Inspection, Monitoring, Repair, and Maintenance of HRSGs

Guidelines Based on Review of Worldwide Plant and Research Experience

(*Acronym:* **HRSG Guidelines**)

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Executive Summary

This report reviews worldwide plant and research experience on HRSGs and presents recommendations and guidelines for inspection, monitoring, repair and maintenance. In addition, detailed background information is provided on the influence of HRSG type (horizontal or vertical gas flow), materials of construction and weldment issues, mode of operation, damage mechanisms, and novel inspection and repair technologies. The information has been obtained from the plant experience of ETD experts and consultants, personal contacts in the industry worldwide, in-house reports, industrial sponsors' feedback, and recently published literature.

The information and guidelines contained in this report are ***aimed*** at the plant operators carrying out their inspection and maintenance work, and also at the plant designers and manufacturers for understanding not only the issues involved in the integrity of HRSGs but also the development of new technologies for future design, development and monitoring of the plant.

The report starts with an introduction to Combined Cycle Gas Turbine (CCGT) power plants and HRSG systems. CCGT units have been the preferred choice for new build power plant because of their low capital cost, high efficiency and low emissions, and also the low price of natural gas. Such plants now offer thermal efficiencies of over 50% and significantly outperform coal-fired plant. However, as the price of gas has increased in recent years, newer CCGT plants with higher efficiencies and lower maintenance requirements are supplying the base load, while many of the earlier CCGTs have been relegated to load following duty and are now operated in two shifting mode (cyclic operation).

HRSGs can be of the *drum boiler type*, in which water circulates through a boiler section with the steam taken off in the steam drum, or a *once-through design*, in which the elimination of the thick-walled steam drum results in faster start-up times. The HRSGs are manufactured as units with either *horizontal* or *vertical* geometries. In a horizontal unit the gas flow is horizontal passing over vertical tubing. In a vertical HRSG the gas flow is vertical passing over horizontal tube banks. The advantages and disadvantages of each type are discussed in detail.

Materials and welding issues for HRSGs are discussed, with particular reference to the application of P91 martensitic steel in place of the traditional low alloy ferritic steels. The creep strength of P91 is critically dependent on its tempered martensite microstructure, and so the material has to be handled with care during welding and heat treatment. The susceptibility of P91 to Type IV cracking and its steamside oxidation behaviour are discussed. The new low alloy ferritic steels, T23 and T24, are also considered. These materials have creep strengths comparable to that of P91 and have the advantage that thin sections can be welded without post-weld heat treatment. Weld repair, dissimilar metal welds and weld quality issues in HRSGs are also discussed.

Earlier HRSGs were designed for base load operation using the philosophy applied to conventional boilers. As a result, many problems have been encountered in these units during *cyclic operation* due to the much faster ramp rates in HRSGs compared

with conventional boilers, differential thermal expansion between components and condensate accumulation due to ineffective drainage. More recently, designers have paid some attention to thermal fatigue and condensate management issues. However, recent experience on plant has highlighted problems in superheaters and reheaters due to differential thermal expansion, condensate migration and attemperator overspray, and problems in economisers and preheaters due to poor flow distribution and thermal quench.

The *principal damage mechanisms* are identified for the various components in HRSGs. Most of the tube failures in cycling HRSGs are caused by thermal fatigue (creep-fatigue), flow assisted corrosion (FAC), corrosion-fatigue and various forms of corrosion under deposits in the evaporators. All of the major damage mechanisms are discussed in detail. Water chemistry control is also discussed.

In both horizontal and vertical gas flow HRSGs, the heat transfer tubes are finned and are typically arranged in dense tube banks in order to improve heat transfer. In general, due to the compact nature of the design, the *accessibility* to components in HRSGs is restricted and this presents difficulties for inspection and repair. Access to the headers is easier in vertical units but, for both types of HRSG, inspection and repair of damaged tubing is difficult and, in some cases, impossible using conventional techniques. Repairs to tubes within tube bundles requires "cutting your way in and welding your way out". The re-welding of large numbers of tubes under site conditions and with limited access and limited visibility, particularly in difficult locations such as header/tube welds, results in welds of dubious quality and further failures may occur after a relatively short time. Instead of tube replacement, the leaking tubes are frequently blanked off at the header stubs to allow the unit to be returned to service as soon as possible. These issues have been discussed in this report together with the recommendations for overcoming these difficulties.

New developments for repair of tube-to-tube welds and tube-to-header welds are discussed, and a number of novel inspection techniques are considered:

- Remote inspection of extended lengths of finned tubing using long-range guided wave ultrasonics.
- Time-of-Flight Diffraction (ToFD) ultrasonic testing for locating and sizing cracks in piping welds, header ligaments and T-piece connections.
- Linear phased array ultrasonic testing for inspection of tube-stub welded joints, girth welds and header ligaments.
- Focused annular-array imaging ultrasonic inspection for detection of incipient creep damage in piping welds.
- Development of sensors and systems for wireless on-line monitoring of strain (etc) in high temperature plant components.

Guidelines and recommendations are presented for:

- Maintenance and inspection of the waterside/steam-side and the gas-side of HRSG pressure parts, casings, ducts, exhaust stack and other structural components, and valves.
- Monitoring temperature, strain and water chemistry (conductivity, pH, dissolved oxygen, etc) in HRSGs.
- Repair of tubes, headers and piping.

- Asset and maintenance management, including pre-operational cleaning, procedures for start-up, shutdown and lay-up, and plant life management philosophies, including probabilistic assessment of component integrity and Risk Based Maintenance.

For ease of reference, a detailed chart of components, their maintenance problems and the engineering strategies/ solutions to deal with them has been produced and can be found in Appendix A.

In this report, recommendations are presented for the design and operation of HRSGs which will mitigate problems in superheaters and reheaters due to differential thermal expansion, condensate migration/quenching and attemperator overspraying, and improve the cycling capability of economisers and preheaters, steam drums and interconnecting piping.

In the final section of the report, recommendations are made for *further R&D* and demonstration work related to materials and welding issues, advanced ultrasonic inspection techniques, on-line monitoring, and application of probabilistic component life assessment and Risk Based Maintenance.