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FREQUENCY RESPONSE MEASUREMENTS OF THE EBWR
AUTOMATIC STEAM BY-PASS VALVE CONTROL SYSTEM

by

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4 FREQUENCY RESPONSE MEASUREMENTS OF THE EBWR AUTOMATIC STEAM BY-PASS VALVE CONTROL SYSTEM

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ABSTRACT

The steamby-pass system is designed to permit reactor operation at full power while varying the turbine-generator output from no load to rated power by diverting excess steam to the condenser.

System performance was checked prior to reactor power experiments by means of frequency response measurements which were made to ensure that operation was smooth over the entire flow range and that response times were adequate.

A number of malfunctions of the equipment were detected by means of the measurements and subsequently cleared up to provide adequate control response.

A brief description is given of a pressure signal generator which was developed to perform several of the measurements.

I. INTRODUCTION

The design concept of a direct-cycle reactor steam generator coupled to conventional electric power-generating equipment presented a unique combination. The BORAX experiments had demonstrated that in a boiling water reactor the power output of the core is strongly influenced by the volume of steam voids: large variations in the steam void content of the core must be avoided. These steam voids are sensitive to pressure; therefore reactor steam flow load has a strong influence on reactor power stability.

The EBWR is designed for normal operation at constant pressure and constant steam flow load irrespective of steam demand by the turbine. This is accomplished by the steam by-pass control system shown in Fig. 1. The difference between reactor pressure and a manually set pressure reference ($P - P_0$) is used to determine the total flow, as shown in the schematic diagram, Fig. 2. A signal is provided from the turbine admission valve (TA) to decrease the by-pass dump (BP) in direct proportion to the

FIG. I
STEAM BY-PASS REGULATING
VALVE AND CONTROLLER

amount of steam taken by the turbine. Also, a trip is provided so that, if the turbine-generator is dropped off the line, the steam load, ranging up to 20-mw output (68,000 lb/hr), is automatically diverted through the by-pass system. In this way, a constant load is maintained on the reactor to improve stability. If the steam load differs from the steaming rate, the pressure will change and adjust the by-pass valve until equilibrium between load and steaming rate is re-established.

The conditions for equilibrium are:

$$K_1 (P - P_0) = BP + TA = K_2 (RS) \quad (1)$$

where

P = reactor pressure

P_0 = manually set pressure

BP = by-pass valve position

TA = turbine admission valve position

RS = reactor steaming rate

K_1, K_2 = constants

The ratio of the constants gives the setting of the proportional band. The proportional band is adjustable in the controller by means of a mechanical linkage. The band has been set at a value of 25 psi for 20-megawatt steam load of 68,000 lb/hr.

In order to ensure that the dynamic response of the steam by-pass control system was adequate, and to provide data required to design automatic rod-positioning controls, a series of tests was devised to measure the transfer functions of the system. A detailed description of the control system follows to provide background for the tests which are described later.

II. DESCRIPTION OF CONTROL SYSTEM

A schematic diagram of the by-pass valve control system is shown in Fig. 3. The valve drive piston is operated by hydraulic oil at a pressure of 1000 psi. The piston is controlled by three jet-pipe hydraulic amplifiers, using oil at 100 psi from a pressure reducer. Each amplifier is a jet-pipe pivoted on a perpendicular axis, so that it directs a stream of oil between two holes in a face plate. When the jet-pipe is displaced toward either of the holes, a differential pressure between the holes results, with the higher pressure at the hole to which the jet-pipe is directed. Small mechanical directing forces on the jet-pipe can achieve a pressure differential of up to 50 psi.

FIG. 3
BYPASS VALVE CONTROL SYSTEM

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(1) A change in governor valve position moves a cam which transmits a force (through a spring) to jet-pipe A. This moves the pipe off center and changes a hydraulic pressure signal. The pressure change produces a force in opposition to the original force by means of a bellows and linkage. When the two forces are equal, the jet-pipe is returned almost to center. The hydraulic pressure signal produced is proportional to the position of the turbine governor valve, and it is piped from the turbine unit to the by-pass valve controller.

(2) Reactor pressure is transmitted to a bellows assembly in the controller through a water line connected to the reactor sight gage standpipe. The difference between the bellows force and the force exerted by the pressure reference spring, which is set by a motor operated from the control room, moves jet-pipe B off its center position until the force applied by the auxiliary piston through the feedback linkage recenters it. The auxiliary piston position is thus proportional to the difference between reactor pressure and the pressure reference. The proportional band may be set by varying the feedback linkage.

(3) The opposing forces on jet-pipe C are that of the bellows, which receives its pressure signal from the turbine governor valve, and a force proportional to the displacement of the feedback point of the summing bar. The displacement of this point is the weighted average of the displacements of the end points of the bar. If jet-pipe C is off center, the differential pressure will force the pilot valve to move until the differential is zero. With the pilot valve off center, the high-pressure oil supply will drive the by-pass valve piston to reposition the feedback point of the summing bar which forces jet-pipe C, and consequently the pilot valve, back to center position. The by-pass valve position is therefore equal to a constant times the reactor pressure error minus the turbine governor valve position. Both the by-pass and the turbine governor valves have linear flow versus valve position characteristics to maintain constant system gain.

III. MEASUREMENT OF CONTROL SYSTEM RESPONSE

Two series of frequency response measurements were made. The first obtained by-pass valve position response to reactor pressure variation or $[BP/(P-P_0)]$. The second measured by-pass valve position response to turbine admission valve variation or (BP/TA) .

The reactor pressure measurement required a pressure signal generator capable of producing nearly sinusoidal pressure variations with peak-to-peak magnitudes of about 15 psi at average pressures of several hundred psi with a frequency range of from 0.1 to 3 cps. A pneumatic device was designed and constructed (see Appendix A). The pressure signal was applied at a "tee" connection to the reactor pressure signal pipe near

the bellows. A fast response pressure transducer (variable capacitance-diaphragm type) and amplifier were used to measure the pressure signal. A differential transformer unit was used to measure by-pass valve position. The rectified differential transformer output and the pressure signal were graphed on a fast two-channel oscillograph. Magnitude and phase readings were taken from the chart, and the normalized response:

$$\frac{BP}{P - P_0} = \left(\frac{K}{X} \right) \left(\frac{x}{p} \right) ,$$

where

K = proportional band
 X = valve stroke
 x = valve motion
 p = pressure variation ,

was plotted. The comparison of response for proportional band settings of 25 psi and 50 psi is shown in Fig. 4. The difference in response results from the use of the internal loop feedback as a means for adjusting the proportional band.

Figure 5 compares the valve response at a proportional band setting of 25 psi for two conditions. One condition is the same as in Fig. 4. The second is with a "snubbing" valve in the leads from the pilot valve to the by-pass valve piston. The "snubbing" valve is a two-way check valve which blocks oil flow in either direction to the piston for pressures less than 350 psi. The purpose of the valve is to reduce by-pass valve motion for very small disturbing signals by the introduction of a dead band.

Measurement of the by-pass valve response to sinusoidal variation of the turbine governor valve was accomplished by disconnecting the cam drive rod from the governor linkage (Fig. 6) and connecting it to a variable speed reducer with a crank pin. The crank drive permitted sinusoidal excitation of the cam in the frequency range of interest. The response of by-pass valve position to turbine governor valve position with, and without the "snubber valve" in operation is plotted in Fig. 7. It was unnecessary to make proportional band setting a variable in this test. From the schematic in Fig. 3, it may be seen that the proportional band setting has no influence on the by-pass valve response to turbine valve variations provided the reactor pressure is held constant and jet-pipe B is centered. Such was the case in this test.

FIG. 4
MAGNITUDE AND PHASE OF BYPASS VALVE RESPONSE
TO REACTOR PRESSURE CHANGE WITH PROPORTIONAL
BANDS OF 25 psi AND 50 psi

FIG. 5
EFFECT OF "SNUBBING" VALVE ON MAGNITUDE AND PHASE
OF BYPASS VALVE RESPONSE TO REACTOR PRESSURE

FIG. 6
TURBINE ADMISSION VALVE POSITION TRANSDUCER

MAGNITUDE AND PHASE OF BY-PASS VALVE RESPONSE
TO TURBINE GOVERNOR SLIDE POSITION

IV. RESPONSE OF THE STEAM SYSTEM TO AUTOMATIC BY-PASS VALVE CONTROL

The general performance of the steam by-pass controller in solving Eq. (1) has posed some minor problems. Pressure errors arise because of inexact interchange between the turbine and by-pass flows. Minor adjustments in the P_0 reference setting are now used to correct these errors. Adjustment of the turbine admission slide cam ultimately will be used to overcome this problem, because, during periods of dynamic interchange, the total reactor steam flow load is altered until the reactor steam pressure integrates to the new value required to compensate for the interchange error. Another problem is a hunting action inherent in the hydraulic system, partly due to oil leakage past the valve actuating piston. This appears as random positioning of the by-pass valve, independent of the input to the control system. The "snubbing" valve reduces the magnitude of this variation, as shown in Fig. 8. The random positioning causes small variations in reactor steam flow. A portion of a 24-hour record of reactor steam flow is shown in Fig. 9 to indicate the improvement that results from the use of the "snubbing" valve to reduce drift.

FIG. 8
EFFECT OF "SNUBBING" ON BY-PASS
VALVE POSITION DRIFT

FIG. 9
"SNUBBING" ACTION ON BY-PASS STEAM FLOW

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V. CONCLUSIONS

The pre-power response measurements proved very worthwhile, not only in determining response time, but also in detecting improper operation of the system; rubbing pressure bellows, binding push rods, and the like, were found and corrected. At the completion of the testing, the system was performing properly and with adequate response times, as indicated in Figs. 4, 5 and 7. The turbine governor valve position transducer is unduly sensitive in adjustment, with only a narrow range permitting both stable operation and sufficiently fast response. Considerable effort failed to correct this condition. Further reduction in the speed and backlash of the P_0 setting device would improve its maneuverability.

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APPENDIX

In order to test the by-pass valve response to pressure signals, it was necessary to apply a nearly sinusoidal pressure variation at the bellows which terminates the water line from the reactor water level sight pipe. Pneumatic and hydraulic devices for generating the signal were considered. The pneumatic device was chosen because of its simplicity and ease of construction. Experimentation indicated that the pressure in an enclosed tank could be made to vary with time in a triangular waveform by connecting the tank alternately to high- and low-pressure sources through a needle valve. The magnitude of the variation depends on the tank volume, the valve opening, the pressure differential, and the period of switching. This device is the pneumatic analogue of the electrical R - C circuit shown in Fig. 10.

FIG. 10
SIMPLE TRIANGULAR WAVE GENERATOR

The equipment is shown in Fig. 11. Two solenoid valves served to switch the tank between high- and low-pressure sources. The high-pressure source was a helium bottle and a Hoke reducer-regulator. The low-pressure source was a tank maintained at a pressure of about 75 psi. The pressure signal tank had a volume of about 300 in.³ The needle valve was a 1/4-in. Hoke valve. Pipes, fittings and tubing were all 1/4 in.

The pressure signal was coupled from the tank to the controller pressure line by a water-filled tube connected below the water level within the tank. The purpose of the water in the tank was to adjust the tank gas volume to the desired value.

Switching of the solenoid valves was performed by cam-driven microswitches. A variable speed d-c motor powered the cam shaft and enabled control of the frequency of switching.

SCHEMATIC OF PRESSURE SIGNAL GENERATOR

SWITCHING SEQUENCE OF SOLENOIDS BY ROTARY CAM

FIG. II
PRESSURE SIGNAL GENERATOR

The triangular waveform which the device produces is a rough approximation of a sine wave. Examination of the circuit shows that the time graph of pressure change is exponential. If, however, the time constant of the exponential is long compared with one-half of the wave period, then the pressure change is very nearly a straight line. This time constant is proportional to the tank volume and inversely proportional to valve opening.

The harmonic distortion attributable to a triangular or trapezoidal wave is small. The Fourier analysis of the trapezoidal wave shows that no even harmonics are present, and that the odd harmonics decrease in proportion to the square of the order number. If the flat portion of the trapezoid is 60 degrees of the cycle per half-cycle, the third harmonic is zero. Waveforms with a flat portion of 20 degrees were used because, at low frequencies of operation, the waveform with a flat portion of 60 degrees per half-cycle acquired additional distortion from thermodynamic changes in the state of the helium gas. The magnitude of the third harmonic present in this trapezoid relative to the fundamental is

$$\frac{\cos 30 \text{ deg}}{(3)^2} = 0.096 \text{ or } -20.4 \text{ decibels} \quad .$$