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New Windows into Boiler Wall Health and Performance using Non-Intrusive Scanner Technology

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Achieving a greater awareness of the real-time fireside conditions of power generation boilers is an important objective for many plant operators to help avoid damage to the boiler fabric or to optimise performance. Damage to boiler tubing, which forms the basic boiler structure, can be one of the biggest factors influencing plant shut down and repair costs. To help assess fireside conditions, several techniques are available for monitoring the integrity or thermal behaviour of the tube walls. A traditional approach has been to use discrete temperature sensors, insert probes or test specimens at individual or point locations. Some of these methods require significant modification to the wall tubing, a time-consuming and costly process.

Using a quite different approach, and one that enables plant operators to 'see the wider picture', Rowan Technologies Ltd. (UK) has developed and refined techniques that monitor and map both wall integrity and thermal behaviour over large areas of wall, not just at point locations. These 'scanner' systems have two principle features: firstly, sensing electrodes used to establish fireside conditions are welded to external (cold-side) tube surfaces, Figure 1, so there is no need to intrude into or through the boiler wall. Secondly, by using rectangular matrices of electrodes, two dimensional maps of boiler wall conditions can be produced on-line and in real time by 'scanning' each sensor location in sequence.

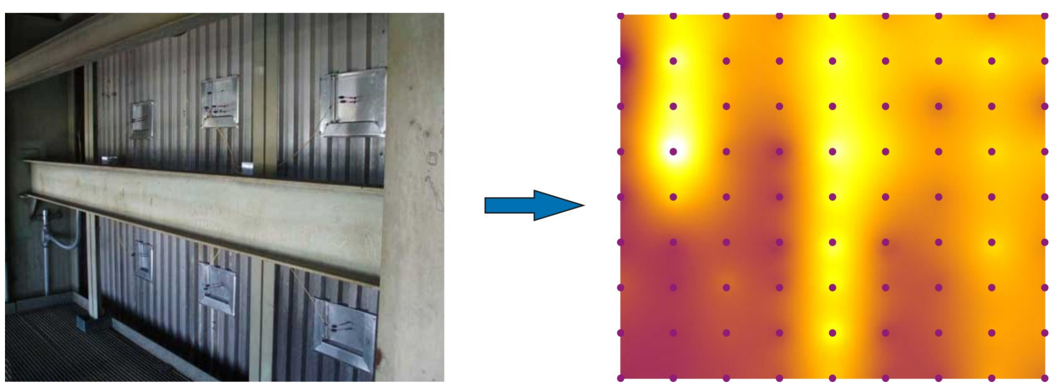

Figure 1: The six scanner electrode locations (left) form part of a larger electrode matrix defined by the dots in the fireside wall temperature map (right).

The scanner's technique of mapping whole areas of wall essentially creates large 'windows' into fireside wall performance, providing new insights into conditions that include wall corrosion and cracking, surface temperature, heat transfer and effectiveness of wall cleaning. This greater awareness allows boiler operations to be fine-tuned to avoid damaging conditions and improve efficiency, creating opportunities for substantial cost-saving and revenue generation.

Drax Power Station, UK

Early Scanner Trials

The concepts behind the scanner technology first became practical reality in the late 1990s when a system was installed on the sidewall of the Unit 4 660MW boiler at Drax Power Station, UK. Drax is Western Europe's largest coal-fired plant with six boilers providing a total generation capacity of around 4GW. The plant operators were keen to establish the performance of weld overlay on the Unit 4 sidewalls, field-applied to selected bare tube panels, and which was designed to inhibit corrosion (or 'wastage') of the fireside tube surfaces. In extreme cases this corrosion may lead to complete tube failure; boiler shut-down and wall repair is then imperative if further operational problems are to be avoided.

Using the scanner technology, the weld overlay thickness on the Unit 4 tube panels could be monitored on-line and compared with adjacent bare tubing to assess its performance, without the need to shut down the boiler for inspection, Figure 2. The scanner system was soon able to show that the weld overlay was performing well, a fact confirmed two years later using ultrasonic wall thickness measurements and visual inspection during a scheduled shut-down. Ultimately, due to the high cost of installation, Drax decided not to pursue further weld application, choosing instead to closely monitor the existing 'bare' tube walls.

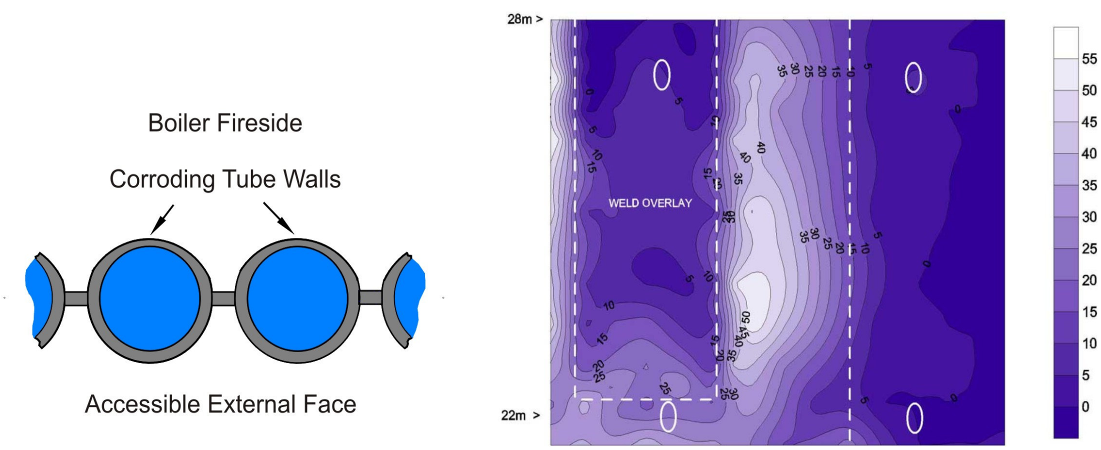

Figure 2: Tube wall corrosion (left) was quantified and mapped in real time (right). Corrosion rates (nm/hr) are far higher on the bare tubing either side of the overlay.

Scanner Measurement Principles

To monitor wall integrity, the scanners make use of well proven electrical resistance techniques. During the measurement cycle for corrosion monitoring, current passes through the tube wall via pairs of electrodes spaced roughly 1 metre apart and welded to external (cold-side) tube surfaces. On entering the wall, current rapidly spreads out through the bulk metal. Metal thinning from corrosion hinders the passage of current through the fireside tube wall which in turn increases the measured potential gradient (hence resistance) between current source and sink.

Measured resistance values are also heavily dependent on metal temperature and, as part of the measurement and data processing cycle for corrosion monitoring, the scanner also measures the dynamic tube wall temperature variations and then compensates the resistance measurements accordingly.

The scanner's thermal data, besides helping to quantify tube wall corrosion, was also shown in the early Drax trials to predict good estimates of tube wall heat flux and fireside tube temperatures, as confirmed by intrusive heat flux probes installed in the same area of wall, Figure 3. Because the scanner sensors are laid out in rectangular matrices, this enables complete two-dimensional maps of the tube wall's fireside thermal conditions to be produced in real time, a feature which has been further developed in later system designs.

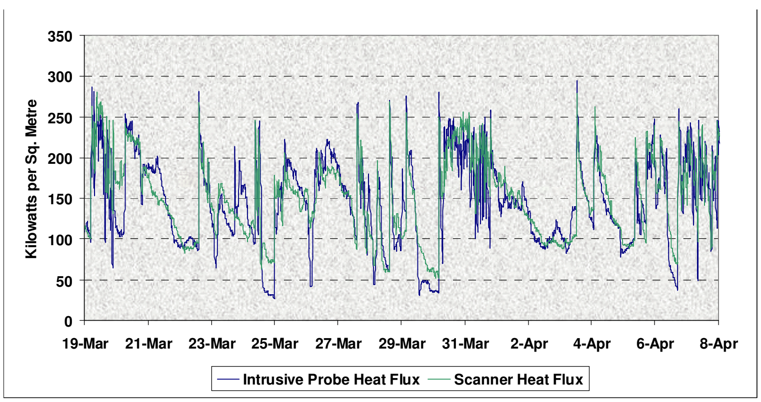

Figure 3: Comparison of scanner and intrusive probe heat flux data acquired some four tubes apart

Since the early scanner trials, the scanner systems have followed an evolutionary path of improved accuracies, reduced installation costs and greatly enhanced data management and processing capability. There are now two main scanner variants: combined integrity and thermal monitoring systems or dedicated thermal monitoring systems. Flexible hardware configurations cater for a variety of sensor layouts and possible site restrictions such as high ambient temperatures and boiler exclusion zones. Systems directly interface to plant information systems for immediate or retrospective data processing.

Drax, UK - Unit 1

For all six units at Drax, tube wall corrosion is an on-going issue towards more central areas of wall and is caused by a combination of high tube temperatures, reducing conditions and corrosive species within the combustion products. Drax's current strategy is to control corrosion at an acceptable minimum level by trying to ensure that it does not result in unscheduled down time for tube repair or in extensive tube panel replacement during scheduled (four-yearly) shut downs.

In 2001 a second scanner system was installed at Drax to monitor the rate of sidewall corrosion following the installation of low NOx burners on Unit 1. This system monitors both sidewalls using two arrays each of 120 sensor locations covering some $280m^2$ of boiler wall. In 2005 the existing sensor arrangement was extended further upwards because of concern that a newly-installed over-fired air system, designed to reduce NOx emissions, might result in substantial wall corrosion higher up the boiler. Using Unit 1 as a test-bed, the scanner's data provides a guide to the likely outcome of similar boiler modifications on Drax's other five units.

Amongst other tasks, the scanner hardware on Unit 1 provides early warning of excessive corrosion. To date, the scanner's real-time data has shown that changes to the boiler since 2001 have not resulted in significant increases in background corrosion activity, a fact confirmed by ultrasonic surveys during scheduled shut-downs in 2004 and 2008. The scanner's on-line information has helped give boiler operators the confidence to keep the boiler running in the knowledge that corrosion rates are relatively low and will not result in unscheduled downtime for tube wall repair.

From a more proactive angle, the scanner's real time information has also enabled the boiler personnel to reduce excess oxygen levels within the boiler to help maximise efficiency, with the reassurance from the scanner's data that tube wall integrity is not being compromised by accelerated corrosion rates. Excess oxygen or air that is not used for combustion helps to avoid reducing conditions that can cause substantial tube wall corrosion. However, this excess has the drawback of removing heat from the combustion process and so keeping it to a minimum helps overall efficiency.

Brunner Island, PA, USA - Unit 3

Brunner Island Unit 3 is an 800MW coal-fired supercritical unit. Like many supercritical units, the boiler is prone to circumferential cracking of the fireside tube walls under particular operating regimes, Figure 4. Plant modifications to reduce NOx emissions, together with the introduction of tube weld overlay to inhibit corrosion, have resulted in a greater prevalence of this type of cracking. Wall cracking is thought to have a number of causal factors including high wall temperatures, large tube wall temperature differences and corrosion fatigue.

Brunner Island Power Plant, PA, USA

Although cracks are initially superficial in nature, severe cracking of the tube walls at Brunner Island has resulted in a number of tube leaks and subsequent unscheduled shut downs for repair.

Figure 4: Fireside circumferential cracking of weld overlaid tubing

As part of a US EPRI research project, a scanner system was installed in 2006 on Brunner Island's Unit 3 to monitor areas of both front and side wall that had previously suffered tube wall cracking, the scanner performing a dual role of integrity and thermal monitoring. This unit is one of two supercritical units to have scanner systems installed in the US as part of this project.

The scanner technology can detect circumferential crack growth under laboratory conditions, although resulting signal changes are small. The Brunner Island installation provided the first field trial for this technique: a combination of small signal changes and some inevitable background 'noise' makes this task significantly more challenging than on-site monitoring of corrosion and work is on-going to prove the technique's viability.

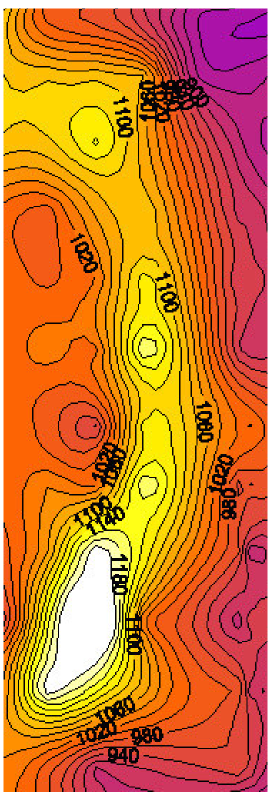

Figure 5: 10m high arc of flame impingement at Brunner Island

More crucially, the system helps identify the thermally-related root causes of the cracking phenomena so that appropriate action can be taken to minimise or eliminate it completely. Because cracking is partly attributable to high and variable tube wall temperatures, monitoring and analysis of the walls' thermal characteristics forms a critical part of this project. To date the scanner has provided a wealth of thermal data to help understand the underlying causes.

To ensure adequate data sampling, the scanner typically performs a thermal scan cycle of roughly 200 sensors once a minute, enabling rapid thermal transients to be captured and analysed. Data is sent directly to the plant historian, allowing immediate data processing and presentation. Techniques devised at Drax to predict estimated fireside tube wall temperatures, have been refined and applied at Brunner Island to show fireside thermal behaviour over some 150m^2 of wall.

The scanner's ability to 'see the whole picture' has allowed previously unseen phenomena to be visualised for the first time. These include the real-time impact of mechanical wall cleaning, the nature of natural slag shedding and identification of likely flame impingement, Figure 5. All these phenomena are possible contributory factors to wall cracking. Maps can be compiled into 'video' sequences; as well as having obvious visual appeal, these help to interpret more subtle time-dependant behavior. Using another investigative approach, time-dependant traces from individual scanner sensor locations can be correlated with boiler operations to help understand the dynamics of the wall's thermal behaviour. Of particular interest is a behavioural comparison between areas prone to cracking and those that are not.

Oil firing during boiler start-ups/shutdowns, mechanical wall cleaning, flame impingement and natural slag shedding have all been shown to expose the fireside tube walls at Brunner Island to 'excessive' heat levels. In addition, a far greater understanding of spatial temperature variations across the tube wall has been gained. For example, wall cleaning and natural slag shedding can expose localised areas of wall to high radiant heat whilst leaving adjacent areas relatively cool. These large temperature differentials can lead to large stresses within the walls. It is cycling of these stresses, perhaps compounded by additional residual stresses from initial tube fabrication and application of weld overlay, that is partly responsible for tube surface cracking.

Following the initial findings of the research project, the plant made operational changes to tackle the cracking problem on Unit 3. These seem to be having the desired effects, resulting in reduced down time over the last 12-18 months together with improved performance.

Smoother, more Efficient Operations

Fundamental to the scanners' capabilities is that of using their real-time information to avoid unscheduled shut-downs and to extend operating time between shut-downs that are planned well in advance. In either case down-time is reduced. For larger power generation boilers each additional day of operation may mean an extra $1 million US in revenue. Based on these figures, scanner systems, whilst providing many years of service with minimal maintenance, will have recovered their installation costs within just a few hours of additional boiler run time.

To further exploit the scanner's capabilities to their advantage, Drax has been able to fine-tune operational efficiency in the knowledge that tube wall integrity will not be compromised.

The scanner's ability to 'show the bigger picture' in terms of boiler wall performance provides a far clearer understanding of fireside behaviour, knowledge than can have very substantial long-term benefits.

For more information on the scanner technology, please visit www.rowantechnologies.co.uk and click on 'Monitoring of Industrial Plant'.