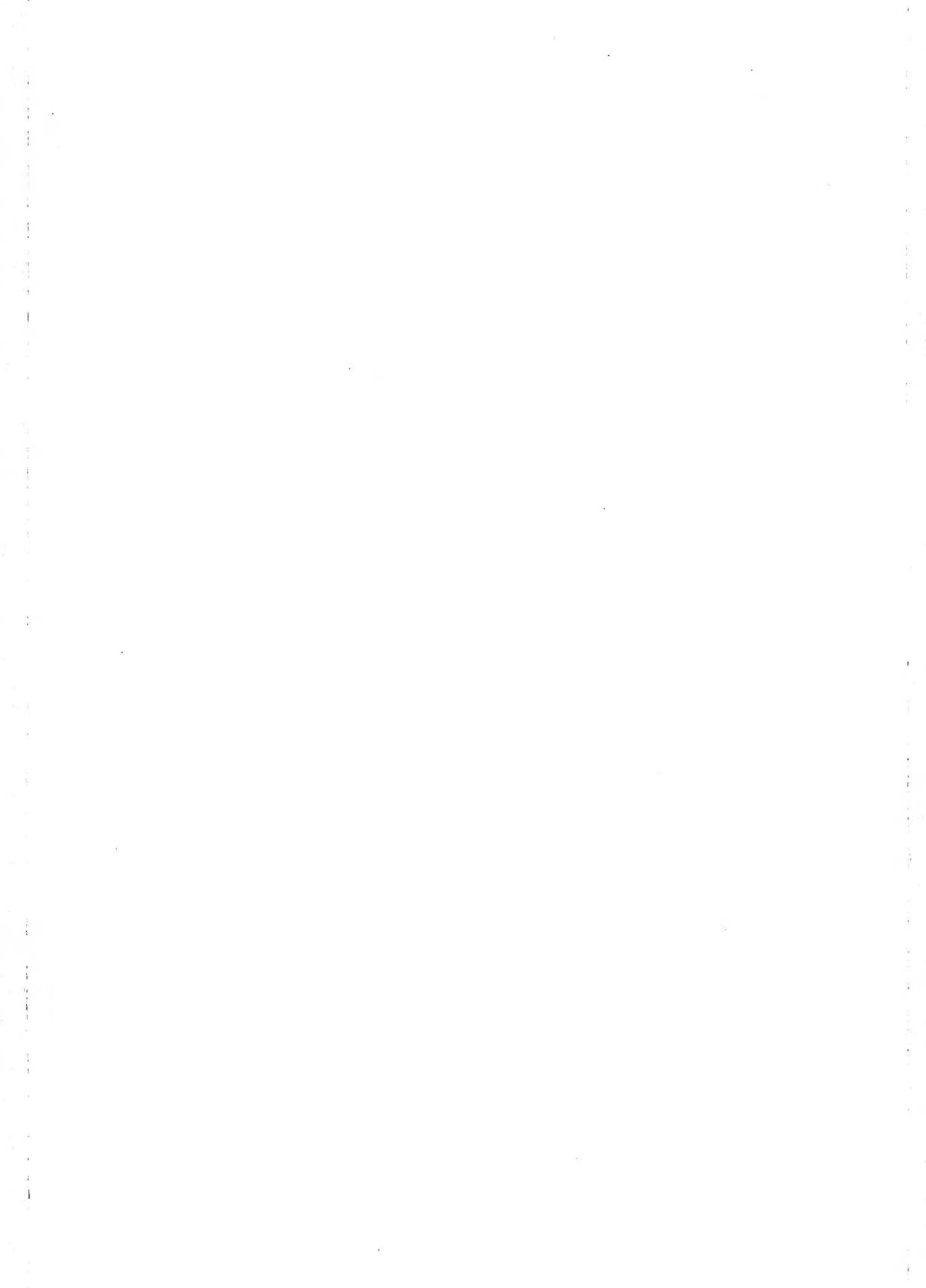


SOPHT-B Verification  
Bruce NGS-A Turbine Load Rejection Test From 83% FP

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## 1.0 INTRODUCTION

The SOPHT (Simulation of PHWR Heat Transport) program<sup>(1-4)</sup> was developed to simulate the operating conditions in the CANDU PHWR heat transport and steam generating systems. For this reason it is important to verify its predictions by using actual operating data from the plant.

The station commissioning turbine load rejection tests were chosen for the SOPHT program verification for the following reasons:

- (1) In-plant tests are extremely expensive. A specially designed test for simulation model verification cannot be justified.
- (2) Station commissioning requires the load rejection test be performed at four different power levels. One of these tests can be used to check and calibrate the test instrumentation and, therefore, provide a better chance to successfully obtain all required data during a second test.
- (3) A turbine load rejection will produce one of the largest plant system disturbances during operation and cause the response of almost all control system actions designed for the thermal-hydraulic system.

Therefore, it is possible to evaluate most of the SOPHT models and verify the program's ability to simulate the overall response of a nuclear plant system.

The SOPHT prediction was first verified against Pickering NGS load rejection test data.<sup>(5)</sup> Because of the limited amount of data obtained on the control and thermal-hydraulic systems and the failure of some steam discharge valves during the Pickering NGS test, it was only possible to compare the results for the first five seconds of the transient, during which period the response to most control actions has little effect on the thermal-hydraulic system conditions. A second verification of the SOPHT program was made by the Bruce NGS-A thermosyphoning test data during commissioning.<sup>(6)</sup> The predicted thermohydraulic system and HT pump rundown conditions were compared with the test data in some detail.

In this verification the Bruce NGS-A test data for a much longer transient period is compared with the SOPHT prediction in an attempt to assess the ability of the SOPHT program to simulate the operating plant transients.

## 2.0 BRUCE NGS-A TURBINE LOAD REJECTION

It is not the intention of this paper to fully discuss the Bruce NGS-A plant systems and their simulation models. However, to aid discussions of the verification it is necessary to include a Bruce NGS-A hydraulic system diagram in Figure 1, a simplified plant control diagram in Figure 2 and a brief qualitative description of the load rejection event.

In a load rejection the generator breaker opens and separates the generator from the external electrical system. This results in a governor valve closure on turbine overspeed and consequently an increase in the boiler pressure. At high operating power, the reactor regulating system senses the load rejection and initiates a reactor power stepback to 60% FP within 0.5 seconds. The stepback is done by dropping the 4 absorber rods into the core and catching the rods when the control computer predicts that the endpoint power will be reached by the time of its next program execution.

To prevent high boiler pressure the boiler pressure control program initiates to fully open the 4 atmospheric steam discharge valves (ASDV) and the 6 condenser steam discharge valves (CSDV) within 2.5 seconds if the turbine power is above 50% FP. This is done by a process interrupt for two sampling intervals (4 seconds). Control is then returned to normal BPC.

The initial increase of boiler pressure will reduce the heat sink of the heat transport system and cause the HT pressure and pressurizer level to rise due to the resulting temperature increase in the boiler. In Bruce NGS-A the foregoing condition is compensated by the reduction of reactor outlet temperature following the reactor stepback. The net HT pressure and pressurizer level response will depend on the direction and magnitude of the power mismatch between the reactor and the preheaters and steam generators.

After the initial disturbance the control system will effectively regulate the ASDV's and CSDV's to match the reactor power, which is set at a level high enough to prevent a reactor poison outage.

### 3.0 DATA COMPARISON

Ninety-three variables of Bruce NGS-A plant system were specially instrumented by Ontario Hydro Research Division and recorded on magnetic tape and numerous control valve positions were recorded by high speed recorders during the test. Also, a large quantity of initial steady state measurements were taken before the test.<sup>(7)</sup> Comparison of the SOPHT predictions is done with this data.

#### 3.1 Steady State

The measured initial steady state conditions and the SOPHT-B solution are given in Table 1. In the SOPHT solution a number of important boundary conditions such as the reactor outlet pressure, the deaerator pressure (FW temperature) and the boiler pressure were adjusted to match the measured operating conditions. The boiler and preheater fouling factors were adjusted to match the measured circuit temperature. Also, the bleed cooler capacity was adjusted to give approximately the same outlet temperature. In order to make the controller output agree with the steady state conditions some of the controller rest signals were adjusted, although these values were not measured during the test. This effort still cannot satisfy all the measured initial conditions because the steady state conditions in the plant are not a real steady state and can never mathematically satisfy the steady state equations.

#### 3.2 Transient Simulation

##### 3.2.1 Simulation Model

A simple "O" HT loop configuration model, as shown in Figure 3, was used in the SOPHT simulation. This is considered adequate for the following reasons:

- (1) Following the load rejection, conditions in the plant system are generally symmetrical with respect to the reactor.
- (2) Because of the fact that not all measured values are consistent, it will be very difficult to consider detailed variations in the steady state solution on the full circuit configuration.
- (3) Computing cost can be minimized.

### 3.2.2 Reactor Power

It was found that after the stepback the predicted reactor power did not drop as low as indicated by the test data. Operations have, in fact, found that the absorber rod insertion in stepbacks is larger than expected. This could be due to the response of power measurement or the effectiveness of the rod catching mechanism.

For a meaningful hydraulic system response comparison the reactivity worth of the absorber rod was arbitrarily increased so that the predicted power can be in agreement with measurement as shown in Figure 4.

### 3.2.3 Steam Pressure

Figure 5 shows the response of the turbine governor valves, the steam discharge valves and the steam pressure at the emergency stop valves immediately following the event. There is no turbine dynamics model in SOPHT and, therefore, it cannot predict the governor valve closure on the turbine overspeed and the resultant steam chest pressure. In the verification runs, instead of using design data the steam chest pressure was made to approximately follow the measured curve as shown in Figure 6.

Under the foregoing described boundary conditions, the comparisons of steam flow and pressures are shown in Figures 7 and 8 from which the following discrepancies are noted:

- (1) The predicted steam flow is lower than the measured value by up to 15% during the first 20 seconds.
- (2) SOPHT predicted a lower rate of initial steam pressure rise and a larger value of total pressure increase in the first 20 seconds.
- (3) After 20 seconds, the agreement is better. This shows the effect of the control system.

It is also noted that the higher measured main steam pressure in Figure 8 must be due to instrument calibration since this pressure measured at the steam header cannot be higher than the steam drum pressure.

Re-examining the data (partly shown in Figure 5) we found that some of the CSDV's did not open as fast as they were designed and that at the valve fully opened condition a higher steam flow was measured than that calculated by the designed valve capacity.

Since the steam pressure transient strongly affects the heat transport system condition, it is necessary to correct the CSDV opening characteristics and capacity. The results of a 40 second SOPHT rerun with these corrections are shown in Figures 9 and 10 in which the first prediction (Run 1) is denoted by a cross, "X", and the second prediction (Run 2) by circles "O".

For a better comparison of the transient responses, Figures 9 and 10 were replotted by shifting the measured plot so that the initial measurement value agrees with the predictions. The new plots are shown in Figures 11 and 12. The overall agreement is fairly good. The lower predicted pressure rise seen in the boiler could be the result of the equilibrium model assumption used by SOPHT.

#### 3.2.4 Steam Drum Level and Feed Water Flow

Each of steam drum levels is controlled by an analog control system which varies the feed water flow according to the level, and steam/feed water flow conditions. The predicted and measured feed water flows and steam drum levels are shown in Figures 13 and 14 respectively.

Although the steam flows of the east and west sides of the reactor are approximately the same, the actual feed water flows are significantly different, as shown in Figure 13. Similar differences are also seen in the steam drum levels (Figure 14). The reason for this different level and feed water behaviour is not

clearly known. It could be a result of the effect of the initial controller conditions (reset, error, etc), the different responses of the level control valves, isolation valves and the differences between the steam and feed water flows. Unfortunately not all of these variables were measured during the test. The predicted feedwater flow and steam drum level fall between the two sets of measurements and their response appears to be similar to the east drum response.

The initial value differences in Figures 13 and 14 were eliminated and replotted in Figures 15 and 16 respectively. Apart from the unexplicable east-west difference at about 10 seconds, SOPHT predicted the feed water flows and boiler level reasonably well.

### 3.2.5 Heat Transport Pressure and Pressurizer Level

The comparison of the heat transport reactor outlet pressure and the pressurizer pressure and level are given in Figures 17, 18 and 19, respectively. Figures 20 and 21 present the variables which may affect the conditions of the heat transport and the pressurizer. However, these variables are not going to be discussed here in detail. From Figures 17 and 18 and 19 the following are noted:

- (1) The pressurizer level prediction agrees with measurement well. The slightly lower predicted level could partially or totally be attributed to the omission of piping heat in the SOPHT runs.
- (2) SOPHT prediction of the HT pressure and pressurizer pressure also agree reasonably well with the measurement data. However, as indicated in the pressure transient curves, SOPHT predicts a lower slope for decreasing pressure and a high slope for increasing pressure. This is expected because of the assumptions of the equilibrium model for the out-surge and adiabatic compressure of the steam for the in-surge in the pressurizer model.

- (3) The larger measured pressure disturbance measured between 3 and 10 seconds (Figures 17 and 18) cannot be clearly explained and is not predicted by SOPHT. This might be due to one, or the combined effects of the factors below:
- (a) The SOPHT reactor stepback occurs at  $t = 0$ , while the actual stepback could take place between 0 and 0.5 seconds. Figure 4 also shows a little less measured power decrease than SOPHT. This may be the cause of the HT pressure rise seen at the station immediately after the load rejection.
  - (b) As noted in Figure 17, the two reactor outlet headers have also a slight difference in pressure during the transient because only one header is connected directly to the pressurizer. There are 6 pressure measurements (with slightly different readings) and 3 pressure controllers which had also different setpoints during the tests (9.0, 9.05 and 9.1 MPa). The steam bleed valves could open momentarily during the early period of the test and cause the rapid decrease in pressure. If this is true, it also explains the momentary increase of reflux flow in Figure 20. However, the bleed condenser pressure, pressurizer level data and an uncalibrated steam bleed valve position measurement do not appear to support this argument.
  - (c) The HT pressure disturbance may also be a result of the unexplainable feed water flows measured during the same period (Figures 13 and 15).

### 3.2.6 Heat Transport and SG Feed Water Temperatures

Figures 22 and 23 show the comparisons of the predicted temperatures of the heat transport system and the steam generator feed waters with one of the many measured values. For detailed comparison all measured data should be used and

the time response of these temperature measurements should also be corrected for the comparison. These figures intend to show the general trend only.

#### 4.0 CONCLUSION

- (1) Consider the complexity of the Bruce NGS system. The SOPHT program predicts the load rejection transient very well. Because of the effect of control actions, the program can predict the plant system response even with some of the equipment failing to behave exactly as designed (eg, the CSDV's in Run 1) and the transient starting without a real steady state.
- (2) The simple pressurizer model and the omission of piping heat are generally satisfactory for HT pressure calculations. However, the analyst must be careful when applying the simulation to a specific problem.
- (3) Although a large number of plant conditions were recorded, the data is still not, or may never be, enough to answer certain specific questions appearing in the verification. However, the present comparison is adequate to validate the SOPHT simulation program.
- (4) Because of too many variables and boundary conditions which cannot be controlled or measured in the plant, it is impractical and uneconomical to rely on the in-plant test data for model development or improvement of specific hydraulic or heat transfer models (eg, two-phase flow pressure drop, heat transfer correlations). Such detailed data would have to be obtained from simple and basic laboratory test.

#### 5.0 REFERENCES

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- (5) Y.F. Chang, J. Skears, "A Preliminary Verification of the SOPHT-B and SOPHT-P Simulation Program, CNS-IR-331-6.1 (October 1974).
- (6) P.L. Bourne, K. Petrunik, Y.F. Chang, "Bruce NGS-A Unit 2 Phase C Commissioning HT Thermosyphoning Test" (October 1976).
- (7) G.R. Seiveright, Bruce NGS-A HT and Feed Water/Steam Data from Turbine Load Rejection Test at 83% Full Reactor Power on Unit 2, CNS-IR-331-20 (September 1978).

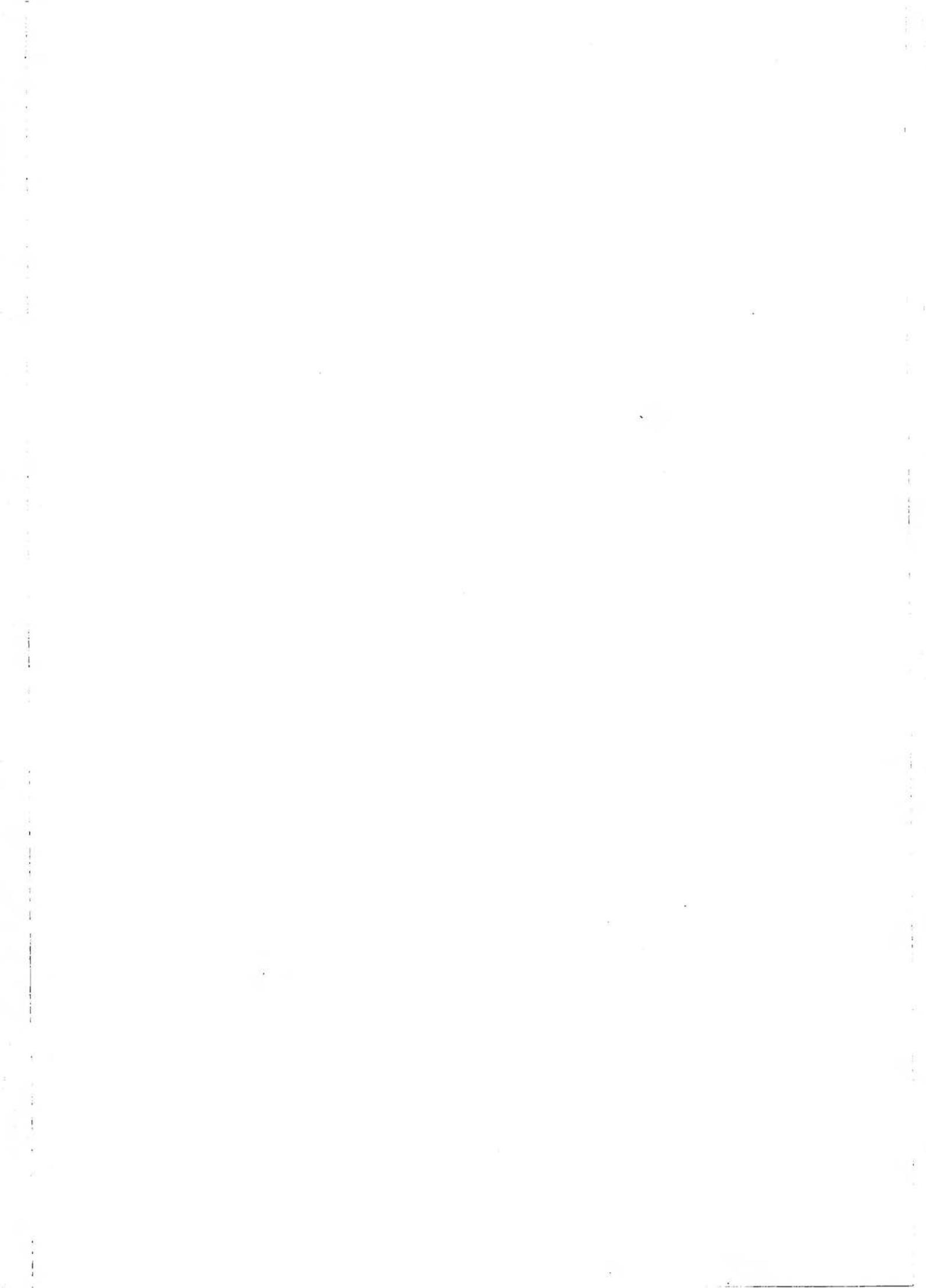


TABLE 1

Steady State Results: 83% FP

	<u>SOPHT Simulation</u>		<u>Station Measurement</u>	
	<u>Pressure</u> <u>(kPa)</u>	<u>Temp</u> <u>(°C)</u>	<u>Pressure</u> <u>(kPa)</u>	<u>Temp</u> <u>(°C)</u>
OZ Inlet Header	10 425.35	261.43	-	261
Outlet Header	9 100.00	292.83	9 120	293
Boiler Outlet	8 868.36	260.97	-	262
Preheater Inlet	10 316.74	261.43	-	261
Preheater Outlet	10 218.63	241.29	-	241
IZ Inlet Header	10 268.79	251.57	-	250
Preheater Inlet FW	4 534.85	165.98	-	166
Preheater Outlet FW	4 473.53	239.00	-	240
Steam Drum	4 376.00	255.08	4 380	253
Bleed Condenser	1 720.00	202.59	1 650	202
Pressurizer	9 185.32	303.57	9 180	303
Bleed Cooler		33.24	-	28
Deaerator	442.00	144.56	-	144
Storage Tank	100.00	38.87	-	36
Steam Chest	3 950.00	249.51	3 945	-

	<u>Flow (kg/s)</u>	<u>Flow (kg/s)</u>
Steam Flow	1 085.0	1 023.0
Feed Water Flow	1 014.0	1 013.0
Reheater Drains Flow	71.0	71.0
HT Channel Flow	25.6	≈25.6
HT Bleed Flow	21.8	18.26
HT Reflux Flow	10.1	8.0



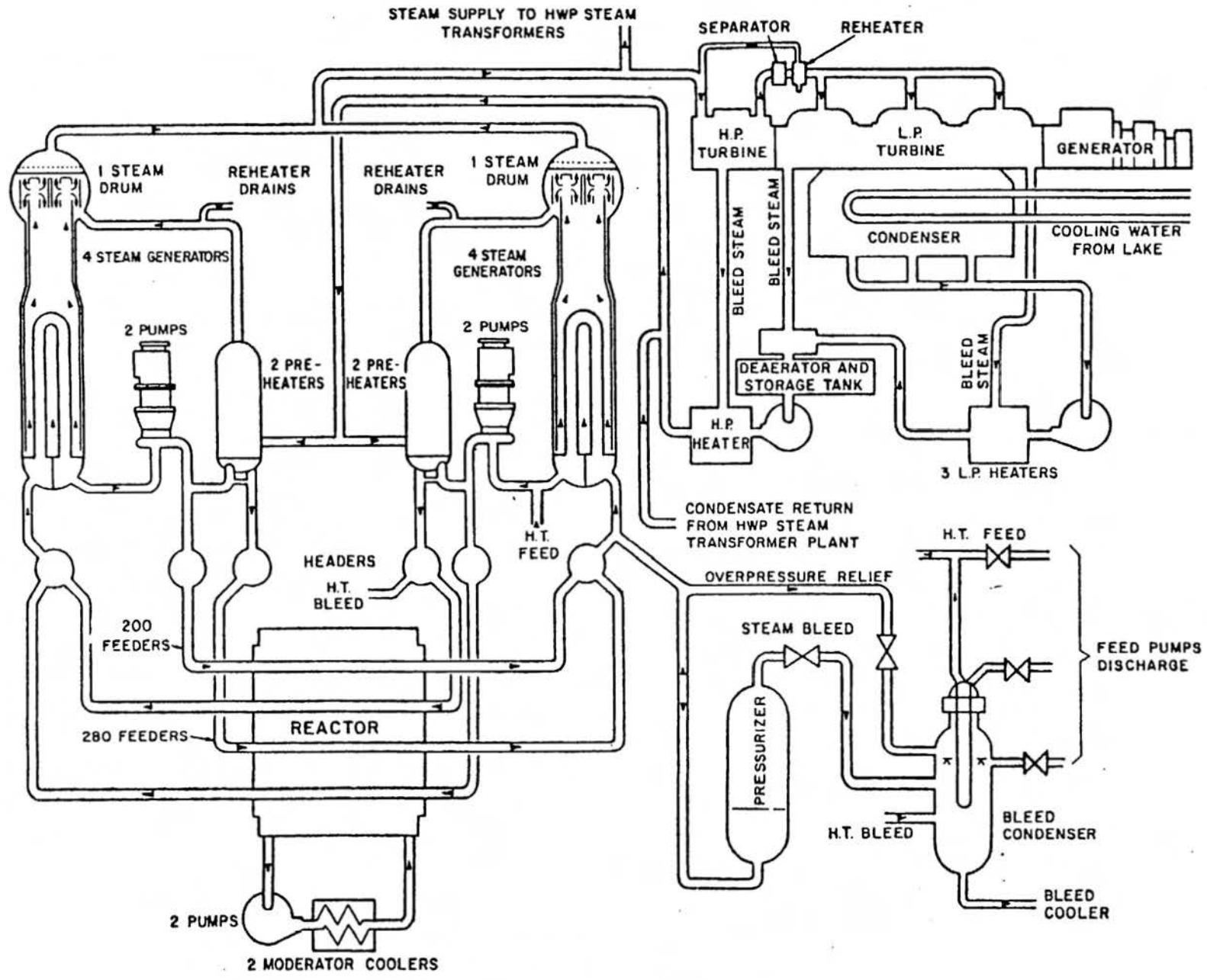


Fig. 1. Bruce simplified station flow diagram.

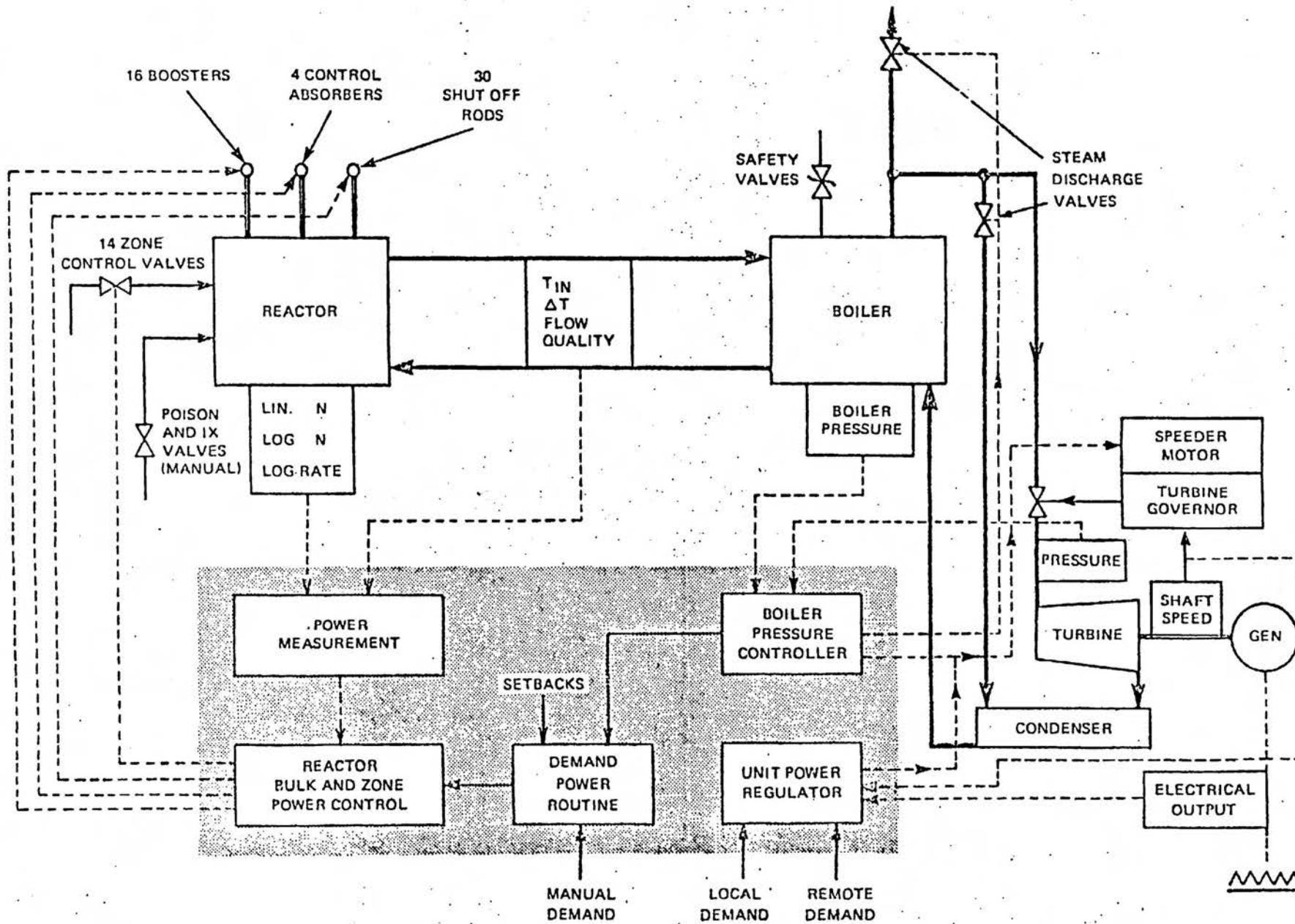


FIG 2  
UNIT CONTROL SYSTEM BLOCK DIAGRAM

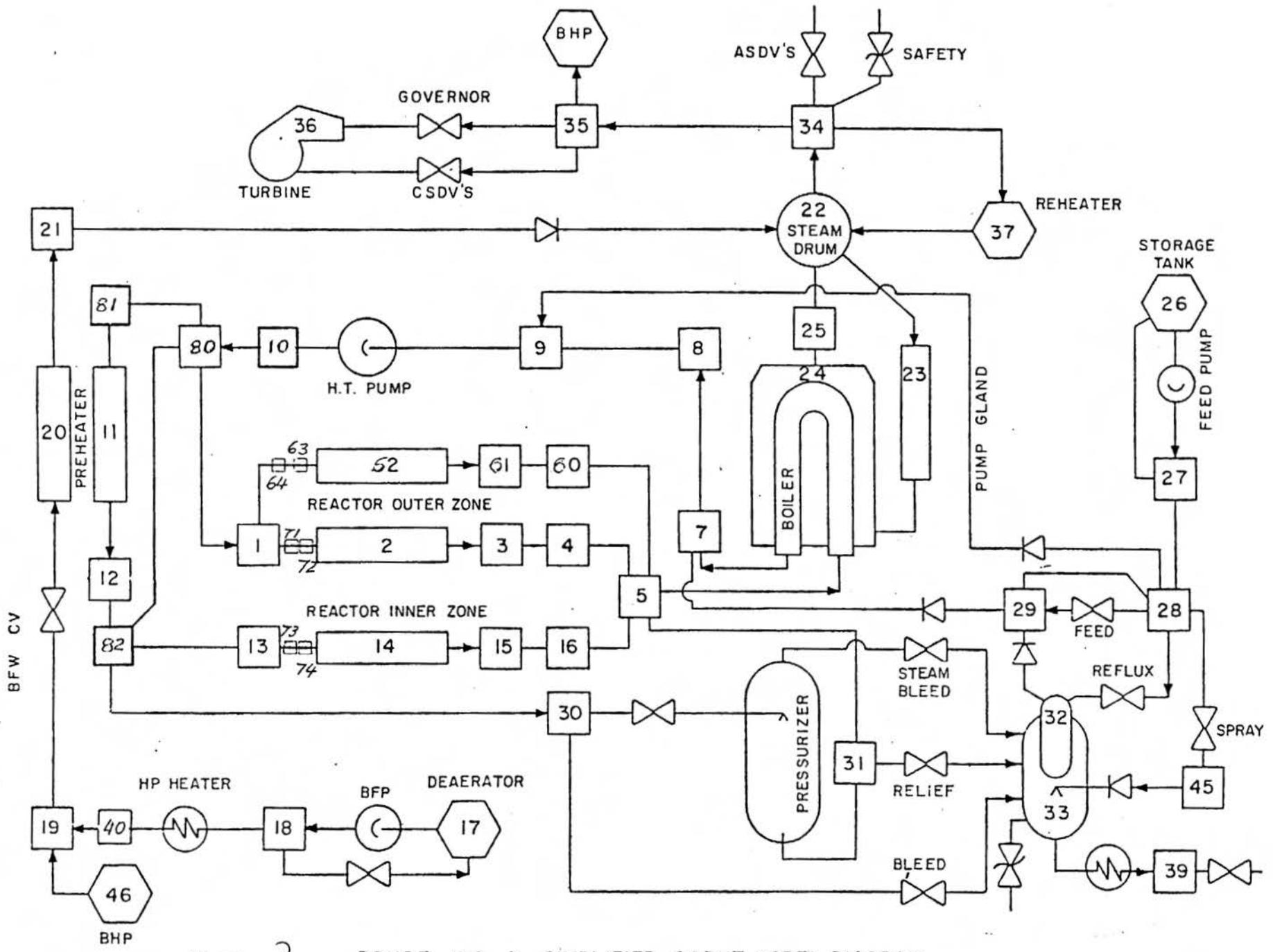
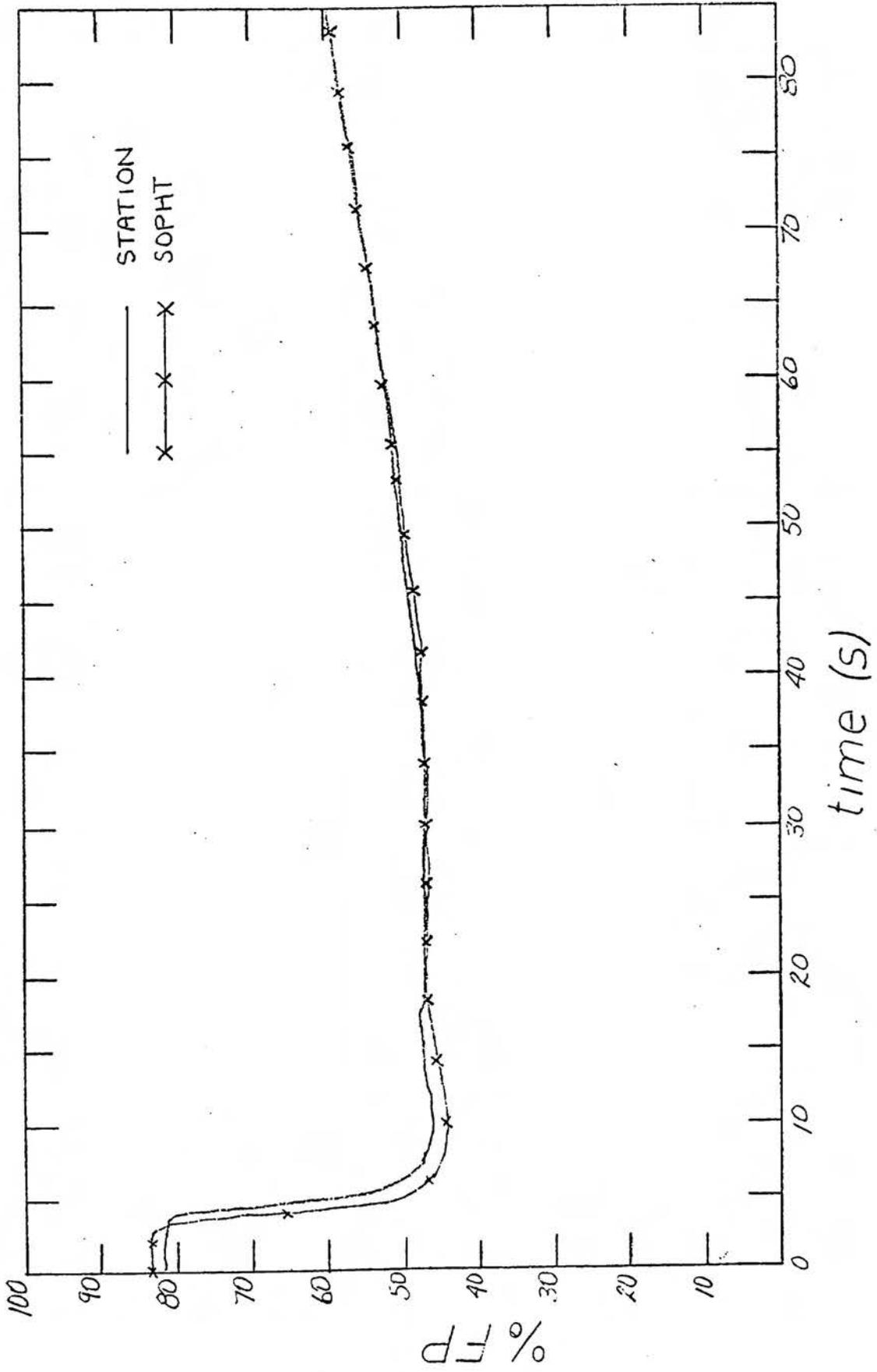


Figure 3 BRUCE G.S. A SIMPLIFIED SOPHT MODEL DIAGRAM

FIG 4 Reactor Power



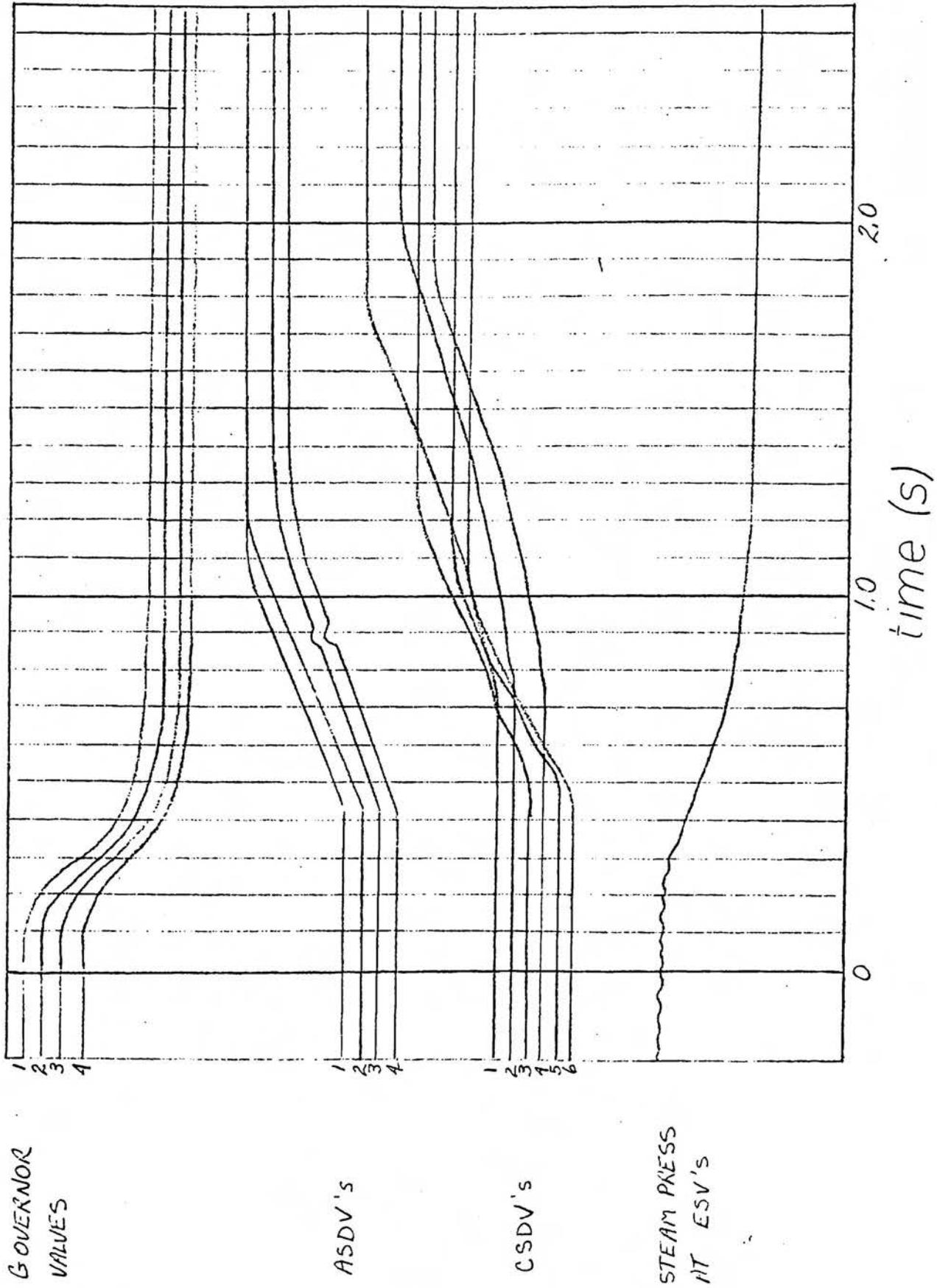


FIG 5 Valve Position

FIG 6 Steam Chest Pressure

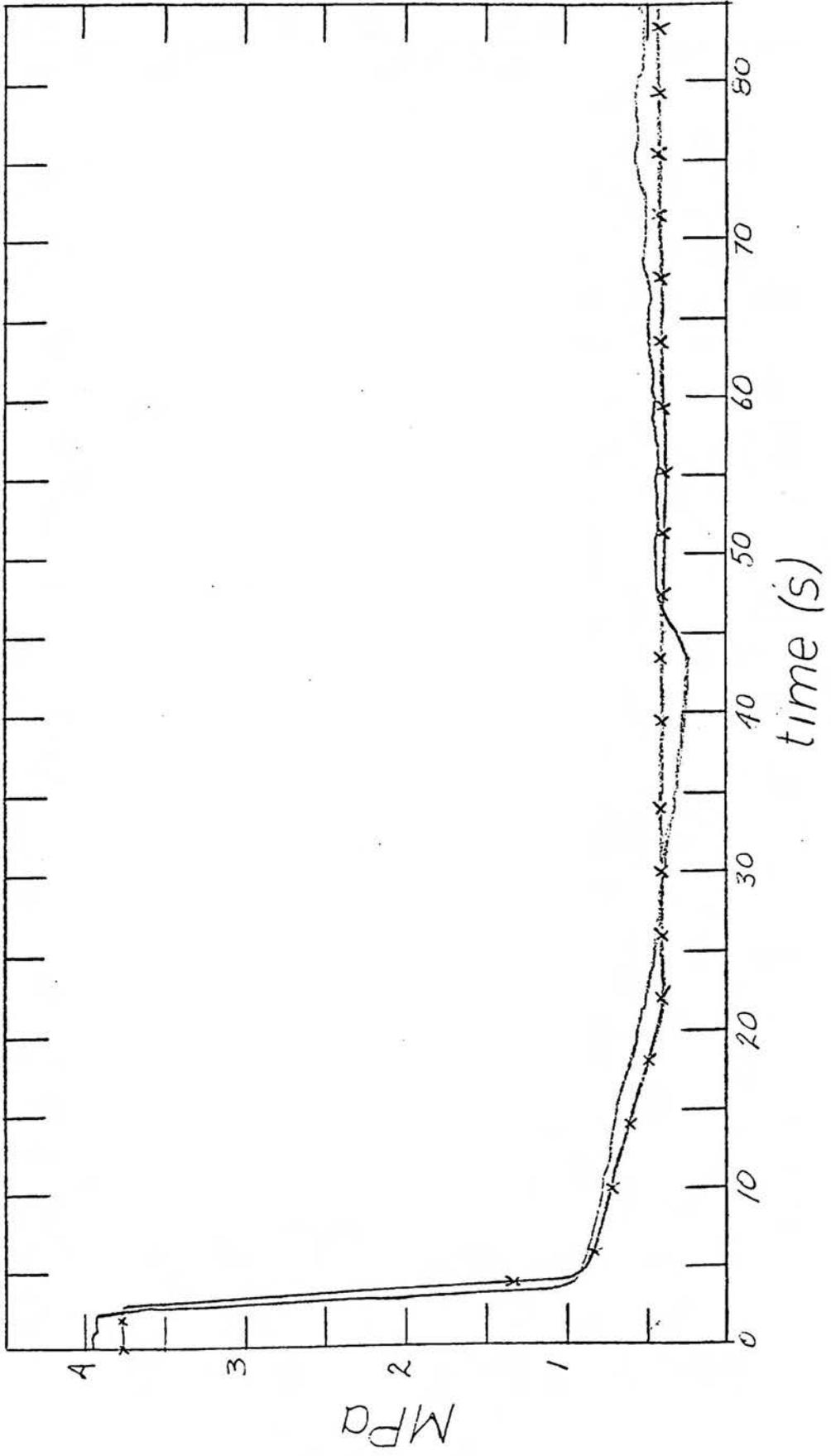


FIG 7 Steam Flow

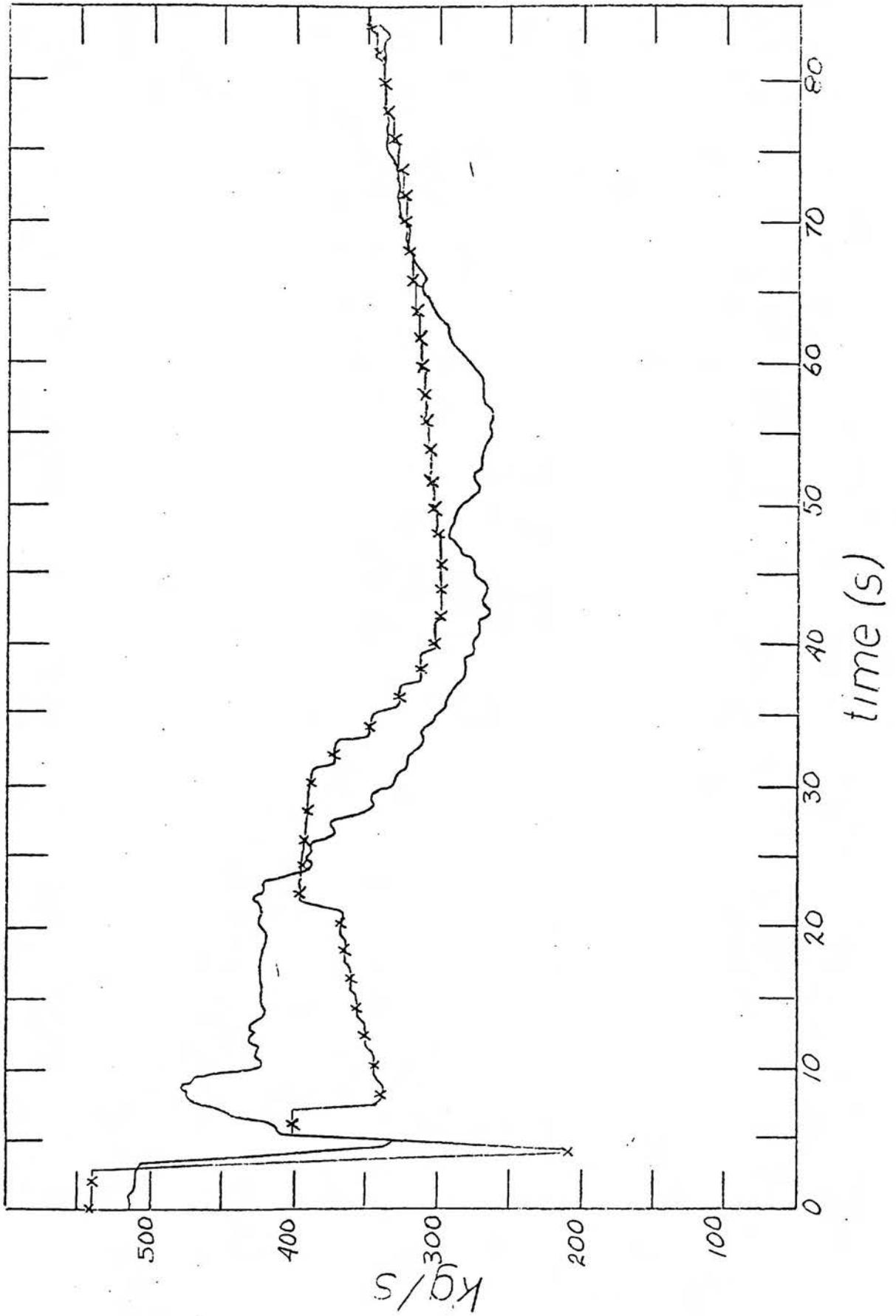


FIG 8 Steam Pressures

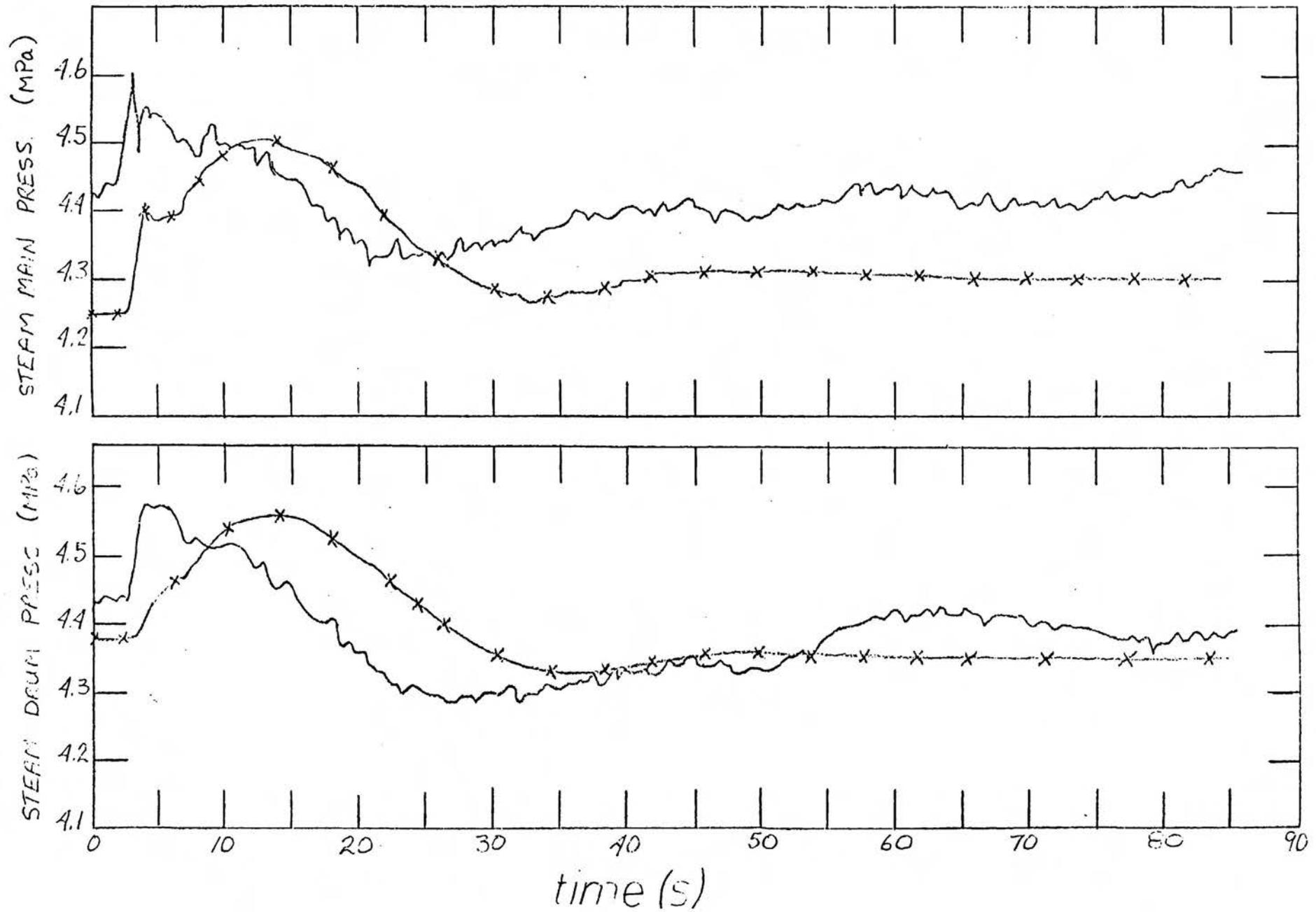


FIG 9 Steam Flow

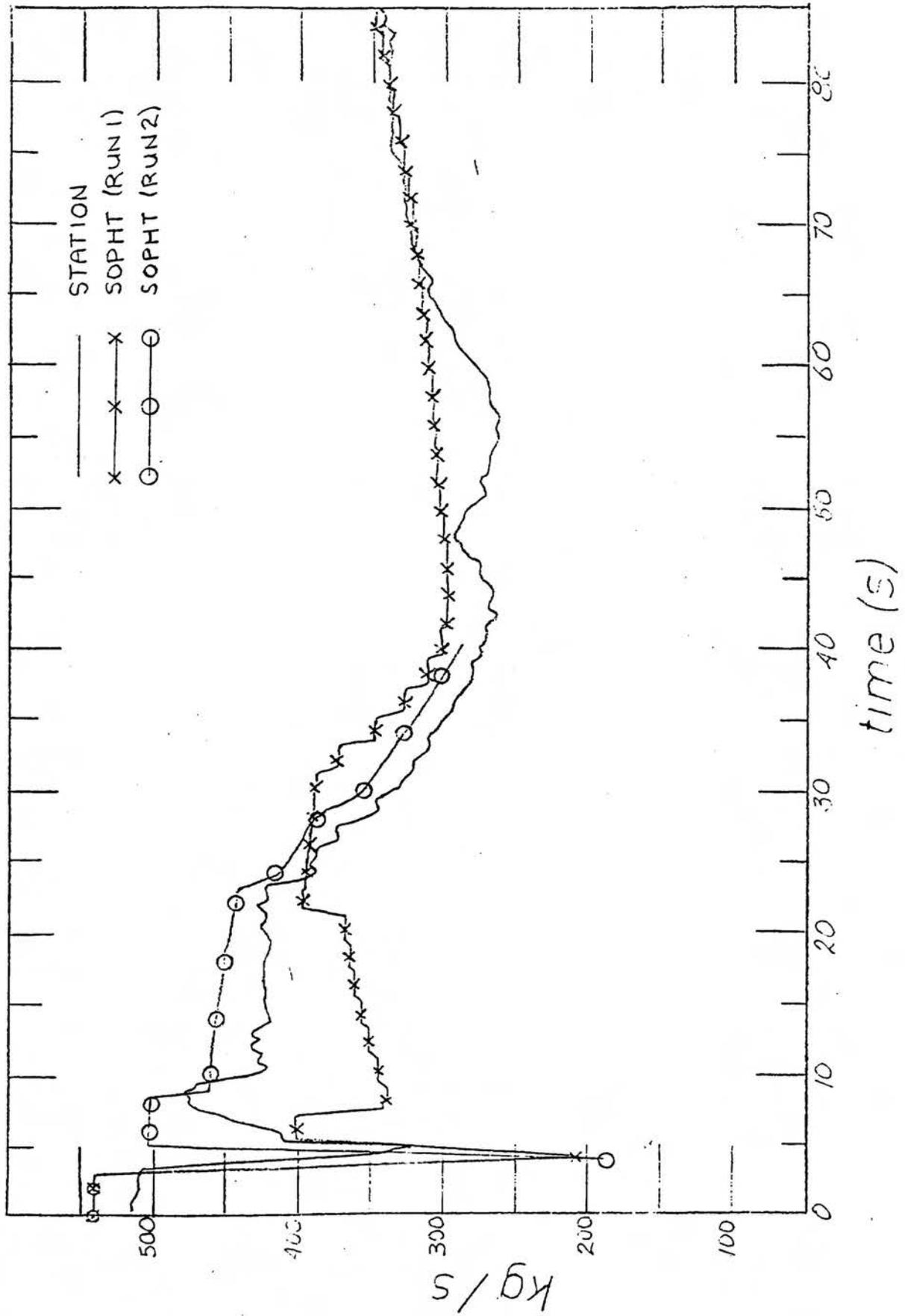


FIG 10 Steam Pressures

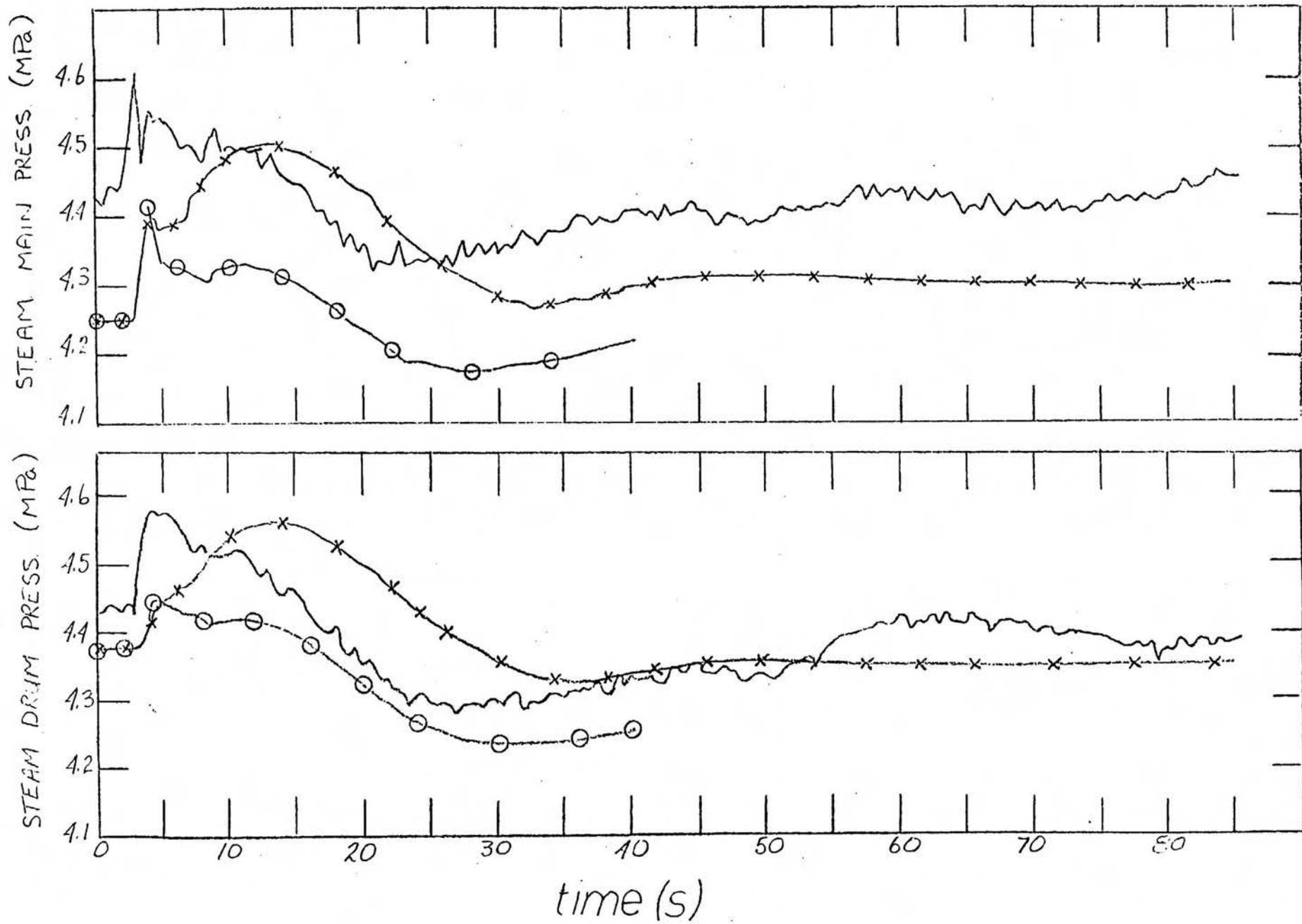


FIG 11 Steam Flow

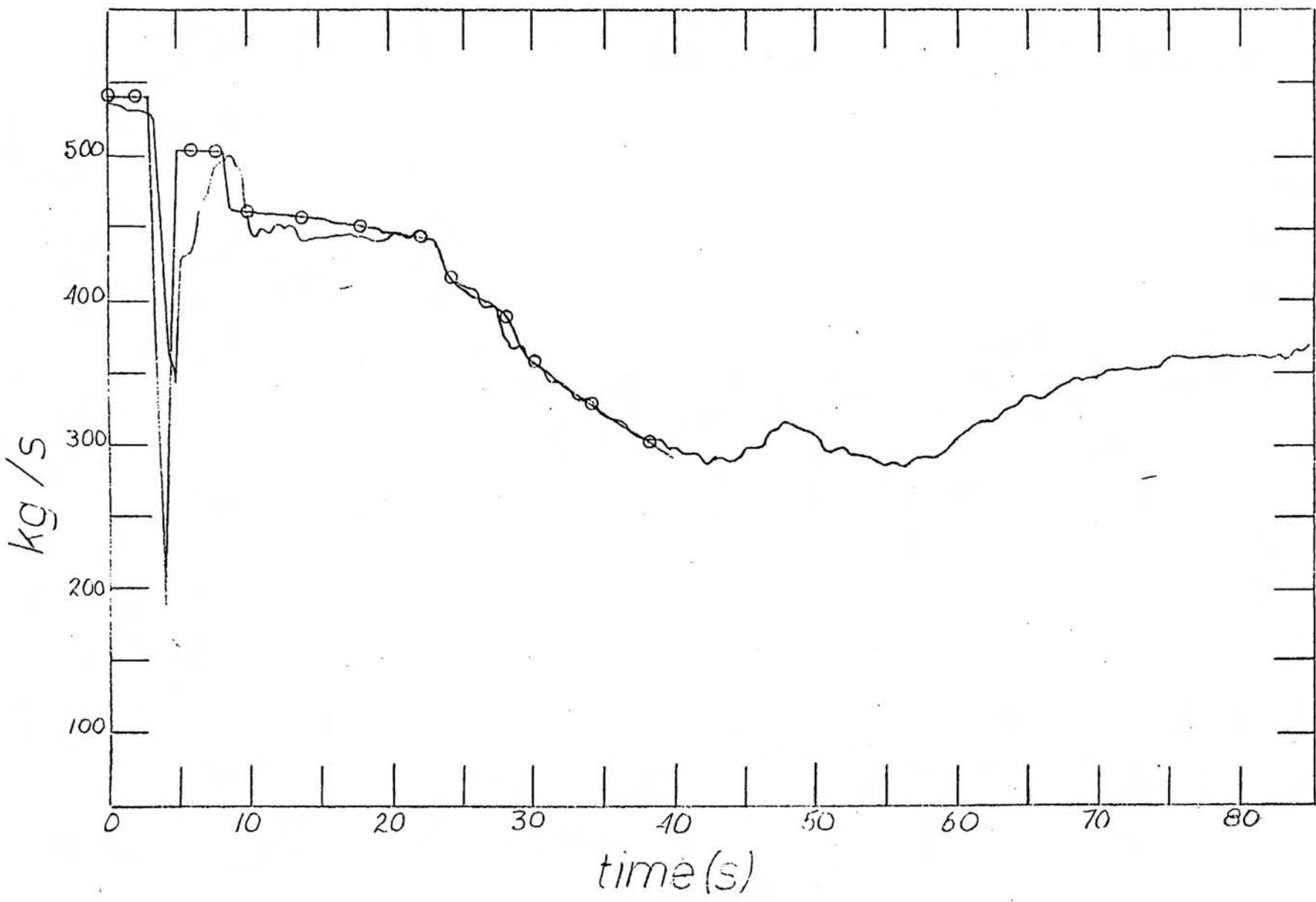


FIG 12 Steam Pressures

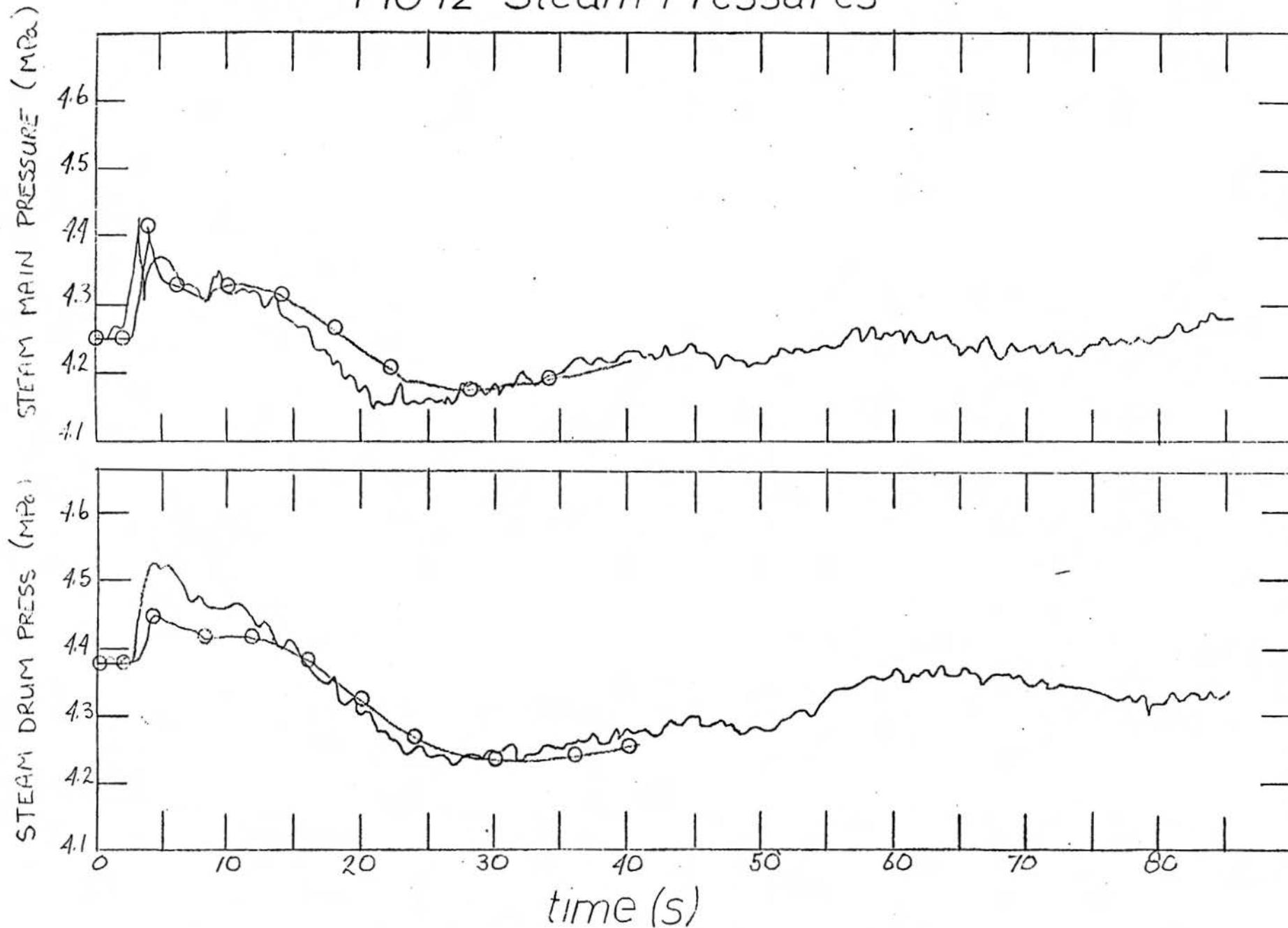


FIG 13 Feedwater Flow

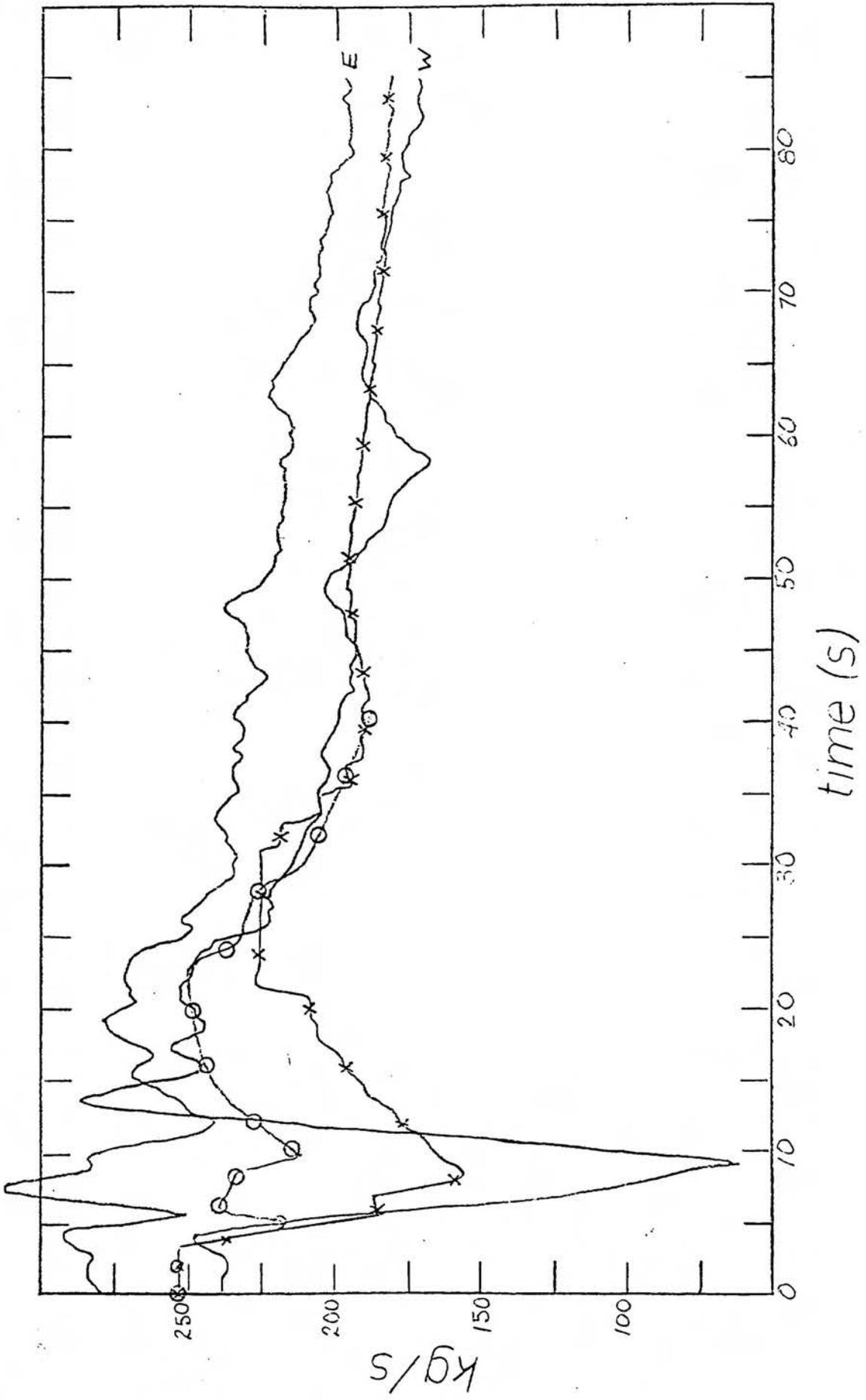


FIG 14 Steam Drum Level

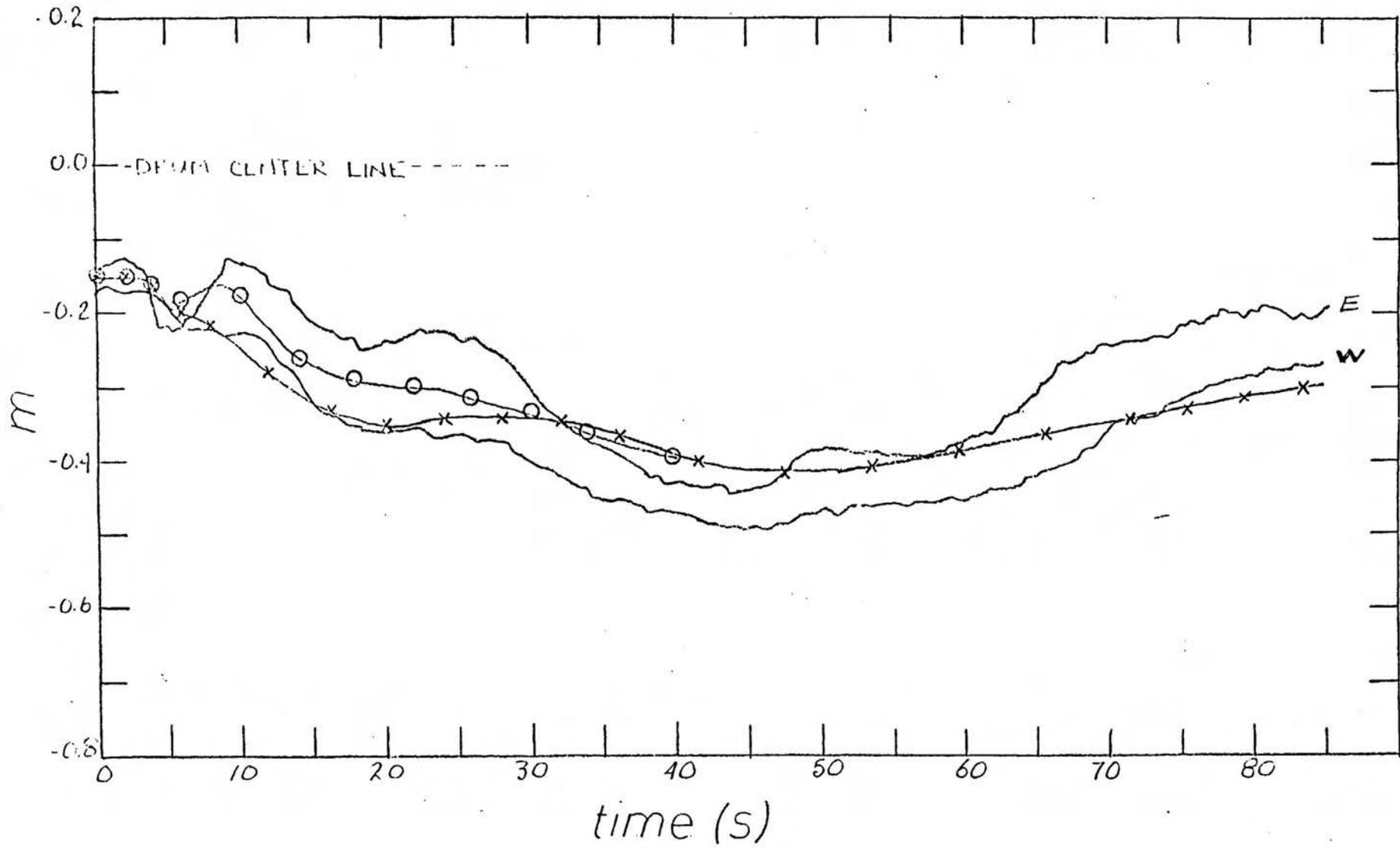


FIG 15 Feedwater Flow

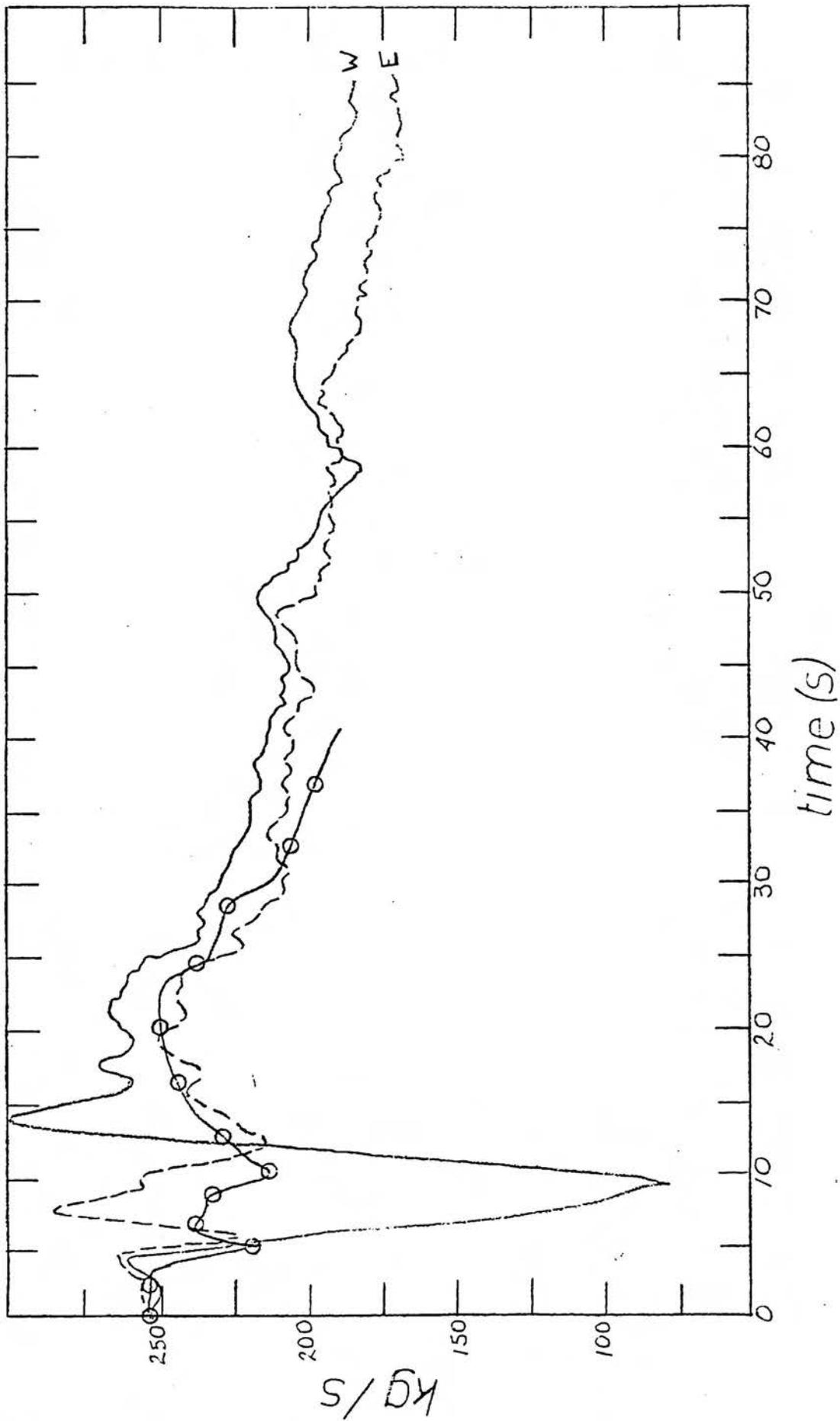


FIG 16 Steam Drum Level

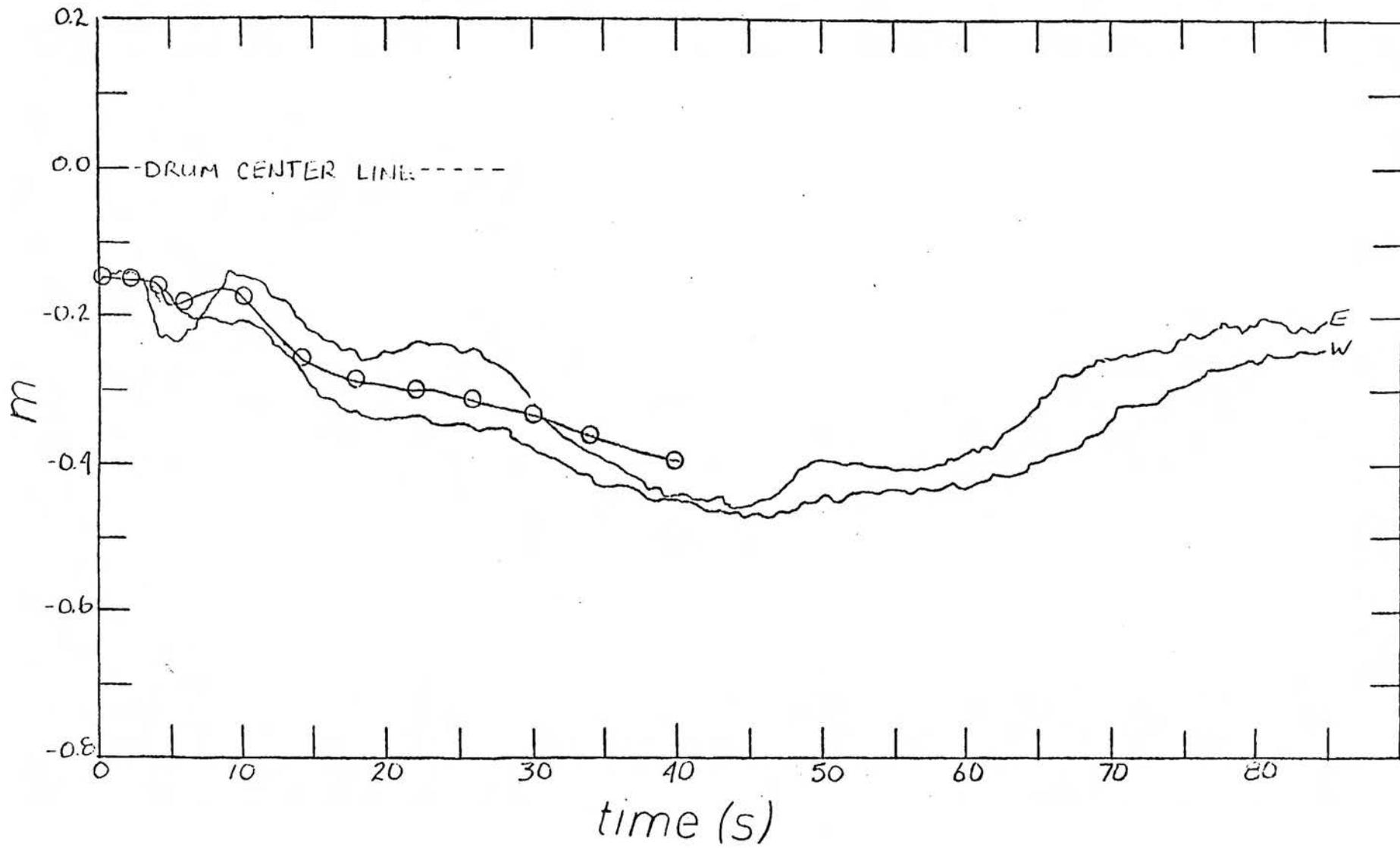
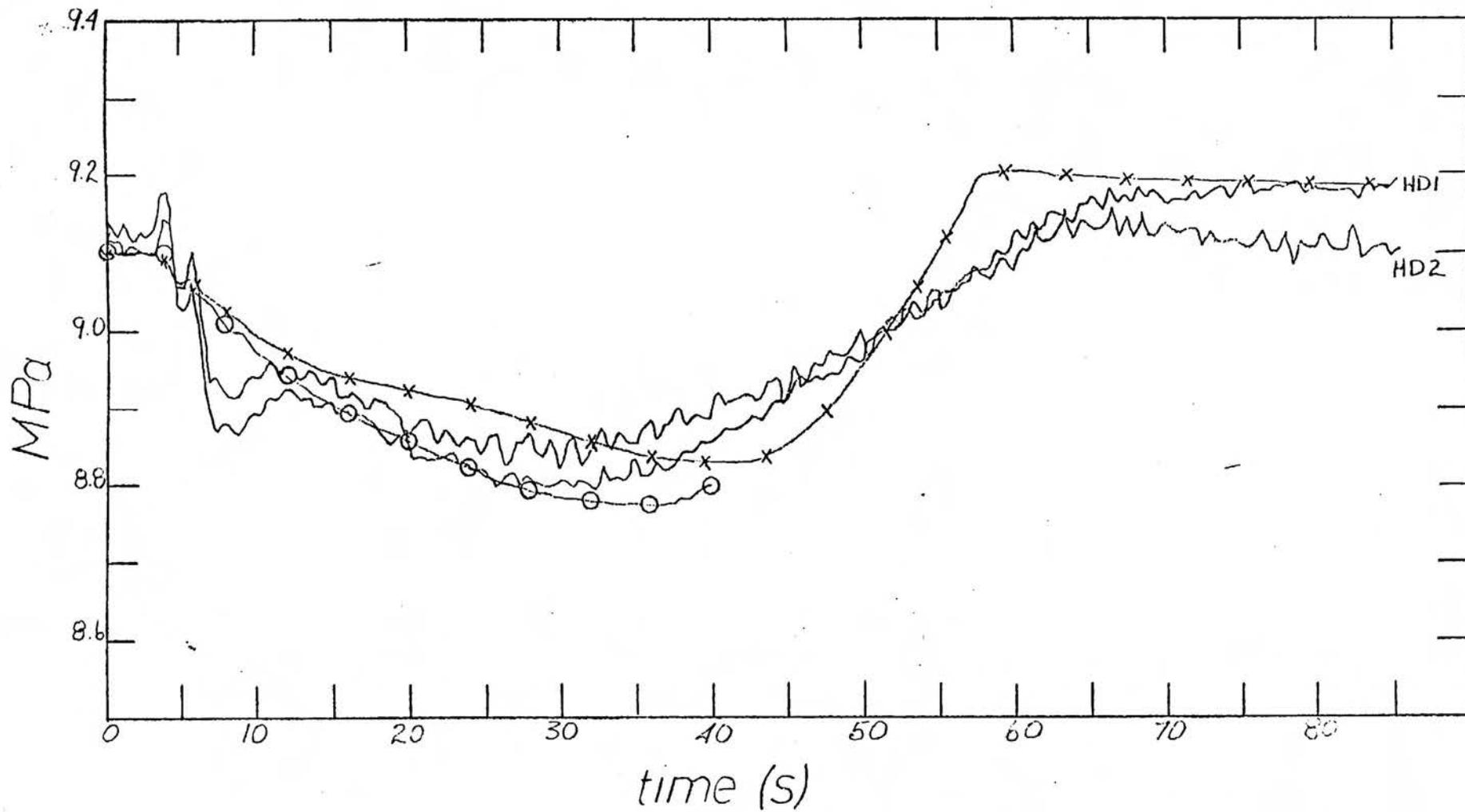


FIG 17 HT ROH Pressure



7.4

FIG 18 Pressurizer Pressure

MPa

9.2  
9.0  
8.8

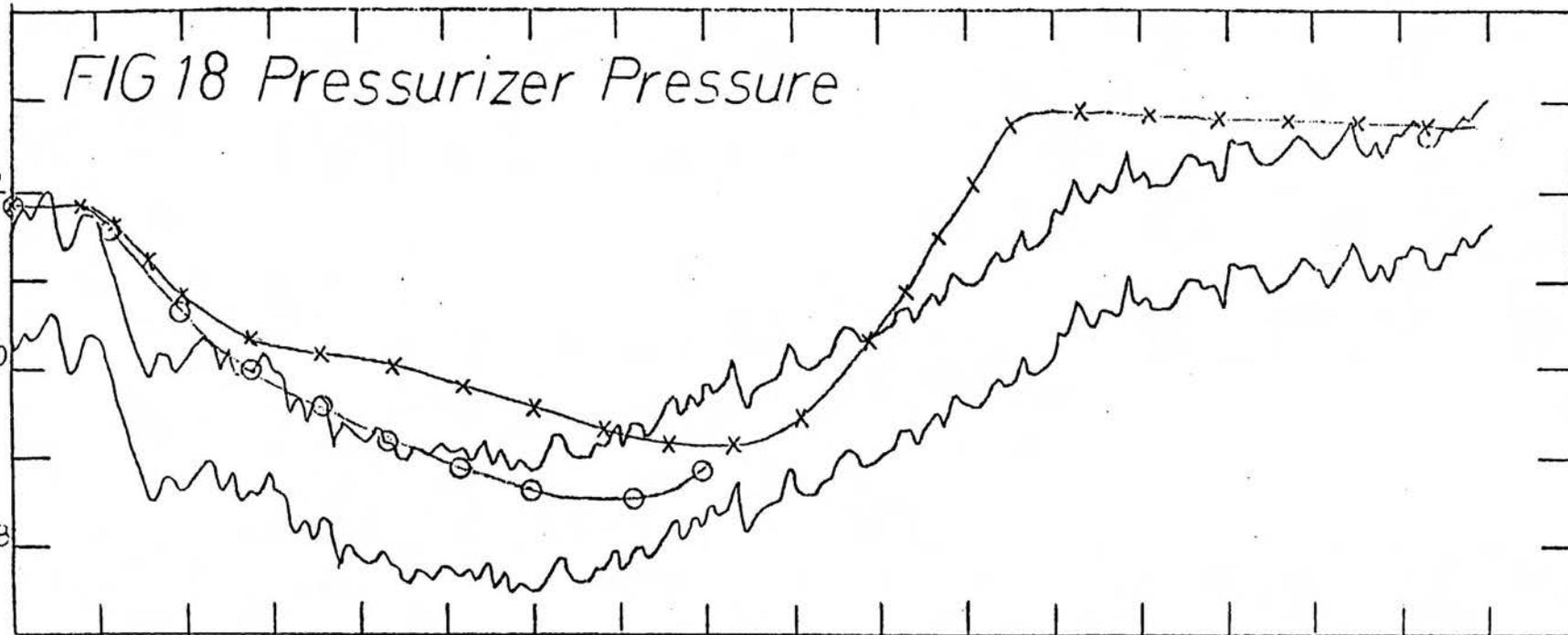
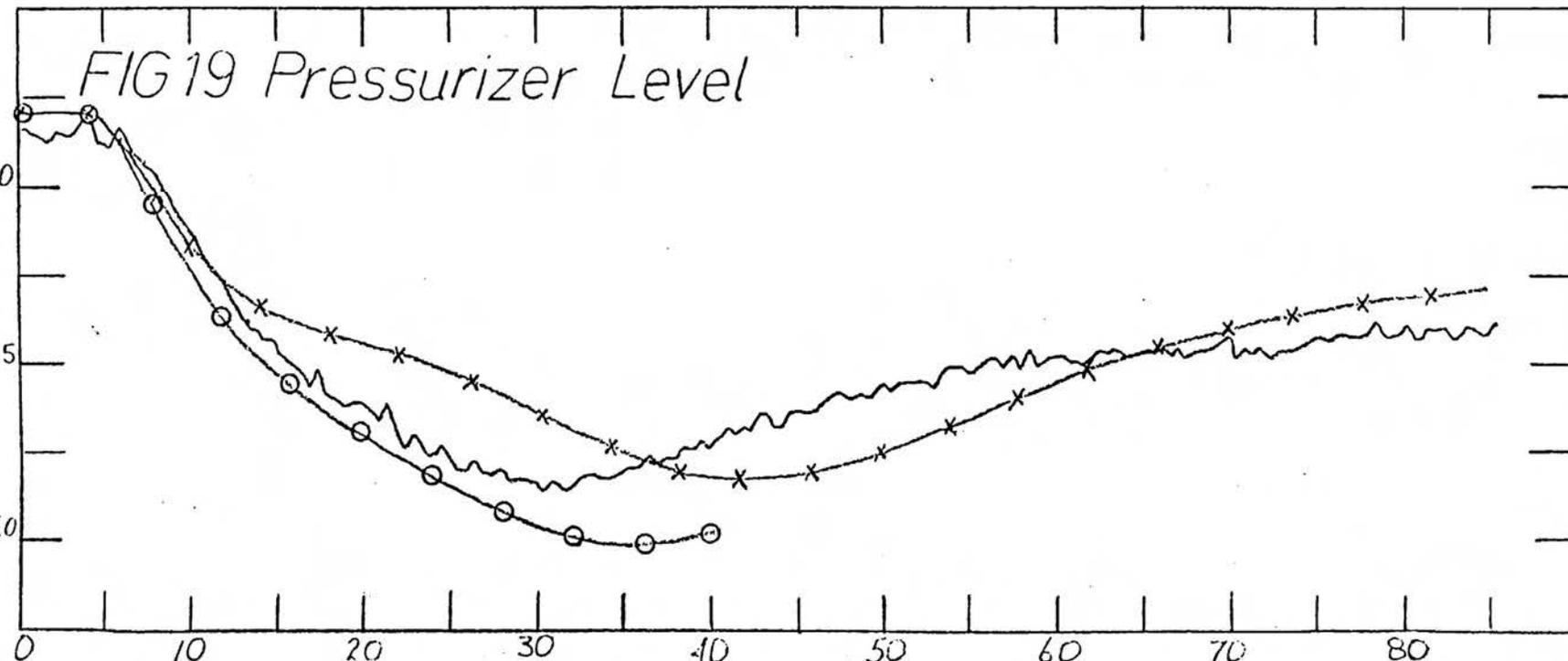


FIG 19 Pressurizer Level

m

6.0  
5.5  
5.0



time (s)

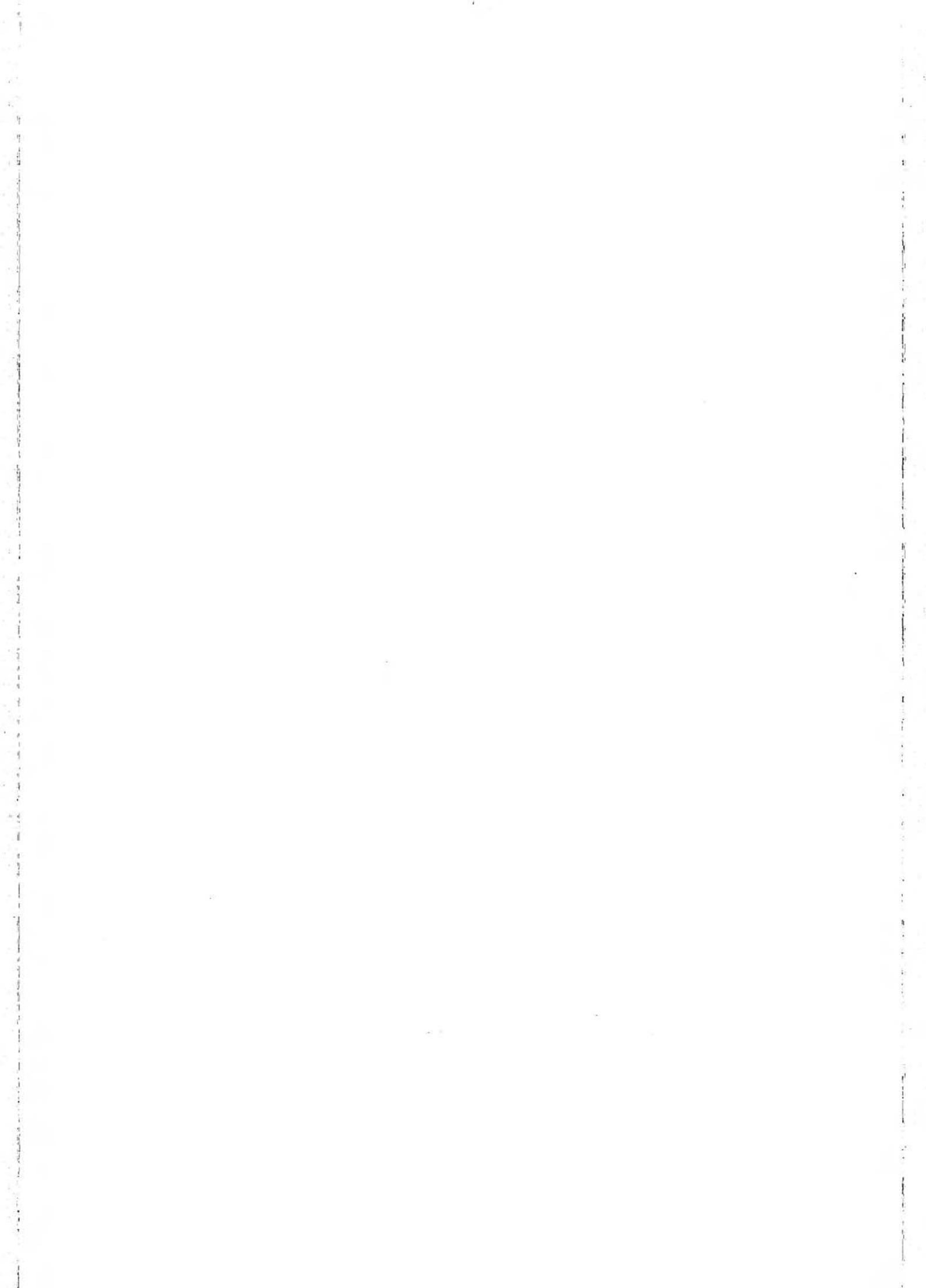


FIG 20 HT Bleed and Feed Flows

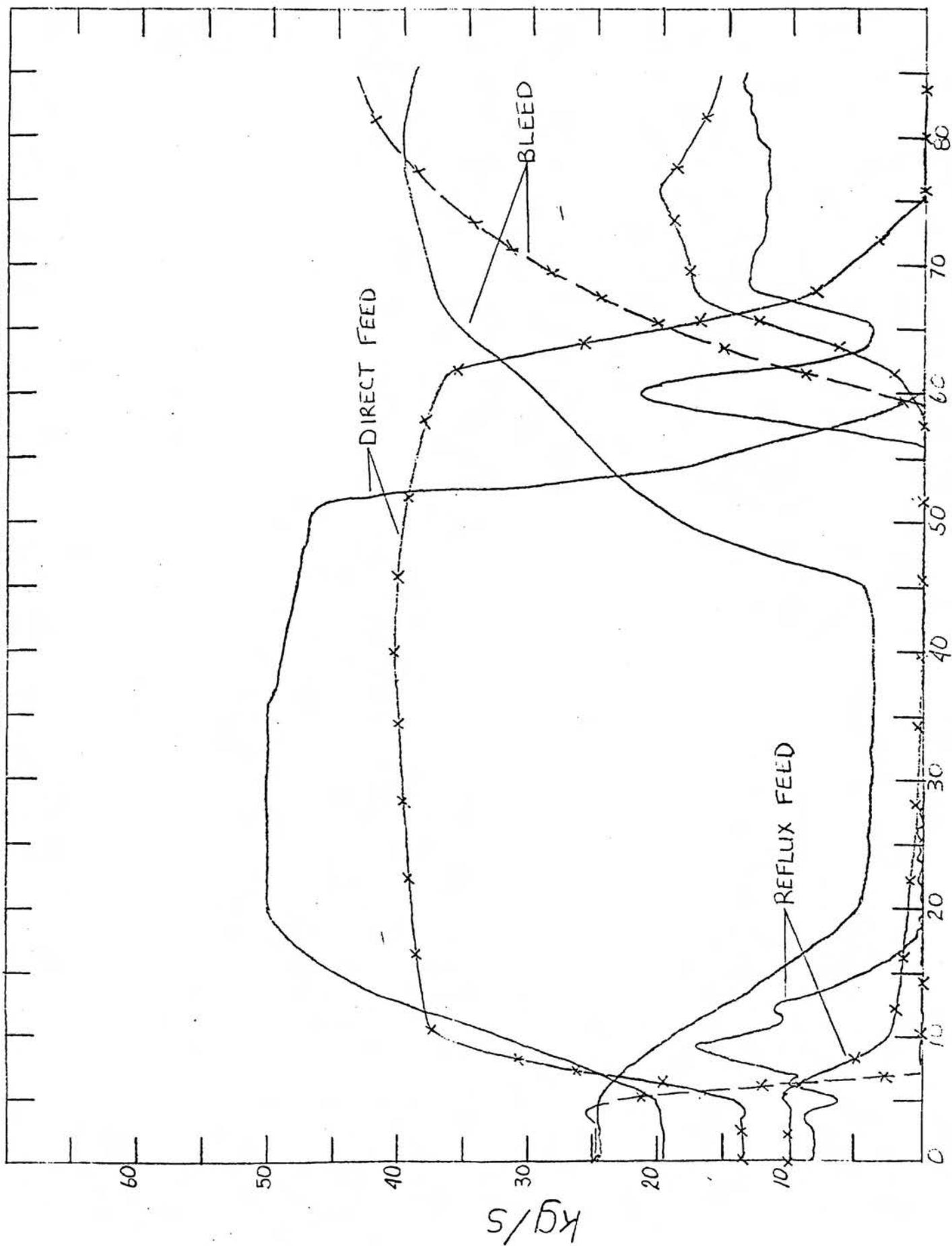


FIG 21 Bleed and Feed Pressures & Level

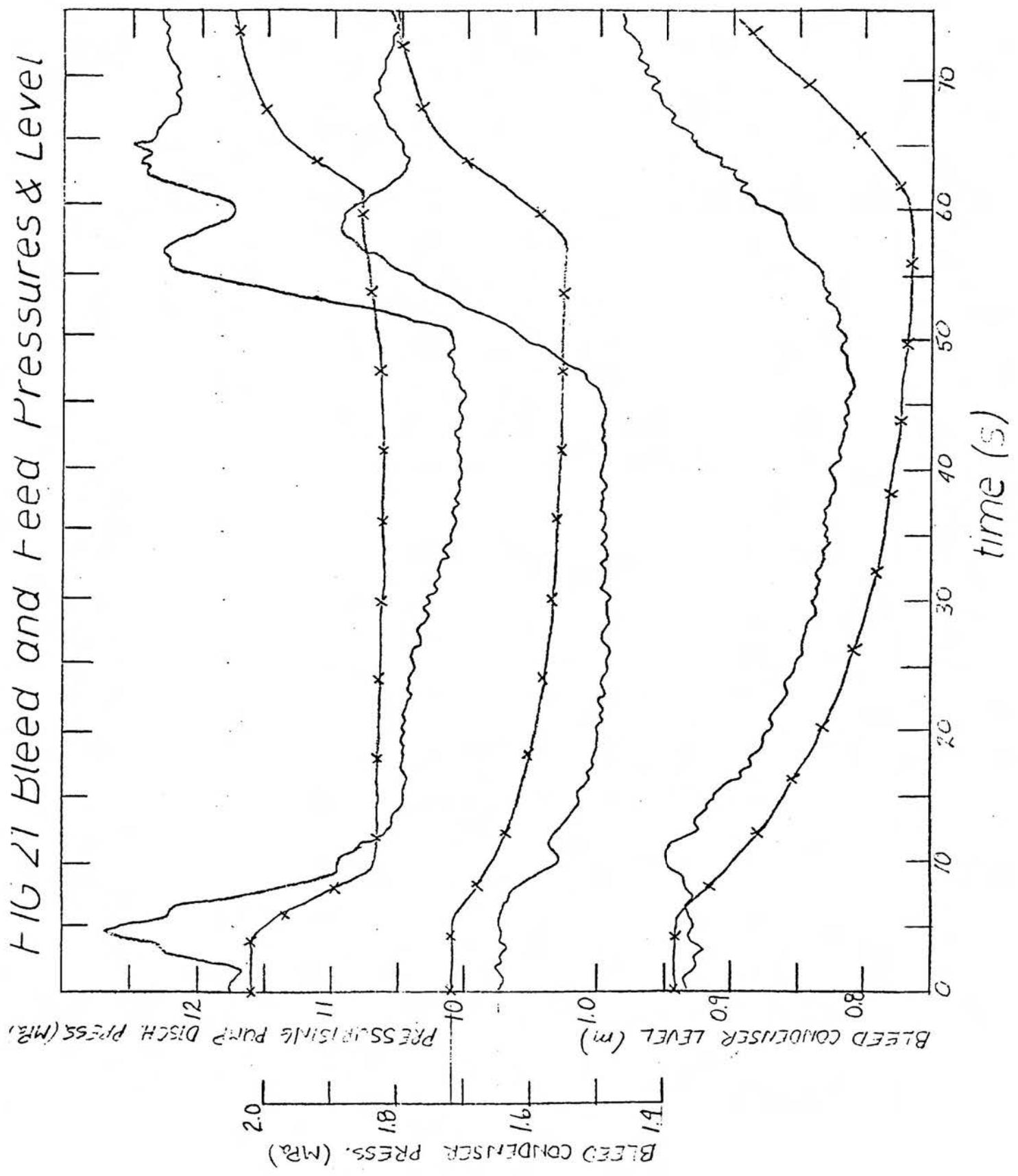


FIG 22 HT Temperatures

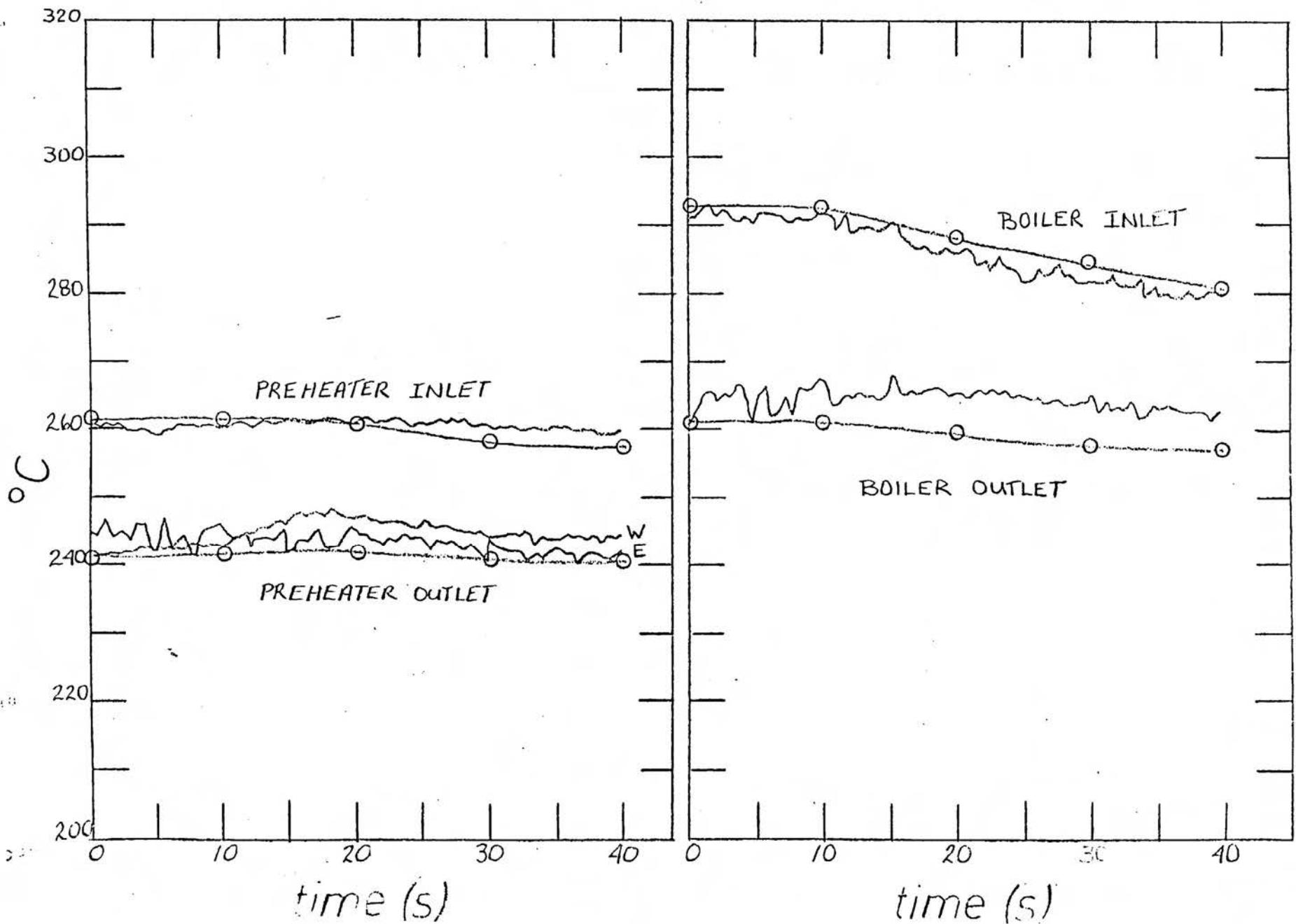


FIG 23 FW Temperatures

