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DATE: November 25, 1952
SUBJECT: An On-Off Servo for the ARE

Delete

FROM: S. H. Hanauer, E. R. Mann, and J. J. Stone

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To: File

Date: November 25, 1952

From: S. H. Hanauer, E. R. Mamm, and J. J. Stone

Subject: An On-Off Servo for the ARE ~~delete~~

The memo of F. P. Green on August 22, 1952, set forth criteria for the ARE ~~delete~~ Servo, and proposed an on-off servo. This has been assembled and tested with the Power Plant Kinetic Simulator, and found to be satisfactory. Construction of the electronic components for the ARE ~~delete~~ will be started in the next few days.

The primary purpose of the servo is to regulate the reactor mean temperature. The basic servo equation is

$$e = \theta_m - \theta_d \quad (1)$$

θ_m - mean fuel temperature

θ_d - mean fuel temperature demand set by operator

e - error signal kept small by servo

Since the mean fuel temperature is not amenable to measurement, it will be approximated by the arithmetic average of the fuel inlet and outlet temperatures. The servo equation becomes

$$e = \frac{\theta_i + \theta_o}{2} - \theta_d \quad (2)$$

θ_i - inlet temperature

θ_o - outlet temperature

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However, the control action is by means of changes in k introduced by the regulating rod; the flux and hence the power will vary much faster than the thermal capacities involved will permit the temperature to change. It is necessary, therefore, to introduce "anticipation" into the error function; since the temperatures are some sort of time-integrals of power, the flux (proportional to power) is a convenient anticipatory signal; in fact, both the flux and its time-derivative are used. In order to introduce the flux signal without steady-state error, one uses the relationship between power developed and temperature drop across the reactor.

$$\frac{P}{P_0} = \frac{(\theta_0 - \theta_i)}{\theta_r} \quad (3)$$

P - reactor power

P_0 - reactor design power

θ_r - design-power temperature drop across reactor

The servo equation then becomes

$$e = \frac{\theta_i - \theta_0}{2} - \theta_d + a \left[\frac{P}{P_0} - \frac{\theta_0 - \theta_i}{\theta_r} \right] + b \frac{dP}{dt} \quad (4)$$

Suitable values of a and b were determined experimentally on the simulator.

Physically, the servo takes the form of a motor whose motion is determined by the aspect of two relays. The motor is connected through suitable gear reduction to the reactor regulating rod.

Information reaches the servo in several ways:

1. Auxiliary slidewires in the existing recording potentiometers associated with θ_i and θ_0 provide voltages proportional to θ_0 and θ_i .

2. A 3" PCP chamber is used for P; the current flow through a resistor produces a voltage proportional to P/P_o .

3. A manually operated potentiometer gives a voltage proportional to θ_d .

The necessary mixing of signals is done in a resistance adding network incorporated into the servo amplifier. This latter is an electronic device in which the error signal is amplified. The output of the servo amplifier is the aspect of two relays; one of which will close if the error exceeds a preset value in one direction; the other, if the error is of opposite sense. Control circuitry then causes the regulating rod to be moved in the appropriate direction.

If the servo equation is used with the parameter $\theta_r = 350^\circ\text{F}$, with the gains adjusted for best operation (on the simulator), the following equation is obtained:

$$e = 0.387 \left[\frac{\theta_i + \theta_o}{2} - \theta_d \right] + 25.8 \left[\frac{P}{P_o} - \frac{\theta_o - \theta_i}{350} \right] + \frac{3.78}{P_o} \frac{dP}{dt} \quad (5)$$

The servo as designed was "wrung out" and tested on the Power Plant Simulator. Performance was as follows:

1. Regulating at 100% P_o : Power varied $\pm 1.6\%$; inlet temperature $\pm 1^\circ\text{F}$; outlet temperature $\pm 2^\circ\text{F}$.
2. Regulating at 30% P_o : Power varied $\pm 1.25\% P_o$; inlet temperature and outlet temperature variations were negligible at this and all lower powers.
3. Regulating at 18% P_o : Power varied $\pm 1.6\% P_o$.
4. Regulating at 6% P_o : Power varied $\pm 1.3\% P_o$.
5. Regulating at 1.8% P_o : Power varied $\pm .6\% P_o$.

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6. When a δK step of $\neq 0.2\%$ was introduced, the power maximum during the resulting transient was $2.4 P_o$, occurring 0.8 sec after the step. The outlet temperature maximum was 125°F above steady-state; the inlet temperature minimum was 30°F under steady-state. *delete*

7. With the reactor under control at $30\% P_o$, the He was turned on to $100\% P_o$ in 20 sec. The power maximum was $1.06 P_o$; the inlet temperature undershot the final value by 18°F ; the outlet temperature overshot the final value by 18°F .

8. Since the θ_i and θ_o information comes from recording potentiometers, the result of "standardizing" the self-balancing potentiometer was determined. It was found that the resulting disturbance is very small if the standardization takes place while the servo is controlling the reactor under steady-state conditions. If, however, the standardization procedure takes place during a transient in reactor conditions (for example, a change in He flow), the resulting disturbances in flux, power, and temperatures are intolerable. Therefore, the automatic standardizing circuits of the two recorders in question will have to be removed if the servo is needed.

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APPENDIX 1

Control Circuitry

The original criteria for turning on the servo were:

- a) P greater than the minimum controllable power
- b) Regulating rod all the way out
- c) Temperature demand at its maximum.

The combination of b) and c) insure that when the servo is turned on the demand is such that the servo will try to withdraw the rod, and the rod is already withdrawn. In this case, of course, no rod motion takes place. The operator then changes the demand to a more realistic value and the servo takes control. This regime imposes two operating inconveniences:

1. The regulating rod must be withdrawn completely (and the shim rods inserted a corresponding amount) before the servo may be turned on.
2. The temperature demand pot must cover a range wide enough that its maximum will always be above any conceivable mean temperature. It is therefore necessary to limit the maximum speed at which the pot can be run -- to drive the pot with a motor. The operator thus must "jog" a motor-driven device to adjust the temperature demand.

For these reasons, it was decided to change the criteria as follows:

- a) P greater than the minimum controllable power.
- b) Error signal small enough that the servo is not calling for rod motion.

The ~~A.R.E.~~ control elementary diagram (Dwg. A-8-0-01) shows how these criteria are met.

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APPENDIX 2

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A.R.E. Regulating Rod Control System

F. P. Green

August 22, 1952

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Studies of the ~~ARE~~ power plant kinetics have shown that the system is stable. The reactor provides power to the heat exchanger load on demand with peak transient surges in neutron flux, fuel temperature and pressure well below values deemed likely to injure the reactor, heat exchanger, auxiliary equipment, or the operating personnel. These studies were based on certain assumptions and specifications provided by the ~~ARE~~ design engineers.

One of these assumptions was that there will be a negative reactivity fuel temperature coefficient of $8 \times 10^{-5} \Delta k/k$ per degree Fahrenheit change in the fuel mean temperature. This assumption has been based on studies made by the ANP reactor physics group.

There seems to be general agreement that it would not be wise to attempt to operate a reactor with a positive reactivity temperature coefficient. However, by means of external control systems the reactor can be operated safely with zero fuel temperature coefficient or a negative coefficient of much smaller magnitude than that assumed for the ~~ARE system~~ study of kinetics.

Since the magnitude of the ~~ARE~~ reactor fuel temperature coefficient is not known and may well be much less than that value assumed, it therefore seems advisable to provide an external servo control system to either assist a weak temperature coefficient or function in a like manner to that of the assumed coefficient.

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Studies with the ORNL reactor power plant simulator show that any one of a number of conventional servo systems is capable of controlling and regulating both the reactor flux and fuel temperature to within five percent of that provided by the assumed temperature coefficients. This capability applies for both steady state and transients produced by an external load demand in the form of a ramp going from a steady state at 20% design point to a steady state at design point.

Suitable criteria for the selection of one of these servo systems are then found to be:

1. The control system must control and regulate the steady state flux and temperature to within 1% of the values provided by the assumed negative fuel temperature coefficient of reactivity. The transient temperature deviation must be held within 5% of that provided by the assumed temperature coefficient. The control and regulation of the latter has already been studied and accepted as satisfactory by both the ~~ANP~~ reactor physics group and the ~~ARE~~ design engineers. This information has been determined by means of the ORNL reactor power plant simulator.

2. The system must be compatible with operation of the manual and safety control equipment.

A rod travel of 12 inches has been designated to produce a total $\delta k/k$ of 0.4%. For purposes of manual control it must be possible to move the regulating rod in increments of 0.001% $\delta k/k$, or 0.03 inches.

The MTR servo is an unnecessarily high speed, heavy duty unit and is unwieldy when used as a rod position control. Sufficient effort is yet necessary to assemble the MTR servo to permit reconsideration of a simpler, yet adequate, on-off servo to replace it. The proposed on-off servo meets the general ~~ARE~~ control criteria given above for a load power buildup of about 3% per second between

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0.20 P_0 and P_0 . It will act on a 1.6° F. fuel mean temperature variation and a 2.0° F. fuel inlet temperature variation, comparable to the accuracy available in the temperature sensory instruments. For servo control the rod speed has been established at $0.1\% \delta k/k$ per second. This is considerably too fast for precise manual positioning of the rod so that an inching control will be provided. Since it is possible through operating error to move the regulating rod so as to produce $0.3\% \delta k/k$ in 3 seconds, it will be necessary to override the manual withdrawal of the rod with the 5-second reverse.

A simulator test of an on-off servo, relay controlled, was made using a rod speed of 3 inches per second, equivalent to $0.1\% \delta k/k$ per second. An 0.1 second accelerating and decelerating time was selected for the purpose of simulating the response of the servo motor. The test was also based on no fuel temperature coefficient of reactivity and for convenience, no moderator temperature coefficient of reactivity. The latter was used to prevent obscuring rod stability after a transient. Several dead zones were selected for tests and a compromise between relay chatter and poor servo stability was found to be $0.02 P_0$, or $\pm 0.01 P_0$. The transient analysis was produced by a step power demand from 35% to 100%. The pressure surge developed was less than one quarter of the maximum permitted. The temperature and power overshoots were tolerable. A 50 watt servo motor will meet the above specifications.

We have on hand the principal components of the servo mentioned in the simulator test. It will consist of a Diehl servo motor rated at 200 watts, two-phase, 60 cycle, 115 volts. A mixer-pilot relay will be assembled by the Reactor Controls Department to actuate the motor. Signals to this unit will be supplied from the servo ion chamber, fuel inlet and outlet temperatures and a demand helipot. The MTR gear box will require an additional 1 to 38 reduction

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ratio ($\frac{1}{2}$ 10%). A brake may be incorporated to provide the 0.1 second servo motor deceleration when it is de-energized.

The Reactor Controls Department will test a mockup of the above listed components. Details of the input signals to the mixer will be worked out ~~be-~~ *delete* tween the Control Department and the ARE Project Group. The Group will furnish the gear reducer and perhaps the brake. The Control Department will furnish the motor, and will indicate the motor, brake, and limit switch connections. Engineering will not be required to install and wire the amplidyne as this will not be used.

APPENDIX 3

Specifications and Parameters

1. Regulating Rod
 - a) Speed $\delta k/k = 0.1\%$ /second average
3 inches/second average
 - b) Total travel 12 inches
2. Gear Reducers
 - a) MTR single spur gear and rack - ratio 5:1
Pinion diameter = 3 inches
 - b) Boston Reductor - Boston Gear Works #T13 Ratio 30:1
3. Drive Motor

Diehl 2 phase servomotor, 115 V, 200 W, 2 pole, Cat #CAD211517
4. Amplifier dead zone is ± 0.035 volt at the amplifier input, approximately equivalent to $\pm 1.3^\circ$ F mean temperature.
5. The θ_i and θ_o recorders are 0-2000 $^\circ$ F; the slidewires are 10-turn 100 K Model A helipots geared to the pen drive so that full scale corresponds to about 9.5 turns.
6. The chamber is a 3-inch PCP boron-coated ionization chamber, described in ORNL-1080.
7. Motor Contactors: G.E. #CR2790 - E100A2
8. Demand Pot 10,000 ohms, 12 watts, General Radio Company Type 371-A

SERVO CONTROL ELEMENTARY DIAGRAM

SERVO BLOCK DIAGRAM

MATERIALS LIST					
ITEM NO.	DWG. NO.	QTY.	NAME	SIZE	MATERIAL

NOTE:
Unless Otherwise Specified All
Resistors 1 Watt ±10%.

NOTES ON METER CIRCUIT
1. Meter is Weston Model 741 0-50ma.
2. Multiplier Resistors Are Selected To Make
Meter Read 25.0ma At The Following
Voltages (±0.25%).
Approx. Resistance
a. 600 24.0M
b. 5575 22.7M
c. 2510 9.92M
d. 522 20.9M
e. 484 19.4M
Use Nodalloy Resistors. Selected On A Bridge.
3. Switch is CRL #P-121 WITH 2-#RR Discs.

1	REVISED AS BUILT	12-9-52	S.H.H.		
NO.	REVISIONS	DATE	APPR.	APPR.	
DRAWN	DATE	CHECKED	DATE	APPROVED	DATE
BISHOP	11-1-52			F.P.F.	11-1-52
DESIGNED	DATE	SUBMITTED	DATE	APPROVED	DATE
HANAUER					
HEALTH PHYSICS	MEDICAL	OPERATIONS	SAFETY		
FIRE PROTECTION	RESEARCH SHOP	MAINTENANCE			

Approved For Construction	
REFERENCE DRAWINGS	DWG. NO.
TEST FACILITY BLDG. 7503	
SERVO AMPLIFIER	
ELEMENTARY DIAGRAM	
OAK RIDGE NATIONAL LABORATORY	
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A DIVISION OF UNION CARBIDE AND CARBON CORPORATION	
OAK RIDGE, TENNESSEE	
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PER: [Signature]	
SCALE:	
CHG. 3341-30	A-8-13