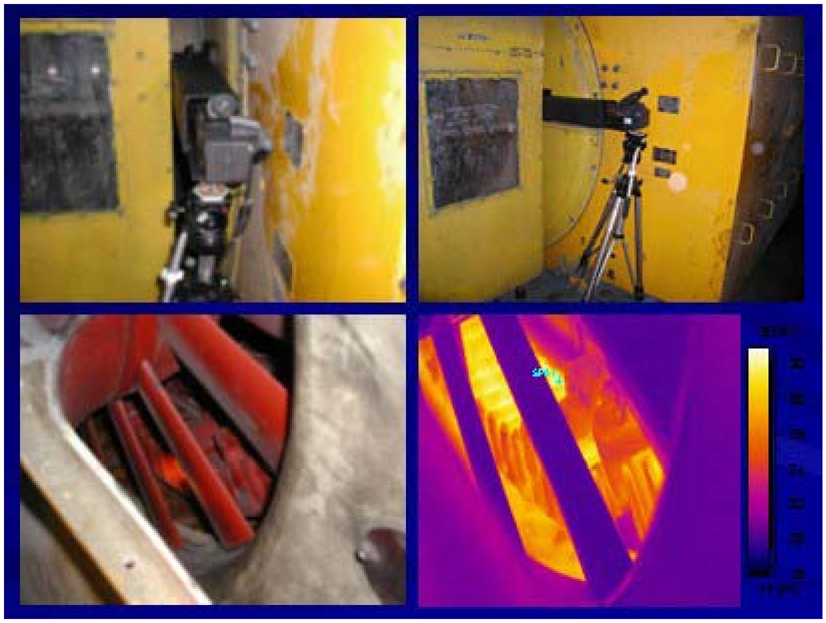


Fig. 6 - Thermographic Condition Monitoring of SSBFP Motor

The top two pictures (see Fig. 6) shows how we fabricated a periscope that allowed us to view the end winding bars through the air cooling section of the exciter housing; the periscope was then fitted to an infrared camera and a condition monitoring survey was carried out. The bottom two pictures show the view of the end windings through the fan blades using digital and thermographic cameras. Following laboratory trials, the application was successfully carried out at Aberthaw Power Station, which allowed us to monitor the temperature of the windings over a 10 minute running period and also to monitor the temperature increase when the cooling fans were switched off.

Acoustic Emission: In past years, acoustic emission has been tried on power generation plant without much success, other than applications applied to conventional boilers; the harsh acoustic environment makes it difficult to apply acoustic emission techniques. The boiler applications monitor/detect the existence of tube leaks and although this may seem to be "after the horse has bolted" there are considerable benefits in preventing consequential damage and pin-pointing the source of the leak in order to enact a speedy repair. More recently, acoustic emission has been trialed on other critical components, such as steam pipework, the benefit of developing a working application would be to install a global detection system that would give early warning of impending failures; the internals of a steam pipework system are pressurised to 2000psi at a temperature of 500ºC -600ºC.

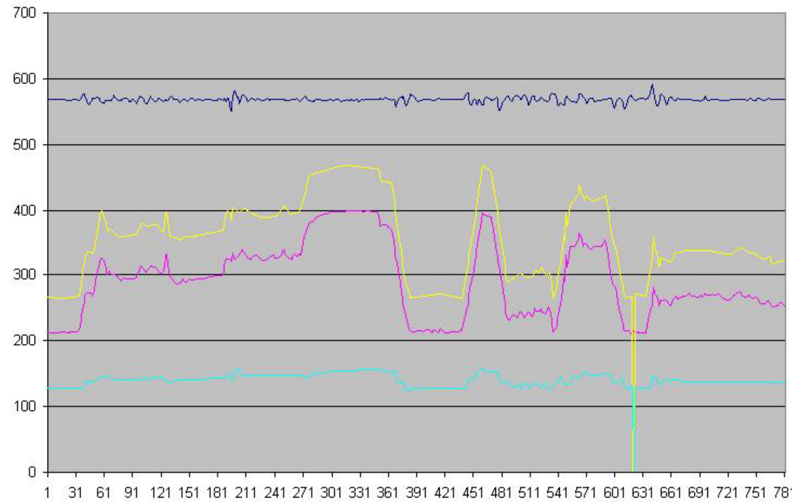
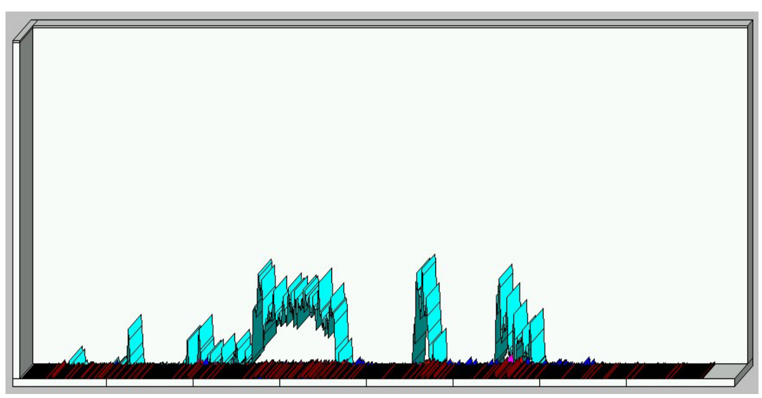


Fig. 7 - Power Station Operational Data gathered by OIS

RWE Innogy uses a highly sophisticated system called OIS to monitor the operational panemetrics of each power generation unit. The above graph (see Fig. 7) represents a 26 hour period commencing at 0500 one morning; you will see from the top line (dark blue) that the temperature remained fairly constant at around 575ºC; similarly, the pressure, bottom line (light blue) also remained reasonably constant at around 150 bar. However, the unit load (yellow) and the steam flow (pink) tell a different story; within the fluctuations there are three significant drops, identified at positions 421, 511 and 631.

From the Acoustic Emission system fitted to steam pipework on the same unit (see Fig. 8), the above graph indicates that the acoustic emission sensors have also picked up the major events at 421, 511 631 but arguably it has also detected minor events at 61, 121 and 211, also identified on the OIS graph. So what does all of this mean? Do we ignore these acoustic emission signals simply because OIS has confirmed that the acoustic signals are consistent with an operational event? Not so, acoustic emission signals may well coincide with operational events but in some cases, these events may be a contributing factor toward crack growth, such as thermal fatigue cracks. The key development area is in being able to determine the difference between acoustic noise produced as a result of operational activities and acoustic noise generated by crack growth.



61 121 211 421 511 631

Fig. 8 – Acoustic Emission output from Steam Pipework

A recent "Type" problem in the UK has been the discovery of steam pipework thermal fatigue cracks (bore cracks). These cracks emanate from the bore, are usually vertical, are usually completely facetless and have largely gone undetected by conventional NDT. The picture (see Fig. 9) gives an illustration of a bore crack:

Fig. 9 – Steam Pipework Thermal Fatigue Crack

Previously we have installed a remotely accessible AE based structural monitoring system designed for permanent installation. The capabilities of the system were focussed on identifying when and where something was happening in a section of steam pipework. Experience has shown that significant bursts of AE are detected by the system and a scheme was required to discriminate in favour of crack growth related AE activity and against other noise type activity. It is known that AE activity associated with sub-critical crack growth generally takes the form of isolated bursts. In addition to this type of AE activity other noise processes can be present, which also generate detectable high frequency activity from processes such as turbulent flow and mechanical rubbing. Single transient excitations lie along a characteristic curve (depending upon the peak amplitude) and noise type activity lies to one side of this curve since it has a disproportionately large area for its peak amplitude. This effect shows the separation of transients (singular excitations) and noise type activity (multiple excitations) during development testing on a metal block (see Fig. 10). Very good separation is achieved (the only exception being an insignificantly low amplitude burst).

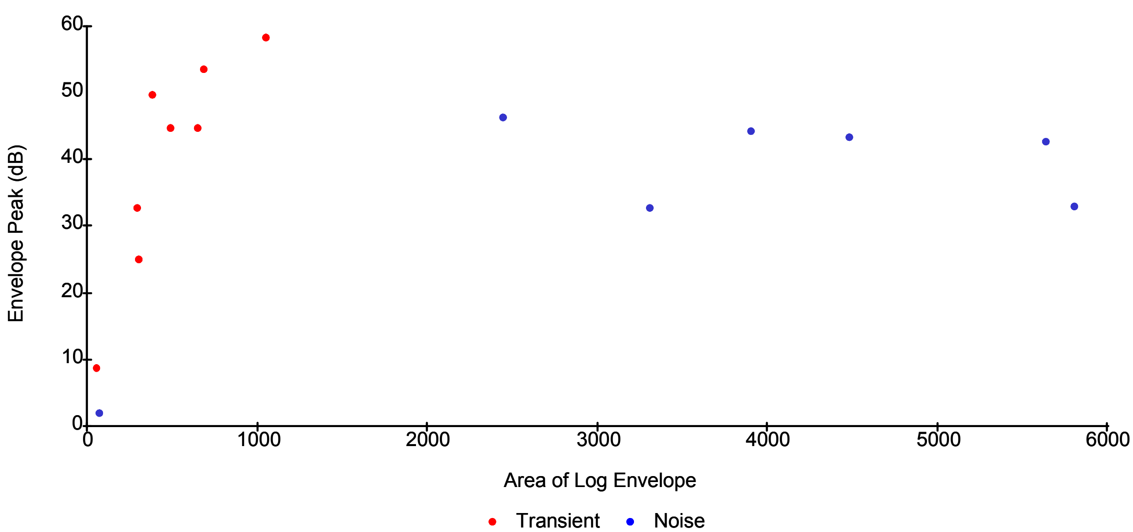


Fig. 10 – Separation of Acoustic Events

Discussion: The UK industry gets significant assistance from Universities in the pursuit of advanced technology, to further the already excellent Academia/Industry relations; the Department of Trade and Industry (DTI), through a department called Engineering and Physical Sciences Research Council (EPSRC) has sponsored the creation of an organisation called Research Centre in Non-Destructive Evaluation (**RCNDE**). RCNDE is made up from six universities (Imperial College London and the Universities of Strathclyde, Bath, Warwick, Nottingham and Bristol) together with a similar number of industrial sponsors. The Core and Targeted work programmes worked up by the centre include both Acoustic Emission and Thermographic technologies, which will lead to significant advances in Condition Monitoring, a better understanding of the technological capabilities and applications that can be applied to power generation plant. RWE Innogy is one of the industrial sponsors of RCNDE and intends to support both the core and targeted work programmes; together with other NDE technologies, it anticipates considerable success in Thermographic Condition Monitoring and Acoustic Emission Condition Monitoring. The thermographic programme will include combining laser generation with thermographic evaluation, miniaturisation and remote access, all of which will benefit the power generation industry. The Acoustic Emission programme will support the existing initiatives already taken by RWE Innogy, it will facilitate a better understanding of Acoustic Emission as applied to Steam Generating plant and will contribute towards the development of a global warning system.

Conclusions: Structural Integrity strategies rely on the detection of plant problems/defects prior to plant failure. Condition Monitoring has a proven track record in some industries and some applications but there is more to be done in Power Generation; whereas RWE have already developed Power Plant Vibration Diagnostics and Transformer Oil Dissolved Gas Analyses applications, which contribute towards structural integrity, it wants to further its progress in Thermography and Acoustic Emission. Collectively, Condition Monitoring applications contribute towards failure avoidance, thus improving safety and enhancing commercial success.

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