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ABSTRACT

The HRT feedwater control system was reviewed to determine adequacy of the present controls and to evaluate alternate systems as to feasibility and desirability. Results indicate that the present system is adequate for operation from one to five megawatts, but that trouble may be experienced below one megawatt and above five megawatts. Recommendations for improving operations of the present system are presented. Alternate systems of feedwater control are discussed.

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REVIEW OF HRT FEEDWATER CONTROL SYSTEM

I. PURPOSE

A. The HRT feedwater control system was reviewed in order to:

- (1) Determine adequacy of present controls.
- (2) Evaluate alternate systems for feasibility and to determine whether such alternate systems offer sufficient advantages to justify revision of the HRT system.

Members of the I&C Section contributing to this review were S. J. Ball, R. L. Moore, J. L. Redford, and H. D. Wills.

II. PROCEDURE

A. Analytical

The following areas were investigated analytically:

- (1) Valve sizing and characteristics.
- (2) Feedwater pump and pump speed control characteristics.
- (3) Frequency response of the heat exchanger level and feedwater bypass control loops to determine:
 - (a) Characteristics of the control system.
 - (b) Controller requirements (proportional, proportional + reset, etc.).
 - (c) Recommendations for approximate controller settings.
- (4) Effects of feedwater control on reactor operation and vice versa.

B. Field Observation

Operation of HRT feedwater system, as presently installed, was observed.

III. CONCLUSIONS

- A. The HRT fuel heat exchanger feedwater system, as presently installed, is capable of smooth operation at design power of 5 mw and at 10 mw. However, due to sizing of valve LV-545 for 10 mw operation, some difficulty may be experienced at low power (below 1 mw).

- B. The HRT blanket heat exchanger feedwater valve (LV-546) has insufficient capacity (C_v) for operation at 10 mw. The error in sizing apparently resulted from an error in the flowsheet data which specified blanket pressure at 5 mw as 560 psia instead of 900 psia.
- C. The maximum speed of the large feedwater pump drive (Item 65b) is too high, resulting in a maximum calculated pump rate of approximately 120 gpm. At the maximum speed of the present drive, approximately 68 hp input at the pump shaft and 80 hp input (electrical) at the motor is required. Therefore, as both motor and drive are rated at 50 hp, they will be seriously overloaded at the maximum speed. Partial confirmation of the calculated values was obtained from field measurements which gave a flow rate of 96 gpm at 85% indicated speed and an electrical power requirement of 64 kw at 97% indicated speed and 1000 psia feedwater pressure.
- D. The capacity (C_v) of the bypass valve (PCV-559) was increased in the field to a value of 6 to enable the bypass valve to pass the full flow of the present pump (120 gpm). This larger size is unnecessary if the pump is operated within its rating.

The present bypass control system, using a C_v value of 6, appears from analysis and observation of operations to be capable of satisfactory operation provided that the accumulator is properly charged and that there is sufficient bypass flow to keep the valve well off the seat. However, the operation of the system at low values of bypass flow (pumping rate minus feedwater flow rate) appears to be marginal with the present bypass valve trim, particularly insofar as response to large transient disturbances are concerned.

The accumulator appears to be of sufficient size for steady state control but is marginal when large transient disturbances are considered. In this respect, the worst case would occur with zero heat exchanger feedwater flow. Under these conditions, a transient disturbance in the feedwater pressure control loop can result in large swings in feedwater pressure, and, if the swing is sufficient to allow the accumulator diaphragm to bottom and close off the accumulator, excessive pressure fluctuations may result. As the accumulator will bottom at the charge pressure, the feedwater pressure set point should be set well above the charge pressure (preferably at twice the charge pressure).

- E. Frequency response analysis of the feedwater pressure control loop (559) indicates that:
 - (1) Sensitivity (proportional band) should be set at a value less than 2.1 in/psi (70% proportional band). This value represents a maximum controller gain as entrance and exit pressure drops into the accumulator were unknown and were neglected in the analysis. Actual optimum sensitivity setting will probably be somewhat lower and should be determined in the field using

the procedure outlined in Section IV-5.

- (2) System gain increases directly as the square of the feedwater pressure and inversely as the accumulator charge pressure. Therefore, as the maximum allowable controller gain varies as the inverse of the system gain, the sensitivity should be set for stable operation at the highest expected operating pressure, and with maximum allowable accumulator pressure. If accumulator charge is reduced (through leakage) during the course of operations, the system will approach instability.
- (3) The accumulator charge pressure should be as high as possible but should not exceed the lowest expected heat exchanger operating pressure if good recovery from large transients is desired. The 500 psi design value for charge pressure appears to be optimum.
- (4) The controller reset should be set at highest value (5 repeats/min) available on the controller in order to obtain minimum overshoot on start-up and fastest recovery to load changes. Analysis indicates that the reset range of the controller in PC-559 is well below the point where reset will affect system stability.
- (5) Addition of a positioner to bypass valve PCV-559 would increase system stability and improve response to large transients.

F. Frequency analysis of heat exchanger feedwater control loops (545 and 546) indicate that:

- (1) There is no point of instability and that "on-off" control (zero proportional band) could be used. However, since "on-off" control would introduce large transient disturbances into the feedwater pressure control loop (559), it appears desirable to use proportional control and limit controller gain to a value of 10 or less (10% proportional band or greater). If it is found in the field that the 10% proportional band setting is satisfactory, the reset function action could be removed from the controller. If a proportional band wider than 10% is found to be necessary, in order to limit transient disturbances of the feedwater pressure control loop, the reset action should be retained and the reset rate set at its minimum value (0.1 min/reset).
- (2) A Taylor pulsation dampener should be added in series with air lines (545-2 and 546-2) between fuel and blanket D/P transmitters and their associated controllers. Addition of these filters will reduce noise resulting from level fluctuations during power operations, with the resultant reduction of transient disturbances in the control loops. Dampening should be limited to one Taylor

dampener since additional dampening would result in excessive lag of the recorder pen for fast level changes, such as would occur during blowdown. Therefore, when the external dampening is added, the internal dampener on the recorder pen should be adjusted for maximum response.

G. Alternate Systems

The following alternate systems were considered:

- (1) Feedwater flow control from heat exchanger level with feedwater pressure control from feedwater valve differential pressure (Fig. 1).

Advantages of this system are:

- (a) Constant pressure drop across the level control valve, over the range from low to high power operation, would allow the use of larger C_v in the valve with resultant lower pressure drop across the valve.
- (b) Pressure drop across bypass valve would be reduced at high power and rangeability of bypass valve would be increased.

Disadvantages are:

- (a) The rangeability of the feedwater control valves would be reduced.
- (b) Added complexity to the system.
- (c) The feedwater pressure control system would be required to operate over a wide range of pressures.
- (d) Separate fuel and blanket feedwater systems would be required unless fuel and blanket heat exchanger steam lines are interconnected.

The present system could be modified to incorporate the control illustrated in Fig. 1 by replacing the present feedwater pressure controller with a pneumatic pressure transmitter and a pneumatic recorder-controller with remote pneumatic set point, and by adding a pneumatic difference relay with manual bias (Moore Model MF or equivalent). The steam pressure pneumatic signal can be obtained from the presently installed transmitter (PE-551). The present trim in the feedwater valve (LCV-545) would be satisfactory for this application. As stated previously, this type system could be used only if the fuel and blanket heat exchangers are interconnected, or if separate feedwater systems are used. If separate feedwater systems were used, it appears feasible to obtain blanket feedwater control from on-off (limit control) of the small (21 gpm) pump with the pump adjusted for minimum (3.3 gpm) flow. The

blanket feedwater valve, in this case, would be manually controlled and normally open, and should have a much larger trim size, since the present trim ($C_v = 0.25$) would require an average pressure drop of 600 psi at the minimum flow rate of the small pump.

In general, the advantages of this system do not appear to be sufficient to offset the added complexity, cost, and, particularly, the decreased control rangeability.

(2) Feedwater pump speed control from heat exchanger level (Fig. 2)

This system appears satisfactory for feedwater control at higher powers but might result in reactor power fluctuations at the lower power levels. Proportional + reset control of pump speed is recommended as on-off (limit) control might result in undesirable fluctuations of reactor power. Ideally, the pump speed control should have a rangeability from zero to full flow; however, the present speed control drive has a rangeability of only 6 to 1, and a brief search of the literature available indicates that drives of the capacity required and rangeability greater than 10 to 1 are not available as standard items. Therefore, it appears necessary to depend on on-off (limit) control at the lower powers which require feedwater flow below the minimum pump capacity. In order to avoid excessive feedwater pressure, which might damage the feedwater flow meter, the feedwater pump motor should be interlocked to stop when the feedwater valve closes.

(3) Present system with addition of feedwater pump speed control from feedwater flow (Fig 3)

This system would be essentially the same as the present system except that feedwater pump speed would be controlled to maintain constant bypass flow. The advantage of this system is that the rangeability requirements of the bypass valve would be reduced and the trim size (C_v) of the bypass valve could be reduced. Decrease of bypass valve C_v would result in increased stability of the feedwater pressure control. Bypass flow control insures that the bypass valve will operate in a region which will maintain control stability and reduces the power loss in bypass flow at low reactor power levels. Although this operation may be performed manually, it is possible that the addition of this control might be justified by the reduction in responsibility on operating personnel. As is evident from the sketch, the only additional piece of equipment required would be a "Conoflow" positioner. However, the speed of the present pump drive would have to be reduced to allow operation within the present pump rating.

IV. RECOMMENDATIONS

A. Changes required to assure good operation of present system at 5 mw:

- (1) Add Taylor Model 58S104 pulsation dampener in pneumatic signal lines (545-2 and 546-2).
- (2) Set internal pen dampening in recorders IR-545 and IR-546 for maximum response.
- (3) Set proportional band of LC-545 and LC-546 at approximately 10%.
- (4) Set reset rate of LC-545 and LC-546 at minimum (approximately 0.1 min.).
- (5) Set controller PC-559 as follows:
 - (a) Close heat exchanger valves LCV-545 and LCV-546.
 - (b) Set feedwater pump at maximum anticipated operating speed.
 - (c) Set reset control at minimum (.05 resets/min).
 - (d) Adjust sensitivity to the point where cycling is barely sustained. Note cycle frequency and sensitivity setting.
 - (e) Set sensitivity to $1/2$ the value observed in step (d). Set reset at a value of $\frac{1.2}{f}$, where f is the frequency of oscillation in cycles/min. observed in step (d)
- (6) Charge accumulator at 500 psi. Accumulator should be checked occasionally for leakage of charge.

B. Changes required to assure operation of present system at 10 mw:

- (1) Same as step IV-A, 1 through 6.
- (2) Increase C_v of valve LCV-546 from 0.25 to 0.6

C. Changes required to improve control of present system at low power levels:

- (1) Same as IV-A, 1 through 6.
- (2) Decrease C_v of valve LCV-546 from 6 to 4.
- (3) Decrease C_v of valve PCV-559 from 6 to 4.
- (4) Reduce maximum speed of feedwater pump (Item 65b) or provide stop on speed control to limit maximum pumping rate to 75 gpm at 1000 psi.

(5) Add positioner on valve LCV-559.

D. Other possibilities for improving control:

- (1) If, after changes IV-A, 1 through 6, have been made, field experience shows that there is excessive interaction between feedwater level and pressure control, the accumulator capacity should be increased. While analysis indicates that the accumulator capacity is sufficient for steady state control, it appears marginal for large transient disturbances.

Fig. 1

Fig. 2

Fig. 3

APPENDIX A

Calculation of Required Valve Sizes

I. COMMON FEEDWATER SYSTEM

A. General

Feedwater pressure must be maintained above 920 psi in order to supply blanket feedwater.

B. LCV-545 Valve Size

(1) 10 MW Operation

Feedwater pressure (P_f) = 1000 psi

Steam pressure (P_s) = 460 psi

Feedwater flow (Q_f) = 66.6 gpm (average)

$$C_v = \frac{Q}{\sqrt{\Delta P}} = \frac{66.6}{\sqrt{460}} = 3.1$$

(2) 5 MW Operation

P_f = 1000 psia

P_s = 520 psia

Q_f = 33.3 gpm (average)

$$C_v = \frac{33.3}{\sqrt{480}} = 1.52$$

(3) 0.5 MW Operation

P_f = 1000 psia

P_s = 860 psia

$Q_f \approx 3.3$ gpm (average)

$$C_v = \frac{3.3}{\sqrt{140}} = 0.28$$

(4) Conclusions

For good control, valve LCV-545 should have rangeability to 1/2 the minimum flow required. Present valve has a maximum C_v of 6.3. Rangeability required at 0.5 MW is

$$R = \frac{6.3}{0.14} = 40$$

While the valve has a rangeability of 50 when new, a rangeability of 20 is a more practical number. Therefore, the present valve cannot be expected to control well at low power with 1000 psi feedwater pressure over an extended period. Reducing feedwater pressure will help, but since flow varies as the square root of the pressure drop, the feedwater pressure would have to be controlled very close to the heat exchanger pressure to affect significant improvement.

While the size of the present valve appears to be satisfactory for 10 MW operation, the control at low power will be poor. Of the standard available trims, a C_v of 4 appears to be the best compromise between low and high power operation and a " C_v " of 2.5 appears best for 5 MW operation.

C. LCV-546 Valve Size

(1) 10 MW Operation

$$P_f = 1000 \text{ psi}$$

$$P_s \approx 840 \text{ psi}$$

$$Q_f \approx 3 \text{ gpm (average)}$$

$$C_v = \frac{3}{\sqrt{160}} = .237$$

(2) 5 MW Operation

$$P_f = 1000 \text{ psi}$$

$$P_s \approx 900 \text{ psi}$$

$$Q_f \approx 1.5 \text{ gpm}$$

$$C_v = \frac{1.5}{\sqrt{100}} = 0.15$$

(3) 0.5 MW Operation

$$P_f = 1000 \text{ psi}$$

$$P_s \approx 920 \text{ psi}$$

$$Q_f \approx 0.15$$

$$C_v = \frac{0.15}{\sqrt{80}} = 0.167$$

(4) Conclusion

Present valve has C_v of 0.25, which is adequate for 5 MW operation at 1000 psi feedwater pressure, but not large enough to pass the flow required at 10 MW with 1000 psi feedwater pressure. Raising the feedwater pressure would help but 1400 psi feedwater pressure would be required to obtain good control at 10 MW. This would result in a pressure drop of 916 psi across valve LCV-545 and 576 psi across valve LCV-546, with the result that the life of the valves would be materially shortened. The above considerations indicate that valve LCV-546 is satisfactory for 5 MW operation, but that the trim should be increased in size for 10 MW operation. A trim having a C_v of 0.6 is available and appears to be satisfactory.

D. PCV-559 Valve Size

(1) General

The bypass valve should have a C_v which is sufficiently large to pass the maximum flow at the lowest anticipated operating pressure. The present pumps have a combined capacity of 140 gpm at 1000 psi. However, the large pump (Item 65A) will be overloaded above 75 gpm. The maximum rated flow of both pumps combined is 96 gpm.

(2) Calculations

(a) 140 gpm flow at 1000 psi

$$C_v = \frac{140}{\sqrt{1000}} = 4.42$$

(b) 96 gpm flow at 1000 psi

$$C_v = \frac{96}{\sqrt{1000}} = 3.03$$

(3) Conclusion

The present trim size, having a C_v of 6, should be used as long as the pumps have a capacity of 140 gpm. If the maximum speed of the large pump (Item 65A) is restricted to 75 gpm, the C_v of valve PCV-559 could be reduced to the next lower standard size ($C_v = 4$).

II. SEPARATE FUEL AND BLANKET FEEDWATER SYSTEMS

A. General

Separation of the Fuel and Blanket Feedwater Systems would relax the restriction imposed of minimum feedwater pressure by the blanket heat exchanger and would allow the fuel feedwater pressure to be reduced at the higher reactor power levels with consequent lower pressure drop across valve PCV-545 and PCV-559. Lower pressure drop would result in lower velocity across the seat of the valve and, therefore, less wear. Reducing the feedwater pressure has the disadvantage of reducing the effective rangeability of the level control valve (PCV-545) as the valve no longer has the added pressure drop to aid in increasing the flow. Conversely, this method of operation would result in increased rangeability of the feedwater bypass valve (PCV-559). The sizing of the bypass valve (PCV-559) would not be affected by this method of operation as the valve would still be required to pass the full flow of the pump at maximum operating pressure.

It is assumed, in this analysis, that:

- (1) The bypass valve would be retained on the fuel side.
- (2) The blanket side would have no bypass valve.
- (3) Feedwater control would be obtained by on-off control of the small feedwater pump (Item 65b).
- (4) The present drive on the small pump would be retained.

B. Calculations

- (1) Pressure drop across LCV-545 with present trim, at 10 MW operation, and valve at midstroke

$$\Delta P = \left(\frac{Q}{C_v} \right)^2 = \left(\frac{66}{3} \right)^2 = 500 \text{ psi}$$

- (2) Pressure drop across LCV-545 with present trim, at 5 MW operation, and valve at midstroke

$$\Delta P = \left(\frac{33}{3} \right)^2 = 121 \text{ psi}$$

- (3) Pressure drop across LCV-545 with present trim, at 0.5 MW operation, and valve at midstroke

$$\Delta P = \left(\frac{3.3}{3} \right)^2 = 1.21 \text{ psi}$$

- (4) Pressure drop across LCV-545 with present trim, at 0.5 MW operation, and valve at 5% stroke

$$\Delta P = \left(\frac{3.3}{6} \times 20 \right)^2 = 121 \text{ psi}$$

- (5) Pressure drop across LCV-546 with present trim at minimum (3 gpm) speed of pump (Item 65b)

$$\Delta P = \left(\frac{3.5}{0.25} \right)^2 = 195 \text{ psi}$$

- (6) Pressure drop across LCV-546 with present trim at maximum (21 gpm) speed of pump (Item 65b)

$$\Delta P = \left(\frac{21}{0.25} \right)^2 = 7240 \text{ psi}$$

- (7) Required trim size in LCV-546 to limit pressure drop across valve to 500 psi at maximum speed of pump (Item 65b)

$$\Delta P = \frac{Q}{\sqrt{\Delta P}} = \frac{21}{\sqrt{500}} = 0.95$$

C. Conclusions

The trims presently installed in valves LCV-545 and LCV-546 would be satisfactory for use when the system is operated as described above, provided that the speed of the small pump was set at minimum. Higher speed operation of the small pump would result in excessive feedwater pressure unless the trim size of LCV-546 was increased to a C_v of 1.

The rangeability of fuel feedwater control would be decreased if the feedwater pressure were reduced as the power was increased, but as the present fuel feedwater valve (LCV-545) has a larger capacity than is needed in the present (constant feedwater pressure system), there would be no sacrifice in effective control range.

APPENDIX B

FEEDWATER PUMP CHARACTERISTICS

I. MANUFACTURER'S DATA

A. Item	65A
(1) Vari-speed motor drive	
Mfg.	Reeves Pulley Co.
Size	8402-F-12
Gear Ratio	4.5 - 1.0
Max. RPM	452
Min. RPM	76
(Motor) H. P.	25
(2) Motor	
Mfg.	Allis-Chalmers
NEMA Design	B
Type	APZZ
Frame	404
Rating	24 hrs - 55°C Rise
Code	F
H. P.	25
Phase	3
Cycles	60
Volts	220/440
(Lo Volt) Amps	63
(Hi Volt) Amps	31.5

(3) Pump

Mfg.

Worthington Corporation

Size

1-1/2 x 2

B. Item

(1) Vari-speed Drive

RPM (Min.)

583

RPM (Max.)

1750

Frame

83 - 504 - 5 (60 H. P. Frame)

(2) Motor

Mfg.

U. S. Electrical Motors, Inc.

Type

Ve - Sev

H. P. ₆

50

Volts

220/440 - Cycles 60

Motor RPM

1250

(Hi Volt) Amps

77.6

(Lo Volt) Amps

155.2

Rating

55°C

(3) Gear Drive for above

Size Model

S101-51

Manufacturer

Link-Belt

Input RPM

1750

Ratio

4.71

A.G.M.A. H.P.

88

(4) Pump

Size

2-1/2 x 5 VTE-2

Manufacturer

Worthington Corporation

II. MAXIMUM PUMP RATE (Item 65b)

A. Calculated

$$Q = \left(\frac{1750}{4.71} \text{ RPM} \right) \left(3 \text{ cylinders} \right) \left(\frac{x (1.25)^2 x 5}{1728} \frac{\text{ft}^3}{\text{cylinder}} \right) \left(7.48 \frac{\text{gallons}}{\text{ft}^3} \right) \left(.90 \text{ efficiency} \right) = 140 \text{ GPM}$$

B. Measured

The pumping rate of Item 65b was measured by HRT operating personnel as 97 gpm at 85% indicated speed and 1000 psi operating pressure.

The electrical power requirement was measured as 64 KW, 96 amperes, 450 volts, 0.82 PF at 97% indicated speed and 1000 psi operating pressure.

III. CONCLUSION

The pump drive and motor on Item 65b will be overloaded if the drive is set at maximum speed. Additionally, the excess capacity available in the pump imposes undue limitations on the feedwater pressure control system. The maximum speed of the pump (Item 62b) should, therefore, be limited to maintain the maximum speed of the pump within the rating of the pump.

APPENDIX C

Frequency Response Analysis

A. GENERAL

Calculated frequency response characteristics for the feedwater pressure control loop (559) and fuel heat exchanger control loop (545) are shown in Figs. 4 and 5 respectively. Characteristics are not shown for the blanket heat exchanger control loop (546) since the systems are identical except for control valve sizing. The blanket characteristics may be obtained by multiplying the magnitude ratio scale of the fuel loop by the ratio of the flow coefficients of the fuel and blanket feedwater control valves.

Fig. 6 shows the transient response characteristics of the level recorder pen with one Taylor pulsation dampener inserted in the differential pressure cell transmission line and under blowdown conditions.

More detailed information on this analysis will be issued in separate reports.^{(1), (2)}

B. DISCUSSION OF RESULTS

(1) Loop 559

The characteristics shown in Fig. 4 indicate that the system will have 180° phase shift at 20 cycles per minute and that the gain at this frequency will be 0.16. This indicates that the system would oscillate (cycle) at a frequency of 20 CPM if the controller gain was equal or, or greater than, 6.25, which is equivalent to a proportional band setting of 16%. For optimum response the controller should be set to give an overall gain of one at 150° phase shift. This condition would be obtained with a controller gain of 1.4 (70% proportional band). The above gain settings are probably optimistic and final tune up should be done in accordance with Section IV-5.

From the curves, it is apparent that the reset action of PC-559 on the gain and phase characteristics will not have any appreciable effect on the stability of the system since, at the maximum reset rate, the phase contribution of the reset action is low in the region where the phase contribution of other portions of the system are significant.

Considerations of overshoot on start-up and response to load changes dictate that the reset rate be set as high as consistent with stability considerations. Therefore, in this case, the reset should be set at the maximum rate.

(2) Loop 545

The characteristics shown in Fig. 5 indicate that no stability problem exists in the control of loop 545 since the phase shift of the system never exceeds 180° . Thus, the system could (from the standpoint of level control) be operated on "on-off" (zero proportional band) control. However, if loop 545 were operated on "on-off" control, excessive transient load disturbances would be imposed on the feedwater pressure control loop (559) with the result that large pressure excursions would occur. In order to reduce the magnitude of these load disturbances, proportional control of loop 545 should be used. The proportional band setting should be as low as is compatible with smooth feedwater pressure control. A value of 10% proportional band should be sufficient. If lower proportional band settings can be tolerated, the reset action of the controller could be removed since the offset (without reset) would be small. Removal of the reset would be desirable from the standpoint of elimination of overshoot on start-up. Also the reset action of the controller, together with the 90° system phase shift, produces a total phase shift of approximately 170° at low frequencies, where the system gain is high. While the 170° phase is insufficient to cause oscillation, it is uncomfortably close to the point of oscillation and could be the source of low frequency instability. For this reason, it would be desirable to eliminate the reset action of controller LC-545, if possible.

The previous consideration has been made on the basis of steady state control and does not include the effect of "signal noise" and transient load disturbances. From inspection, the only load disturbance which would be of sufficient magnitude to disturb control would occur during blowdown. Due to the large size of the present blowdown valve, the blowdown rate can exceed the feedwater rate, and therefore, the controller cannot be expected to maintain heat exchanger level during blowdown. If other considerations permit, it is recommended that the trim size of the blowdown valve (HCV-540) be decreased in size.

Signal noise, which can originate from level variations due to boiling and sloshing, can introduce transient disturbances into loop 545 which would be reflected into loop 559 and cause feedwater pressure transients. In order to minimize such disturbances, it is recommended that a pulsation dampener be installed in the transmission line from the differential pressure cell (LE-545) to the recorder-controller (LRC-545). The addition of the dampener introduces additional phase lag to the system; however, Fig. 5 shows that its effect is very low in the region where appreciable system gain exists. Therefore, the addition of the dampener will not produce instability.

The effect the addition of the pulsation dampener on the response of the level recorder pen is illustrated in Fig. 6. From Fig. 6 it can be seen that the maximum pen lag is 0.2 inches which corresponds to $3/4\%$ of full scale reading. Thus, it may be con-

cluded that the addition of the dampener will not seriously affect the indication of level change during blowdown. However, as the recorder has an adjustable internal dampening, care should be exercised in this adjustment in order to avoid an excessive indication error.

(3) Loop 546

As loop 546 is similar to loop 545, the response characteristics of loop 546 will be similar to those of loop 545, except that the system gain (magnitude ratio) will be decreased by the ratio of the flow coefficients of valves LCV-546 to that of valve LCV-545; i.e, by a factor of 20. Since the resultant system gain is so small, and since the maximum feedwater flow of loop 546 is low compared to that of loop 545, it should be possible to operate loop 546 on "on-off" control and to remove the reset action from controller LC-546.

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6. S. E. Beall	54. H. F. McDuffie	
7. A. M. Billings	55. H. A. McLain	
8. E. G. Bohlmann	56. R. A. McNees	
9. S. E. Bolt	57. J. R. McWherter	
10. E. S. Bomar	58. H. J. Metz	
11. C. J. Borkowski	59. R. L. Moore	
12. J. R. Brown	60. C. A. Mossman	
13. W. D. Burch	61. L. F. Parsly, Jr.	
14. R. H. Chapman	62. F. N. Peebles	
15. R. D. Cheverton	63. M. L. Picklesimer	
16. H. C. Claiborne	64. R. M. Pierce	
17. E. L. Compere	65. J. L. Redford	
18. R. S. Crouse	66. S. A. Reed	
19. J. S. Culver	67. D. M. Richardson	
20. D. G. Davis	68. G. W. Rivenbark	
21. J. R. Engel	69. R. C. Robertson	
22. J. L. English	70. M. W. Rosenthal	
23. D. E. Ferguson	71. J. A. Russell	
24. J. D. Flynn	72. H. C. Savage	
25. C. H. Gabbard	73. C. L. Segaser	
26. W. R. Gall	74. E. M. Shank	
27. G. W. Greene	75. M. D. Silverman	
28. J. C. Griess	76. M. J. Skinner	
29. J. D. Grimes	77. I. Spiwak	
30. R. S. Greeley	78. R. W. Stoughton	
31. P. A. Haas	79. J. A. Swartout	
32. C. S. Harrill	80. E. H. Taylor	
33. P. H. Harley	81. D. G. Thomas	
34. P. N. Haubenreich	82-85. D. S. Toomb	
35. F. G. Herndon	86. W. E. Unger	
36. J. W. Hill	87. C. S. Walker	
37. E. C. Hise	88. R. Van Winkle	
38. C. J. Hochanadel	89. A. M. Weinberg	
39. G. H. Jenks	90. K. W. West	
40. D. T. Jones	91. H. D. Wills	
41. S. I. Kaplan	92. J. C. Wilson	
42. P. R. Kasten	93. C. E. Winters	
43. F. Kertesz	94. F. C. Zapp	
44. J. O. Kolb	95-96. REED Library	
45. R. B. Korsmeyer	97-98. Central Research Library	
46. K. A. Kraus	99-100. Document Reference Library	
47. C. G. Lawson	101-114. Laboratory Records	
48. R. E. Leuze	115. ORNL-RC	
	116. R. J. Davis	

FREQUENCY RESPONSE DIAGRAM

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PEN RESPONSE TO LEVEL CHANGE WITH BLOWDOWN VALVE WIDE OPEN
 HRT CORE HEAT EXCHANGER LEVEL INDICATOR
 WITH ONE TAYLOR PULSATION DAMPING UNIT IN LINE TO INDICATOR

5/11/68 P. L. OAK