Non-Intrusive Scanners for Monitoring the Thermal Conditions of Furnace Walls - Recent Applications

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Abstract

Rowan Technologies has, over the past eleven years, been designing and supplying non-intrusive systems that monitor the integrity (corrosion, erosion, crack formation) and thermal behaviour (heat flux, fireside tube temperatures) of boiler membrane walls [1,2,3]. These patented systems have two main features: system sensors are installed on external (cold-side) surfaces, without the need for mechanical insertions into the walls and they are designed to monitor and map large areas of wall, as compared to point locations.

Systems typically employ rectangular matrices of sensing electrodes. The sensors are scanned in sequence and the acquired data processed to produce two dimensional maps of the wall integrity or thermal characteristics. Systems were originally developed for corrosion/erosion monitoring where there is a need to measure the wall's thermal behaviour as part of the data processing cycle. More recently the thermal monitoring capabilities of the technology have been refined to produce dedicated thermal monitoring systems in their own right.

Systems with thermal monitoring capability are now installed on large sub-critical and supercritical boilers both in the UK and in the USA. This paper describes how these systems have been applied to assist power plant personnel gain new insights into boiler operations and to help address operational issues.

Introduction

In the late 1990s, Rowan Technologies developed non-intrusive (scanner) systems capable of measuring corrosion/erosion of boiler tube fireside surfaces on-line. To achieve this, signals are applied, and measurements made, using rectangular matrices of sensors welded to the external (cold side) tube surfaces.

Figure 1: Drax Power Station, UK - Site of the First Scanner Installations

The first such scanner system was installed at Drax power station in the UK in 1999, a sub-critical coal-fired plant, to evaluate the performance of tube weld overlay on the sidewalls of Unit 4, a 660 MW unit. Subsequently, two further systems have been installed on Unit 1 (in 2001 and 2005) and are scheduled to operate to at least 2012. These systems use well-established electrical resistance techniques to monitor the fireside tube wall wastage. To help compensate for metal temperature variations, the tube wall's thermal characteristics are also measured, and compensated for, during data processing.

It soon became apparent that the thermal monitoring capability of such systems could be a very valuable tool in its

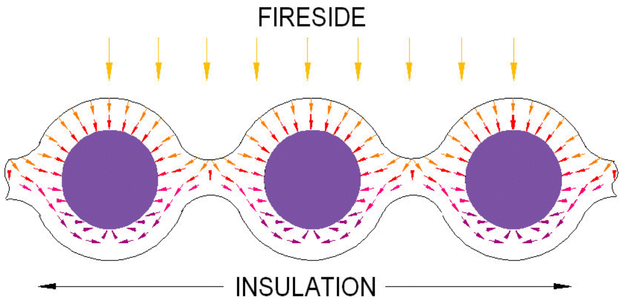

Figure 2 - Membrane Wall Heat Flow

own right. Early tests at Drax which compared scanner data with that of intrusive heat flux probes (which use thermocouples embedded in fireside tube walls and replace original sections of boiler tubing) showed that the scanner systems, using their externally applied sensors, were capable of providing good estimates of tube wall heat flux and fireside tube temperatures, but at a fraction of the time and cost of installing intrusive probes.

A schematic of heat flow through furnace membrane walls is roughly as shown in Figure 2, where the arrows indicate the direction of heat flow - brighter colours indicate higher temperatures. The membrane between the tubes acts as an additional heat sink and helps to transfer heat around the sides and rear of the tube wall before entering the cooling medium.

Recent comparisons of scanner and intrusive probe heat flux data, from a US scanner installation, are shown in Figure 3. In these examples the intrusive probe was located a few tubes away from the scanner sensor electrodes and so, at times, some localised differences in tube temperatures and heat flux are inevitable.

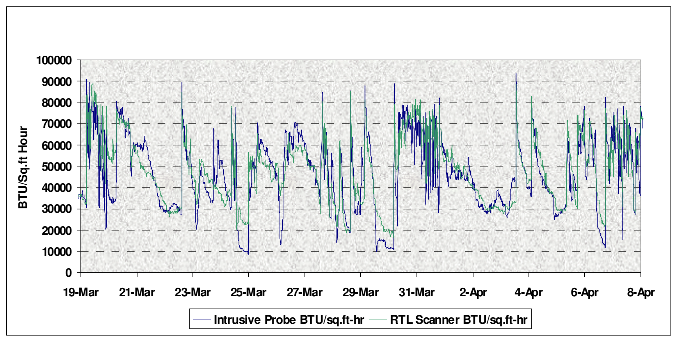

Figure 3 - Comparison of Scanner and Intrusive Probe Heat Flux Data

Because the scanners use rectangular matrices of sensors, two dimensional mapping of thermal behaviour, over large areas of furnace wall, could be produced and with real-time capability. Existing installations typically use sensor locations spaced about 1 metre apart, the largest system currently installed uses two sensor arrays each of 120 sensor locations, covering some 240 square metres of boiler wall. Scanner systems can, however, have as many as 500 sensor locations and as few as 10 or less. Each sensor location is measured in rapid sequence (scanned) and the acquired data then processed within a few seconds to produce complete thermal maps of the boiler walls.

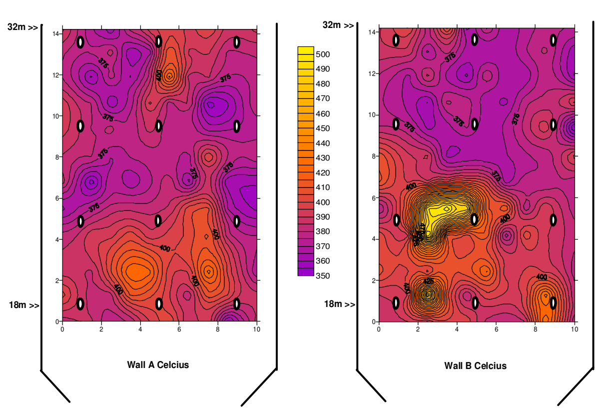

Figure 4 - Surface Temperature Maps, Drax Unit 1

Example mapping from the sidewalls of Drax's Unit1 boiler is shown in Figure 4. Each monitoring area has 120 sensor locations that are used for both corrosion/erosion and thermal monitoring.

All systems have the ability to store and retrieve data via the local plant information system (historian) so enabling both historical and real time analysis and presentation of scanner data. As the scanner systems have evolved, both the hardware and software capabilities of the systems have been refined and enhanced: system installation has been simplified, sensitivity and accuracy improved and software developed to facilitate data storage and presentation.

Case Study 1 - Brunner Island Supercritical Boiler, Pennsylvania

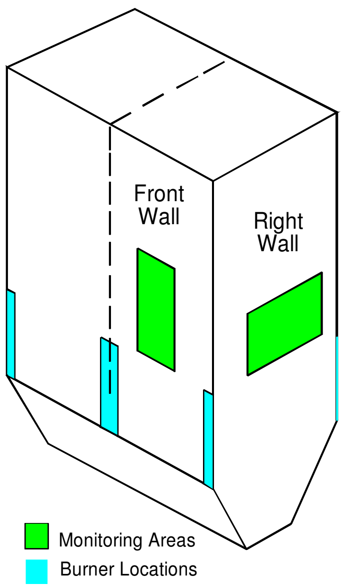

Figure 5 - Unit 3 Monitoring Areas

The first supercritical coal-fired boiler to have a scanner system installed was on Pennsylvania Power and Light's Unit3 (800MW) boiler at Brunner Island; this was commissioned in early 2007. The thermal monitoring capabilities of the scanner are used to detect and evaluate possible damaging fireside tube wall conditions that might be responsible for circumferential cracking of the tube walls, and is part of an EPRI-sponsored research project[4].

Two scanner monitoring areas use arrays of 81 and 91 sensor locations, Figure 5. These areas had previously experienced some of the highest densities of tube wall circumferential cracking which, in severe cases, ultimately leads to tube failure. The scanner system has quantified and mapped thermally-related causal factors for circumferential crack growth, which include both high fireside tube temperatures and substantial tube-to-tube temperature differences.

The scanner rapidly performs a complete thermal measurement cycle of both monitoring areas and the acquired data is directly transferred to the plant information system (historian). These rapid scan cycles enable short-term changes in wall temperature to be identified and accurately quantified - shorter, more dynamic temperature variations will contribute to stress cycling of the tube walls which encourages crack initiation and propagation.

To provide operators with real-time access to the fireside tube wall conditions, the latest scanner data is retrieved from the plant historian and immediately processed to produce 2D maps of fireside tube wall temperatures. The latest maps are then directly uploaded to internet web pages which can be readily viewed by anyone with direct access to them, Figure 6. Boiler operators and engineers are able to view immediately the effect of changes in boiler operations. These maps are also archived for examination at a later date and by combining a sequence of maps in chronological sequence, 'videos' can be created which, besides highlighting more dramatic changes, help to identify more subtle thermal behaviour.

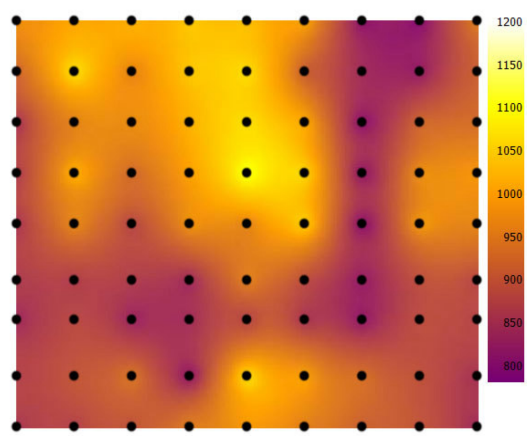

Figure 6 - Right Wall Fireside Tube Temperatures (Deg. F). Sensor Locations are defined by Black Dots

Data acquired by the scanner has identified a number of contributing factors to excessive tube fireside thermal behaviour. These include flame impingement, cleaning operations to control slag build up on the tube walls and natural slag shedding.

Flame impingement is caused by unwanted instability in the central fireball which ideally should be kept well away from the boiler walls to avoid excessive tube heating. An arc of high fireside tube temperatures within the front wall scanner monitoring area is shown in Figure 7.This was a transient event, lasting for a short period before disappearing once again.

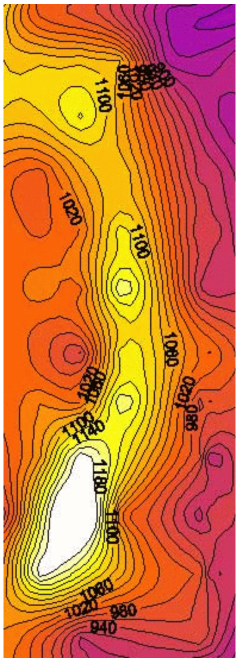

Figure 7 - Flame Impingement

The plant's sootblowers use jets of steam to clean the furnace walls - during the cleaning cycle these blowers protrude a short distance through the tube wall, slowly rotate and at the same time blow a powerful jet of steam onto the area of wall immediately surrounding the sootblower. If the sootblowing is successful it will remove most of the slag in the immediate vicinity. However, cleaning can have a detrimental effect of exposing the clean wall to very high radiant heat until deposits starts to reform once again. It can also result in a patchwork of locally clean and slagged areas of wall, which may result in high tube-to-tube temperature differences between clean and slag-covered tubes.

Natural slag shedding can occur in a number of ways: it can be of a continuous nature where very frequently small, localised areas of slag fall under their own weight. Slag avalanches can also occur where the removal of one small area of slag can cause the slag above it lose its grip on the wall and so result in an avalanche, Figure 8. Natural slag shedding inevitably results in excessive tube-to-tube temperature differences with abrupt changes in tube fireside temperature between slagged and unslagged areas. In extreme cases, slag falls are so large that they can physically damage the boiler as they crash to the bottom.

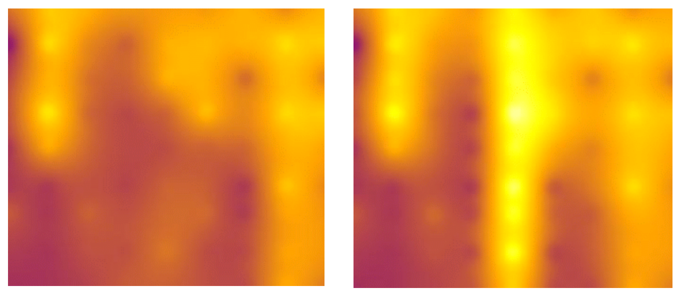

Figure 8: Maps of Fireside Tube Temperatures, 2 Minutes Apart, showing a Central Slag Avalanche

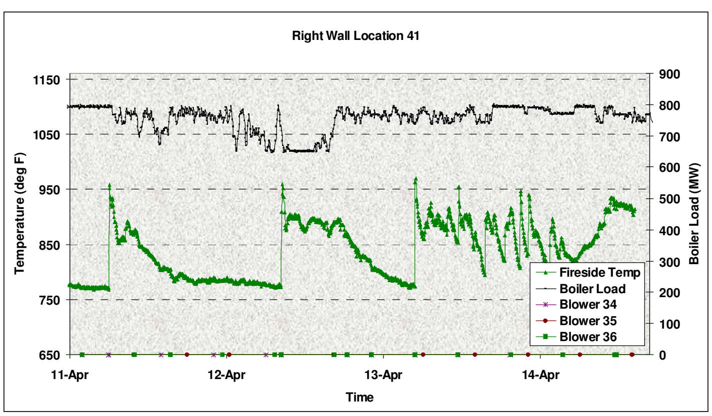

Figure 9 : Correlating Data from Individual Sensor Locations with Boiler Operations

Analysis of data from individual sensor locations allows localised variations in tube temperature or heat flux to be corelated with boiler operations including boiler load, burner configuration, wall cleaning etc., Figure 9. Statistical analysis from individual locations enables possible causes of cumulative stress or stress cycling to be quantified. Temperature differences between adjacent scanner sensor locations can be analysed in a similar manner to help build up a clear picture of stress patterns and contributions.

Case Study 2 - Martin Lake Power Plant, Texas

Martin Lake's scanner application is similar to that of Brunner Island in that this installation is also on a large supercritical coal-fired boiler (850 MW). However the installation differs in that the unit uses water cannons to control wall slagging rather than steam sootblower jets.

Figure 10 - Martin Lake Power Plant, Texas

Matin Lake's three boilers, Figure 10, have also previously experienced circumferential cracking in a similar manner to Brunner Island and is participating in the EPRI funded research project on this issue. Various changes have recently been made to boiler hardware and operations to help minimise crack formation, including the replacement of sootblowers for an automated water cannon cleaning system. A scanner system was installed to help evaluate the current 'state of play' with regard to boiler tube wall fireside temperatures and the effects of wall cleaning by the water cannons.

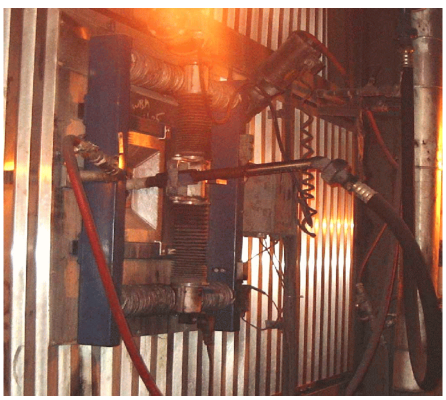

Figure 11 - Water Cannon, Unit 3

Martin Lake's scanner system employs two arrays of sensors (56 and 77 sensor locations) on two adjacent walls of the boiler - front wall and right wall. For the front wall, slag removal by the water cannons is automated - if the heat flux within a particular area of wall drops below a pre-determined level then the relevant water cannons will activate to clean that area. Water is fired from a cannon installed in the opposite (rear) wall, through the fire ball and on to the front wall. The water penetrates the slag surface and the rapid expansion to steam causes the slag to weaken and spall off. For the right wall, wall cleaning is manually controlled, using cannons from both front and rear walls.

The intention was that the water cannons would provide much better 'targeted' and controlled cleaning as compared the previous steam sootblowers, so helping to minimise unwanted and possible damaging tube wall conditions such as high wall temperatures and temperature differences. The scanner's data is providing a new insight into the boiler wall's thermal behaviour and the consequences and effectiveness of water cannon activity.

The resulting increase in tube fireside temperatures within the front wall monitoring area, as a result of water cannon activity, is shown on Figure 12. This monitoring area is both between and above two over-fired air inlets, represented by the white squares in the figure.

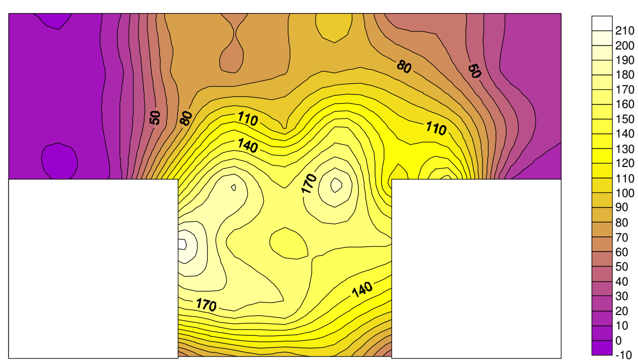

Figure 12 - Increases in Fireside Tube Temperatures following Water Cannon Activity

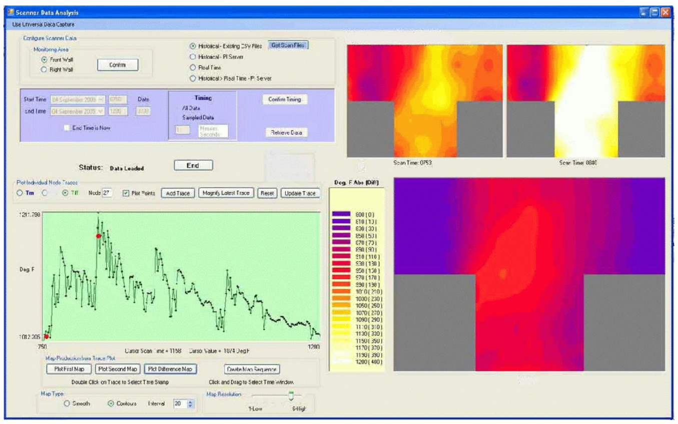

Figure 13 - Scanner Data Analysis Package

Dedicated software, designed to facilitate analysis and presentation of scanner data, can be used by plant personnel to retrieve data from the plant historian and examine both real-time and historical data in a number of ways, Figure 13. Individual scanner sensor locations can be selected and analysed in the form of linear time-dependant traces of localised thermal behaviour. 2D maps, map sequences and map differences can also be produced and archived. Both maps and traces can be readily correlated with boiler operations.

Summary

The scanner systems are proving to be invaluable tools in helping to understand the thermal behaviour of both sub-critical and supercritical boiler walls, not just at point locations as with intrusive probes, but over large areas of wall. They have helped to understand the impact of wall cleaning and natural slag shedding on wall temperatures, temperature differences and heat flux, have identified flame impingement and other causes of high tube wall temperatures and have also been used in modelling the dynamics of the central fireball.

The scanner systems allow operators to fine-tune boiler operations, operating closer to optimum conditions without straying into areas of operation which may result in damage to the boiler walls. This ultimately helps to avoid unscheduled boiler downtime for repairs, helps prolong tube lifetime and improves boiler efficiency.

It is possible to instrument complete walls with scanner sensors to provide a full, comprehensive picture of thermal behaviour. New scanner hardware makes installation a very straight forward process. Installation costs are a fraction of alternative intrusive technology, making monitoring of large areas of wall a very viable proposition, both for power plant boilers and incinerators alike.

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