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Flash Chamber Design for the AM600

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1. Introduction

The AM600 (Advanced Modern 600 MWe) represents the conceptual design of a turbine island with a capacity in the range of 600 to 700 MWe, a 'grid appropriate' design for emerging markets with growing electricity demands. The AM600 is intended to be coupled with a Nuclear Steam Supply System (NSSS) with a capacity of 1800 to 2000 MWt.

Feasibility design studies have been previously reported [1, 2]. Continued design work has advanced the concept to a fully completed and documented initial design. Reported here are details for one innovative aspect of the design not previously used in the nuclear steam cycle, condenser flash chambers made possible by the single cylinder low pressure turbine used for the AM600.

2. Background

The AM600 incorporates the conventional Rankine steam cycle with regenerative heating and reheat employed for all modern day Light Water Reactor (LWR) plants. By constraining the AM600 to using a half speed turbine-generator (T/G) set in 50 Hz markets for countries with high heat sink temperatures (>20°C), the design is able to be based on a single low pressure turbine rotor. This T/G design has been developed and analyzed to demonstrate excellent rotordynamic characteristics [3]. Using this design along with the detailed design of the low pressure feedwater heaters [4], dimensional specifications for the AM600 layout were completed including the arrangement of the T/G shaftline and the span of the main condenser along the shaftline.

The AM600 design incorporates a single condenser shell with access to both sides of the shell. This permits extensions of the condenser pressure boundary to accommodate various services such as dumps for feedwater heater drains and turbine bypass steam flows. This extended boundary, termed 'flash chambers' enhances conventional condenser design in many areas ranging from thermal efficiency to modular design, as well as simplified construction of components and erection activities. The design and other aspects for the AM600 flash chambers are described below.

3. Design

The AM600 main condenser sizing is based on the AM600 steam cycle and the dimensioning of the T/G shaftline. Once these dimensions are established, the layout of the flash chambers can be developed as shown in the exploded three dimensional view per Fig. 1 below.

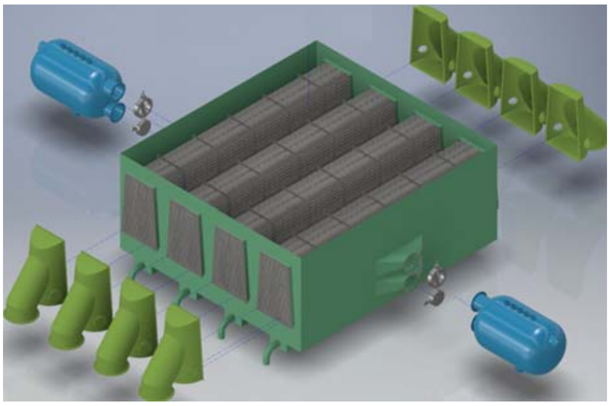

Fig. 1. AM600 condenser showing flash chambers (exploded)

Design considerations related to flash chambers (depicted in blue) and the interface with the AM600 steam cycle are provided in the sections below.

3.1. Functional design

In the AM600, the main condenser is designed to accept exhaust flow from the low pressure turbine and low pressure glands. All other flows are directed to the flash chambers. This includes normal flows from the 1st point feedwater heater drains, normal and startup feedwater heater vent flows, emergency feedwater heater drain flows, turbine bypass flows, valve leakoffs, as well as startup vents and drains.

Drain flows are introduced to the flash chambers via spargers which run the length of the flash chambers similar to standard designs found in deaerators.

Steam flows are introduced directly to the chamber with minimal need for impingement plates or (dispersion) spargers as there are no condenser tubes which require protection.

During normal operations, the flash chambers are isolated from the condenser. Steam introduced to the chambers condenses on the sprayed liquid producing a flash chamber pressure which is slightly higher than the operating pressure in the condenser. Drains from the flash chamber then leave via a bottom nozzle to be piped to a lower elevation (i.e., to avoid flashing) where they are mixed with leaving hotwell drains to provide suction for the condensate pumps.

To control flash chamber pressure, particularly when accepting turbine bypass flows, the chamber is separated from the condenser shell by a large butterfly valve with control 'shark tooth' trim. This permits the differential pressure to be regulated via automatic control of the position of the butterfly valve. On High-High flash chamber pressure, the valve will open to the condenser to pass sufficient steam and control pressure. In the event of loss of pressure control, each flash chamber is provided with a large bore rupture disk vented to the condenser shell.

3.2. Design criteria

The normal operating liquid inventory in the chambers and associated header piping will be combined with useable volume in the hotwell to meet the required inventory requirements for the Condensate System (e.g., 5 minutes of full flow).

Sizing of the sparger and inlet nozzles will follow standard industry guidelines for deaerator and condenser design.

Criteria related to fabrication and construction details will follow standard industry practice and incorporate lessons learned from more than fifty (50) years of commercial nuclear power operations (e.g., Flow Accelerated Corrosion (FAC) concerns).

3.3. Thermodynamic design

There are several motivating factors related to incorporation of flash chambers into the AM600 design, including some benefits to the steam cycle efficiency.

In particular, the isolation of non-turbine flows from the main condenser shell allows these flows to be heated relative to leaving hotwell flows. This reduces the heat load to the condenser (>3%) resulting in a slightly lower condenser backpressure, reducing exhaust losses.

In addition, by preserving the 'mixed' energy of the drains and vents, the temperature of condensate entering the 1st point feedwater heater is increased, reducing the demand for steam extraction from the low pressure turbine. Typical mass and energy flows for the condenser system are illustrated per Fig. 2 below.

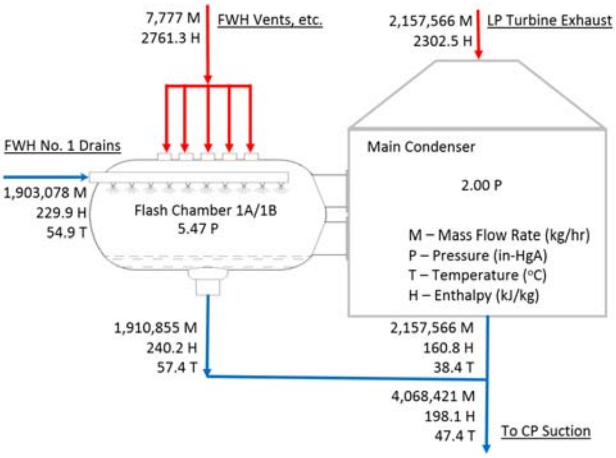

Fig. 2. AM600 condenser / flash chamber heat balance

3.4. Hydraulic design

Hotwell and flash chamber drains are initially separate requiring combination prior to reaching the condensate pump suction. This is accomplished by standard pump suction piping design and headering. Note that the drains must be mixed at a lower elevation to prevent flashing. However, the degree of heating of the flash chamber drains and the differential saturation pressure relative to hotwell drains is small (<0.5-m). Thus the pipe routing and mixing header location, which must accommodate an elevation change of ~6-m between the hotwell operating level and the condensate pump suction nozzles can be easily accomplished using standard design practice.

The vapor pressure of fluid entering the condensate pump will be elevated by ~1/2 the saturation pressure difference between the two equal flows hotwell vs. flash chamber, or <0.25-m. This change to NPSHa is small can be easily addressed in the specification of the pumps.

3.5. Mechanical design

Flash chamber pressure boundary design is addressed in Section 3.6. The flash chamber sparger will be designed for low head with liquid spray and dispersal consistent with the design duty for condensing the steam which is introduced to the chamber. The size of the chamber is not particularly constrained by available space adjacent to the condenser shell and thus sizing can be adjusted to meet internal spray and inventory requirements (see Sections 3.2 and 3.3).

The pressure control valve is a standard design as commercially offered for gas flows. A typical example of the type of valve to be used is illustrated in Fig. 3 below.

Fig. 3. Flash chamber pressure control (butterfly) valve

When in the open position, this valve will introduce high velocity steam flow to the condenser shell. Structures to disperse the flow and protect the condenser tubing will be required. The design duty for such structures is expected to be within past vendor design experience and covered by standard industry practice. Despite very high flows, liquid entrainment can be addressed within the flash chamber and is expected to be minimal.

3.6. Structural design

The flash chambers and associated piping, fittings, flanges, and appurtenances are specified for design to the ASME Boiler and Pressure Vessel Code (e.g., Section VIII for the vessel, ANSI/ASME B31.1 for power piping).

3.7. Configuration

While the detailed design of the flash chamber will be left to experienced vendor designers, a 'mock up' design configuration is illustrated in Fig. 4. below.

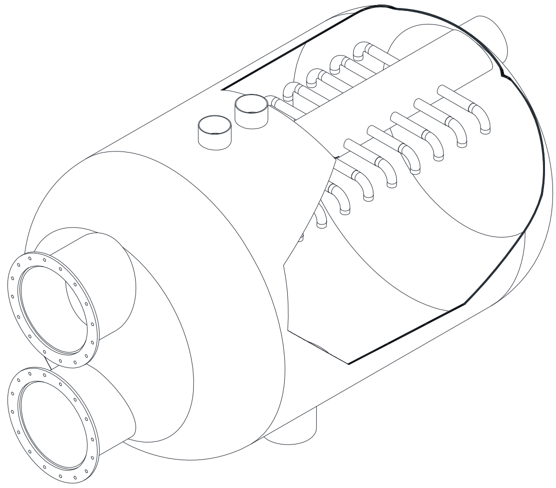

Fig. 4. Flash chamber configuration (preliminary)

Nozzles are indicated as steam inlet (top), drains inlet (backside, extension of sparger), drains outlet (bottom), and interface with condenser (venting valve – top nozzle, and rupture disk – bottom nozzle). Venting of non-condensables will be accomplished via a small bypass hole drilled in the pressure control valve disk.

3.8 Layout

The detailed general arrangement for the AM600 turbine building has been developed and is available separately [5]. Provided below (Fig. 5.) is the general arrangement of the lowest turbine building elevation showing the flash chambers in relation to the main condenser and condensate pump pit.

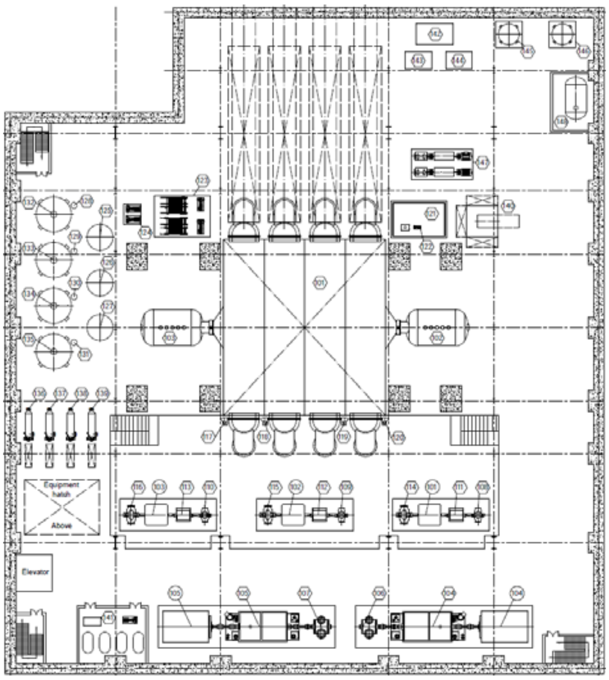

Fig. 5. Layout of flash chambers and condensate pumps

4. Summary

The flash chamber design for the AM600 is made possible by the single cylinder low pressure turbine section (which allow access to both sides of the condenser shell along the length of the T/G shaftline). By reducing the flow in the hotwell, and isolating the feedwater heater drains and vents from the condenser shell, several benefits accrue. These include:

1) <u>Fabrication</u> – A smaller condenser shell improves the potential for modular fabrication.
2) <u>Transportation</u> - The condenser shell is made smaller with use of flash chambers, reducing the effort for the heavy haul of the shell to the turbine building and for setting the shell on the foundation.
3) <u>Erection</u> – Use of flash chambers improves the ease of field installation. Vent and drain lines can be routed to prefabricated header pipes local to the flash chambers, eliminating welding to nozzles on the condenser shell.
4) <u>Corrosion Potential</u> - Reduced hotwell flows reduce corrosion potential.
5) <u>Response to Tube Leak</u> - Reduced hotwell flows improve the efficacy of condenser zone isolation on indication of condenser tube leak (e.g., on high conductivity).
6) <u>Condenser Shell Size</u> - Design constraints (i.e., which require clearance between the tube bundles and side walls for condenser dumps) are eliminated permitting a shorter span for the condenser and for turbine table support columns.
7) <u>Feedwater Heater Design</u> - The 1st point feedwater heater can be designed with a smaller drain cooler zone without incurring a significant penalty on heat

rate (i.e., since the heat in the drains is not rejected). With a smaller drain cooler zone the potential: (i) for feedwater heater tube damage, and (ii) for turbine water induction due to drain cooler flashing following turbine trip is significantly reduced.

8) <u>Heat Rate</u> – Also as a consequence, the unit heat rate is improved when capturing the heat content of normal operating feedwater heater vent flows. In addition, the condenser heat load is reduced >3%, improving backpressure and turbine performance.

5. Future Work

The inclusion of the flash chambers in the design presents the potential for future design development and further optimization. Specifically, since the flash chamber flows are sourced from condensed steam, by nature they are demineralized. In the current design, flash chamber flows are combined with flows from the hotwell, and sent to the filter units and mixed bed demineralizers. This mixing of drain flows: (i) reduces the concentration of contaminants (e.g., silica, halides, sodium, etc.) while increasing (ii) the volumetric flow rate, and (iii) operating temperatures. All three of these consequences of the mixed flow steam add to unit cost (e.g., higher capacity demineralizer system) and reduce the efficiency of demineralization (reduced concentrations and higher temperatures impacting sulfate release).

Flash chamber drains represent ~50% of total condensate flow and do not require demineralization as they are equivalent to flows in steam cycles which employ drain forwarding (i.e., drains which do not require demineralization). Considering this, potential design improvements can be evaluated. Specifically, the design could be modified along the following lines:

1) <u>Hotwell Drains</u> – Hotwell drains would be segregated and passed through (reduced capacity) condensate pumps to filters, demineralizers, low temperature heat recovery services, and then on to the condensate booster pump suction header.
2) <u>Flash Tank Drains</u> – Flash tank drains would be send to new high head condensate pumps, then on to filter units, and then to the discharge header of the condensate booster pumps, bypassing the mixed bed demineralizers and low temperature heat recovery services.
3) <u>Condensate / Condensate Booster Pumps</u> - The capacity for the current condensate and condensate booster pumps would be reduced by 50% to accommodate only the hotwell drains, possibly reducing the number of pump trains from three (3) to two (2). Developed head for the pumps would be unchanged.
4) <u>Filter / Demineralizer System</u> – The capacity for the current filter and demineralizer trains would be reduced by 50% to accommodate only the hotwell drains.

To effect the changes identified above, proposed system and component changes are as follows:

1) eliminate one set of condensate and condensate booster pumps (the three (3) set design becomes two (2) sets),
2) reduce low pressure filter capacity by 50%,
3) reduce low pressure demineralizer capacity by 50%,
4) add high pressure filter capacity for flash chamber drains (equal in capacity to low pressure system),
5) add variable speed high head pumps for flash tank drains (two (2) pump sets), and
6) add level control instrumentation to flash chambers.

The proposed changes identified above are expected to show benefits in the following areas:

1) reduced space requirements and cost associated with installation and operations for mixed bed demineralizers,
2) lower operating temperatures in demineralizers, reducing leaching of sulfates,
3) lower service side operating temperatures for heat recovery services, improving operability,
4) improved response to condenser tube leaks and chemistry upsets in the condensate system, and
5) reduced size of headers improving the layout and design for the condensate system.

The proposed changes also present challenges in the following areas:

1) increased component count (for pumps and pump drivers) increasing complexity and cost, and
2) increased complexity for operations.

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