Minutes of Meeting

VGB-Technical Committee:	Generation and Technology
VGB-Technical Group:	PGMON Power Generation Maintenance Optimisation Netzwork **60th Meeting on 14 May 2020; Onlinemeeting**

Participants:

Andrejkowic	Milan	CEZ
Hoffmann	Martin	CEZ
Kapr	Michal	CEZ
Krickis	Otto	Latvenergo
Le Bris	Yves	EDF
Linkevics	Olegs	Latvenergo
Martin	Conor	ESB
Morris	Andy	EDF
Smith	Henk	
Tereso	Bruno	EDP
Wels	Henk	DNV GL
Wolbers	Patrick	DNV GL

VGB Secretariat:

Göhring	Sven	VGB

Agenda

Welcome (Henk Wels)

TOP 1: The electricity market in the Czech Republic in the current crisis
Milan Andrejkovic, CEZ

TOP 2: CCGT Plant shift cycle set up and shift staffing arrangements
Martin Hoffman, CEZ

TOP 3: Heating supply from the NPP Temelin to the County city of Ceske Budejovice, replacement of a coal heating plant
Michal Kapr, CEZ

TOP 4: Impact of the pandemic on ongoing construction projects
Otto Krickis, Latvenergo

TOP 5: MTBF in CCGT, benchmark between VGB and EDF data for OPTISPARE
Yves Le Bris, EDF

TOP 6: a) Update on Predictive Maintenance Project
b) Update on implemented COVID-19 measures
c) CCGT Plant shift cycle set up and shift staffing arrangements
Conor Martin, ESB

TOP 7: Introduction to Citrus, new predictive approach for critical components
Andy Morris, EDF

TOP 8: p-F intervals, testing problems and maintenance issues from US nuclear LERs
Henk Wels, DNV GL

TOP 9: Place and date of next venue

TOP 1: The electricity market in the Czech Republic in the current crisis
Milan Andrejkovic, CEZ

The introductory presentation presented the scope of ČEZ, its long-term strategy and the impact of the current pandemic crisis on the current development of the economy and energy market in the Czech Republic in comparison with this year's and last year's figures. The current situation will put considerable pressure on the economy, incl. Energy. However, the long-term strategy remains unchanged.

TOP 2: CCGT Plant shift cycle set up and shift staffing arrangements
Martin Hoffman, CEZ

In first part of the presentation, CEZ presented actual operated CCGT units. CEZ is currently operates 1 CCGT power plant, which was started in 2014 at the perimeter of the coal-fired power plant. The operations are independent of each other, power plants have a common raw water supply. Total power output of CCGT is over 800MW, multi-shaft arrangement of 2 gas turbines, HRSG boiler and steam turbine. Since commissioning, the market demand for operation of the power plant has been steadily rising. Subsequently, CEZ presented the possibilities of adjustments to the employees´ time fund; these possibilities are approached very sensitively and very rarely. At the end of the first part of the presentation, CEZ presented the current staff arrangement of shifts and daily staff. Part of the services is provided from the headquarters.

In conclusion, CEZ considers, the staffing is a maximally effective, while maintaining very high availability.

The second part of the presentation was devoted to the current topic and discussion about the measures that were taken at the power plants in an emergency state. CEZ presented which important general measures were applied to it in this situation. Internal measures applied at power plants were also discussed.

Finally, it was stated that CEZ measures following official government regulations and rules, decisions of its own crisis staff, as well as general hygiene recommendations.

TOP 3: Heating supply from the NPP Temelin to the County city of Ceske Budejovice, replacement of a coal heating plant
Michal Kapr, CEZ

CEZ Group is established corporation which operates its energy assets mostly in Central Europe. As well as other utilities CEZ faces the pressure on decarbonization which is growing further year by year with all the new movements, deals and agreements.
Nuclear energy is substantial part of the solution for CEZ and Czech Republic. Core of CEZ´s strategy for upcoming decades is long term operation of NPP, which is planned to operate until 2045 – 2047 in Dukovany and at least until 2060 – 2062 in Temelin.
The potential of heat supply from Temelin to České Budejovice was part of the original project in 80´s. It had many obstacles. Main obstacle was the fact that the district heating supply in České Budejovice was provided mostly by steam supply, so this was a challenge that was not easy to overcome because of the distance.
Project of heat supply for České Budejovice came to life again in 2011 and 2016 when the negotiations with CHP and City of České Budejovice were reopened. The negotiations in 2016 were finally successful mainly thanks to the market conditions and growing pressure on environmental aspects as well as wide modifications to district heating system by the city. The sides came to agreement on terms of the contract which was signed in December 2018.
Major benefits of the project are, that the emissions in the area from coal fired CHP plant are about to be significantly reduced. The CHP doesn´t have to consume about 80 000 tons of lignite per year in the following two decades. Modernization of the district heating system in the city brings future potential to maximize the environmental benefits. The customers in the city will be less dependent on the market conditions which have been turbulent recently for lignite fired plants.
Thanks to the planned long-term operation until at least 2060 it brings potential to renegotiate the contract for another decade or two in the future.

TOP 4: Impact of the pandemic on ongoing construction projects
Otto Krickis, Latvenergo

Pandemic, which was caused by COVID-19 virus, impacted various sectors of businesses differently. Caused restrictions impacted development of projects, at the same time some businesses were completely blocked, as well as major EU borders were closed for travellers.

In the autumn of 2019 AS Latvenergo started construction of the thermal storage tank, starting with piles. The workflow was staged and construction of the metal tank (project height 47.8 m) started in December 2019. The tank is being built by Finnish company normally involving 9-12 specialists on site. After emergency situation announcement in Latvia on site left 3 specialists and overall construction progress slowed in average three times comparing with a normal situation. Taking into account that this project is financed partly involving EU funds, the final deadline of the project should remain unchanged or deviations in deadline should be legislatively proved.

The most dramatic impact on the project deadline has equipment supply terms and now there are a lot of uncertainties regarding main and auxiliary equipment delivery dates and final project deadlines. As the result every company will use the gathered experience managing such projects in Force Major Conditions and it allows them to become more flexible in future.

TOP 5: MTBF in CCGT, benchmark between VGB and EDF data for OPTISPARE
Yves Le Bris, EDF

The ability for power plants to manage assets can be significantly enhanced through the application of innovative digital solutions, like OPTISPARE solution. EDF have used a data mining method on a CMMS datalake of 250 MW coal plant fleet and 400 MW CCGT, which enables to carry out reliability data.

During the 59th PGMON on line meeting, EDF INGEUM presented their experience of this case study. This experience of benchmark analysis with VGB CCGT results has been shared and the discussion covered the following three areas:

1.) Methodology for a data mining work in EDF, 2.) Analysis of critical components on a 250 MW coal plants and 400 MW CCGT,

3.) Benchmark of EDF results with VGB results issued from Mr Henk Wells' book.

A conclusion and recommendation has been shared to increase quality and accuracy in collecting reliability data in a CMMS, their codification, to build a CCGT component data base for OPTISPARE.

TOP 6: a) Update on Predictive Maintenance Project
b) Update on implemented COVID-19 measures
c) CCGT Plant shift cycle set up and shift staffing arrangements
Conor Martin, ESB

Conor Martin from ESB Generation & Trading introduced Dave Carson as a new attendee at PGMON from ESB. A high level introduction to the ESB Group was presented for the benefit of new members of PGMON.

ESB Generation & Trading then presented a generation portfolio update detailing upcoming thermal plant closures and new wind generation capacity being brought online. Details of the level of penetration of non-synchronous generation sources on the transmission system in Ireland and Northern Ireland was also presented to give an understanding of the challenges facing conventional generation. This also highlights the opportunities for technologies which can provide grid stabilizing services such as reserve, voltage and inertia.

A COVID-19 related update was also presented detailing the changes in system demand, demand profiles, commodity prices, and their overall effect on the I-SEM electricity market in Ireland and Northern Ireland. The COVID control measures employed within ESB Generation & Trading were detailed including changes to operations practices (new shift cycles, control room isolation, changes to shift handover protocols), maintenance practices (segregation of key staff, deferral of major overhauls, critical maintenance works only) and working from home and temporary shutdown of office locations for non-station staff.

An update to the use of data analytics in ESB Generation & Trading was presented included the pilot of a predictive maintenance system at a recently commissioned CCGT plant and the pilot of a performance analytics platform in wind generation. Findings from the research undertaken in this area and the setup of the pilots is that implementation costs for such systems have reduced significantly with improvements in cloud computing and server performance. The research also indicated that the optimum setup for monitoring of this nature is remote from the asset This requires permanent dedicated resources to complete the monitoring. Benchmarking analysis has also shown that power generation businesses have shown quantifiable improvements by deploying data analytics for monitoring of power generation technologies.

Finally, an overview of the typically shift cycle patterns in ESB generating stations was presented, which is typically a mix of 8 and 12 hours shift cycles. A more detailed breakdown of the plant organization setup in a recently commissioned CCGT plant was also presented as a reference case.

TOP 7: Introduction to Citrus, new predictive approach for critical components Andy Morris, EDF

The increasing penetration of renewables generation systems on the electricity grid will, over time, further displace the use of fossil-fired generation plant operating at high temperatures and pressures. In the UK for example, coal fired power stations will not be allowed to operate beyond 2025. Combined cycle gas turbine stations (CCGT) will continue operating, but under increasingly challenging commercial conditions and environmental obligations. Similar pathways to a low carbon future are in various stages of implementation around the world. CCGT plants provide a capability for fast response to meet market demand and they will play an important part in the transition to a low carbon future. The requirement to operate plant safely and reliably puts an emphasis on understanding material behaviour and implementing the right decisions at the right time when faced with changes in operation, inspection, maintenance planning and integrity issues.
The purpose of this short article is to provide a concise and contemporary view of how these challenges are being addressed, from the perspective of the end user operating power plant and with particular reference to CITRUS (Component Integrity Tracking and Utilization System), which is being developed to provide a new predictive approach for critical components.

Current In-Service Assessment of Material Condition

The current process for assessing the condition of high temperature materials in service is strongly dependent on the statutory periodic physical inspections undertaken during major outages when the units are off-load. A wide range of techniques are used [1] to provide an estimate of the life consumed and residual life remaining. These inspection methods include internal visual inspections of components and non-destructive inspection using ultrasonic techniques to detect and size macrodefects extending through section. Surface examinations using replica and hardness techniques are used to assess the metallurgical condition and to identify trends over successive inspections. These inspections are focussed at weldments and only later in life is the adjacent parent material routinely assessed. Furthermore, targeted measurements of creep strain accumulation are undertaken on certain strategic components. As the plant ages the inspection scope is significantly increased to address the effects of thermal ageing and supported by expert elicitation and assessment of findings from other sister stations. Other periodic inspections include surveys of the performance of the pipework hanger systems, comparing the position when hot and cold against the design intent. However, the use of predictive models is relatively limited; for example, parametric expressions are used to estimate creep rupture life using the component creep reference stress and operational steam temperature and pressure conditions [1], and is a common approach. Hence the current assessment process is heavily weighted towards periodic (4-yearly) physical inspections. This reliance on physical inspections and an increasing sample size as the plant ages comes at a commercial cost. Recent mechanical testing and modelling of high temperature parent pipework material retired from service on this basis, as part of a wholesale plant replacement scheme, has been shown to have significant useful life remaining [2, 3]. Figure 1 shows a through thickness creep replica cavity count on some of these life expired pipework sections, for a bend and straight section. The pipe thickness extends to 60mm, with considerable variability at the surface and in the through thickness distribution.

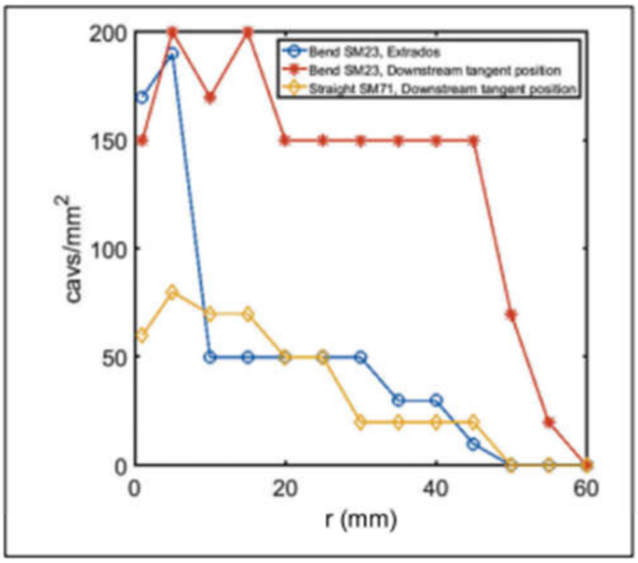
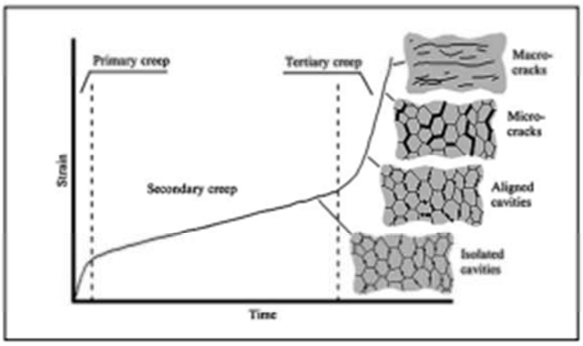


Figure 1. Life expired 0.5%Cr0.5%Mo0.25%V steel; Main steam pipe through thickness creep cavity count [2]

Critical run-repair-replace decisions are influenced by the data from such creep cavity count examinations; with replicas taken at the external surface. For illustration, Figure 2 shows a schematic of the progression of creep damage as the component ages and the VGB classification scale. The technical inspection body responsible for assessing the condition of the assets can use the VGB scale or devise their own criteria for assessment. Material samples are usually extracted once the site examinations indicate notable damage progression, in order to provide a more informed view on residual life.



Assessment class	Structural and damage conditions
0	As received, without thermal service load
1	Creep exposed, without cavities
2a	Advanced creep exposure, isolated cavities
2b	More advanced creep exposure, numerous cavities without preferred orientation
3a	Creep damage, numerous orientated cavities
3b	Advanced creep damage, chains of cavities and, or grai boundary separations
4	Advanced creep damage, micro-cracks
5	Large creep damage, macro-cracks

(a) (b)

Figure 2. (a) Creep degradation through life [1], figure adapted from Guglielmino et al [4]; (b) VGB creep cavity classification [5], figure adapted from [1]

Broader plant condition assessments are achieved with surface hardness measurements to identify any material softening trends or abnormalities. Options to improve how this data is interpreted and how it aligns with results from creep replicas is being explored and is discussed later in this article.

On current CCGT stations, with design temperatures up to ~ 600oC, the use of creep strength enhanced ferritic steels (CSEF), such as P91, for the high temperature part of the steam circuit is commonplace. The performance of CSEF steels in-service has been well documented and researched by many leading establishments over the years. A catastrophic failure of a P91 superheater outlet header end cap welding 1996 at West Burton A power station in the UK after only 35,000 hours in service emphasized the need to improve understanding of the critical factors that might affect the through life performance of this material. The failure mechanism was creep crack growth in the weld Type IV region, initiating at the inside surface. The factors contributing to this in-service failure included, a) poor end cap design, b) very low end cap hardness (186Hv) attributed to poor manufacturing heat treatment. Much research has been expended over the intervening years to identify best practice with respect to manufacturing, inspection methods, repair procedures, novel small specimen material testing and life assessment [6-9]. It's clear these advanced steels are not as forgiving as more traditional ferritic steels used for many years [2] in power plant construction, such as 0.5%Cr0.5%Mo0.25%V; they continue to present a serious challenge for the operators. Steels are being developed that can reliably operate on ultra-supercritical plants at up to 650°C and above, to improve thermal efficiency. One example of these developments is MarBN steel [10-12], which are martensitic 9Cr steels strengthened with additions of Boron and Nitrogen and are intended to achieve the ultimate in performance, with high creep strength and fatigue durability, allowing components to be designed in thinner sections. The challenges presented by operating at temperatures approach 700-750°C are considering the use of Nickel alloys; however, these are very expensive compared to power generation alloys in current use. Other approaches being explored use cooling steam flow and thermal barrier coatings that allow the use of P91 steels in an attempt to provide more cost-effective options [13]. Materials derived from 9Cr steels, where the Mo and Nb is replaced with W and Ta, such as reduced activation ferritic-martensitic F82H steel [14, 15], are candidates for use in fusion reactors. Hence, there is a continual requirement to improve our understanding of the high temperature behaviour of these advanced materials.

From the perspective of the end-user power station, the critical aspects of material behaviour to understand once in service are;

- Sensitivity to the operating conditions,
- Rate of deterioration in service, since this influences the time to plan and implement
- monitoring, repairs or replacements,
- How the material might fail in service,
- Practical inspection methods to detect a change in condition.

It's clear that addressing the above is not just dependent on the materials science, but also dependent on the techniques used to inspect the material on site, control and monitoring of plant operating conditions and the use of appropriate assessment methods and predictive models. Hence, a holistic approach to provide a reliable assessment of material condition for these advanced steels is required.
The following section describes some of the innovations that are being researched and implemented to support the operating power plant, which provides the driver for developing CITRUS

Potential Improvements

Improvements in the capability to reliably predict the rate of degradation of materials in-service are needed in order to rebalance the current heavy reliance on invasive plant inspections. Ideally, data extracted from current plant inspections would be used in more informative predictive models, thereby allowing more timely improvements to plant operation and a reduction in the rate of damage accumulation. Recent and current research to improve utilisation of this data and initiatives to develop practical deployment tools are discussed below.
The 1996 P91 end cap failure emphasised the importance of understanding the geometry detail of the component, in this case the end cap was a flat plate design which resulted in the end cap to header shell closure weld being located directly where there is a significant structural discontinuity. Other components of significant interest are bends on high temperature main steam pipe systems. These are manufactured by induction bending and result in a significant thinning of the extrados and a thickening of the intrados region of the bend. The applied loading on the bends is further complicated

when considering the effect of gross pipe displacement as the power plant comes on load, which results in additional bending loads on the pipework systems. The research on the effect of these geometrical variations [16] and the creep damage model used [17] emphasise the importance of accounting for the geometry and the selection of the appropriate creep damage model.

The capture of surface hardness data has become a common approach for the health assessment of plant, not least because the data can be relatively easily acquired during an outage. It is much more challenging to separate the actual reduction in hardness due to ageing at temperature from the natural variability associated with the field testing technique. Figure 3 shows hardness data captured from a large dataset spread over two outages, with outage 2 ~ 20,000 hrs later in life, on 0.5%Cr0.5%Mo0.25%V main steam pipework operating at 568°C and 168 bar. The data is more fully discussed elsewhere [18], and shows a definite softening trend. Correlations with field surface replicas are investigated, however robust relationships between surface hardness and replica cavity counts are much more difficult to determine at this juncture. An exploration of how surface hardness might be included in a modified Liu and Murakami [19] creep damage models has been illustrated. This hardness modified creep damage model defines a relationship between minimum strain rate and hardness derived from uniaxial creep and small specimen impression creep tests. This provides a potential route to use in-service hardness data in a predictive model.

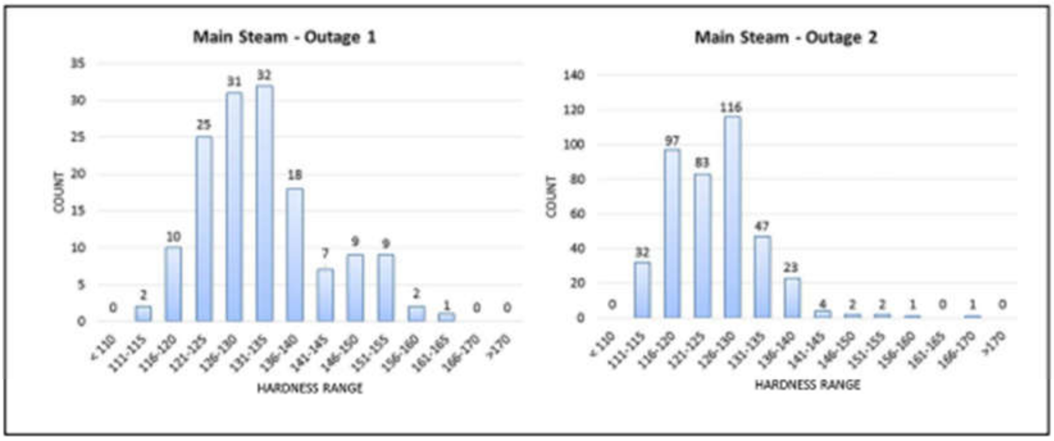


Figure 3. Surface hardness reduction for a large population on field inspections over two successive outages [18]

Clearly different materials show a different creep response and rates of deterioration over time. Inservice examination of P91 materials show much less pronounced creep cavitation prior to failure and a seemingly more elusive relationship between hardness [20] and residual life. Contemporary guidelines for the best deployment of hardness testing in the field have been produced [21], to help end-users reduce measurement errors and produce larger and more reliable datasets.

The measurement of the creep strain rate presents a good opportunity to develop useful life prediction tools, especially if the measurements are reliable and if the sensitivity is sufficient to identify an acceleration in the strain rate that might be indicative that end of life is being approached. During an outage some measurements of pipe diametral strain will be captured at key locations on the system [1]. These measurements must be very carefully controlled if accurate data is to be acquired; it is not unusual in practice to find a lot of variability in such measured data, hence currently this data is not usually robust enough to be used in a life prediction. Equipment has been developed to provide more precise local strain measurements on welds or adjacent to welds, examples being the ARCMAC passive optical strain gauge [22] and the alternating current potential drop (ACPD) creep damage sensor [23] for on-load use. Each of these approaches has been tested in the laboratory and with site installations. The failure forecast method [24] has been demonstrated using high temperature data sets, on laboratory specimens instrumented with the ACPD sensor and shown to produce good predictions of remaining life.

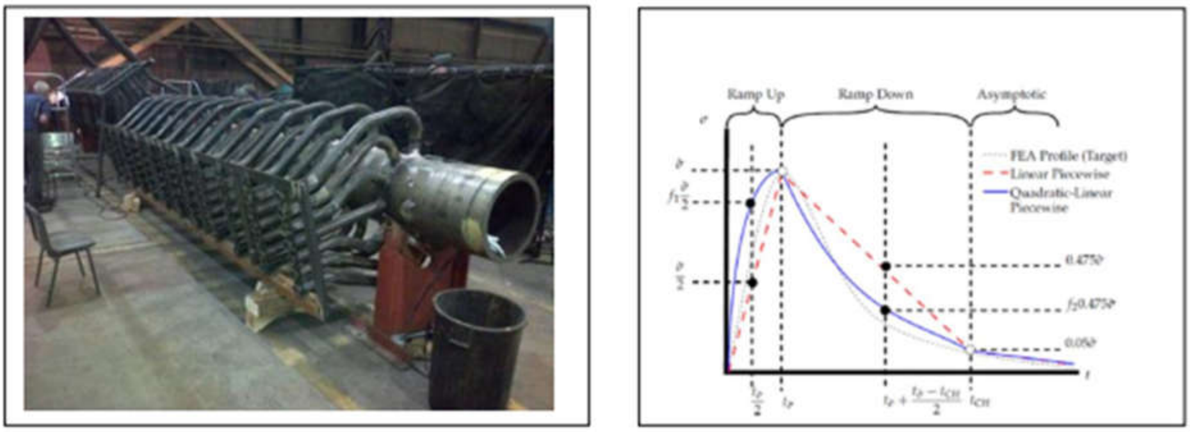
The above discussion describes some of the recent studies that permit the development of improved life assessment models and importantly to promote better exploitation of data that is routinely acquired from physical inspections.

One of the important aspects not addressed by the above approaches is the use of practical tools that allow the evaluation of the in-service stress vs. time response. This would enable the subsequent use in a relevant material model to predict residual life and the rate of damage accumulation.

Currently EDF, EPRI and the University of Nottingham are collaborating on a project (CITRUS) to develop a holistic tool that can take account of the component geometry, in-service steam temperature and pressure data and using a suitable material model, predict the rate of damage accumulation and residual life. The stress vs. time extraction approach is based on the use of temperature dependent green's functions to determine the appropriate constants for a particular location on a component geometry. The analysis capability has been expanded by using a trained neural network to allow a wide range of sister geometries to be modelled [25]. The demonstration of the analytical process was based on the complex geometry in a steam header, illustrated in Figure 4. The approach uses key characteristics in the structural response of the steam header (Figure 4a) to a unit step change in steam temperature (Figure 4b). Key parameters (maximum stress, time to maximum stress and the time for the stress to fall to 5% of the maximum) can be extracted from this unit step response and used in the green's function method to rebuild the in-service stress vs. time history. The trained neural network provides the capability to derive the parameters for a range of similar geometries, thereby proving very cost effective and eliminating the need to construct multiple finite element models of similar components.

The similarity of component design in CCGT heat recovery steam generators, means that the vast majority of the complex headers and manifolds geometries can be assessed by the trained neural network; hence evaluating the three key response parameters.

CITRUS is arranged to allow the user to deploy a range of different assessment models, based on available materials data and operating conditions. These can for example range from more simplistic monitors of the quality of a unit start, using elastic thermal stress metrics to a more comprehensive thermo-mechanical fatigue model that is able to distinguish between the response of the parent weld, heat affected zone and adjacent parent material. Great effort is being made to ensure that CITRUS communicates relevant and meaningful information to a range of stakeholders from operations, engineering through to asset management functions.



(a) (b)

Figure 4. (a) Steam header geometry, (b) Transient stress response to a unit change in temperature

CITRUS is designed with a modular architecture to facilitate updates for different damage mechanisms, components and materials data. Importantly CITRUS is aligned to the following four core functions;

- Day to day operational feedback: typically summarized at the end of the day and fed back to operations and engineering,
- Inspection scheduling: to allow engineering teams to correlate the most recent physical inspection findings against life prediction and thereby assist with future inspection planning,
- Assess the impact on monitored component life due to different operating scenarios, which might be requested by traders or required due to future changes in legislation,
- Implementing detailed sensitivity analysis to support the assessment of adverse operational events or the robustness of safety cases.

It is anticipated that other functions that could be include would be associated with optimizing design, whilst maintaining code compliance.

CITRUS is scheduled to be ready by the end of 2021 and for the first time will allow the easy deployment of a range of material models on a limited number of components. This will allow

predictions of remaining life to be made and compared against physical inspection results, hence ultimately promoting improvements in operation and inspection planning.

CITRUS attempts to redress the current imbalance between physical inspections and life prediction, so it should in the fullness of time provide a healthy challenge to material models, site examination techniques and traditional approaches to defining inspection strategies.

Closing Remarks

The commercial climate has a great bearing on the approach that operating stations take with respect to run-repair-replace decisions. Clearly for thermal plant the revenues available from generation are under great pressure due to the increasing penetration of renewables. Hence, approaches to improve condition monitoring strategies and optimizing inspection schedules are considered crucial. The discussion in this article emphasizes the great challenge that this presents.

The experience gained in operating the existing fleet of coal fired power stations for 50 years has necessarily led to the development of some quite intricate inspection and repair strategies for high temperature materials. The relatively recent introduction of more advanced steels, such as P91, has emphasized the importance of rigorously defining acceptable chemical compositions and manufacturing heat treatments if acceptable service life has any chance of being achieved.

There is a constant challenge associated with field examinations and use of such data to estimate residual life. The key to continuing safe and commercially viable operation of modern plant at high temperatures will depend on the capability to target effective physical examinations and to obtain data that can reliably be used to determine the rate of damage accumulation, whether this involves surface replicas, hardness or strain; or more probably some combination of these. Deployment tools, such as CITRUS are being developed with this specific purpose in mind, and importantly focused on the needs of all stakeholders.

References

1. A. Morris, B. Cacciapuoti & W. Sun (2018) 'The role of small specimen creep testing within a life assessment framework for high temperature power plant', International Materials Reviews, 63:2, 102-137, DOI: 10.1080/09506608.2017.1332538
2. B. Cacciapuoti., A. Morris., W. Sun., D.G. McCartney., J. Hulance., 'Correlation and capability of using site inspection data and small specimen creep testing for a service-exposed CrMoV pipe section', Materials at High Temperatures, 36:2, 173 186, DOI: 10.1080/09603409.2018.1503148
3. M. Ejaz., 'Creep life prediction of new and service exposed 0.5Cr-0.5Mo-0.25V steel pipework', PhD Thesis, Imperial College London, 2019
4. E. Guglielmino., R. Pino., C. Servetto et al. Chapter 4 – creep damage of high alloyed reformer tubes A2. In: M. Aliofkhazraei, editor. Handbook of materials failure analysis with case studies from the chemicals, concrete and power industries. Oxford: Butterworth-Heinemann; 2016. P. 69-91
5. VGB-TW 507. Guidelines for the assessment of microstructure and damage development of creep exposed materials for pipes and boiler components. Essen: VGB technical association of large power plant operators; 1992.
6. J. Parker., J. Siefert., 'Metallurgical and stress state factors which affect the creep and fracture behaviour of 9% Cr steels', Journal of Advances in Materials Science and Engineering, Vol 218, (2018), https://doi.org/10.1155/2018/6789563
7. T. H. Hyde, W. Sun & J. A. Williams (2007) Requirements for and use of miniature test specimens to provide mechanical and creep properties of materials: a review, International Materials Reviews, 52:4, 213-255, DOI: 10.1179/174328007X160317
8. A.H. Yaghi., T.H. Hyde., A.A. Becker., W. Sun., 'Numerical simulation of P91 pipe welding including the effects of solid-state phase transformation on residual stress', Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, (2007), https://doi.org/10.1243%2F14644207JMDA152
9. L. Li., P. Zhu., G. West., R.C. Thomson., 'The effect of duration of stress relief heat treatments on microstructural evolution and mechanical properties in Grade 91 and 92 power plant steels', 6th International Conference on Advances in Materials Technology for Fossil Power Plants, USA, 2010

10. F. Abe., M. Tabuchi., H. Semba., M. Igarashi., M. Yoshizawa., N. Komai., A. Fujita., 'Feasibility of MARBN steel for application to thick section boiler components in USC power plant at 650°C', 5th EPRI International Conference, October 2007, USA11. J. Guo., X. Xu, M.A.E. Jepson., R.C. Thomson., 'Influence of weld thermal cycle and post weld heat treatment on the microstructure of MarBN steel', International Journal of Pressure Vessels and Piping, 174 (2019) 13-24.
12. M. Li., A. Benaarbia., A. Morris., W. Sun., 'Assessment of potential service-life performance for MarBN steel power plant header under flexible thermomechanical operations', International Journal of Fatigue, 135 (2020). https://doi.org/10.1016/j.ijfatigue.2020.105565
13. X. Guo., W. Sun., A.A. Becker., A. Morris., M. Pavier., P. Flewitt., M. Tierney., C. Wales., 'Thermal and stress analyses of a novel coated steam dual pipe system for use in advanced ultra-supercritical power plant., 'International Journal of Pressure Vessels and Piping 176 (2019) https://doi.org/10.1016/j.ijpvp.2019.103933
14. R. Klueh, 'Reduced-activation bainitic and martensitic steels for nuclear fusion applications', Curr Opin Solid State Mater Sci. 2004;8(3):239-250
15. M. Bruchhausen., K. Turba., F de Haan., et al, 'Characterisation of a 14%Cr ODS steel by means of small punch and uniaxial testing with regard to creep and fatigue at elevated temperatures', J Nucl Mater. 2014;444:283-291
16. J.P. Rouse., M.Z. Leom., W.Sun., T.H. Hyde., A. Morris, 'Steady-state creep peak rupture stresses in 90° power plant pipe bends with manufacture induced cross-section dimension variations', International Journal of Pressure Vessels and Piping 105-106 (2013) 1-11
17. J.P. Rouse., W.Sun., T.H. Hyde., A. Morris, 'Comparative assessment of several creep damage models for use in life prediction', International Journal of Pressure Vessels and Piping 108-109 (2013) 81-87
18. A. Morris., B. Cacciapuoti., W. Sun, 'The role of hardness on condition monitoring and lifing for high temperature power plant structural risk assessment', Measurement 131 (2019) 501-512
19. Y. Liu., S. Murakami., 'Damage localisation of conventional creep damage models and proposition of a new model for creep damage analysis', JSME Int. J. Series A 41 (1) (1998) 57-65

20. EPRI Publication, ‘An informed perspective on the use of hardness testing in an integrated approach to the life management of grade 91 steel components’, 2016
21. EPRI Publication, ‘The use of portable hardness testing in field applications for grade 91 steel’, 2012
22. A. Morris., M. Kourmpetis., I.D. Dear., M. Sjodahl., J.P. Dear., ‘Optical strain monitoring techniques for life assessment of components in power generation plants’, Proc. IMechE Vol. 221 Part A: J. Power and Energy, 1141-1152
23. J. Corcoran., P. Hooper., C. Davies., P.B. Nagy., P. Cawley., ‘Creep strain measurement using a potential drop technique’, International Journal of Mechanical Sciences 110 (2016) 190-200
24. J. Corcoran., C. Davies, ‘Monitoring power-law creep using the failure forecast method’, International Journal of Mechanical Sciences (2018), doi: 10.1016/j.ijmecsci.2018.02.041
25. J.P. Rouse., C.J. Hyde., A. Morris, ‘A neural network approach for determining spatial and geometry dependent green’s functions for thermal stress approximation in power plant header components’, International Journal of Pressure Vessels and Piping 168 (2018) 269-288

TOP 8: p-F intervals, testing problems and maintenance issues from US nuclear LERs
Henk Wels, DNV GL

In literature p-F intervals are the bases for condition dependent maintenance, however only a few quantitative data can be found[1]. Condition monitoring centers should have this type of data, however never presented it as p-F intervals. It does make sense to gather data, as a difference between components from practice is noted.
In the US a large set of data (20700 LERs between 2009 – 2019) is present with free access to the public and abstracts can be loaded in 1 Excel file for analysis. However detailed reports (to check the direct cause or root cause) must be downloaded one-by-one.
LER's are written by US NPP operators whenever there is operation outside technical specification limits, a reactor trip, etc. or actuation of specific safety systems. Auxiliary and emergency feedwater systems are so-called engineered safety systems. Surely there is something to learn for feedwater systems in fossil fired plants.
A search was carried out using an Excel file in combination with keywords. It was found that some of the plants are 40 – 50 years old and still the "bathtub curve" for feedwater events does not rise. Uncertainty is present both yearly and between plants. Teething troubles are present. Surprisingly there appears to be little ageing.
The analysis has resulted in dominant components and dominant fault types. In the feedwater LERs the dominant components causing LERs are breakers, E-motor, governor of the aux turbine, lube oil problems, pumps and valves.
Dominant fault types are equipment faults (f.i. wear), maintenance faults and, especially at valves operator errors. The detailed reports regrettably focus much on the events leading to reactor scram, etc. starting at the first event, rather than when the cause could have been noted due to condition monitoring, testing, etc. Therefore p-F intervals were not always found. Yet, depending on the dominant component, 40%-70% LERs led to p-F intervals for in total 162 events. The range of faults is enormous. ALL types are possible (painters both making things stick as well as noticing faults, wrong assembly after maintenance, oil dirty for a long time, filter breakthrough after transients, trips after

[1] Prof. Christer (†2006) at Salford University, Manchester UK, introduced delay-time modelling to industry in 1984. Delay-time modelling is based on a similar concept. Also in delay-time modelling quantitative data from practice, especially power plants, are VERY scarce.

taking pictures with a digital camera, inadvertent grounding due to multimeter settings… there is no end to the list! Yet, even when there is a human failure, equipment may invite such failures due to f.i. inadvertent grounding because of inaccessibility.
The p-F intervals suggest that E-motors may have electrical faults arising over a large time horizon therefore can benefit from condition monitoring. Valve monitoring, given it is sufficient fast as the p-F interval is short, could be interesting.
The estimated p-F interval in feedwater systems appears to be either large as the problem stems back from design or very short (less than a day) for instance due to maintenance or operator errors that are immediately clear. In other categories in between long and very short (f.i. at equipment fault) there appears to be much spread, a Gaussian distribution is questionable. It is unclear what statistical distribution should be applied.
As the amount of problems with stepup-transformers in NPPs is limited compared to feedwater systems, this was also analyzed. Stepup (main, generator) transformer problems at NPP's cause diesels to start, as the grid connection is lost, therefore main transformer problems are the subject of a LER.
The numerical failure times as a system (2 transformers generally per plant) can easily be modeled as a Crow-AMSAA model which shows ageing with beta = 1.793. The failure rate as if random (1.4 E-6 / hr) is well comparable with the value in EREIDA for French NPPs (λ = 2.9E-6 (1978-1987, 0 failures) and λ = 2.2E-6 (added data up to 1993, 0 failures between 1978-1993)).
It appears that ageing stepup-transformers, even with DGA gas monitoring, cannot be trusted and should be investigated during life extensions. DGA gas values can reach unacceptable values within days at which the transformer needs to be taken out of operation. Some failures will not be preceded by any deviation in DGA trends. A fire as the result of a dielectric fault is very real.

TOP 9: Place and date of next venue

The next meeting will be held on 14./15. October 2020 in Riga/Latvia.