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Status of Siemens Steam Generator Design and Measures To Assure Continuous Long-Term Reliable Operation

By

Günter Hoch

Siemens AG / KWU NDM 2

P.O. Box 3220

91050 Erlangen

Germany

Abstract

Operating pressurized water reactors with U-tube steam generators have encountered difficulties with either one or a combination of inadequate material selection, poor design or manufacturing and an insufficient water chemistry control which resulted in excessive tube degradation.

In contrast to the above mentioned problems, steam generators from Siemens/KWU are prooving by operating experience that all measures undertaken at the design stage as well as during the operating and maintenance phase were effective enough to counteract any tube corrosion phenomena or other steam generator related problem.

An Integrated Service Concept has been developed, applied and wherever necessary improved in order to ensure reliable steam generator operation. The performance of the steam generators is updated continiously, evaluated and implemented in lifetime databases. The main indicator for steam generator integrity are the results of the eddy current testing of the steam generator tubes. Tubes with indications are rated with lifetime threshhold values and if necessary plugged, based on individual assessment criteria.

1. Introduction

Operating pressurized water reactors (PWRs) with U-tube steam generators (SGs) have encountered difficulties associated with either one or a combination of inadequate material selections, poor design and an insufficient water chemistry which resulted in excessive tube degradation. Tube degradation is related to corrosion phenomena such as wastage, pitting, intergranular attack (IGA), primary water stress corrosion cracking (PWSCC), intergranular stress corrosion cracking (IGSCC) and other phenomena, such as denting, flow induced vibration fretting and wear (Figure 1-1).

In contrast to the above mentioned tube degradation problems that have been encountered worldwide, SGs of Siemens/KWU design have proven by operating experience that they are very efficient in minimizing tube corrosion and wear or any other SG-related problems.

In the beginning a multiple step concept was developed, applied and – wherever necessary – improved in order to ensure troublefree operation. The main elements for this success were thorough design engineering, proper material selections as well as stringent requirements and quality control for fabrication accompanied by adequate water chemistry requirements.

In order to be prepared to counteract tube degradation problems, a wide range of maintenance, inspection and repair techniques were developed and successfully applied.

The performance of the steam generators is continuously monitored and the data added to a lifetime data base. The major indication for the SG integrity is still the eddy-current testing of the SG tubes. Tubes with indications are rated with lifetime threshold values, and SGs affected by tube damages are inspected and repaired, if necessary, based on individual assessment.

2. Design Engineering

2.1 General Criteria

Siemens/KWU steam generator basic design features have been implemented only after careful experimental and/or analytical investigations. That is the reason why for more than 27 years the design of the steam generators has been ensuring continuously troublefree operation and easy inspection as well as maintenance.

The following main design criteria were considered:

- Avoid concentration of impurities by avoiding heated crevices and flow stagnation zones.
- Minimize residual stresses in the tubes by selecting adequate innermost tube bend radii as well as using an improved process for the tube to tubesheet connection.
- Minimize tube vibration by compact tube bundle assembly
- Install sufficient heat transfer area to compensate for tube plugging and fouling as well as to achieve thermal power uprating requirements (e. g. 6 to 12 %).
- Provide adequate access for inspection and maintenance, especially for tube sheet lancing.
- Minimize the moisture carry over
- Minimize thermal shocks on feedwater nozzle and also avoid the potential for water hammer.

Additionally to the a. m. criteria Siemens provided water chemistry guidelines which are especially valid for Siemens/KWU steam generators and enable the utilities to operate the plant more flexible.
Figure 2-1 shows the principle design features.

2.2 Design Improvements

In order to meet customers' requirements for replacement steam generators the standard design was modified in a way to comply with the outer dimensions of the original steam generator as well as with the geometrical locations of the nozzles as far as necessary. All proven design features were then implemented to the replacement steam generator.

Siemens/KWU developed a distribution system for the auxiliary feedwater supply which was decoupled from the main feedwater supply inside the SG (Figure 2-2). The design minimizes thermal loadings of the SG internals as cold feedwater is heated up to near saturation temperature through direct condensation of steam. Additionally it minimizes the potential for water hammer as steam can escape vertically.

In order to exclude any potentials for water hammer in the main feedwater distribution system Siemens/KWU designed a system in a way that the feedwater nozzle is located below the ringline, namely in the cone of the steam generator (Figure 2-3). The inclined admission of feedwater in the nozzle area and vertical connection to the ringline precludes steam trapping if steam should have formed after long feed interruption.

For steam generators having a ferritic flow limiter installed (either a one hole or a seven hole venturi) Siemens/KWU is developing a galvanic procedure to produce a nickel layer on the venturi surface in order to minimize the pressure drop over the flow limiter and to avoid long-term surface roughening effects (Figure 2-4).

By these above mentioned measures Siemens/KWU furthermore improves the design of their steam generators and by this even being more attractive for utilities' consideration.

2.3 Maintenance Aspects

Besides the fact that only proven design features have been implemented in the Siemens/KWU steam generators the accessability into the steam generator as well as the access to the steam generator internals itself is of major importance. Therefore, Siemens provides a wide range of access openings for the steam generator. Sufficient access is for example provided to both chambers of the primary channel head. The design of the manway covers, studs and nuts allows the user of stud tensioners which allows for a time reduction for the opening and closing process, and therefore contributes to the ALARA concept. The secondary side of the steam generator is equipped with a largely sized manhole which also follows the ALARA concept.

All other openings can be located at strategic locations taking into account maintenance aspects as well as operating experience (Figure 2-5).

Four handholes above the tube sheet facilitate the tube sheet lancing procedure as well as the visual inspection of the tube sheet. The pitch of the tubes is selected in a way that lancing and visual inspection can be performed effectively.

Other openings allow for access to the internals such as flow distribution baffle, innermost tube bends, tube bundle head, feedwater ringline, steam driers, and steam outlet nozzle.

All these above mentioned features provide the basis for taking all necessary measures during outages to assure a continuous long-term reliable operation of the steam generators.

3. Long-Term Reliable Operation

In order to achieve the aim to keep the steam generators in service the Integrated Service Concept of Siemens/KWU provides the adequate tool.

This concept incorporates preparation, execution and documentation of all necessary service activities as well as the accompanying engineering activities required for an overall evaluation of the steam generators.

The necessary individual services, such as inspection and cleaning, are harmonized in detail and grouped together on the basis of results obtained from operation and inspections. This reduces necessary interfaces and coordination of work to be carried out by different parties involved. Personnel requirements are planned as well as possible and minimized through the exploitation of synergy effects together with other outage operations.

The operating experience accumulated is utilized to ensure a complete and comprehensive assessment of the steam generators.

The integrated concept is based on a four-step approach (Figure 3-1):
- Creation of a data base, development of a tube integrity concept
- Assessment of components and connected systems
- Maintenance consultancy
- Steam generator maintenance.

These four steps assure optimum steam generator availability from the points of view of both safety and economical efficiency.

4. Operating Experience

All the before-mentioned features and measures result in an excellent operational record of the Siemens/KWU steam generators.

As of the end of 1998 a total of 80 Siemens/KWU steam generators have been in commercial operation worldwide. This number also includes six replacement steam generators for Ringhals 2 and 3 equipped with Inconel 690 TT tubes. The 350,000 tubes in service accumulated 1,107 SG operational years. Only a neglegible number of 0.4 % of tubes are plugged. Figure 4-1 summarizes the operational experiences.

As far as the SG tubes made out of Incoloy 800 mod are concerned, phosphate wastage was in the past the only mechanism of significance experienced in the Siemens/KWU plants operating under phosphate treatment.

In addition to several secondary system improvements and the modification to the water chemistry as well as tube sheet lancing activities during outages have proven suitable means of restricting the progress of wastage. Since 1985, wastage corrosion has no longer been an issue for old Siemens/KWU SGs.

The main degradation phenomenon since then was of the fretting type, mainly caused by loose parts or structural components such as anchor nuts.

Coming to plant outages due to steam generator problems, the average rate in the U.S. is given to 3.3 % until the year 1997.
For the German plants this figure results in less than 0.1 %, confirming the effectiveness of the Siemens/KWU design and operating concept of their steam generators.
Neither at this time nor in the future any replacements of steam generators have to be anticipated for Siemens/KWU steam generators.

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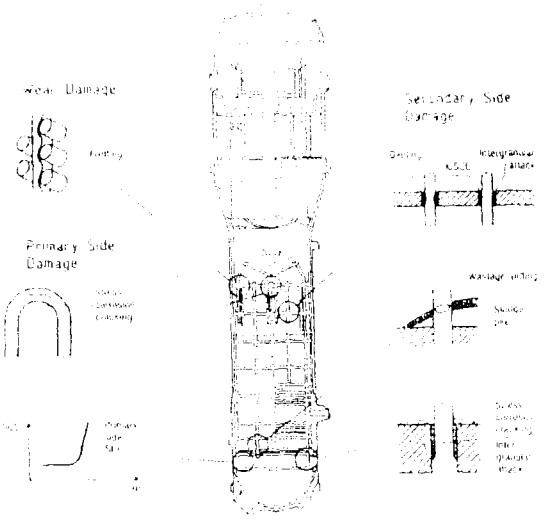
Overview on Worldwide Steam Generator Problems



Main Types of Damage Occuring in Steam Generators

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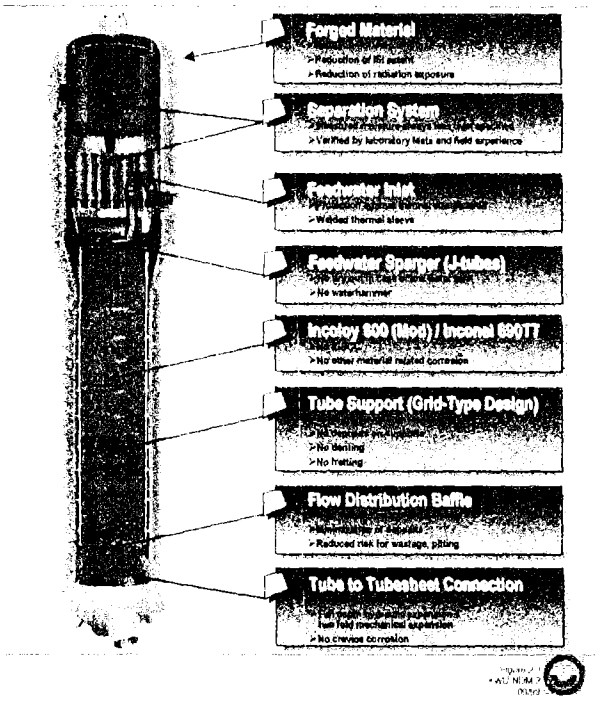
Principle Design Features



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Design Improvements

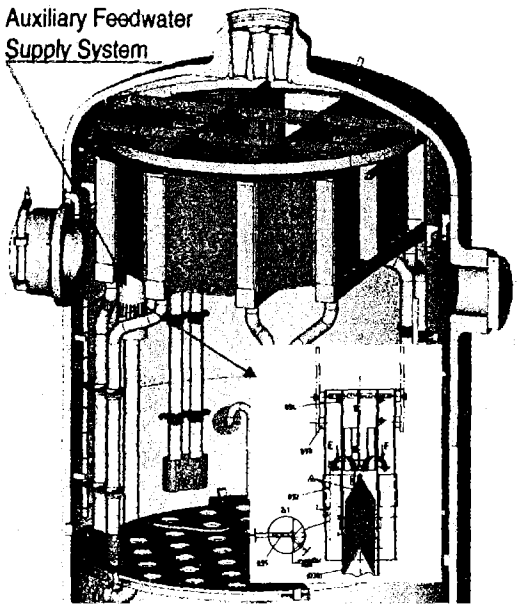

Figure 2-2
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Design Improvements

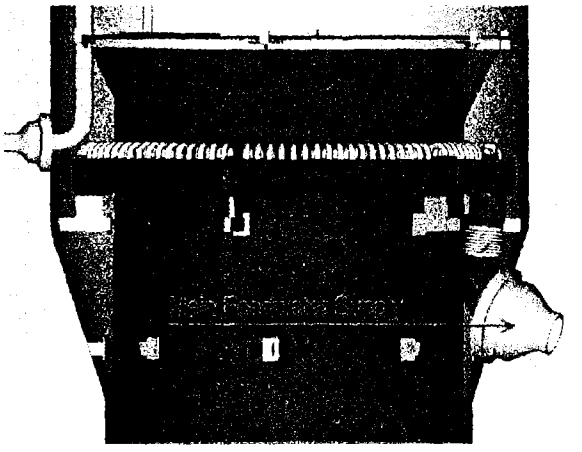

Figure 2-3
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Design Improvements

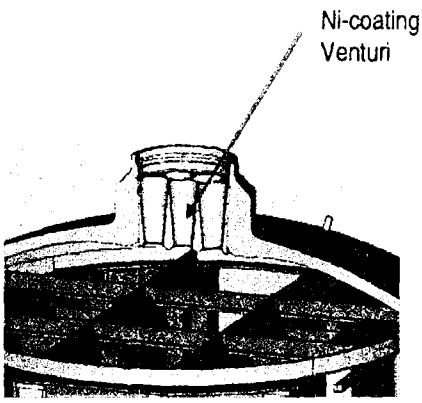

Figure 2-4
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Inspection Openings

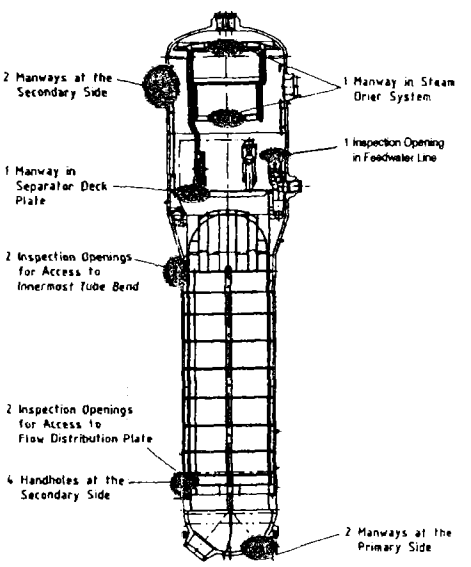

Figure 2-5
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Integrated Service Concept

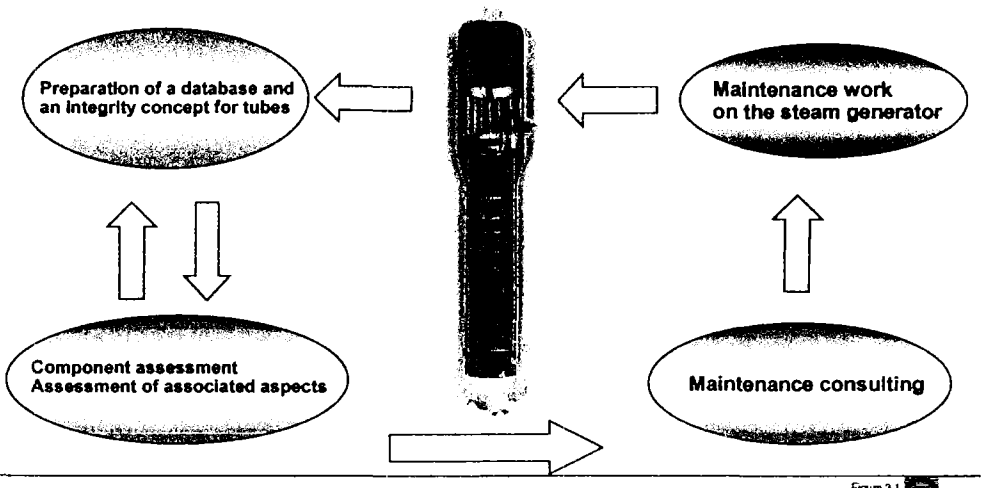

Figure 3-1
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Operating Experience

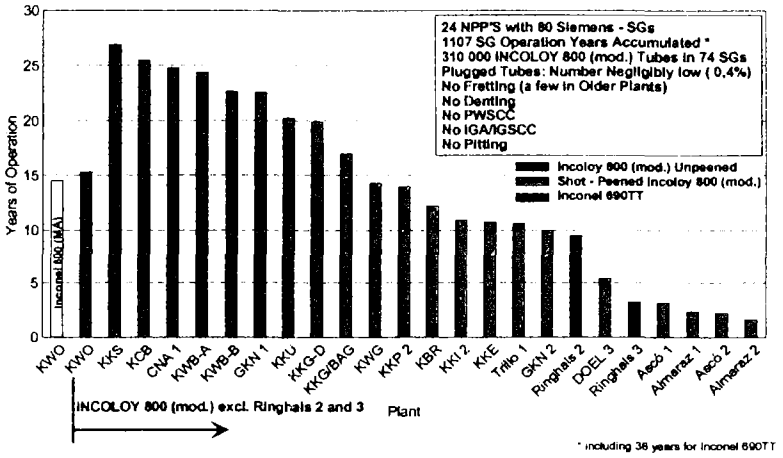

Figure 4-1
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