Condition Monitoring of the SSE Generation Fleet

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Abstract. SSE (previously known as Scottish and Southern Energy) operates a diverse portfolio of generation plant, including coal, gas and renewable plant with a total generation capacity of 11,375MW (Sept 2011). In recent years a group of specialists dedicated to providing condition monitoring services has been established at the Equipment Performance Centre (EPC) based at Knottingley, West Yorkshire. We aim to illustrate the role of the EPC and the methods used for monitoring the generation fleet with the objective of maintaining asset integrity, reducing risk of plant failure and unplanned outages and describe the challenges which have been overcome in establishing the EPC. This paper describes methods including vibration and process data analysis, model-based techniques and on-site testing used for monitoring of generation plant, including gas turbines, steam turbines, generators and steam raising plant. These condition monitoring processes utilise available data, adding value to the business, by bringing services in-house and capturing knowledge of plant operation for the benefit of the whole fleet.

1. Introduction

SSE (previously known as Scottish and Southern Energy) operates a diverse portfolio of generation plant, including coal, gas and renewable plant with a total generation capacity of 11,375MW (Sept 2011). In recent years SSE’s Engineering Team has been built up to provide engineering services to the generation fleet. As part of this Engineering Team, a group of specialists dedicated to providing condition monitoring services has been established at the Equipment Performance Centre (EPC) based at Knottingley, West Yorkshire.

The EPC is a central hub for monitoring of SSE assets. Power stations at Ferrybridge, Fiddlers Ferry, Keadby, Medway, Peterhead and the gas storage facility at Aldbrough are all routinely monitored. Plant data is transferred over the company IT network to facilitate analysis by specialists using a suite of software which can be used to monitor events either in real-time or retrospectively. Examples of real-time monitoring using model based methods are presented in this paper along with retrospective analyses of plant data.

Wind generation is becoming increasingly important to SSE’s portfolio. The EPC has conducted limited trials of condition monitoring of wind assets but does not yet perform routine monitoring of large numbers of turbines. The assets in SSE’s joint-owned, hydro and ‘embedded’ fleets (smaller
generation units and Combined Heat and Power Plants) are also not covered by EPC monitoring at present.

2. Aims and objectives
The objective of the EPC is to provide condition monitoring services to the SSE fleet. The EPC team work closely with SSE's Central Engineering teams situated in the adjacent offices at Knottingley, at SSE head offices in Perth, Scotland and with the individual site engineering teams. The aim of this work is to maintain asset integrity and to reduce the risks of plant failure and unplanned outages.

Historically, aspects of condition monitoring have been contracted out to third party providers so a further aim of the EPC is to displace these third parties and provide services in-house, reducing costs and building knowledge of the plant within the fleet to allow more effective asset management. Greater self-sufficiency in this area is increasingly important as a number of major power generation companies have reduced their availability for third party consultancy work or withdrawn from the market altogether.

The major motivation for the creation of the EPC has been a number of significant plant failures within the SSE fleet. The development and operational costs of the EPC can be justified in terms of saving a single major plant failure, for example a gas turbine failure can cost tens of millions in terms of repair, replacement and lost revenue. Where costs can be identified as adding value to SSE's operation in terms of displacing third parties or preventing failure these are recorded and used to offset the operation costs of the EPC.

3. Condition Monitoring in the EPC
The EPC team members have been recruited to provide monitoring of generation plant, including gas turbines, steam turbines, generators, steam raising plant and transformers. Effective condition monitoring of these plant items requires many different tasks, from vibration and process data analysis, through model-based techniques to on-site testing and data acquisition.

We define ‘business critical assets’ as those which, if compromised, would result in loss of a generation unit, e.g. steam and gas turbines, generators, unit transformers etc. Early in the development of the EPC a set of monitoring priorities were established amongst the business critical assets. These priorities included monitoring of gas turbines, boiler pressure parts, generators and vibration in rotating plant.

Monitoring was facilitated by the introduction of data networks allowing the transfer and archiving of data from the generation and gas storage sites to the EPC. Historical data from each plant is time-stamped and archived in a central database, allowing both live and retrospective data analyses to be performed. Over 250,000 data channels are recorded, so that in order to effectively manage the size of the data base each channel is compressed before archiving. A compression by exception algorithm is used which only records a new data point when it deviates from the previous value or straight line by more than a defined threshold. Software tools used for data processing analysis and visualisation include Microsoft Excel spreadsheets, Matlab, OsiSoft PI Processbook and Datalink.

The following sections describe with examples the methods and routines used by the EPC for condition monitoring on SSE’s business critical assets.
3.1. Monitoring of Gas Turbines.

The early detection of faults in systems such as gas turbines is critical for avoiding significant damage to the system and loss of production. In monitoring such machines sensors cannot directly measure the condition of certain significant components, therefore available signals, often load, temperature, pressure, vibration and flow, are analysed to infer the health of the machine parts. Extracting reliable features from those signals is a common and important approach to condition monitoring. The sensitivity of the features varies considerably under different operating conditions or states of the machine. Therefore, it is challenging to choose effective information or principal components from the original set of data for effective condition monitoring. There are a number of monitoring methods used routinely by the EPC; an approach using a commercial model-based package is discussed in section 3.5 and the methods for vibration monitoring in the EPC are documented in section 3.4, however a number of techniques have been investigated and developed.

A priority of the gas turbine monitoring service at EPC is combustion dynamics because of the critical impact that they can have on gas turbine reliability, health, performance and availability. Combustion instabilities in gas turbines have been correlated with damage to the machine hardware such as combustion-cans, fuel nozzles, burner tubes, combustion liners and transition pieces. Most combustion hardware failures in gas turbines are a result of exposure to combustion dynamics. All modern gas turbines fitted with lean premixed combustion systems are highly susceptible to such dynamics [1].

Combustion dynamics with frequencies greater than 2000Hz, called the radial modes or screech tones, bear high energy due to increased frequency. Combustion dynamics in these modes can cause significant damage to the combustion liner and/or burner tube in very short period. Figure 1 shows the extent of damage caused to a combustion-can; this failure was due to its exposure to high radial screech tones during operation.

![Figure 1. Damage to a combustion-can from Screech Tones.](image)
A condition monitoring scheme using Principle Components Analysis (PCA) has been developed [2] to detect early signs of damage to the combustion hardware. This is a statistical method to predict values of measurable variables.

The factors affecting the dynamics in the gas turbine are load, fuel flow, fuel quality, ambient conditions and the design and configuration of combustion hardware. The key measurable parameters which are available for monitoring the combustion hardware are an array of exhaust thermocouples attached around the circumference of the gas turbine exhaust. The PCA method is used to model the exhaust temperatures and detect deviations in measured temperature away from the predicted values. As the exhaust gases exit the burners there is a circumferential movement around the exhaust known as ‘swirl’. Swirl is related to gas turbine load so that if a deviation on temperature is detected on a particular exhaust thermocouple using PCA then a swirl analysis is performed to identify the corresponding combustion can. Additionally, swirl analysis comparing data from differing gas turbine loads can be used to eliminate the possibility of a faulty thermocouple as the cause of the temperature deviation. If the temperature deviation originates in a combustion can, the deviation will be detected on a different thermocouple at different loads. If the deviation remains stationary with respect to the thermocouples at different loads, then a thermocouple fault is implied.

The PCA method can be used to monitor gas turbine combustion process online, and detection of any hot or cold spots within can indicate presence of an impending failure needing investigation. Based on the results, further investigations such as borescope inspections can be undertaken, focussing on the specific combustors and regions identified from the analysis and thus reducing the risk of catastrophic failure, reducing machine downtime, minimising costs and reducing lost generation.

3.2. Boiler pressure parts.
With many UK coal-fired plants approaching the end of their design life condition monitoring of boiler pressure parts has been identified as one of the EPC’s priorities. There is a strong motivation to extend the life of these assets whilst they are still commercially viable. Effective condition monitoring is important to support management of the asset for safe and cost effective operation.

The EPC in conjunction with the Asset Engineering team have developed stress and creep models [3] which fully adhere to the relevant boiler design code (for example BS1113). The models were developed in-house by an inverse-design code approach to calculate the time to rupture for critical pressure parts (headers, end-caps and pipework) operating under high temperature and pressure conditions. These models drive the pressure parts inspection strategy and findings from conventional Non Destructive Examination (NDE) will feed back into the validation of the models. This helps SSE set up proper inspection schedules, maintenance and operating procedures and also meet legal and insurer’s requirements.

In terms of practical condition monitoring within the EPC the developed models are used to perform life calculations of live or archived plant data. This informs the routine temperature monitoring for pressure parts operating in the range of temperatures where creep damage is expected. The damaging effects of creep on pressure parts and boiler materials are non-linearly related to temperature and pressure. It is a reasonable approximation that for each 10°C increase above the design temperature of the component, the predicted time-to-rupture is halved.

A routine procedure is established in the EPC to produce regular reports to monitor temperatures in creep-affected areas of the boiler. The main metric is a weighted average of temperature referred to as Creep Effective Temperature (CET). For a given operating pressure the CET can be calculated from archived data by summing the duration of exposure to a number of temperature bands over the reporting period. The percentage of the time to rupture consumed can then be calculated for each band
and summed to give total percentage consumption. This can then be used to find an equivalent operating temperature, i.e. an equivalent constant operating temperature which would have resulted in the same calculated time to rupture (figure 2). The calculated data can be used to produce a colour coded map (figure 3) of the boiler header systems to highlight any areas of concern to engineers and operators.

**Figure 2.** Shows the conventional relation between temperature and time to rupture for an HF620 material component with a design temperature of 499°C. The two lines indicate mean and lower bound properties used in calculation of design life.

**Figure 3.** Creep effective temperature map of an SSE boiler unit showing CET’s from primary superheaters, V, through to secondary superheater outlets, Z, and Main Steam MS and hot reheat pipework RH. Element numbers are as indicated in columns ‘el’. Temperatures at or below design are indicated green, greater than design but less than design+8°C are indicated amber and those greater than design+8°C are indicated red. Faulty or suspect signals are indicated ‘F’.

### 3.3. Generator monitoring.

Generators are also considered as a business critical asset. Electrical and thermal models have been identified for the generators and are monitored using the model-based approach described in section 3.5. Vibration in generator bearings is monitored using the methodology discussed in section 3.4.
Aside from these remote methods, the EPC contributes to the in-situ electrical testing of these plant items. The main tests which are performed are described below.

3.3.1. Core Testing. Poor insulation in the stator core stacks can result in low resistance or shorts between laminations, which in turn can result in abnormal current circulations and localised heating in the stator. Therefore generator stator core stacks are subjected to regular testing whenever the rotor is removed from the stator, for example on a major outage, to assess the quality of insulation. This is achieved with the Electromagnetic Core Imperfection Detection, ‘ELCID’ test. The ELCID test is a low power test for detection and location of fault currents due to imperfections in core insulation.

3.3.2. Stator Wedge Tightness Survey. Each stator slot contains two conducting bars, the stator windings. The windings are held in place by wedges, which, if they become loose, can cause problems such as vibration and breakdown of the stator insulation. Traditionally the wedges were given a tap test to assess the audible response of the wedge to an impact and judge the tightness of the fit. A similar approach is used nowadays, however a device is used to standardise the impact forces and ensure objectivity in the analysis. Results for each wedge are mapped so that relative tightness in each area of the stator can be assessed and any problem areas addressed. Routine testing is performed at every major outage, typically every four years.

3.3.3. Online Partial Discharge Measurements. Partial Discharge (PD) is the transfer of a small transient current through a void or gap in the insulation. PD itself is a symptom of several insulation failure mechanisms. The duration of these transient currents is extremely short (~s) but if the discharges persist they can lead to breakdown of insulation until a short-circuit occurs. PD is monitored using a fixed, on-line system of capacitors attached to conductor bars, one per phase, which pick up the PD current pulses. An analyser can be connected onto the capacitors and a commercial software package interprets charge levels. Trends or changes in the analysis results between subsequent tests can be used to provide a health assessment of the machine and the integrity of its insulation. The EPC performs a PD analysis every six months on the CCGT generator fleet.

3.3.4. Rotor condition monitoring. Generator rotors are routinely tested for insulation breakdown and shorted turns on a six monthly basis. Two testing methods are used, air gap search coil (AGSC) and recurrent surge oscillation (RSO).

AGSC sensors are mounted on the stator and used to look at leakage flux across each rotor slot. As the rotor turns through one revolution, each coil passes the sensor twice. The flux indications should be the same for each pass. Analysis of the data looks for areas of asymmetry in the signal which can indicate potential faults (see results figure 4.) Results are recorded and reviewed over a number of tests to look for any trends in the signals which may indicate developing problems.

RSO tests are another means to identify insulation defects. The principle of the test is to inject a travelling wave into the pole conductor and look for timing of the reflected signal. Comparing the return signal between poles can highlight discrepancies which indicate problem areas. Tests are performed as the machine runs down after coming off load pre- and post-outage, approximately every two years or as required if there are other indications of potential problems, vibration issues for example.
Figure 4. Air gap search coil results for a 500MW steam turbine generator Unit on load at 514MW, 75MVAr, 3180A rotor current. Peaks in the difference trace corresponding to coils B and G indicate potential areas of concern.

3.4. Vibration monitoring.
Analysis of vibration signals from rotating plant is a common method for monitoring the condition of the plant [4]. The main objective of routine vibration monitoring is to detect any undesirable plant condition and report it to the site and asset engineers. This means that appropriate action may be taken as soon as possible to maintain safe operation of the plant, prevent plant failure and minimise any loss of production.

The EPC have a number of vibration specialists who are currently responsible for monitoring vibrations from two coal and two CCGT power stations totalling 14 turbo-generator shafts each with up to 16 bearings. One or two additional stations will soon be added to that list. SSE has adopted the Beran™ On Line Vibration Monitoring System (OLVMS) as a standard platform to conduct remote vibration monitoring of the main rotating machines at all its power stations. Data is obtained from plant instrumentation, velocity transducers, accelerometers or measurements of shaft displacement, and captured and stored in the OLVMS’ hard drive. To avoid transferring large data files from the OLVMS to the EPC database, time series vibration signals are processed on the site OLVMS hardware to provide frequency domain (FFT) and root mean square (rms) values. Speed and phase data are obtained from a once-per-rev or ‘key phasor’ signal on each shaft.

The OLVMS system is highly configurable in terms of alarm setting. As a minimum, alarms are set on overall (rms) level relative to the relevant ISO standards, ISO 10816 Pedestal (cap) vibrations and ISO 7919 Shaft vibrations. The standards break down vibration levels into four classes A, B, C and D, or Good, Satisfactory, Unsatisfactory and Unacceptable respectively. Alarms are set up to alert the monitoring engineers as the vibration levels rise from zone B to zone C. Long periods of continued operation in Zone C are inadvisable due to potential for damage and deterioration of the condition of the machine. Additional alarms are also configured, based on the historical vibration levels of the machine to detect changes in operation.

As well as the measurement of overall levels of vibration it is possible to extract other frequency components from the raw signal for monitoring and alarm setting. Monitoring of the harmonics provides insight into particular conditions which may arise, for example 1st order (running speed) vibrations can indicate imbalance, 2nd order, misalignment, 3rd and higher orders, mechanical looseness and subsynchronous (i.e. frequencies lower than 1st order), oil whirl.
The phase signal and the amplitude can be considered as a vector and the trajectories and operating points plotted as a polar plot (fig 5). This representation allows the option of bounding the normal operating points with an ellipse and configuring alarms to trigger if the operating point moves outside that boundary. Another approach which is used within the EPC is vector-step alarm. This method triggers an alarm when a step change in the vectors is detected over a prescribed period which exceeds a defined threshold. This is useful for detecting changes in phase where no significant change in amplitude occurs.

Figure 5. Illustration of Polar Phase-amplitude vector analysis. Comparing vectors from a CCGT steam turbine with historical data points in (blue) and current operating points (brown) indicated by horizontal and vertical cursor.

As well as reviewing alarms, condition monitoring engineers review other characteristics of the signals such as overall trends in data, transient effects and data obtained as the machine is running up or down from its operating speed, 3000rpm for all the machines considered here. As the machine runs up it passes through ‘critical’ speeds or resonances where vibration amplitudes can be high. This point in the run up is also associated with a change of phase. The run-up and run-down characteristics plotted against speed, should be repeatable for a given shaft except in the event of mechanical changes.
to the rotor, a loss of mass from the rotor or changes in bearing characteristics for example. An illustration of this effect is shown in figure 6 where run down data from before and after an in-situ balance is presented, showing a drop in overall levels at running speed but with an increased vibration level at approximately 1900rpm. Thus comparison of run-up and run down data provides further insight into the health of the machine.

![Figure 6](image)

**Figure 6.** Comparison of vibration amplitude (top) and phase (bottom) in run-up data before and after an in-situ balance, showing change in run-up characteristics due to relocation of a balance weight on the rotor.

Data files and alarm logs are downloaded every two hours to the EPC’s central server, the ‘base station’, from the individual site servers. On a daily basis the condition monitoring engineers check the downloaded information to see if there any alarms or alerts for all power stations. If any are received the information associated with the alarm/alert is interrogated to determine the possible cause, communicate the problem and recommendations for any necessary remedial action to site and record event for inclusion in quarterly vibration report. Each alarm or alert is recorded in a data base along with records of notifications and other any actions taken.

On a weekly basis the condition monitoring engineers review trends in data, analyse the previous month’s overall and once-per-rev vibration levels and compare any run-up or run-down vibration amplitude and phase characteristics to ensure there has been no mechanical changes. Any problems or recommendations are communicated to site and events are recorded for inclusion in quarterly vibration reports.

Each month a review is undertaken of overall and once-per-rev vibration trends over the previous 6 to 12 months, or since any outage work which may have affected the dynamic performance. A review of run-up and run-down data is also performed.

Every three months, a report is prepared for each site to summarise plant condition and availability, conclusions and recommendations, detailed vibration data analysis for each machine, details of any outage work carried out over the reporting period, instrumentation status and OLVMS status.
3.5. Model-based diagnosis.

With a limited number of staff to analyse tens of thousands of data channels from around the fleet, selection and evaluation of available software solutions for automating process and vibration data analysis has been a major task. Several solutions have been identified and implemented within the EPC alongside a number of methods which have been developed in-house.

A primary method for condition monitoring in the EPC is SmartSignal Sentinel™, a commercially available software application for model-based condition monitoring. The system employs a Similarity Based Modelling (SBM) [5] methodology and is used by condition monitoring engineers to detect changes in data patterns relating to the assets. The models are non-dynamic and are constructed by importing recorded data from the plant historian to represent the normal operating envelope of the asset as a set of data vectors known as the state matrix. The data vectors are made up from a number of signals representing input, output and internal states of the plant. Signals representing ambient temperatures and pressure for example, can also be included.

Typical asset lists covered by the software include, gas or steam turbines, generators, feed pumps, feed water heating, fans, air heaters, heat recovery steam generators, mills and compressors.

Data is carefully selected for the models to properly represent the operating envelope of the particular asset. A range of data is included to cover a wide range of ambient conditions, different load set points, etc. Once the models are built, data is sampled at regular intervals, typically every ten minutes when the plant is operating. Input data vectors are fed into the model algorithm which compares the input with the state matrix to construct a prediction of the input vector. The difference between the input vector and the prediction is known as the residual. Thresholds are set on the residuals to trigger alerts to the condition monitoring engineers when the measured data deviates significantly from the model predictions.

Models are monitored on a daily basis, 7-days-a-week, by the condition monitoring engineers. Their task is to review each ‘incident’ and to decide whether the item is actionable or not. Non-actionable items include incidents arising due to short-term transient excursions (on start-up for example), unmodelled events such as ambient conditions which are outside of the data history or changes in the mode of operation of the plant. Data is fed from many thousands of signals or ‘tags’, so transducer or data feed problems are not uncommon. The models contain anything from 5 to 220 tags and are robust to the failure of a small percentage (typically 10%) of those. The EPC has two nominated Model Maintenance Engineers (MMEs) whose task is to manage and maintain the models. The condition monitoring engineers refer unmodelled events to the MMEs for appropriate adaptation of models. Failed tags are notified to both the site for corrective action and to the MMEs so that the tag can be switched off as an input to the model without interruption to monitoring of the asset. Actionable incidents are prioritised in terms of criticality of the asset involved. Incidents which might result in loss of output from a business critical asset are notified directly to the site engineers or control room by telephone and confirmed by email. Lower priority incidents are notified by email to the appropriate site engineers. The decision on what action to take in response to a notified incident rests with site and asset engineers, with the EPC providing any additional data to support the decision making process where necessary. All incidents and resolutions are recorded and reported to the stations on a monthly basis.

The philosophy of using a model-based approach is one of providing early warning for a class of incipient problems. Sudden ‘lightning strike’ events cannot be prevented using this method. It for this reason that the EPC does not operate 24 hours per day.
An illustrative example of the model-based monitoring scheme is presented below. In this example the system being monitored is the gearbox of a rolling mill used for producing pulverised fuel. Typically during a period of operation the gear box oil pressure falls slightly as the oil warms and the viscosity reduces. However on the afternoon of the 15th September the gearbox oil pressure began to fall more rapidly due to an oil leak. Historically oil pressure is maintained at around one bar so the model estimate (shown in green in figure 7) reflects that level. As the measured value falls below the lower (negative) residual threshold a series of alerts are indicated as red ‘x’ s at the bottom of the chart. We employ a further persistence threshold to help eliminate short lived transient excursions from generating incidents. Thus it is a requirement that the threshold must be exceeded for 17 of the previous 18 samples (ie approximately three hours) before an incident (indicated by the red diamond shapes at the top of the chart) is raised to the condition monitoring engineers. The incident in this case was referred by email to the site staff who took action to fix the oil leak and replenish the oil. Pressure returned to normal levels by the 19th September. The cost of a replacement gear box is in the region of £100k.

![Figure 7](image.png)

**Figure 7.** Illustration of an incident caused by a fall in mill gearbox oil pressure due to a leak. Alerts are raised (red indicators) on 16th September before the pressure fell to a dangerous level.

This is of course a trivial example used to illustrate model-based monitoring. More complex systems may require other states and residuals to be considered in the analysis and longer periods of investigation for example the swirl analysis described in section 3.1.

4. Discussion

The EPC has been created for condition monitoring SSE’s business critical generation assets. Much has been done to achieve this in the three years since the EPC’s inception and several challenges have been overcome.

The design and implementation of systems to access and transfer data through networks, whilst all the time maintaining security and control of those networks, has been a major task. Transducers are the eyes and ears of the EPC and effective online monitoring depends upon transfer of valid data from the transducers, through the site control systems to the data historian, then via an interface to the EPC central historian. This work requires careful coordination of work between site control, instrumentation and IT teams, with SSE’s central Real-Time Systems, IT and IT security teams.

Model based monitoring of the plant systems is a change from traditional alarm based methods. Monitoring trends in residuals can give engineers earlier warning of incipient faults. However, where systems may once have been monitored by looking at a number of key tags and their values relative to their alarm set-points, the model based approach uses a large number of tags to look at the system as a whole. For example a system may have been monitored by looking at a single output variable to ensure it did not exceed a particular threshold, whereas with the model-based method, values of input variables, internal states and ambient conditions are all considered. Thus some tags take on a new importance as inputs to the models, inferring a new motivation for careful maintenance of those tags.

Effective communication between the EPC and the generation sites is an essential part of the condition monitoring process. SSE’s sites have a range of different ages and some have had a number
of different owners and operators so that each site has a different culture. The setting up of a central Engineering Team represents a change to that culture so that the roll-out and establishment of new lines of communication have had to be carefully managed. Systems and procedures have been implemented for notification of new plant issues arising and regular reporting and summarisation of on-going issues.

The EPC is still developing and extending its capabilities. Work is in progress to extend the condition monitoring service to SSE’s rapidly growing wind fleet and to some other SSE sites not currently covered such as jointly owned stations. Condition monitoring services are constantly reviewed to look for improvements in capabilities and efficiency.

5. Conclusions
The Equipment Performance Centre has been developed to reduce risk of failure and cost of unplanned outages.

Processes have been put in place to provide an effective monitoring service to SSE’s thermal generation fleet, with focus on the business critical assets.

The condition monitoring processes utilise available data, adding value to the business by bringing services in-house and capturing knowledge of plant operation for the benefit of the whole fleet.

References
[1] Lieuwen, T.C., Yang, V.: Combustion Instabilities in Gas Turbine Engines: Operational Experience, Fundamental Mechanisms, and Modeling. AIAA, Vol. 210 (July 2005)
[2] Misha Singh, Sethuraman Muthuraman, Christopher MacLeod. Identification of combustion failures in Gas Turbines using Artificial Neural Networks. Proceedings of the 7th International Conference on Condition Monitoring and Machinery Failure Prevention Technologies 2010 Volume 1 of 2, pp 722-732. Stratford-upon-Avon, United Kingdom 22-24 June 2010 ISBN: 978-1-61839-013-4
[3] Faizan Patankar, John Twiddle, Richard Walton, Development Of Stress Models For Fossil Fuel Power Plants / HRSG Pressure Parts Assessed Life Calculations. Proceedings of the 7th International Conference on Condition Monitoring and machinery Failure Prevention Technologies 2010 Volume 1 of 2, pp 1443-1445. Stratford-upon-Avon, United Kingdom 22-24 June 2010 ISBN: 978-1-61839-013-4
[4] Bently, D., Hatch, C., Fundamentals of Rotating Machinery Diagnostics. Bently Pressurized Bearing Press, 2002, ISBN 0-9714081-0-6
[5] S. Wegerich, 2004. Similarity Based Modeling of Time Synchronous Averaged Vibration Signals for Machinery Health Monitoring. In Proceedings of IEEE Aerospace Conference, 6, 3654-3662. Montana: IEEE Press.