ROUGH DRAFT

UTILIZATION OF A ONCE-THROUGH TWO-TUBE BOILER IN THE DEVELOPMENT OF A CONTROL SYSTEM FOR THE 630A NUCLEAR STEAM GENERATOR

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INTRODUCTION

A two-tube, once-through boiler and associated control was designed and placed in operation to aid in the final determination of the optimum 630A power range control system. It was also used to obtain steady state information to aid in the final boiler design.

SUMMARY

The use of the boiler proved that it was possible to control the steam generator using integrated feedwater and airflow control loops. Test data verified the steady state analytical predictions for the boiler operation. It was also determined that the flow instability normally present in once-through boilers could be suppressed by orifices in the inlet to the boiler tubes.
DISCUSSION

Objective and Description

A two-tube, once-through boiler and associated control was set up to simulate the reactor, boiler, air loop, and control system to assure that the integrated system would be stable under all normal and emergency operating conditions, that both steady-state and transient requirements are met, that the various control loops function together properly, and that satisfactory operating procedures are developed.

An initial analysis had been performed on the analog computer. However, this simulation was not complex enough to take into account the complexities of the various inherent physical interaction of the boiler and also not to account for the actual physical hardware. In order to obtain information for the detailed analysis and final hardware specification, it was necessary to build up an actual boiler and tie the associated controls into it. A picture of the two-tube boiler is shown in Figure 1. Using the boiler with associated controls has several advantages over analog simulation: (1) it permits operation of an actual feedwater control which is probably the most critical loop in the system, (2) very valuable experience was gained in working with actual hardware, and (3) the cost of boiler and associated accessory control equipment was reasonable in terms of the experience and information obtained.

Through the use of the test rig, such things as the method of start up, control parameters, method of system integration, both steady state and transient system accuracy, control system responses and system stability could be determined. Although the inlet pressure to the boiler was only about 110 psia, a significant amount of heat transfer and steam generation data was obtained. Steady-state information relative to stability of boiling in parallel tubes was obtained. Stability of boiling in parallel tubes was investigated and reported on in a separate paragraph of this topical report.

A block diagram of the boiler and its control is shown in Figure 2. Demineralized water from an existing facility storage tank is supplied to the inlet of a high-pressure, triplex piston pump where it can be boosted to pressures up to 1400 psig. A back pressure regulating valve which bypasses flow around the pump is used to maintain the desired pump discharge pressure. The flow then passes through a valve which regulates the quantity of flow supplied to the boiler. The actual flow is sensed in a flow-measuring section just downstream of the control valve and, when the system is on automatic control, any error existing between this signal and the demanded flow causes the valve to move to correct the error. The flow next passes through a closed feedwater heater where its temperature may be increased up to approximately 350°F by steam which is generated in the boiler. The flow is then split to pass through the parallel boiler tubes. Provisions are made in the inlet of each tube for adding orifices to study stability of boiling in parallel tubes. A throttling valve is provided to set the desired back pressure on the valve. Steam for feedwater heating is
Discussion

Optimization and Description

A two-stage, once-through boiler and associated control was set up to simulate the boiler, control, and control schemes to ensure that the integrated system of the boiler, water make-up, and emergency operating condition states would be modelled and understood for general systems and component testing. The various control loops and control properties that are satisfied and operational in the various control loops are also tested to ensure the system meets the required performance.

In testing, a number of tests have been performed to verify the control of the system. These tests have been performed on both a simulated system and on a real system. The tests have been performed to verify the control of the system and to verify the control of the system in both a simulated and a real environment.

In order to obtain information for the general system and component testing, the various control loops and control properties are also tested.

To test the two-stage, once-through boiler and associated control, a number of tests have been performed. These tests have been performed on both a simulated system and on a real system. The tests have been performed to verify the control of the system and to verify the control of the system in both a simulated and a real environment.

In order to obtain information for the general system and component testing, the various control loops and control properties are also tested.
Figure 1 — Boiler assembly (Dwg. 219R847)
Figure 2 – Integrated feedwater-steam pressure loop and airflow-steam temperature loop
is bled off downstream from this valve. Fine control of the steam pressure is accomplished by sensing the steam pressure, referencing it against the desired value and using any error as a proportional plus integral signal to readjust the feedwater flow. An existing electric heater is used to raise the temperature of the 110 psia air supply to approximately 1200°F and to automatically maintain it at this temperature. The amount of airflow for a given operating point is scheduled if the amount of airflow is not correct for the desired steam temperature then it is compared with the reference temperature. Any resulting error is used to correct the airflow by means of proportional and integral control action.

**Test Results**

Initially the control method differed from that shown in Figure 2. The initial evaluation was with the control system arranged so that steam temperature trimmed feedwater flow and steam pressure trimmed airflow. This control scheme gave reasonably good performance as described in Reference (1). It had the disadvantage that the gain and reset adjustment of the feedwater loop were very critical at the higher feedwater flow rates. At feedwater flow below 20 percent stable operation could not be obtained. Investigating this instability it was found that higher steam pressure, lower steam temperature, lower inlet air temperature and higher feedwater temperature tended to make the system more stable. However, at operating points close to that required for the 630A, stable operation could not be obtained below 20 percent feedwater flow, and the control was changed to that shown in Figure 2.

On changing to the control method of Figure 2, stable operation was obtained down to less than ten percent feedwater flow. Gain and reset adjustment of the feedwater loop was not critical. A comparison of the control responses indicated much better stability without a sacrifice in transient or steady-state performance. Response curves are shown in Reference (2). Transient responses were obtained for integrated throttle changes of various amplitudes over the range of 10 to 70 percent power. Good performance was obtained for all of these transients. A typical response for an integrated change from 30 to 70 percent feedwater and airflow conditions is shown in Figure 3.

Test data correlations for steady-state operations indicated that the expected boiler performance related to heat transfer and fluid flow was obtained. These operations covered the range from about 10 percent to about 70 percent of normal flow rates. At about 30 percent flow parallel channel flow instability was noted both by flow measurement and tube temperature measurement indications. The use of inlet orifices to increase the liquid phase pressure drop relative to the boiling phase pressure drop confirmed that the flow instability encountered could be suppressed. With an increase of the design point operating pressure, from 850 psig to 1500 psig for the 630A Mark V, orificing may not be required. This requirement was analyzed in detail but tests indicated that higher pressure level reduces the instability effect. The most significant test results have been documented as follows:
Figure 3 - Transient response for integrated throttle increase from 30 percent to 70 percent of water and airflow conditions
a. Steady-state operating conditions are shown in Reference (3), page 199.

b. Flow stability test results are shown in Reference (4), pages 49 and 50, and in Reference (5).

Uncompleted Work

At the termination of the program a steam flow measuring system was being installed and instrumentation connected to it. Installation of this equipment was approximately 75 percent complete. It was planned to use the steam measuring system to correlate steady-state and transient results obtained during previous testing. The steam flow meter was also going to be used as the feedback element in the feedwater control. This would essentially put a lead into this loop and speed its rate of response.

Changes were also going to be made in the airflow control to make it more nearly approximate the expected 630A system. Airflow is controlled by a V-port type valve with its inherently non-linear gain characteristic. The planned 630A Mark V gas flow control would make use of a coupling control unit scheduled from the throttle. This unit would set the excitation to an eddy current coupling between an A.C. motor and a 20 to 200 cps A.C. alternator. The A.C. alternator would supply two induction motors which would drive the circulators. Information on these components was being obtained so that the throttle movement to gas flow characteristics could be better simulated in the two-tube boiler test setup. The characteristics would be much more linear than that represented by the V-port valve presently used. When component characteristics were available it was planned to schedule the valve position through an analog simulator to make the loop more representative of the 630A system. The effect of this change cannot be fully anticipated, however, it is expected that control performance at high power would be improved.

The control to the electrical air heater would be modified to make it approximate the thermal characteristics of the 630A reactor. For this it would first be necessary to make an analog study of the latest reactor core and obtain the required transfer functions. After obtaining the transfer functions, an analog computer would be used in an attempt to make the power delivered by the electrical air heater closely approximate the 630A reactor. When this was accomplished, all three control loops would represent the actual system and much more assurance of the validity of our testing would be possible.

Upon completion of this work a complete steam generator control system block diagram with appropriate transfer functions would be prepared.
Reports issued previously on the 630A Nuclear Steam Generator which include pertinent information on the two-tube boiler development include:

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