A CENTRALIZED ON-LINE DAMAGE MONITORING SYSTEM FOR POWER PLANT COMPONENTS

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ABSTRACT

A centralized version of on-line structural safety evaluation system (BOSSES) has been installed to monitor damage due to creep and fatigue in various critical plant components of multiple thermal power plants. This can be achieved from a centralized BOSSES server. This version is advancement to the earlier version of BOSSES where it was installed and maintained individually at different plant locations. The process data like pressure, temperature and flow acquired from different power plants is collected centrally. The damage accumulated in the critical components is evaluated from detailed 3-D finite element analysis on real time basis and reported for each of the power plant. The scope of the centralized version can be expanded to monitoring of damage in large number of components in very short time. The present paper describes the implementation of centralized BOSSES for a total 20 critical components from 4 thermal power plant units with some case studies of real life damage assessment.

INTRODUCTION

The issue of remaining life prediction has attracted considerable attention in the power generation industry [1-12, 26]. Integrity of important components is essential for operational safety, reliability and economic plant operation. In the design, the life of a plant is estimated based on assumed process transients. However, because of conservatism in the design the actual lives of these plants are expected to be much more than the estimated value. The sustained interest in the area of remaining life prediction arises from the need to avoid costly outages, safety considerations and the necessity to extend the component operation life beyond the original design life [2]. Many of the structural components used in fossil power plant, nuclear industry and chemical process plants, are subjected to cyclic stresses due to the fluctuation of process transients. On the other hand components like steam pipes, super-heater headers, turbine rotors, casings, operate at elevated temperature [1,2,6,7]. Cyclic stresses with a high mean stress at an elevated temperature lead to a damage mechanism due to combined creep and fatigue. It is worth to note that among the various aging effects, fatigue, creep, creep-fatigue interaction and creep-fatigue crack growth are commonly responsible for most of the failures in various industrial components.

Several researchers have stressed the need to develop a life prediction methodology to address the various aspects of failure mechanisms. Systems have been developed to evaluate the damage for high temperature components of power plants on a real time basis (Sakurai et al. [6], Maekawa et.al [9], Sakai et.al[12], Aufort et.al[5], Morilhat et.al[10], Balley et.al[13], EPRI[14], Samal et.al[26]). In particular, Samal et.al[26] described the on-line creep-fatigue monitoring system “BOSSES” which has been developed over the years in Bhabha Atomic Research Centre, India. The BOSSES was successfully implemented for critical components of Heavy water plants and thermal power plants in India. Until recently, individual installation of BOSSES was in use for selected critical components of different thermal power stations at Dadri. The present paper describes the advancements made to BOSSES software and its implementation for large number of components controlled from a centralized location. The main difficulties with earlier version of BOSSES installation are installation and maintenance of BOSSES software at individual sites of thermal power plants. Each site requires a data acquisition system (DAQ), necessary cables and a dedicate workstation to run the BOSSES software. Any operational difficulties associated with hardware for acquiring the process data will affect the operation of BOSSES software. Recently, there is a change in the strategy of process data acquisition at NTPC (National thermal power corporation) which is responsible for running of thermal power plants in India. All the process data from different thermal power plants are acquired at a centralized location through necessary DAQ’s and cables. The same data is also available at the research centre of NTPC, NETRA (NTPC Energy Technology and research alliance). This strategy eliminates multiple installations of BOSSES software at different sites. A centralized version of BOSSES software installed at NETRA (Durgaprasad et.al[31]) is used to make the residual life assessment of many critical components of multiple plant units simultaneously. The present paper discusses successful implementation of centralized BOSSES for a total of 20 critical components from 4 thermal power plant units with some case studies of real time damage assessment.

ON-LINE STRUCTURAL SAFETY EVALUATION SYSTEM (BOSSES) AND ITS CENTRALIZED VERSION

The on-line creep-fatigue damage monitoring system BOSSES has been developed and maintained over the years by Bhabha Atomic Research Centre, India. A centralized version of the BOSSES is recently implemented at NETRA. The schematic of the centralized BOSSES installation is shown in Fig.1. The highlight of this version of the software is that, from a centralized server, large number of critical components of multiple power plants can be monitored for creep-fatigue damage. The visual and quantitative output of the residual life of the components can be simultaneously made from the same BOSSES server.

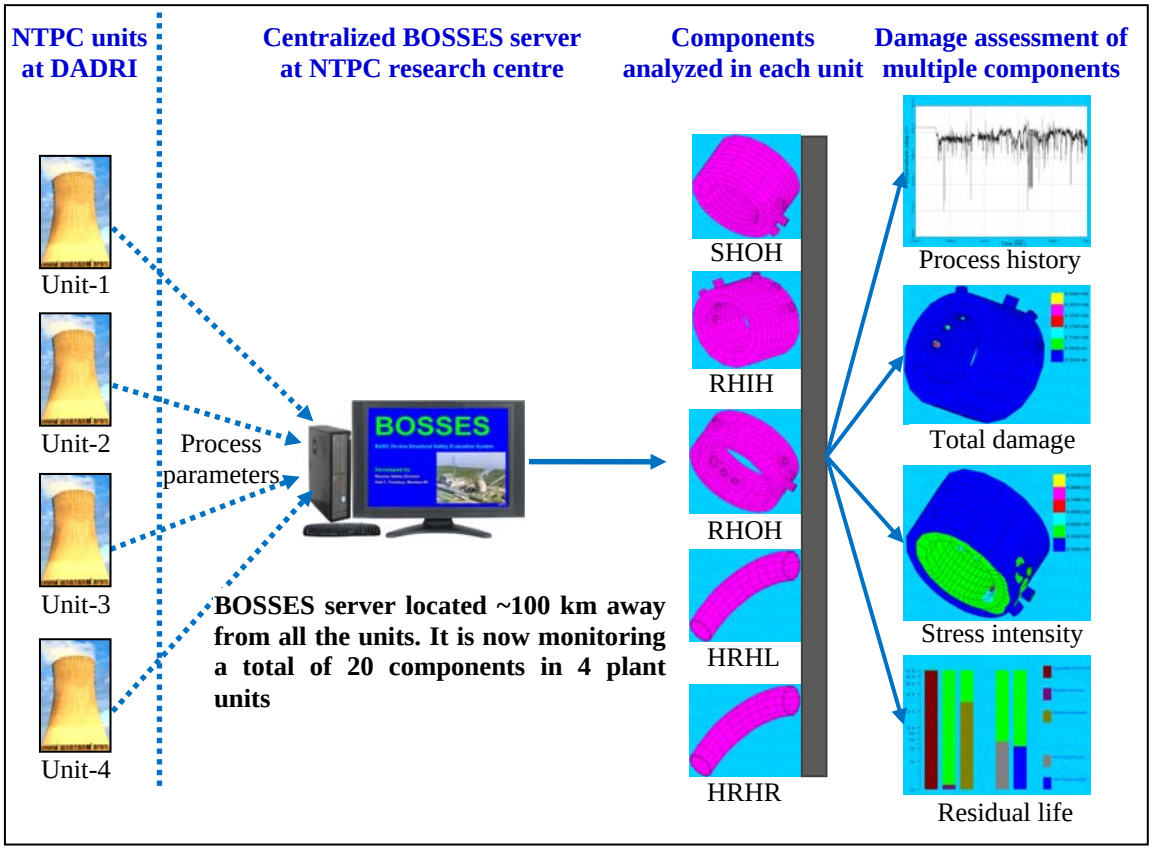


Fig. 1: Schematic diagram of the centralized BOSSES installation for 4 thermal power plants. Creep & fatigue damage assessment is made simultaneously for 5 components of each plant thus a total of 20 components are currently monitored. Components monitored in each unit are Super heater outlet header (SHOH), Reheater inlet header (RHIH), Reheater outlet header (RHOH), Left and right Hot reheat pipe bends (HRHL, HRHR).

On-line centralized BOSSES has many modules which are briefly described here. More details can be obtained from elsewhere [8, 11,17, 26]. The transient acquisition module collects the plant transients e.g. pressure, temperature and flow rate, at pre-defined time interval from each of the plant unit at the centralized server. The server then screens the transients based on severity. The server takes care of any discrepancies in data collection from different units and passes the necessary data for each of the component analyzed in each unit to the damage assessment module. In on-line fatigue creep monitoring, the conversion of plant transients to the temperature/ stress responses in the structure is one of the most important tasks. To utilize the computing power of modern computers, the present system BOSSES employs on-line finite element technique to compute temperature transients and the thermal stresses in the structure due to fluctuation of the process transients. The system can take care of the variations of heat transfer coefficient and can provide whole-field information. The damage evaluation module finds out the fatigue usage factor, creep damage and fatigue-creep interaction effect. Various algorithms are available for cycle counting in an irregular stress history. The most widely used is the rain-flow cycle counting technique. The

stress time history is converted to stress frequency spectrum using the rain-flow cycle algorithm as introduced by Socie [19]. Later various investigators, e.g. Downing and Socie [20], Rychlik [21] and Glinka and Kam [22], have presented various algorithms of rain-flow cycle counting technique. In this method the effect of small stress excursions are separated and the relevant dominant cycles capable of producing damage are computed. The cycle counting algorithm of the present system is based on this method. The fatigue usage factor is evaluated from the computed cycles using material fatigue data [23]. The creep damage index is evaluated from the computed temperature and stress histories and the material creep curve, using the procedure shown in API reports. To account for the combined damage mechanism, the damage accumulation approach is adapted [24, 25].

The visual module of BOSSES provides graphical display of plant transients, computed temperature/stress responses, damage related information and remaining life assessment for each of the component from different power plant units. Data backup module provides efficient data storage at regular intervals, data backup and data restoration capabilities. The system can be integrated to a data recording system and fatigue-creep degradation of several components of a plant can be monitored using a single desktop computer. Theoretical background of creep/fatigue damage assessment calculations is explained next section.

THEORETICAL BACKGROUND OF CREEP AND FATIGUE DAMAGE ASSESSMENT CALCULATIONS

The process parameters of the fluid (pressure, temperature and steam flow) are converted to heat transfer coefficients for the boundary of the component being analyzed and a transient thermal analysis is carried out to calculate the temperature distribution in the whole volume of the model at each time step. This temperature profile is used in the subsequent stress analysis module to calculate thermal stresses in the pipe bend at each time instant. Further, internal pressure, temperature gradient and piping loads are applied at each instant to calculate the stress distribution in the component. The various stress components are used to find the principal stresses and hence the maximum stress intensity seen by the component at each time instant, which is subsequently used to find the creep and fatigue damage. The rain-flow cycle counting algorithm is used to calculate number and stress intensity amplitude of fatigue cycles and the fatigue damage factor is calculated using Miner's life fraction rule [23]. The creep damage is calculated as per the procedure shown in API code [28-30]. The equation used to determine remaining life to rupture due to creep at effective stress level S_{eff} is given as

$$\log_{10} L = \frac{1000.LMP\left(S_{eff}\right)}{\left(T+460\right)} - C_{LMP} \qquad (1)$$

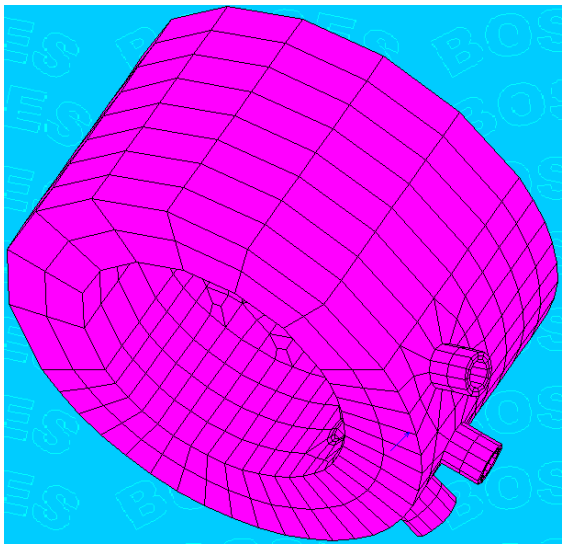
where L is the remaining life to rupture (in hrs.), S_{eff} is the effective stress as defined in [21], and $LMP(S_{eff})$ and C_{LMP} are the Larsen-Miller parameters and T is the material temperature in deg. C. The damage index due to creep is given by the ratio of actual service time and the total life to rupture due to creep (Robinson's life fraction rule). The total damage is then calculated by linearly superimposing the damage due to creep and fatigue [24, 25]. The information on temperature and stresses are also used to assess growth of different postulated cracks at various locations of pipe bend as per R5 and RCC-MR procedures [24,25].

MONITORING OF CRITICAL COMPONENTS OF FOUR THERMAL POWER PLANT UNITS AT DADRI

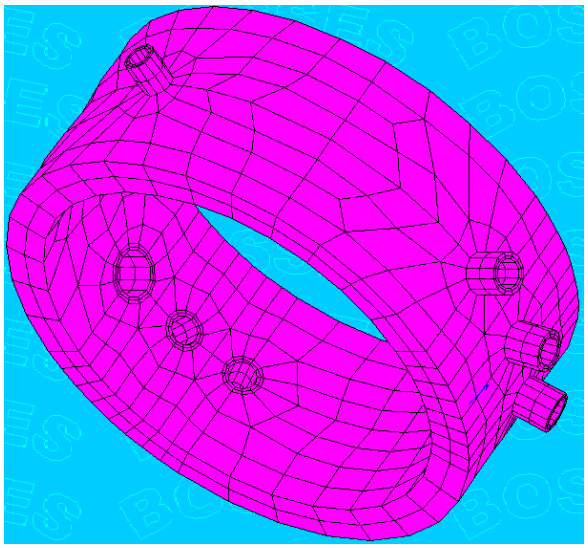
The centralized BOSSES is currently used to monitor the creep and fatigue damage of critical components of four thermal power plant units located in Dadri. The BOSSES server is located at about 100 km from the power plant units. The capacity of the 4 concerned coal-fired power plants is 210 MW. In a thermal power plant, high energy piping, boiler headers, turbine rotors, casings, steam chests, valves, etc., are the most critical components subjected to creep and fatigue damage under service conditions. To prevent any unforeseen outages of the plant due to steam leakage preceded by crack formation leading to plant unavailability and down-time cost, it is necessary to generate some information on localized degradation due to various damage mechanisms in real-time basis.

A centralized BOSSES system has been implemented for selected critical components of the four units. The units are in service for approximately 15 years. Some of the components under monitoring are superheater outlet header (SHOH), reheater inlet and outlet header (RHIH and RHOH) and the hot reheat pipe bends (HRHL and HRHR) etc. SHOH is the final superheater header and one of the most critical components operating in creep regime with a hydraulic pressure of 155 kg/ cm2 and 540°C. The gross dimensions of SHOH are 406.4 mm (OD) x 75 mm (thickness) x 14650 mm (length). The main steam on exit from SHOH is transported to the HP turbine. RHOH is the outlet header of the reheater which delivers the hot reheat steam to Intermediate pressure turbine with gross

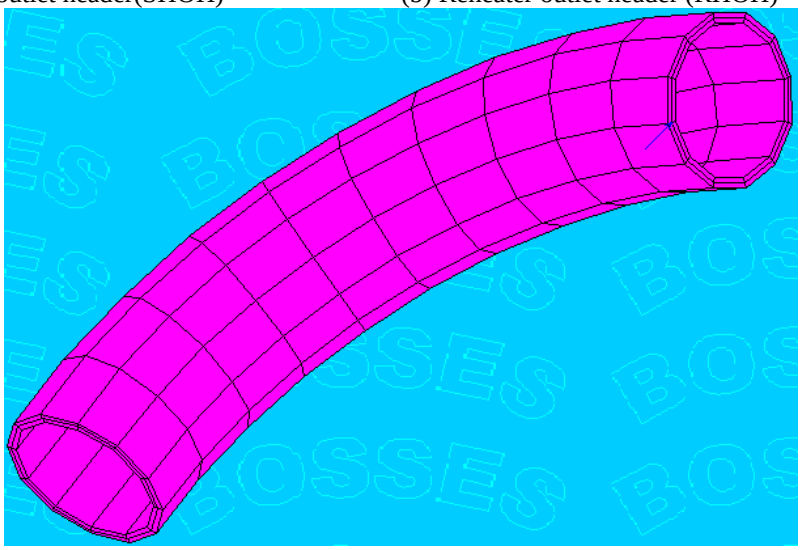
dimensions as 558.8 mm (OD) x 45 mm (thickness) x 14650 mm (length). It operates under pressure of 49 kg/ cm2 and 540°C. RHIH is the inlet header of the reheater receives the cold reheat steam exhausted from high pressure turbine with its gross dimensions as 406.4 mm (OD) x 15.2 mm (thickness) x 14650 mm (length). It operates under pressure of 52 kg/ cm2 and 355°C. The HRPBs are the bends in the hot reheat piping before intermediate pressure control valves with a design temperature and pressure: 540°C at 46.3 Kg/cm2) conveying steam to its intermediate pressure turbine. Its dimensions are 508 mm (OD) x 30 mm (thickness) with a bend radius of 1200 mm. The material of these headers and pipe bends is ASME SA 335 P22 (a low alloy ferritic steel). The importance of these components in an operating plant emerges from the concern of its critical function as a transporter of high-energy steam. In total, 20 components are analyzed for damage by centralized BOSSES simultaneously. To compute the temperature, stress intensities etc., the finite element technique is used for thermal and stress analysis of the components. The finite element model uses 20 nodes brick elements. The finite element mesh of some of the selected components are shown in Fig.2a-c.



(a)Super heater outlet header(SHOH)



(b) Reheater outlet header (RHOH)

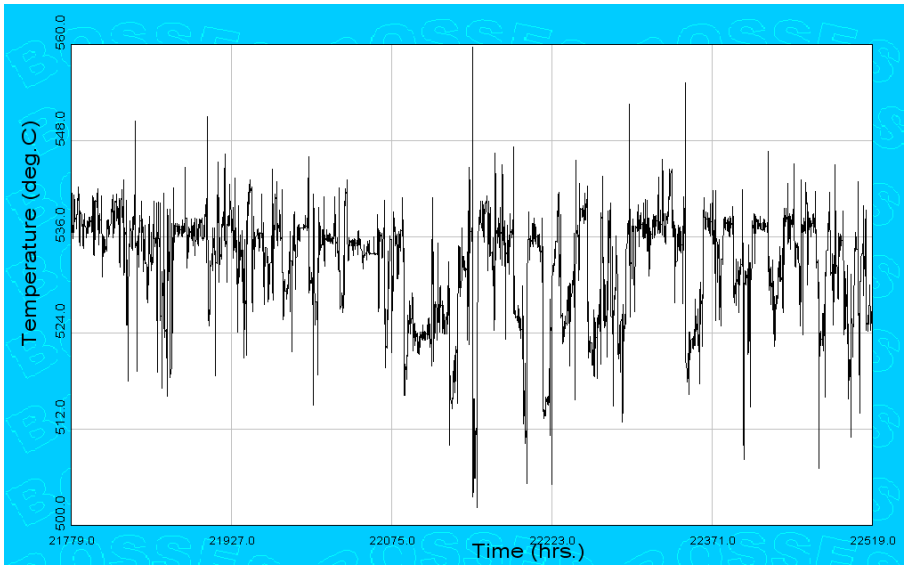


(c) Hot reheat pipe bend (left/right)

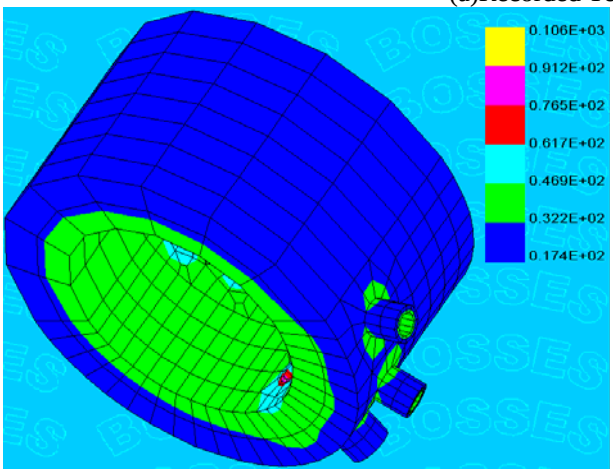
Fig.2a-c: Finite element models of selected components monitored by BOSSES

The actual plant transients used by BOSSES are main steam pressure, temperature and flow and similar parameter in other circuits such as hot and cold reheat lines. It may be noted that the piping load is an important loading on a component apart from internal pressure and thermal stresses. The piping loads on a component are evaluated by carrying out stress analysis of the whole piping loop (with associated supports and restraints) using

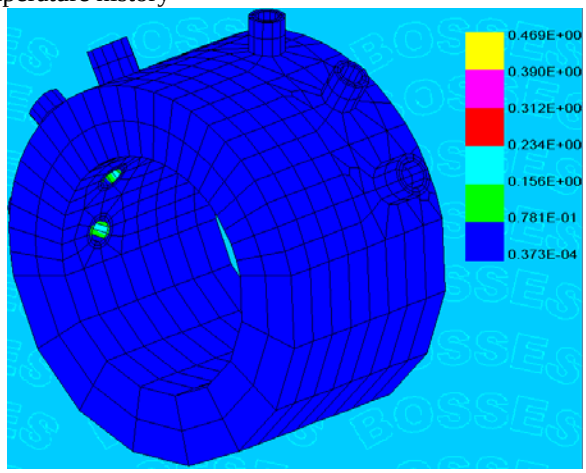
various types of straight and bend pipe finite elements due to various load such as dead weight, pressure and thermal loads. With all the loads known, BOSSES evaluates the material temperature, stress and damage (due to creep and fatigue) in all the components. Some of the sample results of BOSSES monitoring for different units are shown in Figs.3-5. Also note that, the components of each unit have different service and monitoring life. Accordingly, the damage assessment calculations and remaining life assessments are made. The computed values of material temperature, maximum stress intensity and damage history at a shell-nozzle junction of a superheater outlet header of the thermal power plant unit-3 after 22500 hours of operation are shown in Fig. 3. Similarly, one can obtain the whole-field information on stress and damage in a component at any instant of time and as an example, the stress and damage contours of the hot reheat pipe bend after 8650 hours of on-line computation are shown in Figs. 5a and 5b, respectively.



(a)Recorded Temperature history

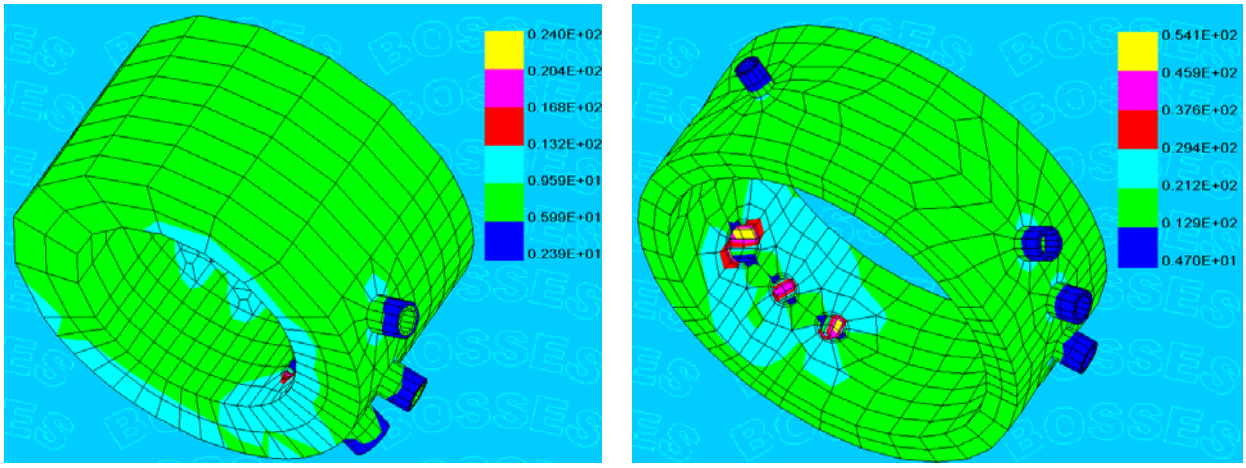


(b) Stress intensity contours



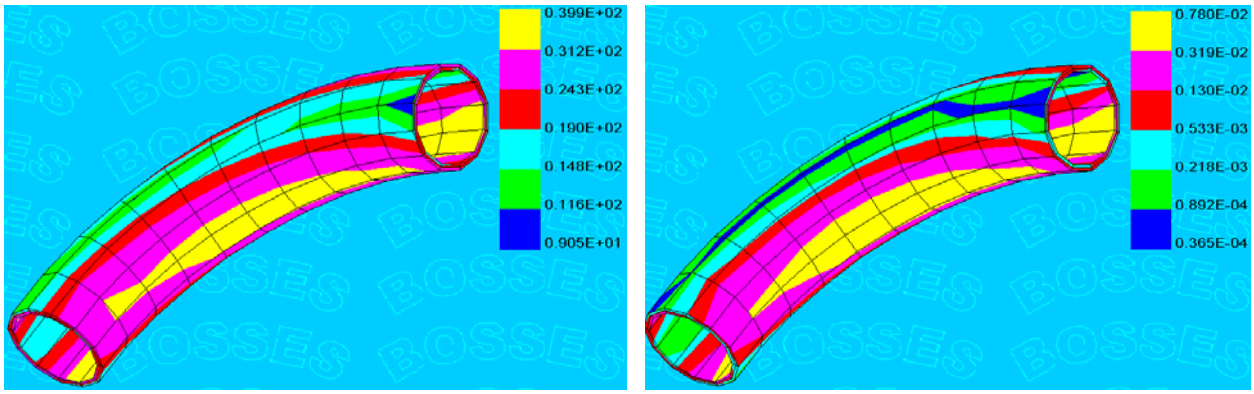
(c) Total damage contours

Fig.3a-c BOSSES results for SHOH (unit-3) for 22500 hrs of monitoring



(a) RHIH (b) RHOH

Fig.4: BOSSES results- stress intensity for RHIH and RHOH (unit-2) for 9300 hrs of monitoring



(a) (b)

Fig.5: BOSSES results for HRHL(unit-4) for 8650 hrs of monitoring, (a) stress intensity (b) Total damage contours

REMAINING LIFE ASSESSMENT

A system of present type should be implemented at the time of commissioning of the new plant. However, BOSSES has been installed at different dates in different units. With the latest installation all the components of different units are brought into purview of centralized BOSSES system. The implementation details of centralized BOSSES for different units are given in table.1. This also necessitates to extrapolate the logged in data to compute the damage of the entire service life of the components. Such extrapolation is based on the assumption that the logged in plant thermal-hydraulic parameters can be considered to be representative of past plant history. Under such assumption, the damage data for fatigue and creep data are extrapolated for entire service life of the components by the code during on-line calculations. The remaining life assessment is also performed on the cumulated material damage. As an example, the results of remaining life assessments for different components of unit-3 are depicted in Fig. 6. All the information are upgraded and restart files are saved for successive computations.

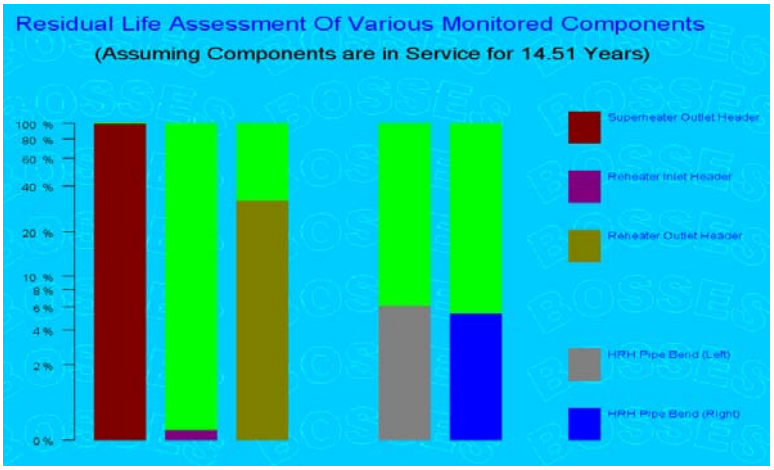


Fig.6: Remaining life predicted for different components of unit-3 as predicted by BOSSES

Table.1: Details of components of multiple units monitored by centralized BOSSES

Unit	Name of the components	Actual service life of the components (in hours)	Service life monitored after installation of BOSSES (in hours)
1	SHOH,RHIH, RHOH, HRHL, HRHR	162060	2800
2	SHOH,RHIH, RHOH, HRHL, HRHR	153300	9300
3	SHOH,RHIH, RHOH, HRHL, HRHR	143660	22500
4	SHOH,RHIH, RHOH, HRHL, HRHR	136650	8650

CONCLUSION

The prevailing approach/ practice of the utilities to estimate the need for inspection is on the basis of off-line inspection and their past O&M experience. These result in frequent inspections of problem-free equipment by the utilities and also often cause unexpected failures. The application of the present centralized BOSSES system would help in making on-line damage assessments of different critical components and take realistic decisions in many operating plants simultaneously. The scope of monitoring of this system can be easily expanded to many components very easily provided the process data is available on the server. The system can be merged with existing O&M planning and scheduling activities for efficient plant management and thus provide a cost effective solution. Such risk based monitoring will be a part of overall concept of risk-based life management.

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