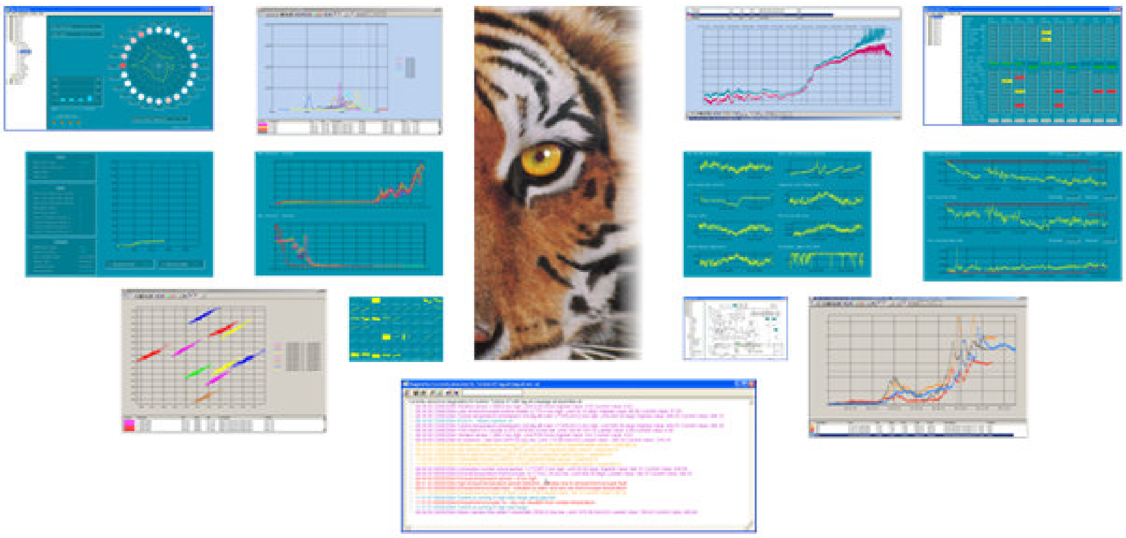
OPTIMIZING REPAIR OUTAGES FOR POWER GENERATION GAS TURBINES USING REMOTE MONITORING AND DIAGNOSTICS



Mr J. Aylett
Senior Diagnostic Systems Engineer
Dr C. Nicol
Diagnostic Systems Manager

TURBINE SERVICES LIMITED
SCOTLAND

Abstract

Detecting faults in a timely manner in plant critical equipment is increasingly important. Detection at an early stage can have multiple benefits including the avoidance of unscheduled outages, and possible equipment damage.

Being able to plan ahead to ensure correct resources are available when a scheduled repair outage is carried out, and being aware of the details of the faults that require repair is a further benefit, ensuring that repairs are quick, effective and efficient.

To achieve this, continuous monitoring is required. This creates issues that need to be solved:

- Availability of personnel for monitoring
- Enabling personnel to filter large quantities of data for significant events
- Identifying the details of the faults that require repair
- Identifying other faults to be fixed during a repair outage, which if overlooked would require future repair outages

We examine two case studies where these issues were solved, and combustion faults were identified early on, which otherwise could have caused a trip and unscheduled repair outage.

Both are gas turbine COGEN sites, so a trip would have impacted the process plant, as well as causing unscheduled loss of electrical generation. No personnel were available on either site for monitoring.

A remote monitoring and diagnostic system enabled the engineering support company to identify these problems early on, enabling planning for scheduled repair outages to be made.
In both cases the faults caused significant exhaust temperature spread changes that were insufficient for controller alarms to occur, but were identified by diagnostic system messages, and through schematic displays and graphing.

The diagnostic system also estimated the temperature for each combustion can, by interpolating the exhaust thermocouple temperatures, and applying exhaust swirl parameters. This enabled the immediate identification of the faulty combustion can, speeding up the repair process.

Introduction

Turbine Services Limited (TS) is a total service provider to owners and operators of industrial gas turbines throughout the world. A key part of the service provision is to carry out repairs and maintenance work for industrial gas turbines. This can either be carried out as part of a long term service agreement (LTSA), or as required by customers.

In order to plan maintenance and repair activates efficiently, TS utilises a proprietary remote monitoring and diagnostic system called: TIGER. TIGER can monitor turbines remotely using modems and phone lines, the internet or internal company networks.

Remote Monitoring and Diagnostics - Overview

One view of remote monitoring and diagnostics (RMD) is that there will be a centralised monitoring centre at which the staff and IT infrastructure is located to support the RMD service.

TIGER has a flexible architecture which enables this approach to be adopted if required, but also enables RMD to be de-centralised to any location that is able to connect remotely to a TIGER system. This provides flexibility in the way RMD services are carried out and also enables staff within the turbine operating companies to use TIGER to carry out RMD themselves, or to view key turbine data as and when required in conjunction with the RMD services provided by TS. It also enables TS employees to carry out RMD activities wherever they may be located, as long as they have a means of connecting to a TIGER system remotely.

Remote Monitoring and Diagnostics – System Architecture

The flexible structure of an RMD system provided by TIGER is achieved by using a client-server architecture. A TIGER data server system is installed at a turbine site. This system will acquire data from the turbine controller (and possibly other sources), normally at a rate of one sample per second, which is displayed and also archived on site.

A typical TIGER data set could contain approximately 400 analog and 1500 digital tags which are acquired every second and have to be analysed 24/7. This is impractical to carry out manually, so the TIGER data server also analyses the data in real time using diagnostic rules and pre-alarm checkers, providing diagnostic messages which are also displayed and archived on site.

The acquisition of digital tag data from the controller allows TIGER to log and display controller alarms, but also enables the diagnostic system to analyse turbine behaviour in the context of the turbine run state (base or part load, etc), and in the context of the detailed operation of the turbine by the control system. This can also enable a detailed post-mortem analysis of controller operation of the turbine to be made, which can be invaluable in the analysis of some faults, such as turbine trips.

Post-mortem analysis can also be assisted by the TIGER replay option, which enables historical data to be replayed through the TIGER system and viewed and analysed, just as it would have occurred at the time of the actual events.

For long term trending purposes, the server also creates trend files of all data for each day. These trend files contain the minimum, maximum and average values of the data sampled within a four minute time window. These trend files can also be used to efficiently create trends over longer periods of days, months or even years as required.

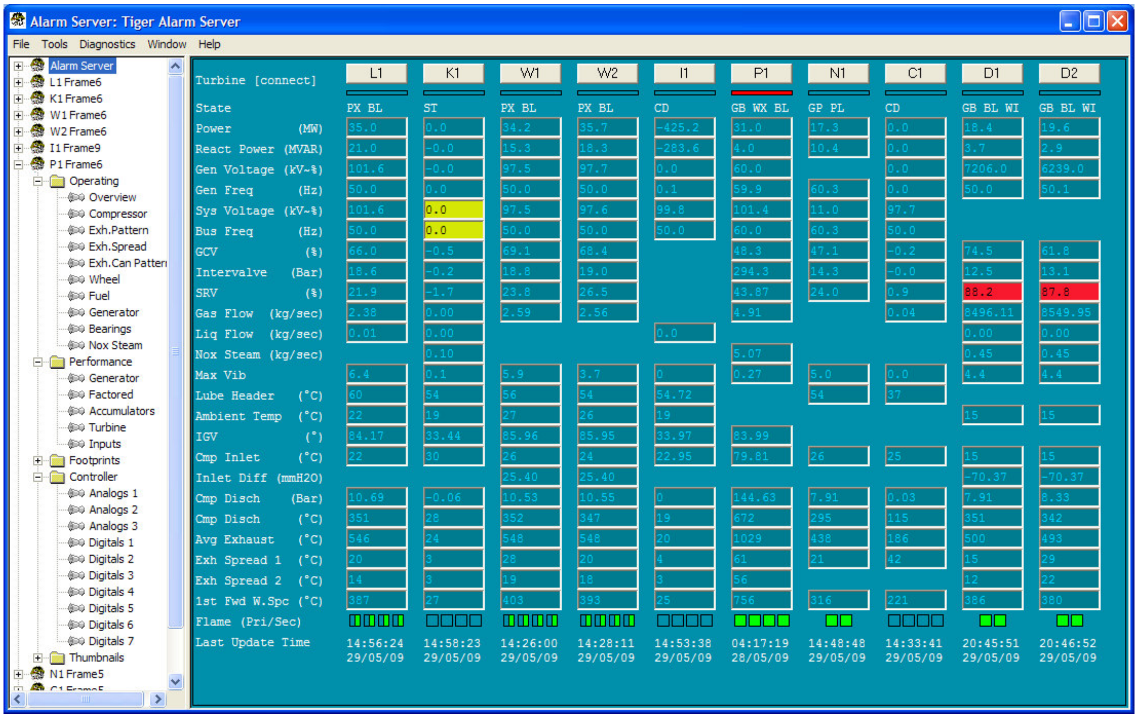
Any number of TIGER client systems can be setup to connect remotely to the TIGER data server. The client systems can connect within the turbine operating company using an internal LAN, or remotely via a WAN, or the internet or via a modem connection.

Data update rates for remote clients can be configured to suit the bandwidth of the connection being used. This could be in real time over an internal LAN, or once per hour for a slow modem connection. In addition, if remote connections have limited bandwidth, the remote client systems can be configured to just download the trend data and diagnostic messages on a daily basis, which reduces the size of the data transferred to a manageable size.

Remote Monitoring and Diagnostics – TS TIGER Remote Server

TS monitors customer's gas turbines worldwide. A vital tool used for this purpose is the TS TIGER Remote Server (TRS), located at the TS Glasgow offices, in Scotland. (See Fig 1).

Figure 1 – TS TIGER Remote Server Overview Screen

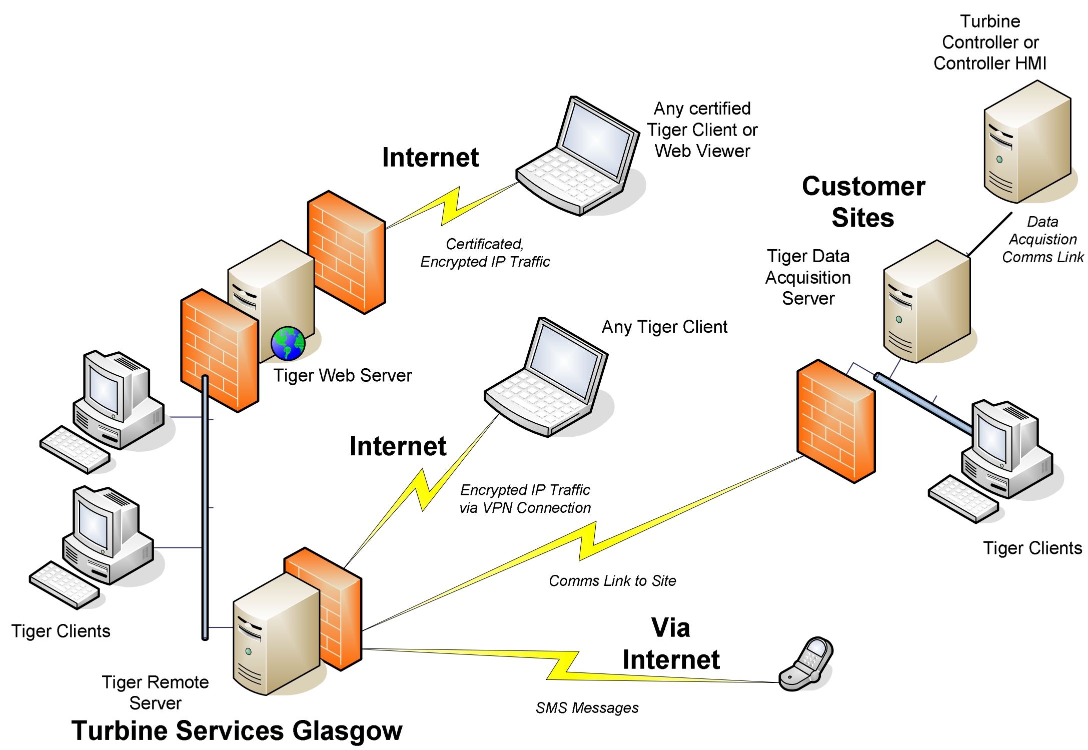


To support the TRS, the TIGER client server architecture was extended. The TRS acts as a client and as server simultaneously. It acts as a client for the onsite TIGER data servers, and connects to these at predefined time intervals to download data. It also downloads trend files and diagnostic message files each day, storing these on the TRS computer. Data can also be downloaded on demand, and it is also possible via the TRS to connect to a remote site in online mode if required. (See Fig 2).

As most of these sites have a modem connection, data is normally by default set to update once per hour, although this can be increased if required, which is feasible if higher bandwidth connections are available, as they are for some of the turbines.

The TRS also acts as a server for remote client TIGER systems. These can connect to the TRS, via LAN, WAN or internet connections, and download data from it. They can also use the TRS to get data from site which is relayed by the TRS to the remote client. The remote client can also connect in online mode to the site, via the TRS if required. (See Fig 2).

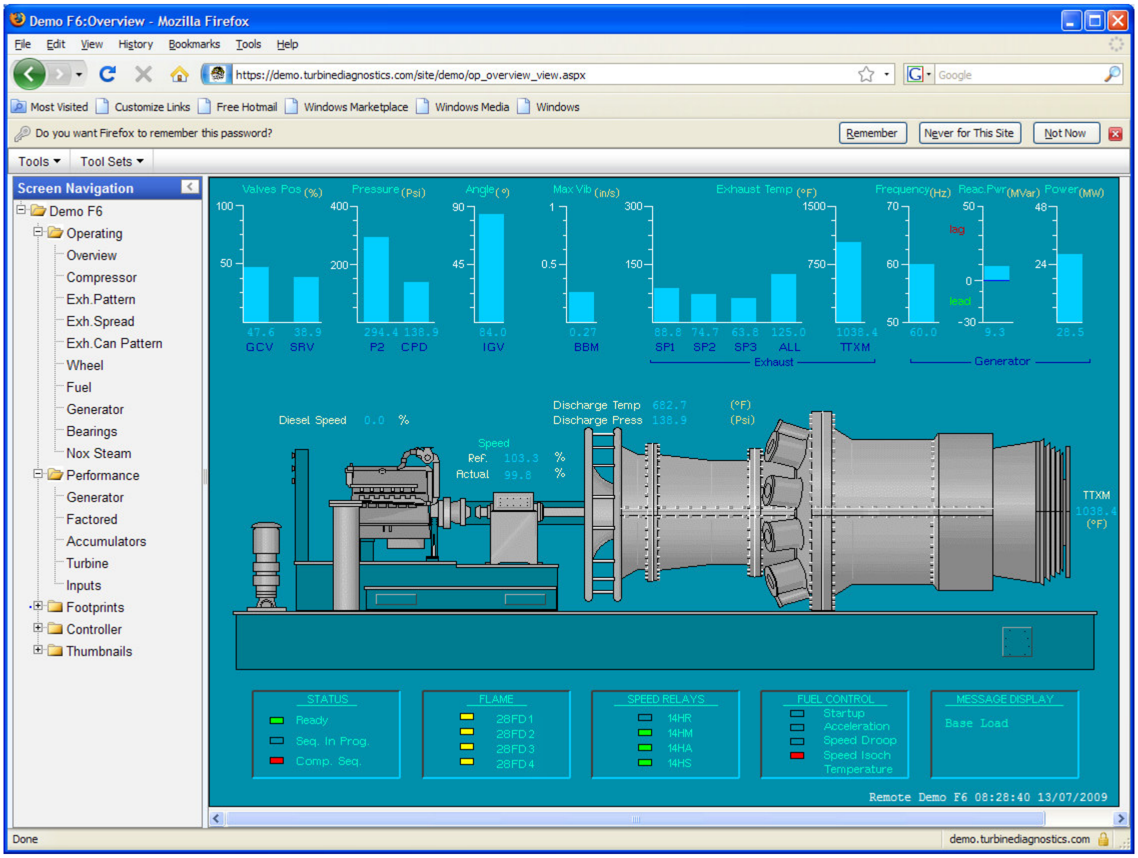
Figure 2 – TS TIGER Remote Server Network Diagram



The TRS can also be configured so that selected diagnostics messages can be relayed to any number of mobile phones using SMS. This feature can be used to ensure site support is provided when monitoring personnel are away from the TS offices, for example outside of normal business hours. (See Fig 2).

The TRS has now been extended so that it can be interrogated via a secure web server (see Fig 3). This enables a version of the TIGER system to be run in a standard web browser, and from any internet access point this can be used to access the data on the TRS, in the same way as if using a remote TIGER client. The customer or TS engineer only needs the URL, login name and password to utilise this option. This is useful in situations where users do not wish to have the overhead of installing and maintaining remote TIGER clients on their PC's or laptops.

Figure 3 – WEB TIGER Remote Overview Screen in Firefox Browser



Using Remote Monitoring and Diagnostics to Support TS Customers

The key benefit of the TRS for customers is that TS engineers can monitor the customer's turbine remotely. They can do this when at the TS offices, or when they are in any other location (such as at home) where they can connect via the internet to the TRS.

To illustrate how this is a direct benefit to the customer, we will detail two real life gas turbine case studies where RMD was used via the TRS to find developing combustion problems, and enable substantial analysis of the problems to be done remotely that otherwise would have required on site visits. One of these case studies was at a UK site, and the other was in the USA.

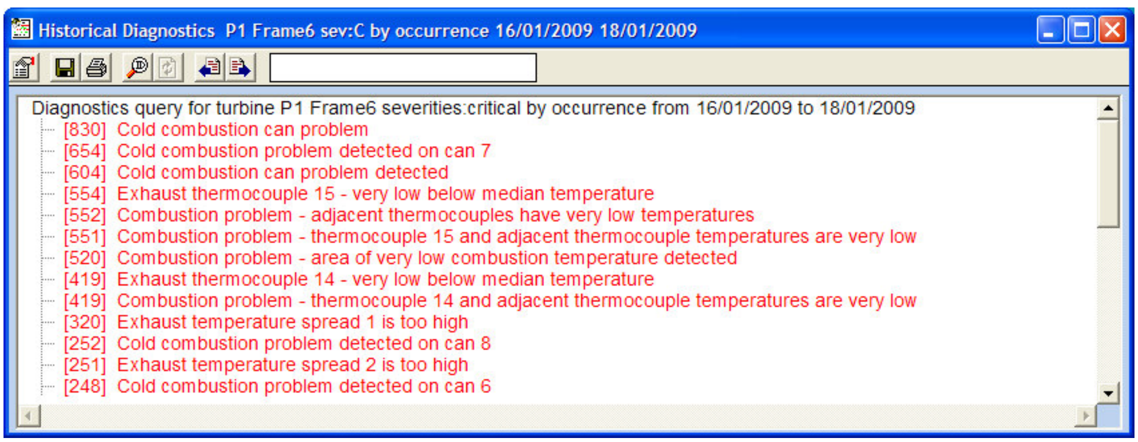
Case Study 1 - Combustion Problems on a GE Frame 6 Gas Turbine in the USA

This gas turbine is a COGEN installation located in an oil refinery, run continuously at base load. It has steam injection used for NOX reduction and also supplies steam for use in the refinery. TS monitors the turbine on a daily basis from the UK, and reports are sent to the customer for any problems detected. In this case, repair and maintenance is carried out by site contractors, not by TS.

On 16th January large transients in exhaust temperature spreads were reported by TIGER diagnostics, after turbine power was increased to base load. See Figure 4.

Figure 4 - Combustion Spread Problem - Diagnostic Messages

This indicates many occurrences of poor transient combustion or partial flameout on can 6 & 7, which was also causing high exhaust temperature spreads. The inferred combustion can temperatures are calculated by TIGER using the exhaust thermocouple temperatures and applying the combustion swirl parameter for the turbine power level.



This was investigated further by the TS engineers using TIGER trend and data graphs and mimic screens (see Figs 5 to 8 and Fig 9), and reported to site. To alleviate the problem and reduce the likelihood of an exhaust temperature spread trip occurring, the customer ramped back power slightly on 22nd January. This stopped the problem occurring for two days, until it restarted again on the 24th .

The customer then began a planning process to coordinate with the refinery a shutdown of the turbine, and to mobilise a repair team and to provide spare parts so that repairs could be carried out.

Figure 5 – Trend Graph of MIN/MAX Exhaust Temperature Spread

Shows large upward transients in exhaust temperature spread started to occur frequently from January 16th .

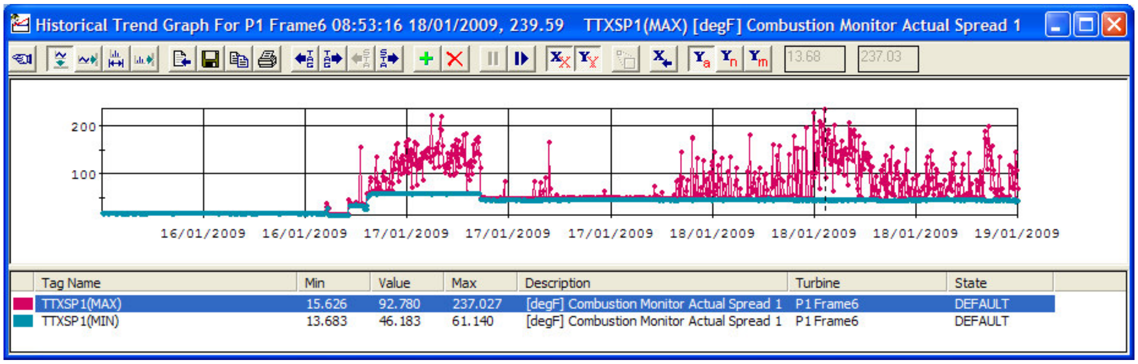


Figure 6 – Trend Graph of MIN/MAX Combustion Can 6 & 7 Temperatures

Shows large downward transients in inferred temperatures for combustion cans 6 & 7 started to occur frequently from January 16th .

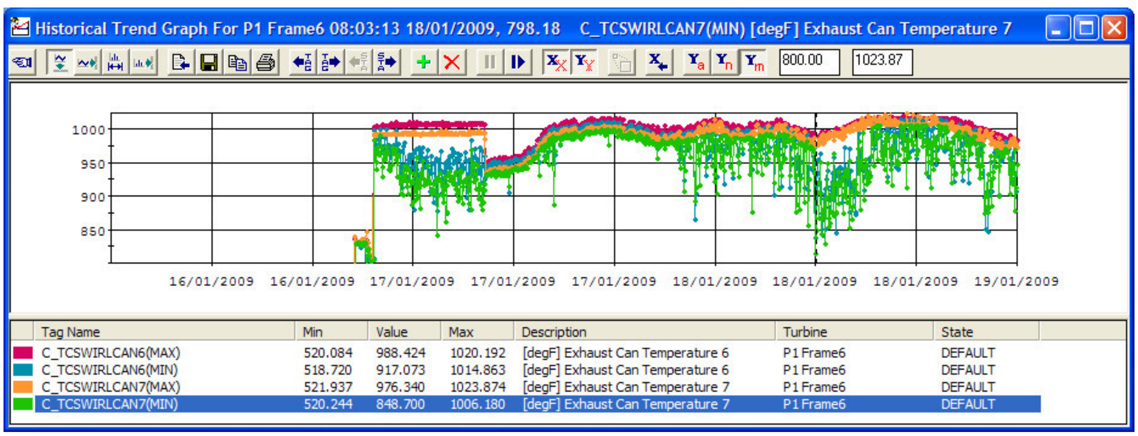


Figure 7 – Data Graph of Exhaust Temperature Spread

A sample one hour data set from the 18th shows frequent and sudden large upward transients in exhaust temperature spread.

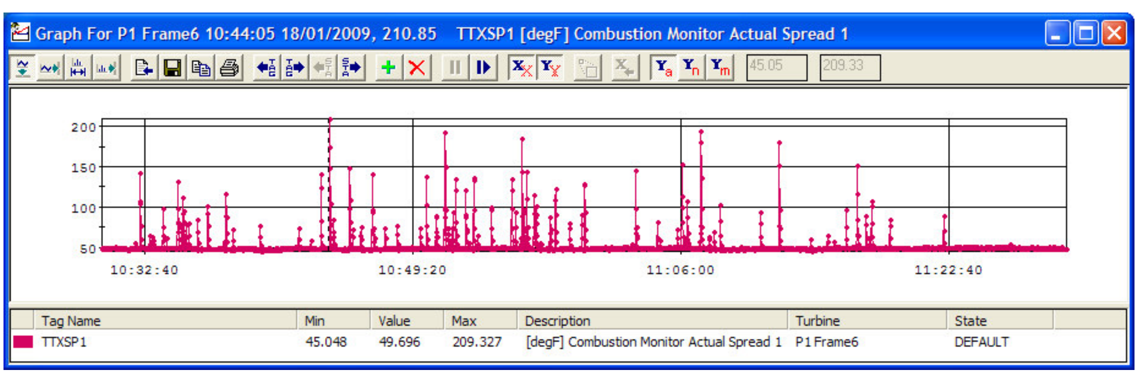
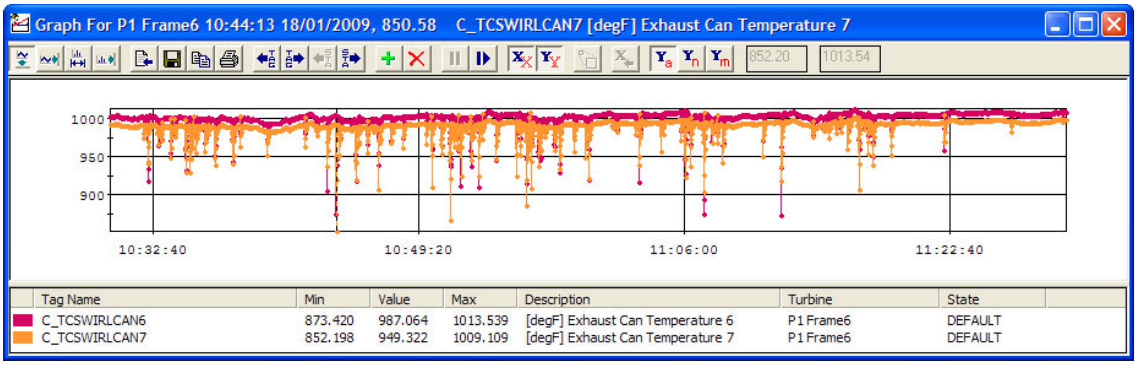


Figure 8 – Data Graph of Combustion Can 6 & 7 Temperatures

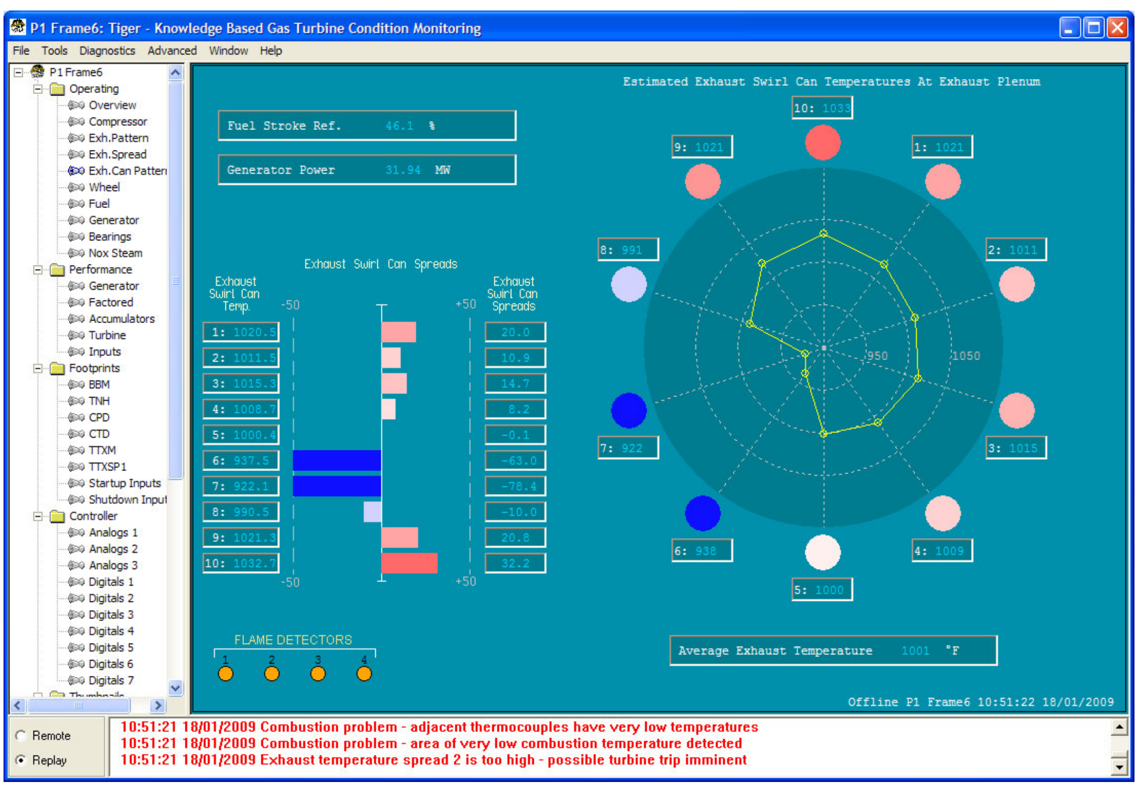
A sample one hour data set from the 18th shows frequent and sudden large downward transients in inferred temperatures for combustion cans 6 & 7.



The problem became more frequent and more severe and eight further reports were sent to site, indicating that it was being caused by transient partial or complete flameouts on combustion cans 6 & 7. TS engineers reported to the customer that the most likely cause of this problem was contamination of the combustion system by dirt in the steam injection.

Figure 9 – Combustion Can Pattern Screen

Replay data of a combustion transient shows a large drop in inferred temperatures on can 6 and 7, causing a large increase in exhaust temperature spreads.



The turbine was finally shutdown on 8th February, and an exhaust temperature spread trip occurred as it was reducing power prior to shutdown.

As suspected, inspection revealed significant contamination had occurred in combustion cans 6 & 7. Repair work and cleaning was carried out on the combustion system and some other problems that TIGER diagnostics had reported since the previous repair outage were also fixed. The turbine was then restarted successfully on 16th February.

Figure 10 – Diagnostic Query of Other Outstanding Faults

This is a list of diagnostic messages by occurrence for other faults detected by TIGER diagnostics during the period preceding the shutdown and exported into PDF format. The messages are colour coded by severity, purple being the lowest, orange the next highest and red the highest.

Diagnostics query for turbine P1 Frame6 severities:critical+fault+warning by occurrence from 01/01/2009 to 07/02/2009
[307] Flame detector problem
[6] Faulty Steam blow down valve 3
[2] Megawatt Transducer Signal Trouble (LDWATT_ALM) changed from 0 to 1
[1] Faulty Steam blow down valve 1 - failed to respond
[151] Battery 125vdc Ground Alarm (L64D_ALM) changed from 0 to 1
[45] Wheelspace 3rd aft outer thermocouple problem detected
[40] Wheelspace 2nd aft outer thermocouple problem detected
[12] Fire Prot Detector Fault Alarm Delay (L45FX_ALM) changed from 0 to 1
[4] Flame Detector Trouble (L28FD_ALM) changed from 0 to 1
[3] Steam blowdown valve 3 not closed when steam stop valve closed
[3] Fire Prot Sys Turbine Compt Area Alarm (L45FT2) changed from 0 to 1
[3] Steam Inj Drain Valve 3 Pos Trouble (L33BS_ALM) changed from 0 to 1
[2] Exciter Trouble (L59E_ALM) changed from 0 to 1
[1] Exhaust Frame Cooling Air Pressure Low (L63TK_ALM) changed from 0 to 1
[1] Steam blowdown valve 2 failed to open when steam control valve shut
[449] Flame detector 4 reading different to other 3
[5] Flame detector 2 reading different to other 3
[1] Steam blowdown valve 1 failed to respond in 2 seconds
[1] Steam blowdown valve 2 failed to respond in 2 seconds

Case Study 2 - Combustion Problems on a GE Frame 6 Gas Turbine in the UK

This gas turbine is a CHP installation located on a chemical production site. The turbine runs continuously at base load. It has DLN1 for NOX reduction and also supplies steam for use in the chemical production process.

TS monitors the turbine on a daily basis from the UK office, and reports are sent to the customer for any problems detected. TS engineers are also on call if problems occur at any time. They can use TIGER on their laptops to check on turbine status, even if away from the office or at home. Repair and maintenance is carried out by TS under a LTSA.

The on-call TS engineer received an SMS message on his mobile phone from TIGER at about 8pm on Monday 5th May indicating the turbine had unexpectedly dropped out of DLN mode and gone to lean-lean combustion. The engineer called the site, to discuss and then analysed remotely with TIGER. The engineer concluded that the drop out to lean-lean mode had been caused by changes in gas fuel pressure which had triggered a combustion flashback.

Figure 11– Flashback – Diagnostic Messages

The diagnostic messages indicate that the turbine dropped out of DLN mode (premix combustion) and into lean-lean mode. It also indicates exhaust overtemperature and problems with the gas fuel valve occurred.

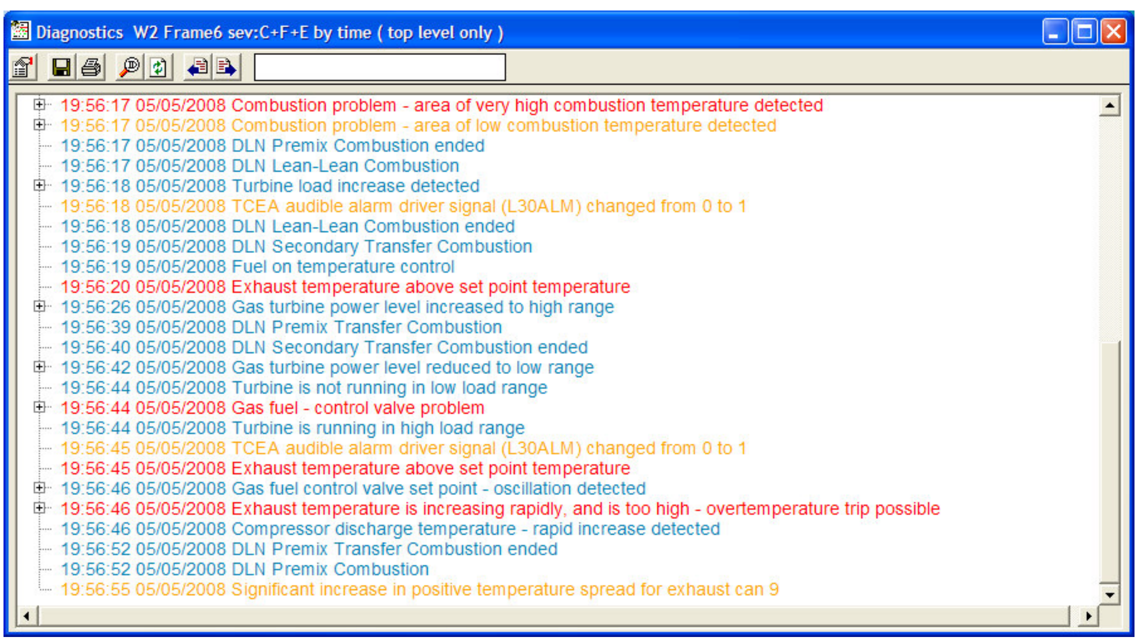


Figure 12 – Trend Graph of MIN/MAX Exhaust Temperature Spread

This shows a large upward transient associated with the flashback, followed by a change in spread level, and behaviour.

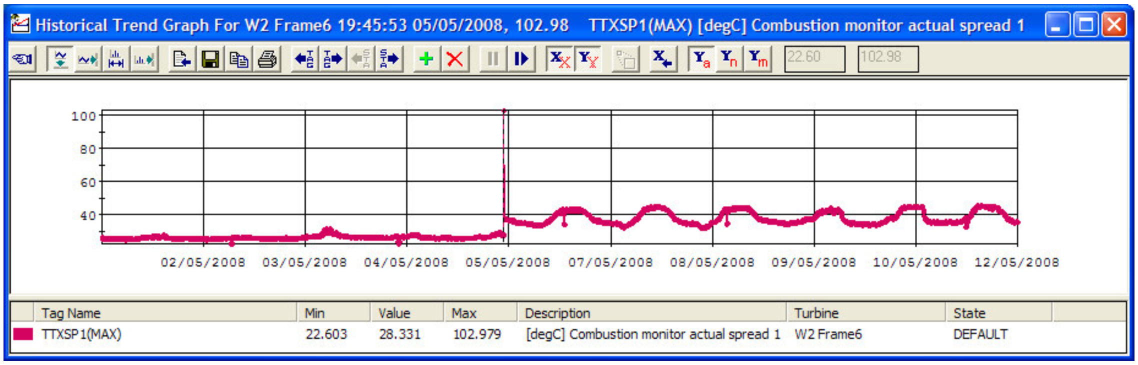
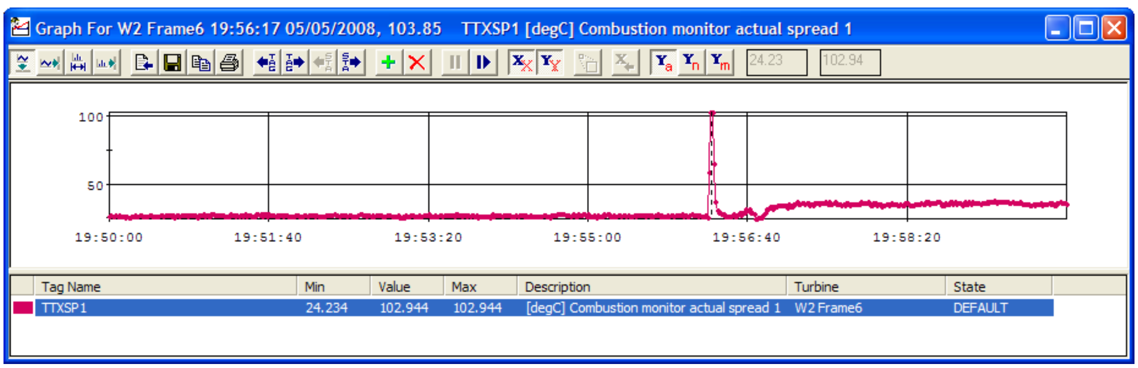


Figure 13 – Data Graph of Exhaust Temperature Spread

This shows a large upward transient associated with the flashback, followed by a change in spread level.



Further analysis using trend and data graphs and the combustion can pattern screen also showed that after the turbine switched back again to premix combustion (DLN mode) there had been step change in exhaust temperature spread from 25 to 35 Deg C, and the spread pattern had changed. It was also now changing in line with ambient temperature and consequent turbine power changes. (See Figs 11 to 14)**.**

Although this was still well below alarm limits, it indicated the flashback may have caused some damage, which had increased the spread and changed the spread pattern.

Figure 14 – Combustion Can Pattern Screen before the Flashback

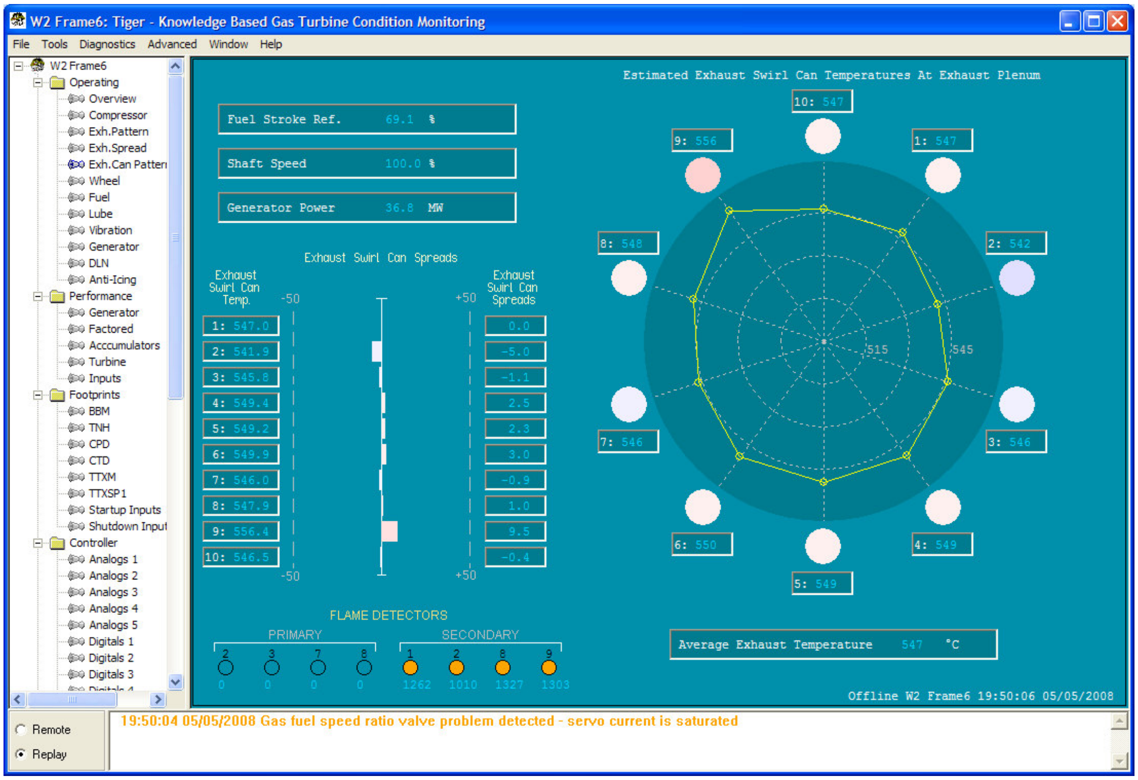
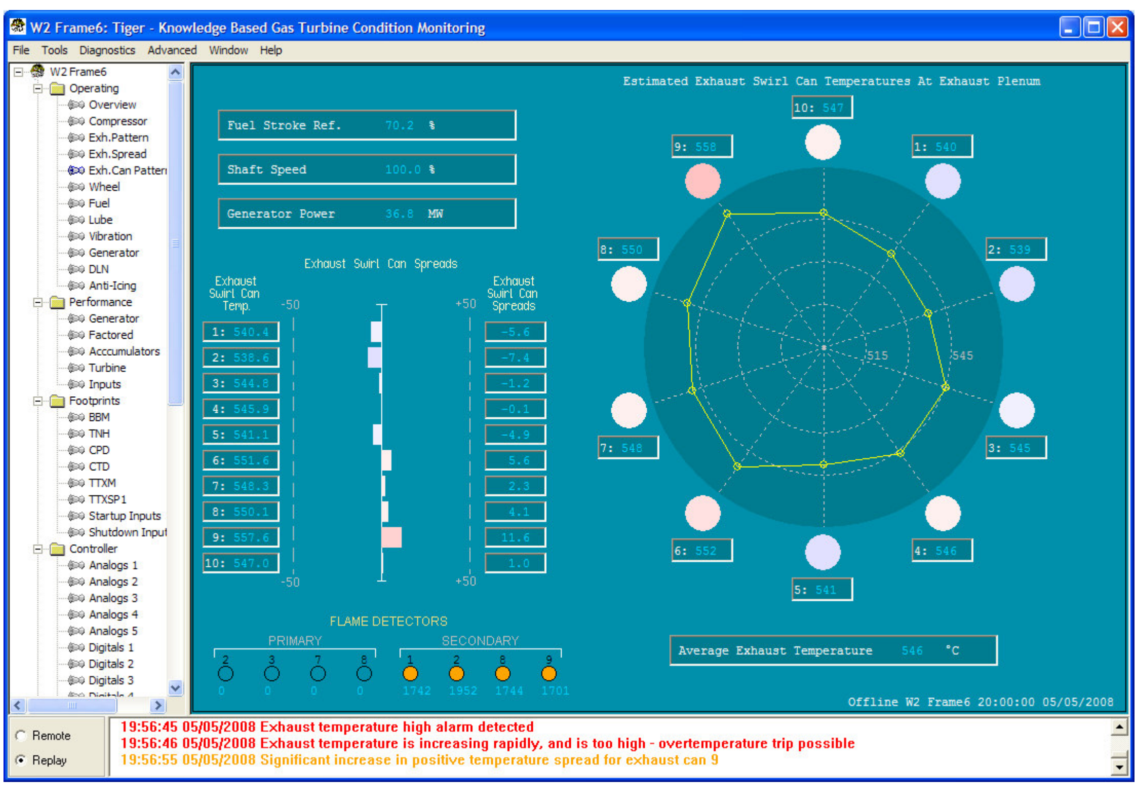


Figure 15 – Combustion Can Pattern Screen after the Flashback



Further analysis also indicated that the gas speed ratio valve (SRV) was operating sub-optimally, and that a poor response by this to a gas fuel supply pressure change had probably caused the flashback to occur, by failing to keep the gas fuel intervalve pressure steady for the gas control valve. The detailed analysis of all these problems was assisted by the ability of TIGER to load up archived historical data and replay it as if the event was actually occurring. (See Fig 14 and 15).

Accordingly, it was agreed with the customer to carry out a hot gas path (HGP) inspection the following week, as the turbine already had a planned shutdown scheduled for work on the heat recovery steam generator (HRSG).

TS has mobile workshop and spares containers, which are deployed to site (see Fig 16) to support maintenance and repair activities. These were immediately mobilised and conveyed to site. Manpower was also mobilised ensuring all resources were available on site in time for the shutdown.

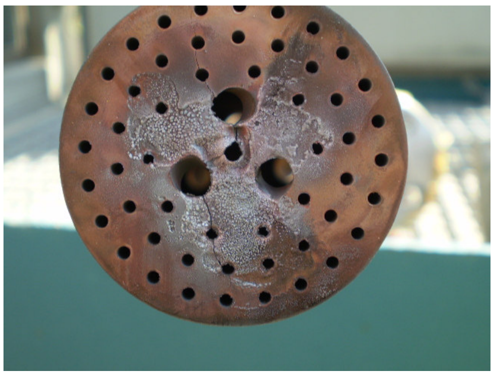
Figure 16 – TS Mobile Workshop Container

The mobile workshop, tools and parts containers are loaded onto trucks for dispatch to the customer site.

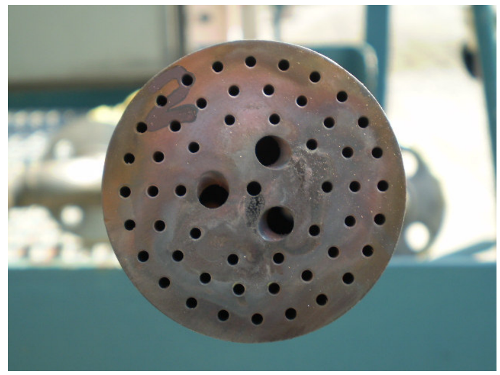
During a three day shutdown, it was discovered that secondary nozzle tip damage had occurred on cans 10, 1 & 2 and the inner gas (pilot) tubing at secondary nozzles 10 & 1 had been dislodged/broken from the nozzle tip. Further inspection also revealed that transition piece number 1 was found to have its inner floating seal dislodged. (See Fig 17).

Figure 17 - Damaged Secondary Combustion Nozzles and Dislodged Transition Piece

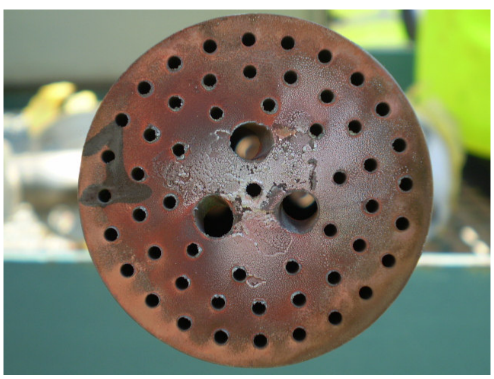
Can 1



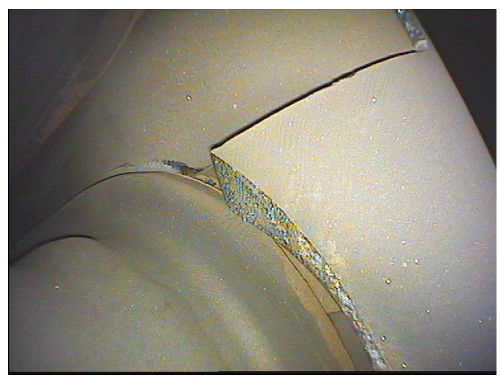
Can 2



Can 10



Dislodged Transition Piece



A replacement transition piece complete with inner and outer seals was installed and the three primary nozzles for can 1, 2 and 10 were reassembled along with a replacement set of secondary nozzles and associated piping. In addition the speed ratio gas valve (SRV) servo and <S> processor TCQA card were also replaced. The turbine was then restarted successfully.

Conclusions

The two case studies detailed above illustrate how the TIGER RMD system was used to ensure personnel were available off site to carry out detailed monitoring of customer turbine status, and could be alerted even if away from the TS offices to developing problems.

The RMD system was also able to identify key problems from a large data set, and via a sophisticated diagnostic and messaging system could alert monitoring personnel.

The comprehensive graphing systems and data replay feature provided also supported ongoing and more detailed analysis of the problems, enabling identification of the details of the faults that required repair, ensuring that repair work could be planned in advance and the appropriate resources were made available for this in a timely manner.

The comprehensive facilities provided by the RMD system, also ensured that other faults that had been identified previously could be fixed during the same scheduled repair outage, thereby optimizing maintenance activities.

References

[1] R. Milne, C. Nicol, M. Ghallab, L. Trave-Massuyes, K. Bousson, C. Dousson, J. Quevedo, J. Aguilar and A. Guasch, **Real-Time Situation Assessment of Dynamic Systems**, *Intelligent Systems Engineering Journal*. Autumn, 103-124 (1994).

[2] R. Milne, C. Nicol, L. Travé-Massuyès, J. Quevedo. Tiger™: **Knowledge Based Gas Turbine Condition Monitoring**. *AI Communications Journal,* Vol 9, N° 3, 1-17. Publishers IOS Press, 1996.

[3] L. Trave-Massuyes and R. Milne, **Diagnosis of Dynamic Systems Based on Explicit and Implicit Behavioural Models: An Application to Gas Turbines in ESPRIT Project TIGER**, *Applied Artificial Intelligence*. Vol 10, N° 3, 257-277. Publishers: Taylor & Francis (1996).

[4] L. Travé-Massuyès and R. Milne. **Gas Turbine Condition Monitoring Using Qualitative Model Based Diagnosis**. *IEEE Expert magazine, 'Intelligent Systems & Their Applications',* Vol 12, N° 3, 21-31. Publishers: IEEE Computer Society, 1997.

[5] R. Milne and C. Nicol. Tiger™: **Continuous Diagnosis of Gas Turbines**. *In Proc. of ECAI/PAIS'00*, edited by Werner Horn, Berlin, 2000.