GA-A--20717

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MHTGR STEAM GENERATOR ON-LINE HEAT BALANCE, INSTRUMENTATION AND FUNCTION

by

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Paper to be presented at the Embedded Topical Meeting on "The Next Generation of Nuclear Power Plants – A Status Report," November 10–14, 1991, San Francisco, California

Work Supported by
Department of Energy
Contract No. DE-AC03-89SF17885

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GENERAL ATOMICS PROJECT 7600
SEPTEMBER 1991

GENERAL ATOMICS MASTER

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ABSTRACT

Instrumentation is used to measure the Modular High Temperature Gas-Cooled Reactor (MHTGR) steam generator dissimilar metal weld temperature during start-up testing. Additional instrumentation is used to determine an on-line heat balance which is maintained during the 40 year module life. In the process of calibrating the on-line heat balance, the helium flow is adjusted to yield the optimum boiling level in the steam generator relative to the dissimilar metal weld. After calibration is complete the weld temperature measurement is no longer required. The reduced boiling level range results in less restrictive steam generator design constraints.

INTRODUCTION

The MHTGR is an advanced reactor concept being developed as a cooperative program between the U.S. Department of Energy (DOE), the nuclear industry represented by General Atomics, ABB-Combustion Engineering, Stone & Webster Engineering Corp., Bechtel National, Inc., and Oak Ridge National Laboratory and the utilities represented by Gas-Cooled Reactor Associates.

The standard MHTGR plant design consists of four reactor modules, each module rated at 450 MW(t) which produces superheated steam at 540.6°C (1005 F) and 17.34 MPa (2515 psia). The four reactor modules are coupled to individual turbine generators to produce a net electrical power output of approximately 700 MW(e). The four - module plant is divided into two major areas; the Nuclear Island (NI) which contains the reactor, steam generator, helium circulator, vessels, enclosures and supporting systems; and the Energy Conversion Area (ECA), which contains the turbine generator and steam and feedwater systems equivalent to a similar sized fossil generating unit. Each reactor module is housed in a vertical cylindrical concrete enclosure which is fully embedded in the earth.

MHTGR STEAM GENERATOR DESIGN

The MHTGR steam generator must satisfy a number of constraints and economic considerations to supply steam at 540.6°C (1005 F) and 17.34 MPa (2515 psia) at 100% to 25% steady-state power levels, and also meet steam generator structural and design life requirements. The steam generator design concept selected for the MHTGR which best meets these requirements is a once-through, uphill boiling unit with two helical bundles. Primary coolant helium is on the shell-side and secondary coolant water is on the tube side. The two helical bundles require differing material properties of 2 1/4 Cr-1 Mo tubing for the economizer/evaporator and initial superheater, and Alloy 800H tubing for the finishing superheater. The two helical bundles are joined with a dissimilar metal weld.

To satisfy the conservative design criteria used for steam generator design, it is important to keep the two phase transition between water and steam at a desired location relative to the dissimilar metal weld during steady-state steam generator operation. The frequency of two phase level variation is affected by the MHTGR operational requirement to cover the load range from 100% to 25% with floating feedwater temperature, and the requirement to follow grid load cycles. Variation of this two phase (boiling) level and long term wetting and drying of the dissimilar metal weld could cause stress corrosion cracking in the Incoloy portion of the tubes. High levels of superheat could cause insufficient margin to creep fatigue code allowable stresses in the ferritic tube portions. Limiting the variation of the two phase level increases the number of constraints on the design process. By accounting for these constraints early in the design phase and utilizing an on-line heat balance, the steam generator design can satisfy the performance requirements without exceeding limits imposed by technical and economical considerations. In addition, the on-line heat balance aids in recalibrating plant operation for maximum efficiency.

INSTRUMENTATION

An earlier attempt at calculating the boiling level utilized the steam generator helium inlet flow, however, this measurement could only achieve an accuracy of +/- 3% . This amount of error combined with steam generator heat transfer uncertainty resulted in an excessively large boiling level range at the dissimilar metal weld making the steam generator design challenging within the constraints of the design requirements, existing materials and manufacturing tolerances. When it became obvious that helium flow could not accurately be used to calculate boiling level, measurement of the dissimilar metal weld temperature was considered. Because the dissimilar metal weld is insulated, the metal temperature closely represents the steam temperature at this location.

With further study, it was determined that installing temperature probes on the dissimilar metal weld for the purpose of steam generator performance measurement is feasible. The only temperature probes considered were thermocouples (TCs) and/or resistance temperature devices (RTDs). By using either of these devices, an accuracy of +/- 1% of reading could be obtained without pushing limits for commercially available instruments. This was found to be adequate to allow a successful steam generator design completely within the vendors' design and material constraints, and manufacturing tolerances. However, due to the necessary routing in the steam generator, these probes would not be replaceable. This would require not only having sufficient measurement locations to provide a meaningful statistical average, but adding spares in case of early probe failure. Of the 559 dissimilar metals welds in the steam generator bundle, 25 locations were chosen for statistical average sampling and spares. This number of measurements is expected to be sufficient to calculate an average temperature for steady-state operating conditions.

For the on-line heat balance effort, instruments were chosen to include those able to monitor the amount of heat entering and leaving the steam generator and the feedwater flow. Primary heat enters the steam generator directly from the reactor via the helium primary coolant loop. Heat is removed via the secondary coolant loop made up of feedwater and main steam. Steam generator parameters to be measured are the following:

1. Inlet helium temperature
2. Outlet helium temperature
3. Inlet feedwater temperature
4. Outlet steam temperature
5. Feedwater flow

These measurements will be made with TCs and/or RTDs and turbine flow meters.

FUNCTION

With the above four temperature and one flow measurements, the on-line heat balance and the efficiency of the steam generator can be determined. The heat balance can also be used to track other steam generator performance data, such as fouling, as an indication of required maintenance. However, the key function of the on-line heat balance is to assure that the correct boiling level in the steam generator is maintained during 40 years of module life. This is accomplished by calibrating the on-line heat balance incorporating the dissimilar metal weld temperature measurements made during start-up testing. The dissimilar metal weld measurements will not be required after completion of start-up testing.

In the process of calibrating the on-line heat balance, the helium flow is adjusted to yield the optimum boiling level in the steam generator over the load range as a function of feedwater flow. This helium flow calibration as a function of feedwater flow (module load) is maintained during module operation until adjusted during recalibration, if necessary. This on-line heat balance methodology results in a significant reduction in the boiling level range thereby resulting in less restrictive steam generator design constraints.

SUMMARY

By incorporating an on-line heat balance calibrated during startup, the temperature range of the dissimilar metal weld can be reduced from 82°C (180 F) to 21°C (70 F). As a result, margins from limits on stress corrosion cracking and creep fatigue code allowable stresses are significantly increased, thus providing relief for the steam generator design. The capability to maintain the optimum boiling level also results in a reduced feedwater pressure requirement for the benefit of the overall reactor module efficiency.

In conclusion, by using the dissimilar metal weld temperature to calibrate the steam generator inlet helium temperature during start-up, and an on-line heat balance to maintain this calibration during plant life, the reactor module performance can be optimized and the steam generator design process simplified. This results in a highly reliable and cost effective steam generator design for the next generation MHTGR.

ACKNOWLEDGMENT

The authors would like to thank the U.S. Department of Energy for approval to publish this work, which was supported by the San Francisco Operations Office Contract DE-AC03-89SF-17885.

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