One-Day International Seminar
(preceded by 2-Day Optional 'HRSG Training Course')

HRSG Cyclic Operation

CYCLIC OPERATION OF HEAT RECOVERY STEAM GENERATORS (HRSGs)

Venue: Institute of Materials, Minerals and Mining
IOM3 (www.iom3.org), **London, UK**

Date: **24 June 2005**

Final Programme

& Registration Form

Organiser

European Technology Development (ETD)
www.etd1.co.uk www.ommi.co.uk

Presentations: Oral presentations will be of 20 minute duration including discussion.

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ABOUT THE ORGANISER

European Technology Development Ltd. (ETD) is a UK based engineering advisory, consulting and R&D company providing services in life assessment/extension, stress analysis, maintenance, materials and engineering issues in all type of power generating plant. The company provides specialist services in asset integrity and related areas including HRSGs. It provides specialist advisory service on the use of appropriate materials and the sources of data for plant integrity / life assessment.
The company has in the recent past organised various international conferences and training workshops/ courses in the UK and other countries (Germany, France, Portugal, Hong Kong, Malaysia, Pakistan etc.) on the issues such as: high temperature materials, welds, component safety and durability, weld repairs, power plant cycling, risk based maintenance, CCGT cycling, plant management and maintenance.
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Seminar Programme

REGISTRATION & WELCOME
0830 – 0930 hours

***Session 1*:** **Design and Modifications for HRSG Cyclic Operation**
0930 – 1050 hrs

1. Cyclic service features for heat recovery steam generators
Gifford Brown, Nooter/Eriksen, Inc., USA

In the recent past much has been learned about features of HRSGs that make them susceptible to premature failures from cycling. The recent trend has been to convert from baseload operation to cyclic mode of operation. This has created concern for owner-operators who worry the equipment originally designed to last twenty five to thirty years may only last a few years without major mechanical revisions or updating. This article outlines some of the areas of concern in procuring new HRSG's or updating existing units, what features should be considered in the design if cycling is required and why these feature can provide a robust unit capable of handling the demands of today's market.

For components such as reheater and HP superheater coils, tube to tube temperature differences can create high internal thermal stresses. The ability of coils to absorb these temperature differences without creating the potential for low cycle fatigue is a necessary design feature. The details necessary to minimize or eliminate these internally generated stresses are discussed. Through thickness temperature gradients are considered important when determining start up and shut down ramp rates. Keeping the headers that are susceptible to creep as thin as possible helps to minimize the stresses associated with start up and shut down. Several techniques for calculating component thicknesses are presented.

For HRSG's that are required to cycle daily, condensate management becomes a real challenge. Condensate quenching will damage boiler tubes, pipes and other hot sections of the boiler faster than almost any other mechanism known. When the boiler is kept pressurized and hot and then restarted, large amounts of condensate are generated in the high pressure superheaters and reheaters. This often floods lower headers and piping. How this condensate is removed is important for boiler design when cycling.

Finally, several other recommendations that can increase equipment longevity such as condensate pots for desuperheaters, feedwater recirculation systems, auxiliary equipment to hold boiler pressure and temperature, and the problems with certain types of piping layouts are all briefly discussed.

2. Cyclic tolerant HRSGs

*Pascal Fontaine, Cockerill Mechanical Industries, **Belgium***

With the onset of deregulation and consequent merchant power, combined cycle plants are now required to supply electrical power to the grid as and when needed with consequent day/night and weekday/weekend cycling. Those merchant plants have to come on and off line with minimal notice and be run sometimes at partial loads. Even units which were originally designed for base load are all eventually forced to cycle as new more efficient power plants are built. Thus, substantial changes in basic HRSG design are needed to cope with these changes.

As generally recognized, the cycling criterion is an integral part of HRSG design. This paper presents solutions to HRSG design issues for cycling tolerant operation. It relates to published data on problems observed with cycling Horizontal HRSGs, and it describes how these problems can be overcome. Concepts, design features and calculation methods applied to cycling tolerant HRSGs are reviewed in detail.

3. The suitability of once through steam generators for cyclic applications

*A Hinde, J McArthur, Innovative Steam Technologies,Ontario, **Canada***

Once through heat recovery steam generators (OTSG’s) are being used in many applications worldwide, which require quick response times, such as those encountered in daily start/stop operation.

The ability of a steam generator to respond to cycling loads depends on four criteria:

a) The position of the boundaries of the steam generator sections.
b) The filling mass, or water/steam inventory, of the steam generator.
c) The capacity of heat accumulation of the steam generator.
d) The response control system of the steam generator.

a) <u>Boundaries</u>

In natural or forced circulation HRSG’s there are definite boundaries for the economizer, evaporator and superheater sections as dictated by the steam drum. As the boundaries (dimensions and surface area) are fixed, the flexibility of the steam generator is set and the steam temperature and/or pressure will fluctuate during the transient. In OTSG’s, there are no distinct boundaries. During the transient, the economizer, evaporator and superheater are free to move throughout the steam generator allowing stable steam outlet temperatures through a wide range of loads.

b) <u>Filling Mass</u>

The filling mass (mass of water and steam contained in the steam generator) for a natural or forced circulation HRSG boiler is much greater than the OTSG. Steam drums, interconnecting piping and large diameter tubes hold a considerable mass of water, which must be heated or cooled.

The OTSG does not have steam drums and uses smaller diameter tubes resulting in a reduced water/steam volume. This reduced volume allows for faster startup and improved response to thermal transients.

c) Heat Accumulation

In natural or forced circulation HRSG's, the majority of the heat accumulation is in the thick walled drums, tubing and interconnecting piping. This makes natural and forced circulation HRSG's slower to both cool down and heat up. The OTSG does not have a steam drum or interconnecting piping and is fabricated from thin wall tubing, minimising the residual heat in the steam generator.

d) OTSG Controls

The OTSG is unique in that it is controlled with a patented combination of feedforward and feedback controls. While the feedback controller is modulating the feedwater flow to maintain the steam temperature (or pressure) set point, the feedforward is constantly calculating the incoming gas energy to predict stable steam flows. This feedforward signal adjusts the feedwater flow rate at the instant a change in gas flow or temperature is sensed.

Innovative Steam Technologies has monitored the cycling behavior of several OTSG's in the field during start up, shut down and other transient conditions associated with combined cycle and gas turbine injection applications. The cycling response of the OTSG will be detailed using field data accumulated through years of successful operation.

4. Input, evaluation and sensitivity of HRSG fatigue calculations

*Peter Rop, NEM bv, **The Netherlands***

Since several years now, awareness has grown among the power generating industry of the impact of cycling operation on hardware of the power plant. Many have learned the consequences for the HRSG the hard way. Much attention nowadays is given to determining the maximum stress ranges resulting from the start-up and shutdown. And based on that, critical components are identified that become governing in the design and operation of the HRSG.

But questions arise: what about the interaction between sub-assemblies? And how are all the occurring stresses (at different moments in different locations, in different directions) combined to a governing stress cycle? Are the identified components then the only critical components? Why and how critical are they? What is the accuracy of all the calculations and the resulting lifetime expectancy?

Many of these questions have to do with the accuracy of the assumptions and boundary conditions for the stress calculations, and how to evaluate the resulting stresses. Especially the accuracy of the dynamics and the resulting thermodynamic responses has a significant influence on the final results. Also assumptions, that are mainly simplifications, may result in evaluation errors of potentially critical items in the lifetime assessment process.

Once the stress curves are determined, all the stress ranges and the resulting cycle count have to be determined. These two parameters result in fatigue damages using the well-known S-N curve, but the logarithmic nature of this curve requires a high accuracy of the input data. Thus the accuracy of the stress ranges and cycle count result in an uncertainty of the end results that emphasizes the necessary quality of the lifetime analysis.

Coffee Break	1050 – 1120 hours

***Session 2*: Experience and Problems Encountered With Plant Operation in Cycling Duty** *1120 – 1300 hrs*

1. **Measurement of damaging thermal transients in F-Class horizontal HRSGs**
   *Robert W Anderson, Progress Energy, **USA***
   *Michael Pearson, J Michael, Pearson & Associates, Ontario, **Canada***
   In 2003 approximately 500 tube temperature thermocouples were installed throughout a new three pressure - reheat combined cycle HRSG behind a General Electric 7FA gas turbine. The subject HRSG is typical of many of the hundreds constructed around the world during the combined cycle plant development "bubble" in that it was designed to the minimum requirements of ASME code, hence evaluation of thermal transients using thermal-mechanical modeling or finite-element analysis was not required nor performed, even though the plant had been specified for cycling service. It is also typical of such plants in that it was procured, designed and constructed with an over-riding focus on lowest initial cost.

   Data, collected over several months from the tube temperature thermocouples, was synchronized with plant process data and analyzed to identify potentially damaging tube temperature anomalies likely to impact the long-term reliability of HRSG pressure parts and determine the extent to which HRSG design, balance of plant design and operating practices contributed.

   Our study shows that poor design practices - most well publicized as such for many years - were repeated in this HRSG's design. Thirteen references are listed, dating from 1994, which identified these poor design practices. It is disturbing to note that so many of the practices remain in use after a decade of warnings about their consequences in cycling service.

   For example, the crucial importance of ensuring that condensate is with certainty removed by the drains systems from all parts of HP superheaters and reheaters before steam flow is established. As has been widely publicized, failure to do so will result in premature thermal fatigue-related failures in tubes and headers of HRSGs in cycling service. Fifty years ago the need for absolute prevention of condensate entering a hot steam turbine was noted by industry following a spate of water induction incidents. Because these events resulted in immediate and lengthy forced outages to refurbish bent rotors and repair other collateral damage the problem was quickly and effectively addressed by detailed attention to the design of drains systems. Effective means of preventing water induction were widely adopted. Because the damage caused by poor condensate management in HRSGs is rarely immediate, and the fatigue failures may not occur until some undetermined time in the future, implementation of the previously identified changes to design and operation necessary to prevent this premature and avoidable fatigue damage is still not occurring on horizontal gas path HRSGs.

Another example of potentially severe fatigue related damage to tubes, headers and pipes of HRSGs presented in the paper is the arrangement of superheater and reheater heating surfaces and their respective interstage attemperators in configurations that lead to gross overspraying during startup and shutdown. This is particularly prevalent in HRSGs behind the GE - 7FA and 9FA gas turbines. The problem is caused by failure to position attemperators within HP superheaters and reheaters where they are capable of desuperheating under all predictable operating conditions without spraying too close to saturation temperatures while also preventing bulk steam outlet temperatures from exceeding design limits. As in the previous example, years ago industry identified the necessity to prevent attemperator overspray in conventional boilers after suffering the pain of replacing many hundreds of cracked final superheater outlet headers.

On these issues we seem to be in denial that history will repeat itself, even when the thermal transients experienced by a cycling HRSG are much more severe than those to which conventional boilers are exposed.

Another previously identified undesirable design feature in HRSGs specified for cycling service covered in the paper is the unvented, upper return bend type of preheater/economizer. The tube temperature data presented here clearly shows that some tubes in many rows of the HP economizer remain “air bound” throughout every startup-operate-shutdown cycle. The tube-to-tube temperature differences caused by this failure to “prime” all tubes result in structural load transfer from (non-flowing) hot tubes to (flowing) colder tubes. Due to the almost infinite variety of dynamics involved (which tubes and how many tubes in which tube rows are air bound during each individual operating cycle) it is not possible to perform a determinate analysis of support loads and resulting peak stresses in each individual tube. It is the authors’ opinion that the path to long term plant reliability in cycling HRSGs is via reasonably accurate quantitative analysis of pressure parts intended for thousands of cycles – not possible with this arrangement.

It is also the authors’ opinion that designers are aware of the problems for which data is presented but are prevented from effectively resolving them due to commercial pressures imposed by owners. All of the problems identified in this paper are soluble at reasonable cost. It is important that owners become better informed so that they may better balance the initial versus long term cost equation and become more willing to pay for important design improvements where justified. While it is hoped that papers like this one are useful in helping owners make better decisions that reduce unwarranted commercial pressure to buy only the cheapest offering, it is hoped that HRSG OEMs might utilize the data presented to inform owners of the long term risks associated with continuing to repeat undesirable design features in new cycling HRSGs.

The authors feel that the readers of this paper will get a better grasp of the thermal-mechanical dynamics at play in a large horizontal gas path HRSG in cycling service.

2. A Once Through 400MW HRSG: Stress analysis of operational transients and the effects on the calculated lifetimes of different headers

*C M Wignall, A C Jones, D M Blood, Power Technology, E.ON **UK***

With the privatisation of the electricity market in the UK, followed more recently with volatility in the fuel markets and the imminent introduction of carbon trading, power stations are facing ever changing demands. These demands are for more flexible operating regimes, faster starts and extended lifetimes; situations that were not envisaged when the power stations were designed. The changes to the operating regimes for the gas fired stations in many cases are driven by the limitations of the operating envelope of the gas turbine and in some cases the effects of these changes on the HRSG are overlooked. Within the HRSG various headers are susceptible to creep and fatigue damage and can be costly to replace.

This paper examines a range of key start up transients for a number of different headers in a once through 400MW HRSG. From these transients the most severe ramp rates and temperature changes have been identified and the stresses these transients induce in the headers calculated using finite element analysis. For three headers the calculated stresses are compared for the range of transients, and using well established methods the relative fatigue damage calculated. These calculations allow changes in operational transients to be assessed and can lead to changes in operating procedure as well as the planning of future inspections and replacement of headers to be anticipated and budgeted.

3. Investigation of leak in a main steamline piping weld joining P91 piping to a 1.25Cr1Mo.25V control valve using 2.25Cr1Mo filler metal: Causes and implications for the use of new high strength steels

*J Henry, ALSTOM Power, Chattanooga, TN, USA; J Fishburn, ALSTOM Power, Windsor, CT, **USA***

The widespread use of creep-strength enhanced ferritic alloys, such as Grades 91, 23, and 92, for high temperature applications in HRSGs has led to a range of problems in the US, some of which are only beginning to be understood. Many of the problems have been related to the processing of the material during component fabrication or erection, and these problems in large part have been resolved by more careful attention to the unique processing requirements imposed by the metallurgy of these steels. However, some of the problems are more subtle in origin, and it is becoming apparent that greater attention will need be paid to the ramifications of the improved performance of these materials, compared to the “traditional” boiler alloys, such as Grade 22, particularly when designing dissimilar metal connections.

A case in point is the recent failure of a girth weld joining main steamline piping to a main steam stop/control valve after less than 5000 hours of total operation. The piping in this case had been fabricated from Grade 91 material and the valve body was a 1.25Cr-1Mo-0.25V alloy; the weld had been made using a 2-1/4Cr-

1Mo filler metal. Analysis of the failure showed that a creep-dominated fracture had propagated through the narrow zone of partially decarburized material in the weld metal immediately adjacent to the fusion boundary. The analysis results indicated that all processing associated with the welding and subsequent heat treatment of the joint had been properly performed.

In this paper a review of the results of the destructive analysis of the joint will be made to characterize the nature of the damage that caused the premature leak. There then will be a discussion of significant design issues that this failure has raised pertaining to a) the design of the joint, and b) the omission of cold spring during installation of the piping and its potential influence on the failure.

4. Inspection, maintenance and reliability of HRSGs manufactured in a decentralised global market

*T Itay, E Rindenau and D Laredo, Israel Electricity Company, **Israel**; and D G Robertson, I A Shibli, European Technology Development, **UK***

Maintenance free equipment for electrical power plants appears to be a very attractive idea, (low installation and operating cost, high efficiency and small area) especially for HRSGs in modern CCGTs. Nevertheless, in some cases, the maintenance free concept is found to be fragile and very sensitive to manufacturing and installation errors. Weld defects, that are very rare in boilers in general, can be very detrimental to the compact maintenance free designed HRSG. The access to the failed welds is, in general, extremely difficult. This disadvantage leads to extended repair periods and to the unnecessary cutting of all the healthy tubes that are in the way. This paper deals with an uncertainty situation: Are there weld defects? How many and where? This catastrophic situation could appear on site during the erection stage if the quality control was not appropriately conducted or supervised and if the specific inspection techniques were not clearly specified in the manufacturing code.

Discussion: Design Flexibility, Operation & Maintenance Issues *1240 – 1300 hrs*

Lunch	1300 – 1350 hours

Session 3: **Materials, Chemistry, Monitoring, Inspection and Integrity Assessment** *1350 – 1530 hrs*

1. **Chemical monitoring of HRSGs: Key measurements for operational control and fault condition diagnosis**

G Bignold, GJB Chemistry for Power Ltd., UK

Safe reliable operation of the steam/water circuits of combined cycle plants requires knowledge of the chemical condition of the feedwater, boiler water and steam. On-line instrumentation, where applicable, must be robust and reliable. When an on-line instrument alerts the operators to the development of a fault, such as a condenser leak, that could cause deterioration of the boiler or turbine, it is essential that there must be sufficient trust in the instrumentation to ensure that appropriate action is taken promptly.

In terms of on-line instrumentation, direct conductivity, conductivity after cation exchange pH and dissolved oxygen are the first line parameters. Their applicability is discussed in terms of impact upon the assurance of safe plant operation. Particular consideration is given to the availability of adequate plant chemical data during start-up and shut-down.

2. **Assessment of resistance to crack propagation by quantitative acoustic emission in creep degraded P22, 15Cr1Mo1V and 14MoV63 steels**

G Muravin, L Lezvinsky, B Muravin, Margan Physical Diagnostics Ltd., Israel

The paper is devoted to investigation of interdependence between acoustic emission (AE) energy and mechanical energy released during fracture toughness test and creep development. Authors examined three types of steel 14MoV63, 15Cr1Mo1V, A335 Grade P22 from operated high energy piping. Part of specimens was prepared from steel in original condition and other, undergone degradation till creep stage 3a-3b.

The created methodology of data recording and image recognition allowed to establish the following:

1. There is a linear interdependence between mechanical and AE energy during deformation of 14MoV63, 15Cr1Mo1V, and A335 Grade P22 steels in original condition and that which underwent degradation (creep at stage 3a-3b).
2. Creep associated processes at stage 3a-3b can significantly decrease the J_{1c} value of examined steels.
3. There is a linear interdependence between the AE energy creep associated processes and the mechanical energy expended on specimen fracturing.
4. There is the possibility to reveal zones of tough and brittle fracture, as well as the presence of inclusions in the specimens and operated piping.

The laboratory experiments, results of high energy piping inspections, and verification tests have confirmed and demonstrated the possibility of using QAE NDI as a reliable tool for revealing flaws, determining their type, and assessment of their danger level.

3. Integrity assessment of a cracked Y-piece using the 'Alias-HIDA' Probabilistic procedure

N Le Mat Hamata, J Korous **; * European Technology Development, Surrey, UK etd@etd1.co.uk ** BiSAFE Ltd., Malebná 1049, Prague 4, Czech Republic*

This paper discusses defect assessment performed on a welded tubular Y-joint typically used in an HRSG / high temperature plant. Life obtained using the European HIDA ***deterministic*** procedure was compared with that resulting from a ***probabilistic*** treatment (using the 'Alias-HIDA' KBS) by considering scatter in the material property data. Results showed that the application of the probabilistic approach enables to significantly reduce over-conservatism in the predicted life obtained using the deterministic assessment, resulting in considerable cost savings for the plant operator.

Introduction: In high temperature plant accurate estimation of safe service life and integrity of components containing in-service or design allowable manufacturing defects is becoming of paramount importance because of the present economic and competitive environment. In the case of HRSGs such assessment is even more important as repair may involve access to difficult-to-access components and therefore may necessitate costly removal of healthy components in the vicinity. Past experience has clearly identified that certain components, such as welded tubular joints, have an inherent risk of premature failure and in-service inspections, or monitoring in the case of HRSGs, can often reveal cracking, particularly in the weldments. Thus decisions on continued operation, in the presence of defects, or repairs during either planned or unscheduled outages have to be made. Such decisions at present are based on 'good engineering practices' or limited individual country/organisation deterministic procedures and guidelines such as R5 [Ref.1], BS7910 [Ref.2], RCC-MR A16 [Ref.3], HIDA [Ref.4], and Ewald et al. [Ref.5].

In these deterministic approaches combination of extreme values results in pessimistic life predictions and are therefore costly for industry. Such over conservatism, however, can be moderated by the application of the probabilistic approach, in which some of the inputs are assumed to be random variables described by selected statistical distributions and failure probability of the structure is estimated. Solution of a real problem is often complex and usually requires application of numerical methods, for example the Monte Carlo Method. The probabilistic concept results in probability of failure of the investigated component and it is essential part of risk based management and inspection.

In this paper, the remaining life of a welded tubular Y-joint with cracking is investigated using both deterministic and probabilistic assessment procedures together with FE stress analysis to show the benefits of the adoption of probabilistic assessment route. The material data input to defect assessment being subject to significant scatter, the reported work mainly focuses on how this may affect the remaining life. Typical life and failure modes obtained deterministically are compared with those obtained using probabilistic approach. The potential uses and limitations of the probabilistic versus deterministic assessment on the integrity and remaining life of the investigated component are discussed.

4. European standardisation activity with respect to Heat Recovery Steam Generators

Corrado Delle Site, Andrea Tonti ISPESL - Dipartimento Omologazione e Certificazione (Inspection and Safety), Rome, ***Italy***

Recently Europe has seen the publication of several standards regarding pressure equipment. Some of them, i.e. EN13445, have been developed considering problems arising during the whole life time of the pressure vessel. Creep amendments of EN13445 cover this kind of possible damage, allowing the designer and the user to manage life time and inspection intervals. This is not true for Steam Boiler standards that need to be amended according to general principle of EN13445 amendment. This modification can be considered more suitable for HRSG and their typical in-service inspection problems.

5. Improving the life expectancy of base load designed HRSGs under cyclic operations

Akber Pasha, Technical Director, Tony Thompson, Engineering Director, Vogt Power International inc., Louisville, Ky. USA

The combined cycle plants installed in mid nineties to early 2000s were mainly designed to operate at base load with planned starts. However, the realities of the gas deregulation made it imperative to operate them with almost daily cycling. This operational mode change was implemented with much caution and apprehension as to the life expectancy of the HRSGs. The concern became more pronounced when it was found that simple addition of fatigue in the life cycle analysis to the existing creep effect is not enough. The alloy material used for superheaters and reheaters now need to consider the added effect of creep and fatigue interaction, which essentially results in further lowering of the life expectancy.

The paper described various damaging mechanisms encountered by the HRSG during fabrication and operation and the impact of cycling on these. However, in addition to the traditional Life Cycle Analysis (LCA), the paper also introduces the concept of a Cycling Operational Analysis (COA). The LCA combined with COA identifies the critical components affecting the life expenditure and the causative operating procedure or a particular phase of the procedure.

The resulting data is used in making recommendations as to the most cost effective means to improve the HRSG life. These may include actual replacement of some of the critical components, installing of some additional equipment to decrease the severity of the cycling effects or modifying of the operating procedures to reduce the stress intensities.

The information thus provided enables the owner to evaluate various options and select the one which is most cost and time effective.

DISCUSSION *1530 – 1600 Hours*

R Anderson (Chairman) + Representatives of HRSG operators, designers and service providers