PRESSURE OSCILLATIONS IN DARLINGTON NGS PRIMARY HEAT TRANSPORT SYSTEM DUE TO TRIPPING OF ONE MAIN CIRCULATING PUMP

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ABSTRACT

The sudden trip of one or several transport PHT pumps will result in a pressure spike in the Primary Heat System. A pressure rise up to 10.7 MPaa might occur at the Reactor Outlet Header, which causes the reactor to trip. A study was conducted to simulate pump trips using the SOPHT code, in order to assess the problem and learn how to avoid it.

It was found that the maximum pressure spike occurs when either one of the pumps farthest from the pressurizer trip. Several solution to the problem have been considered. The selected mode of operation is to lower the reactor trip setpoint, for a limited time, shortly after the pump trip.

1. DESCRIPTION AND ANALYSIS OF THE PROBLEM

1.1 Darlington Primary Heat Transport System

The PHT-System circuit in each unit of Darlington NGS consists of two loops. Each of the two loops contains two circulating pumps, two steam generators, two inlet and two outlet reactor headers. Figure 1.1 shows a simplified flowsheet.

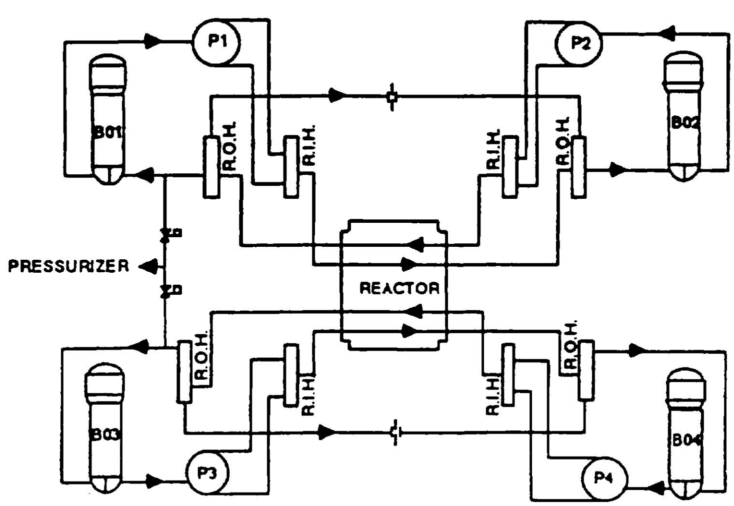


FIGURE 1.1. PRIMARY HEAT TRANSPORT SYSTEM

The two loops are connected to each other and to the pressurizer vessel on the west side. This pressurizer keeps the ROH's at a constant pressure of 10.0 MPaa. In order to dampen any flow or pressure oscillations in the system, the two outlet headers of each loop are also interconnected through a 10 in. pipe, the balance line. Hence, the pressure in all ROHs is the same during normal operation. According to the design, at 100% full power, the ROH's are at 10.0 MPaa and 310°C, while the RIH's are at 11.38 MPaa and 267°C.

The four PHT pumps have to provide the flow and the head required for all operating conditions, among them:

* 100% full power, which requires all four pumps to operate

* 65% power, which can be achieved with only one pump per loop in operation

1.2. Pressure Behaviour During an East Pump Trip

In the case of an East pump trip, there are basically two effects causing an increase of the system pressure, as it manifest itself at the East ROH.

With only one pump per loop operating, which has to provide enough head to overcome the added resistance, the flow ratio in this loop will decrease. The pump moves back on its characteristic curve. So, a pump trip on the East side results in higher head delivered by the remaining West pump and, as a consequence, an initial surge in PHT pressure. Due to the time lag in the adjustment of the pressurizer pressure by the controller this one cannot keep the ROH pressure at 10 MPaa.

Another thing to be taken into account is the sudden increase in system resistance which acts like a temporary back-up pressure for the remaining pump.

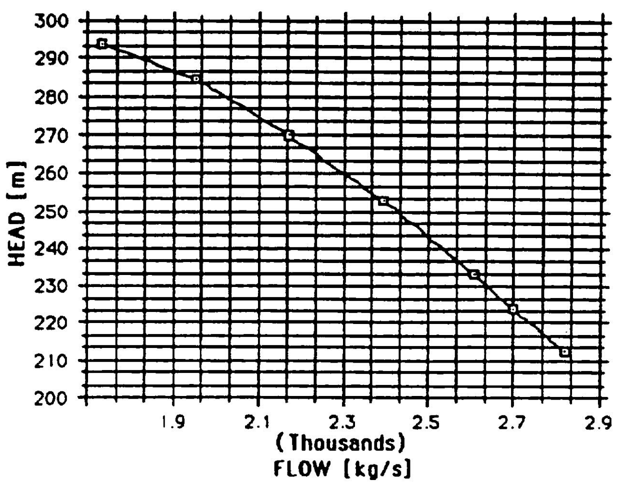


FIGURE 1.2. CHARACTERISTIC PUMP CURVE

Besides that, a series of factors, related to reactor controllers contribute to pressure fluctuations during the adjustment period. The pressure rises to 10.7 MPaa for a very short period of time but this is enough, however, to trigger a reactor trip.

1.3. Pump Trip

A PHT Pump trip may occur due to a motor failure, interruption of power supply, high vibrations etc.

Therefore, one has to distinguish between two different cases when pump trips:

a) The pump can be restarted within a short period of time. Hence the reactor may only step back.

b) It will take some time to restart the pump; accessing the pump is required for repairs or maintenance. Hence the reactor has to be shut down.

Whatever the actual reason for which the pump trips, the reactor will undergo a step back to 65% power and remain at this level until the operator decides what action is to be taken. Following the PHT pump trip, a reactor trip will take place however, because of the pressure spike in the PHT system. This has a number of undesirable consequences, like economical penalties and stressing the piping and equipment.

To avoid these consequences several alternative solutions have been investigated.

2. SIMULATION OF A SOUTH-EAST PUMP TRIP

To have realistic picture of the possible pressure behavior in the PHTS, during a pump trip transient, three different simulations have been performed.

* The pump trip from 100% FP, the most likely case to occur.

* A pump trip from Zero Power Hot condition.

* A pump trip from 75% FP power, a simulation that combines the pump trip transients with the startup transient.

The simulations were conducted using SOPHT (Simulation of Primary Heat Transport) code. This computer code enables the user to analyze steady state or transient problems associated with CANDU systems.

2.1. Pump Trip From 100% Full Power

[Figures 3 & 4]

Within six seconds after the pump trip the pressure in the SE ROH rises from its steady state value to above 10.7 MPaa while the pressure in the other three ROH's drop significantly. Following a reactor trip on high ROH pressure and opening of the PHT pressure relief valves the SE ROH pressure initially decreases to 10.45 MPaa then to 9.0 MPaa. The pressures in all ROH's fluctuate for about 15 seconds before the process of recovery starts. The pressure fluctuations predicted by the computer simulation have been confirmed by station measurements, during a pump trip test performed in Darlington Unit 2.

2.2. Pump Trip from Zero Power Hot

[Figure 5]

The PHT pump trip, from ZPH, produces pressure oscillations of even higher amplitude than the trip from 100% FP. The instability period is longer and characterized by two peaks of 10.48 and 10.59 MPaa, respectively. There is no reactor trip, since the reactor is shutdown, but the liquid relief valves open.

2.3 Pump Trip from 75% Full Power

[Figure 6]

The 75% FP run represents a PHT pump trip during the start up or shut down procedures. It displays a severe transient, similar to one produced by the trip from 100% FP, during which the ROH pressure surges above 10.7 MPaa, in 6 seconds. PHT relief valves open and the reactor is tripped on high ROH pressure.

The three simulations performed, beside confirming the observations during the test in Unit 2, show that the opening of the PHT liquid relief valves, initiated by the present controller when the ROH pressure reaches 10.55 MPaa does not prevent the over pressurization of the system to 10.7 MPaa which leads to a reactor trip. The high pressure spike and the subsequent reactor trip have to be avoided to prevent economic penalty and mechanical stress to the equipment.

3. PROPOSED SOLUTIONS

3.1. Lowering of the LRV's Setpoint

[Figure 7 & 8]

Early opening of the PHT liquid relief valves will help reduce the maximum pressure in the system. Simulations performed show that the pressure spike remains below 10.5 MPaa if the setpoint for the relief valves is changed to 10.2 MPaa. This is valid for a PHT pump trip from 100% FP and also for a trip from 75% FP. Modification of the relief setpoint will prevent a reactor trip. The method has, however, some drawbacks. The controller has to be modified and the entire procedure will have to be analyzed from reactor safety point of view.

3.2 The Use of Steam Bleed Valves for PHT Relief

[Figure 9]

The steam bleed valves are used to control the pressure in the PHT system and open, normally, if the pressure in the Pressurizer vessel exceeds 10.0 MPaa. Opening of these valves, as soon as possible after a pump trip is detected can reduce the spike in the ROH by adding to the PHTS pressure relief capacity.

A simulation was performed, in which the pump was tripped and steam bleed valves were open simultaneously. While this has some effect on the amplitude of the pressure spike, it is only marginal.

3.3 Replacement of Reactor Stepback on PHT Pump Trip Signal by a Reactor Trip.

It is possible to control the system in such way that a PHT pump trip event would trigger a reactor trip instead of a reactor stepback. The simulation performed shows that an unacceptable pressure transient will still be present under these conditions.

4. CONCLUSION

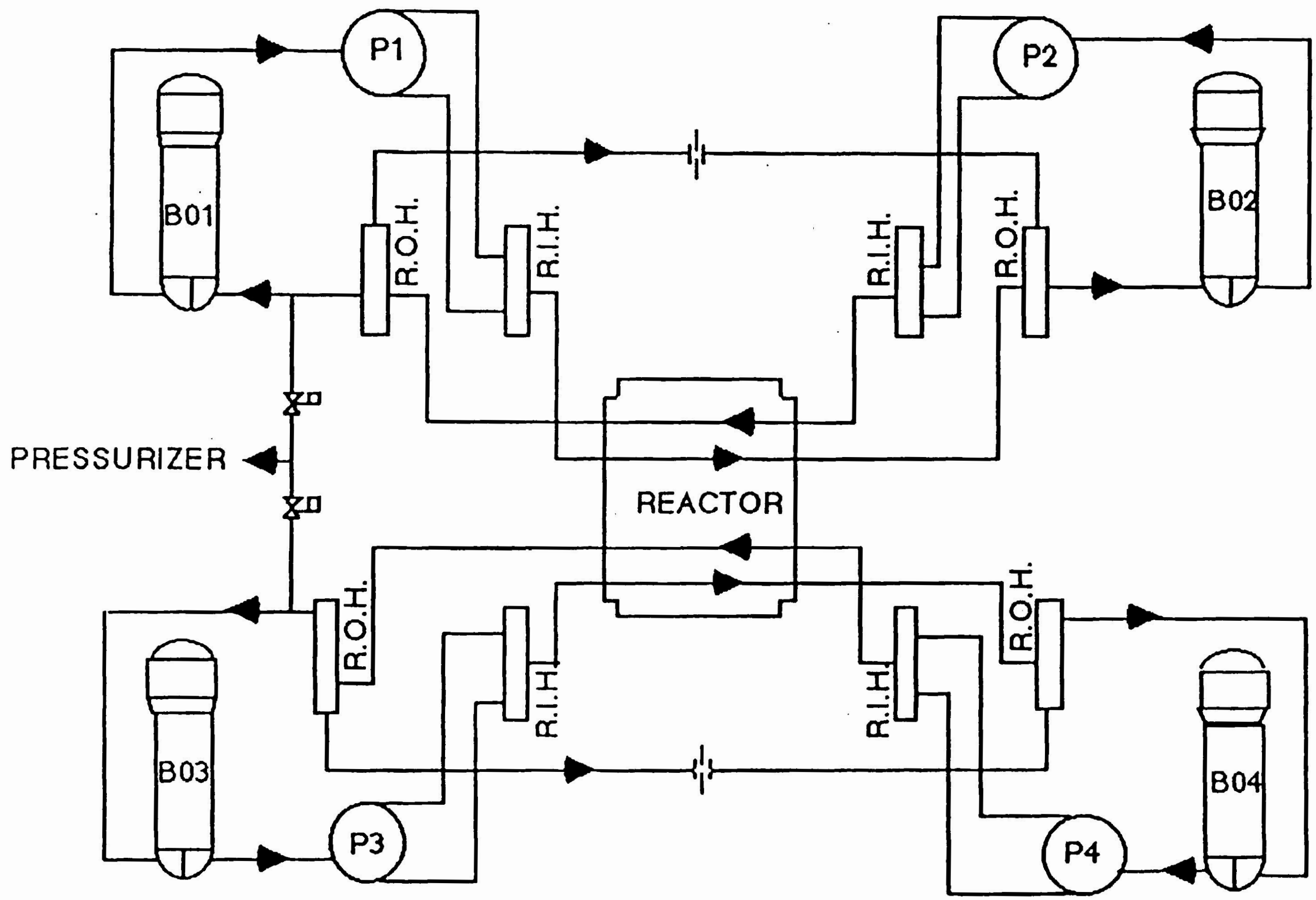
4.1 New LRV's Setpoint Solution

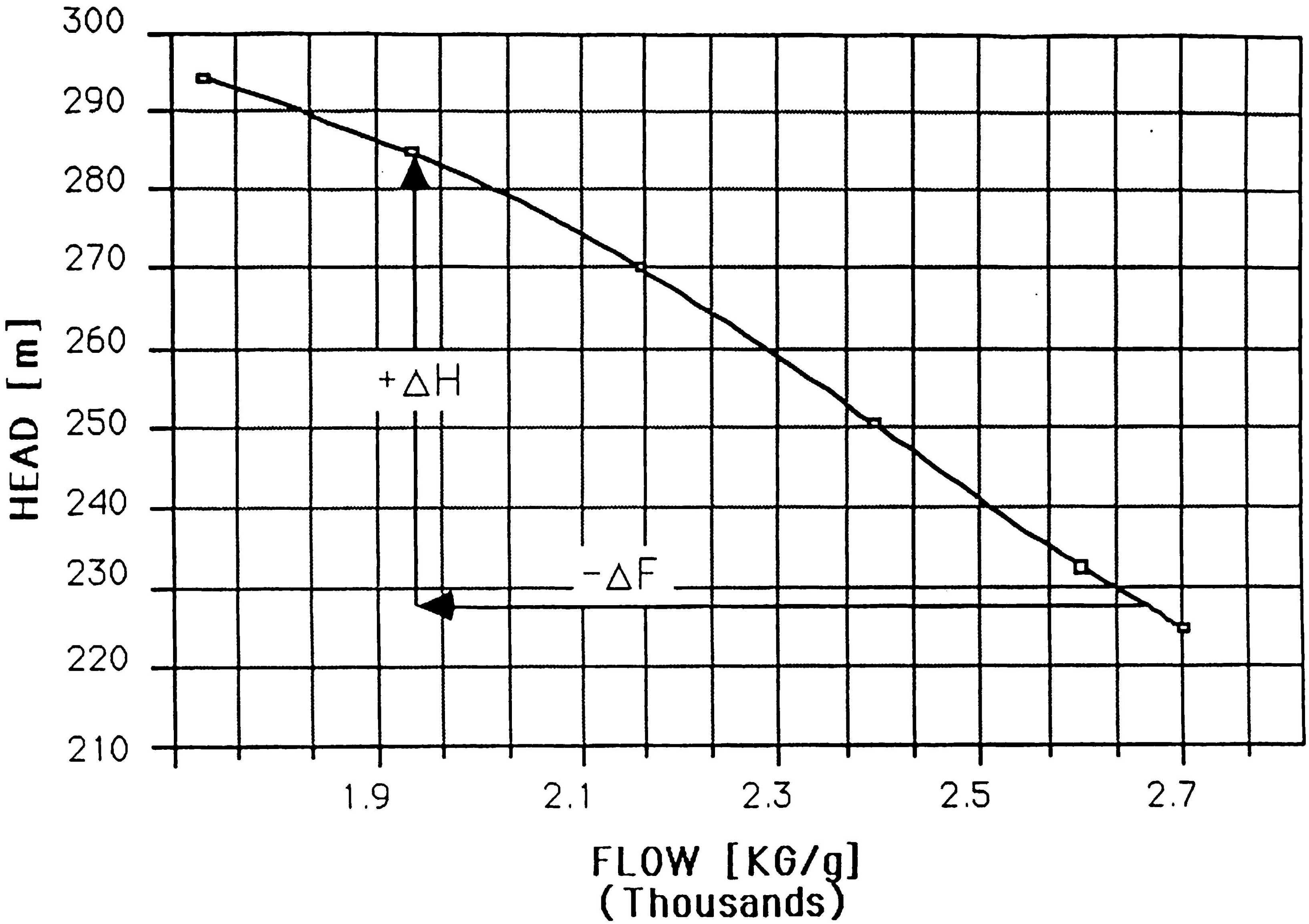
From the data gathered as result of the simulations performed it can be concluded that the most appropriate protection against a pressure surge transient in the PHTS, when one of the four PHT pumps trips, is the changing of the PHT liquid relief valves set point to 10.2 MPaa. This will also prevent a reactor trip on high ROH pressure signal.

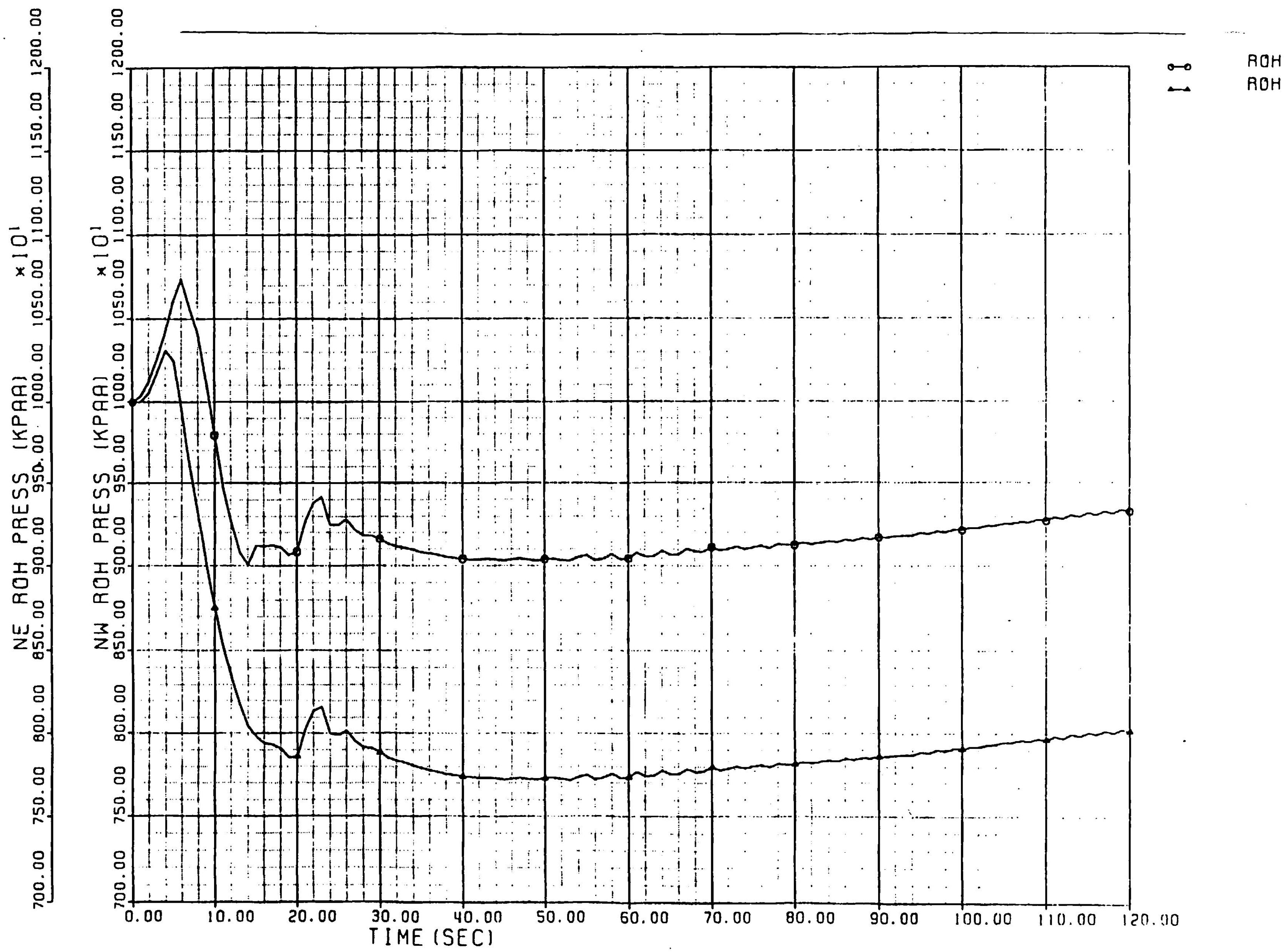
Beside answering both concerns (over pressure and trip), this solution has the advantage that requires a relatively simple adjustment of the controller. However, this adjustment has to be done in such a way as to modify the set point only for the PHT pump trip transients and for a limited time (about 15 seconds). In all other circumstances the LRV set point should be kept at 10.55 MPaa, its present value. This requires a specific controller logic to be designed and tested. Also, the new situation created by the implementation of this logic will have to be analyzed from reactor safety point of view. While we don't foresee any problem, all this work is time consuming and costly.

4.2 Other Solutions

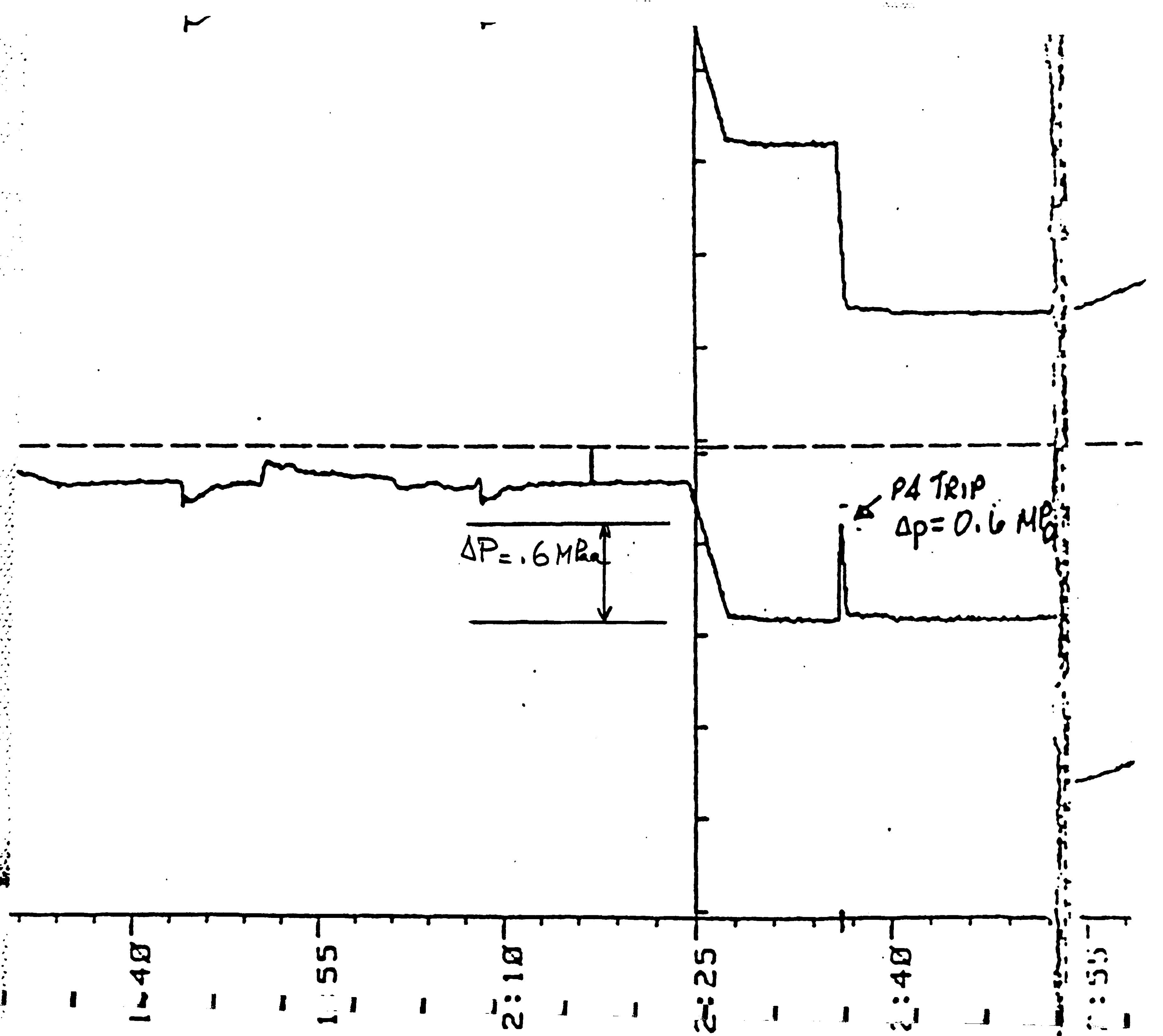
It has to be underlined however that a PHT pump trip while the PHTS is pressurized at 10.0 MPaa is a very unlikely event. The probability of piping and equipment being subjected to stress due to this event is so low that an acceptable solution is to make no modification in the way the system is controlled, avoiding by this the cost and effort involved.

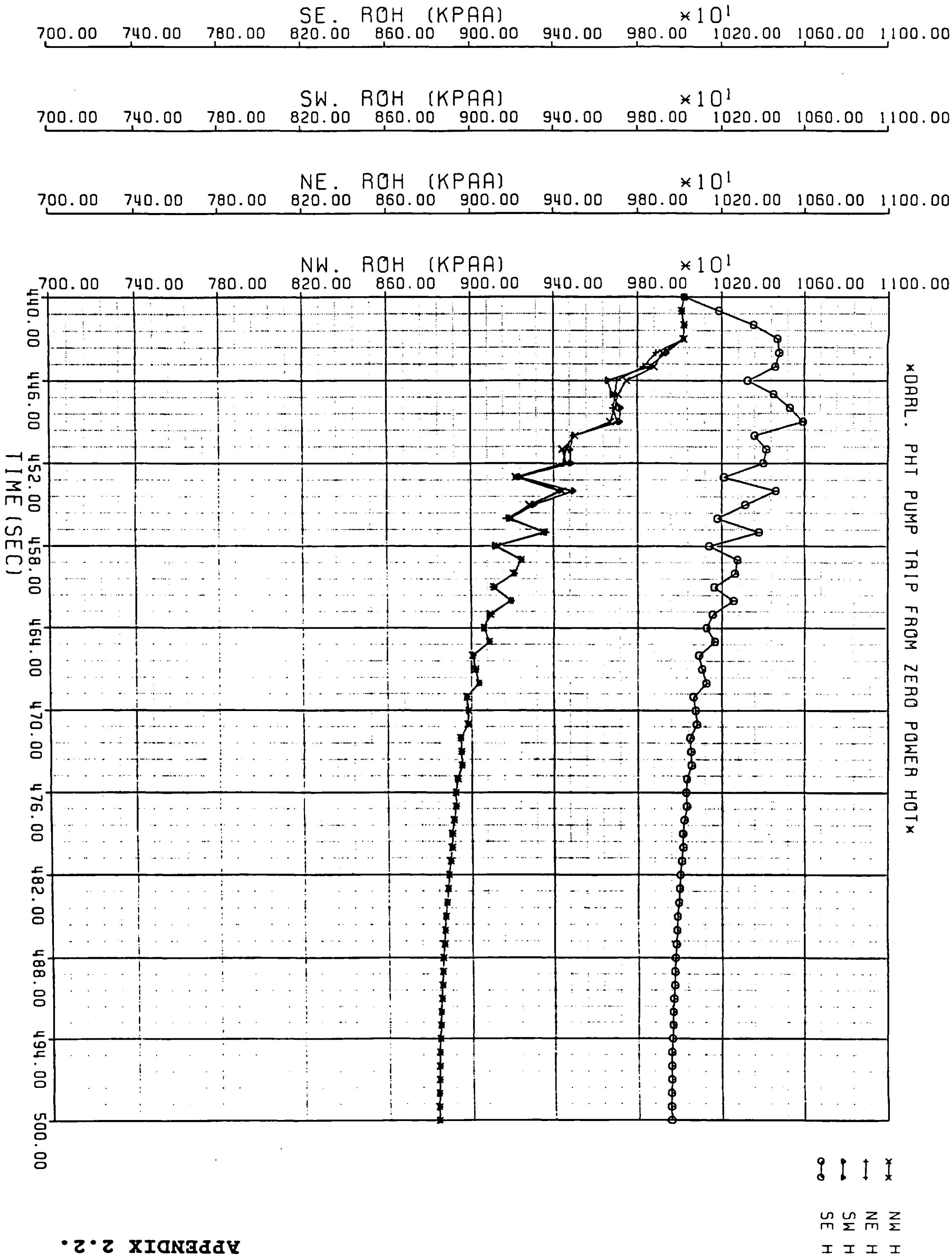

P1
P2
B01
B02
R.O.H.
R.I.H.
R.I.H.
R.O.H.
PRESSURIZER
REACTOR
R.O.H.
R.I.H.
R.I.H.
R.O.H.
B03
B04
P3
P4


HEAD [m]
300
290
280
270
260
250
240
230
220
210
+ΔH
−ΔF
1.9
2.1
2.3
2.5
2.7
FLOW [KG/g]
(Thousands)

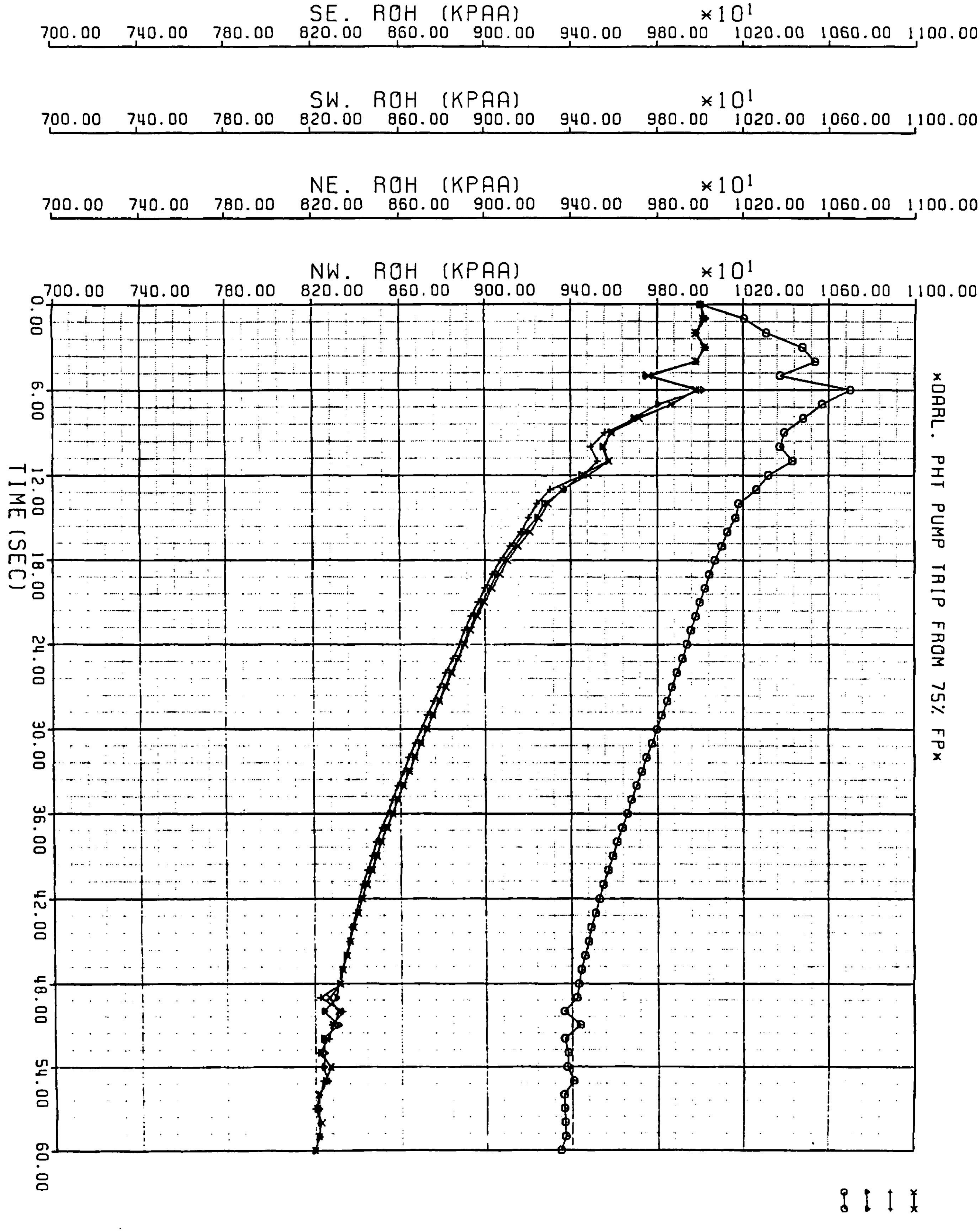


ROH
ROH
NE ROH PRESS (KPAA) ×10¹
NW ROH PRESS (KPAA) ×10¹
700.00
750.00
800.00
850.00
900.00
950.00
1000.00
1050.00
1100.00
1150.00
1200.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
110.00
120.00
TIME (SEC)


PA TRIP
Δp=0.6 MPa
ΔP=.6MPa
1:40
1:55
2:10
2:25
2:40

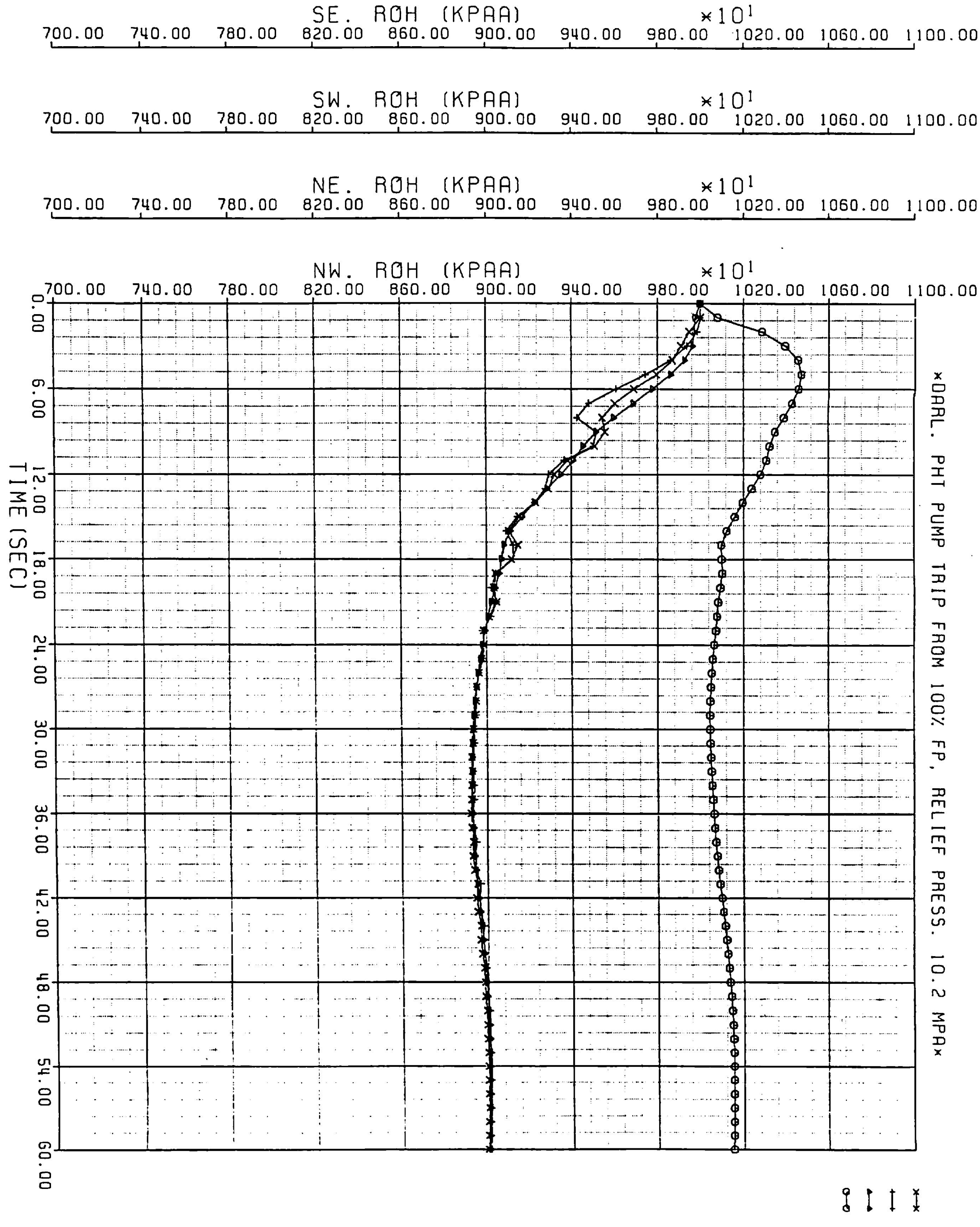

SE. ROH (KPAA) ×10[1]
SW. ROH (KPAA) ×10[1]
NE. ROH (KPAA) ×10[1]
NW. ROH (KPAA) ×10[1]
700.00 740.00 780.00 820.00 860.00 900.00 940.00 980.00 1020.00 1060.00 1100.00
TIME (SEC)
440.00 446.00 452.00 458.00 464.00 470.00 476.00 482.00 488.00 494.00 500.00
×DARL. PHT PUMP TRIP FROM ZERO POWER HOT×
NW H
NE H
SW H
SE H

APPENDIX 2.2.

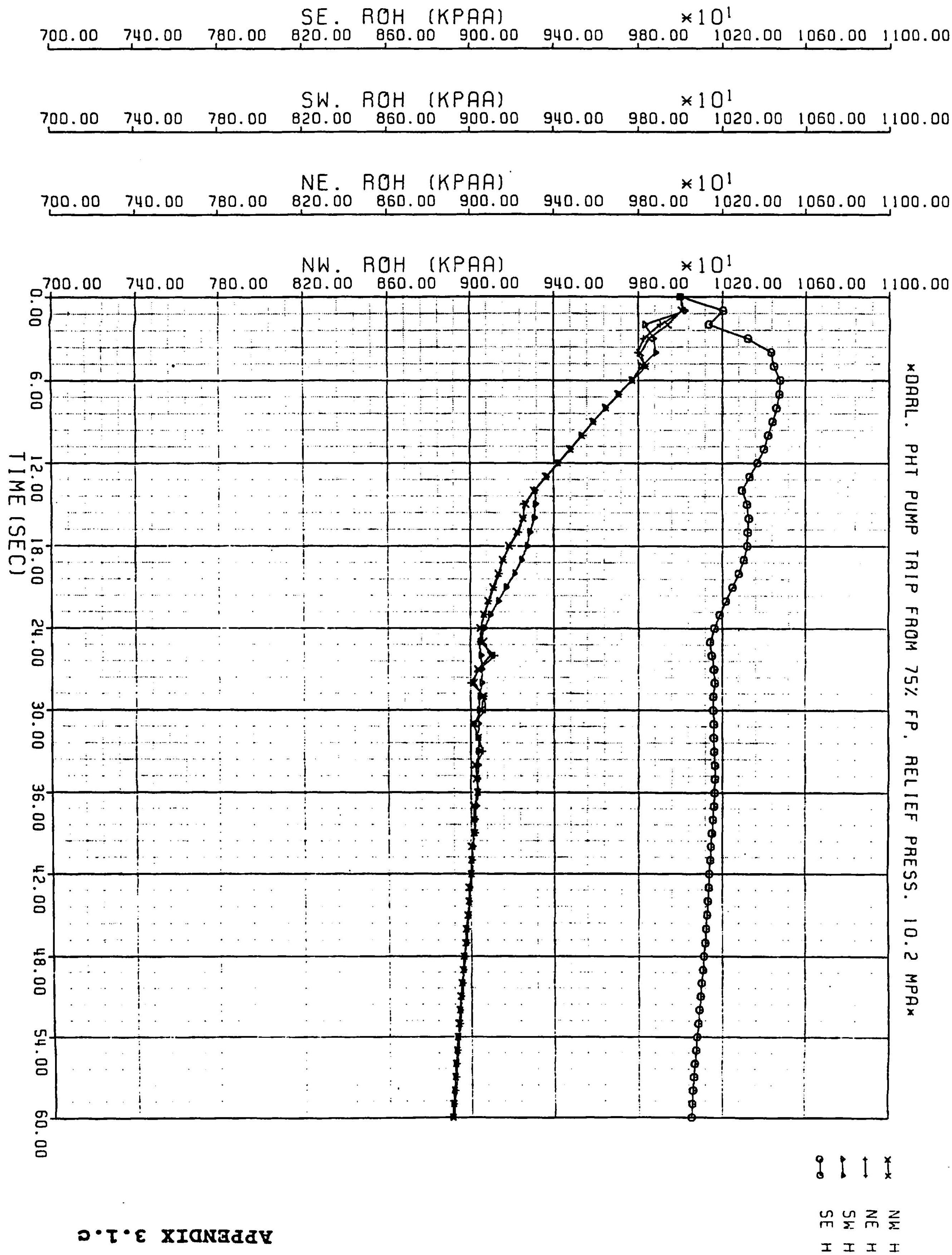


SE. ROH (KPAA) ×10¹
SW. ROH (KPAA) ×10¹
NE. ROH (KPAA) ×10¹
NW. ROH (KPAA) ×10¹
700.00 740.00 780.00 820.00 860.00 900.00 940.00 980.00 1020.00 1060.00 1100.00
TIME (SEC)
0.00 6.00 12.00 18.00 24.00 30.00 36.00 42.00 48.00 54.00 60.00
DARL. PHT PUMP TRIP FROM 75% FP
NW H
NE H
SW H
SE H

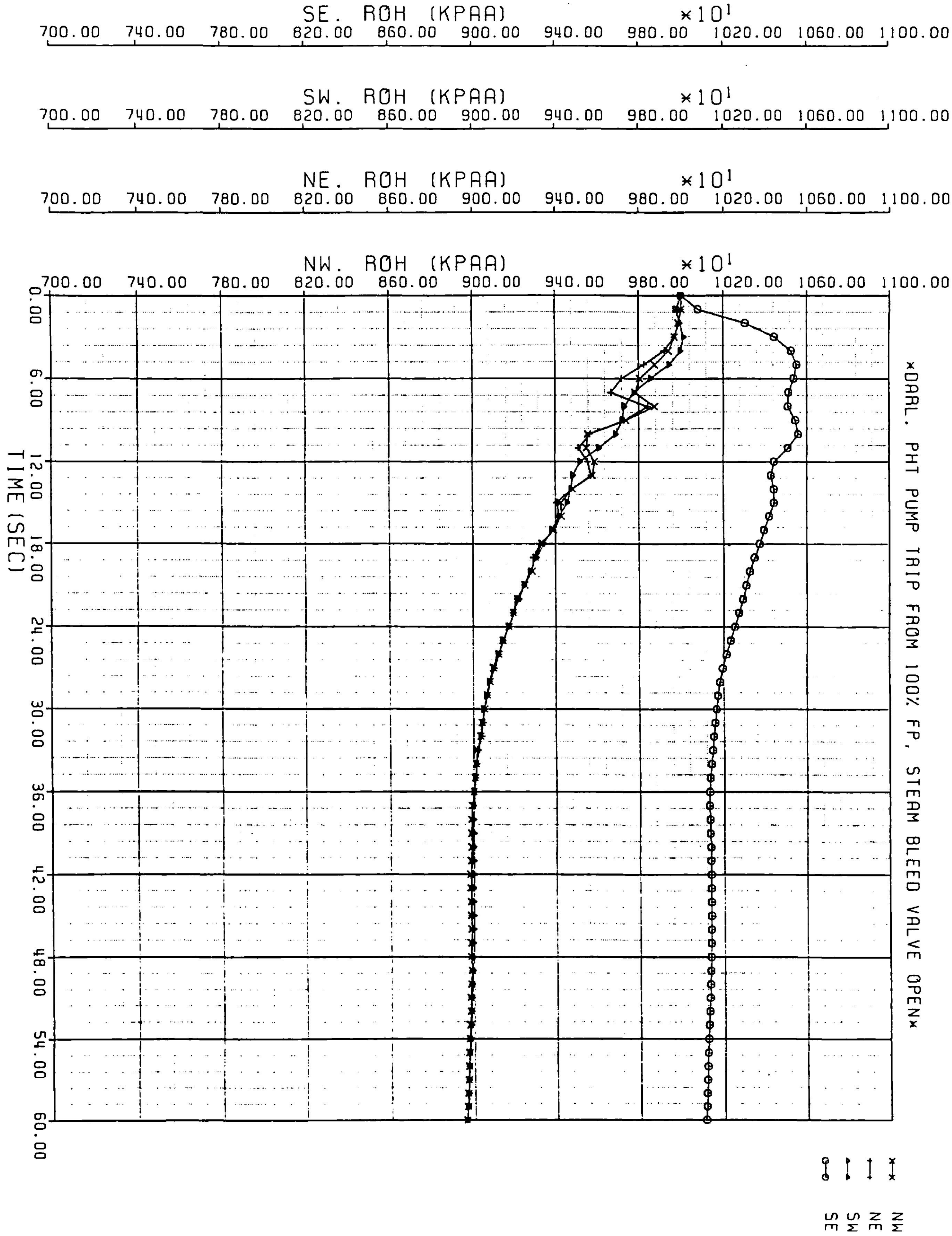
APPENDIX 2.3.



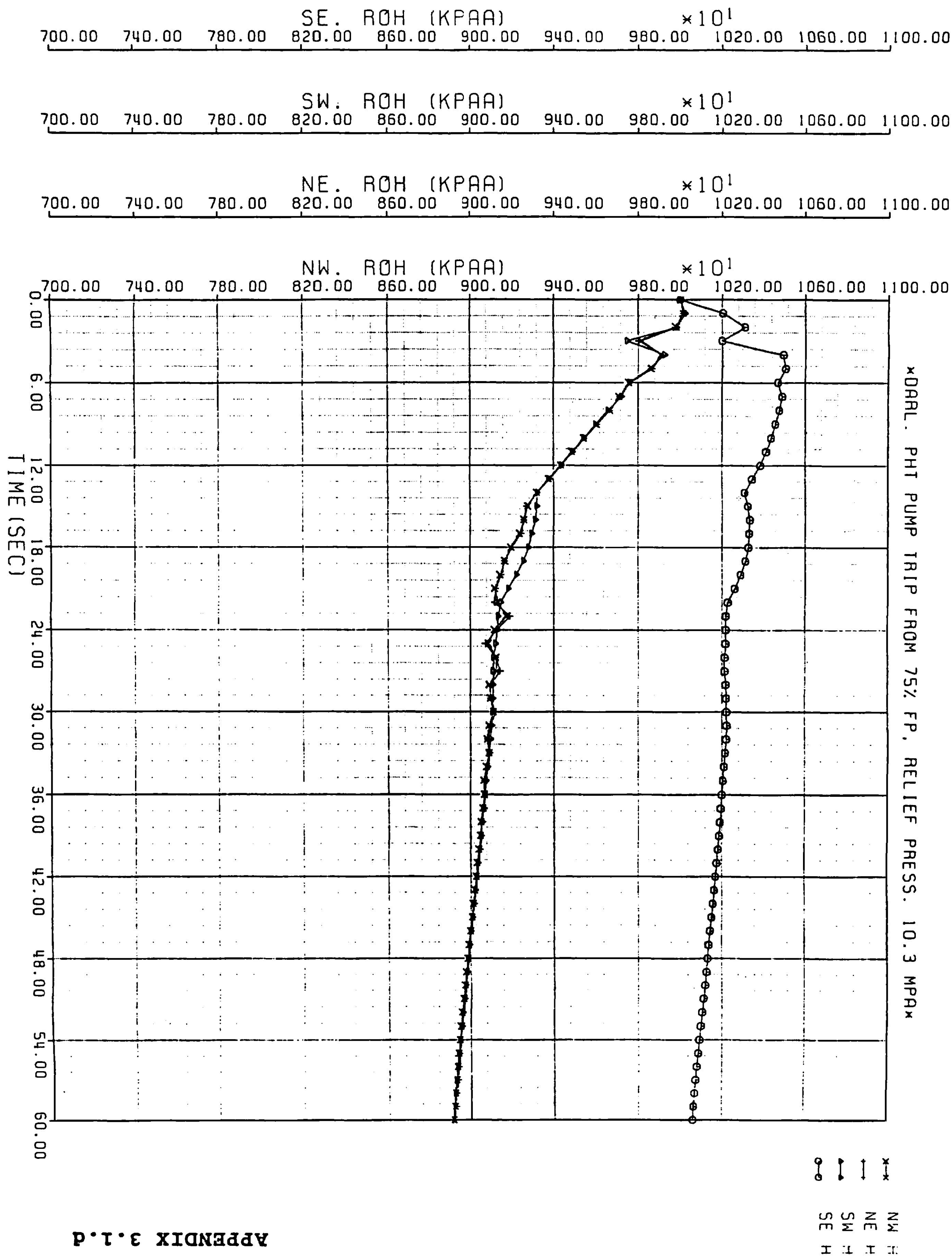
APPENDIX 3.1.a



APPENDIX 3.1.C


SE. ROH (KPAA) ×10¹
SW. ROH (KPAA) ×10¹
NE. ROH (KPAA) ×10¹
NW. ROH (KPAA) ×10¹
700.00 740.00 780.00 820.00 860.00 900.00 940.00 980.00 1020.00 1060.00 1100.00
TIME (SEC)
0.00 6.00 12.00 18.00 24.00 30.00 36.00 42.00 48.00 54.00 60.00
DARL. PHT PUMP TRIP FROM 100% FP, STEAM BLEED VALVE OPEN
NW H
NE H
SW H
SE H

APPENDIX 3.2.



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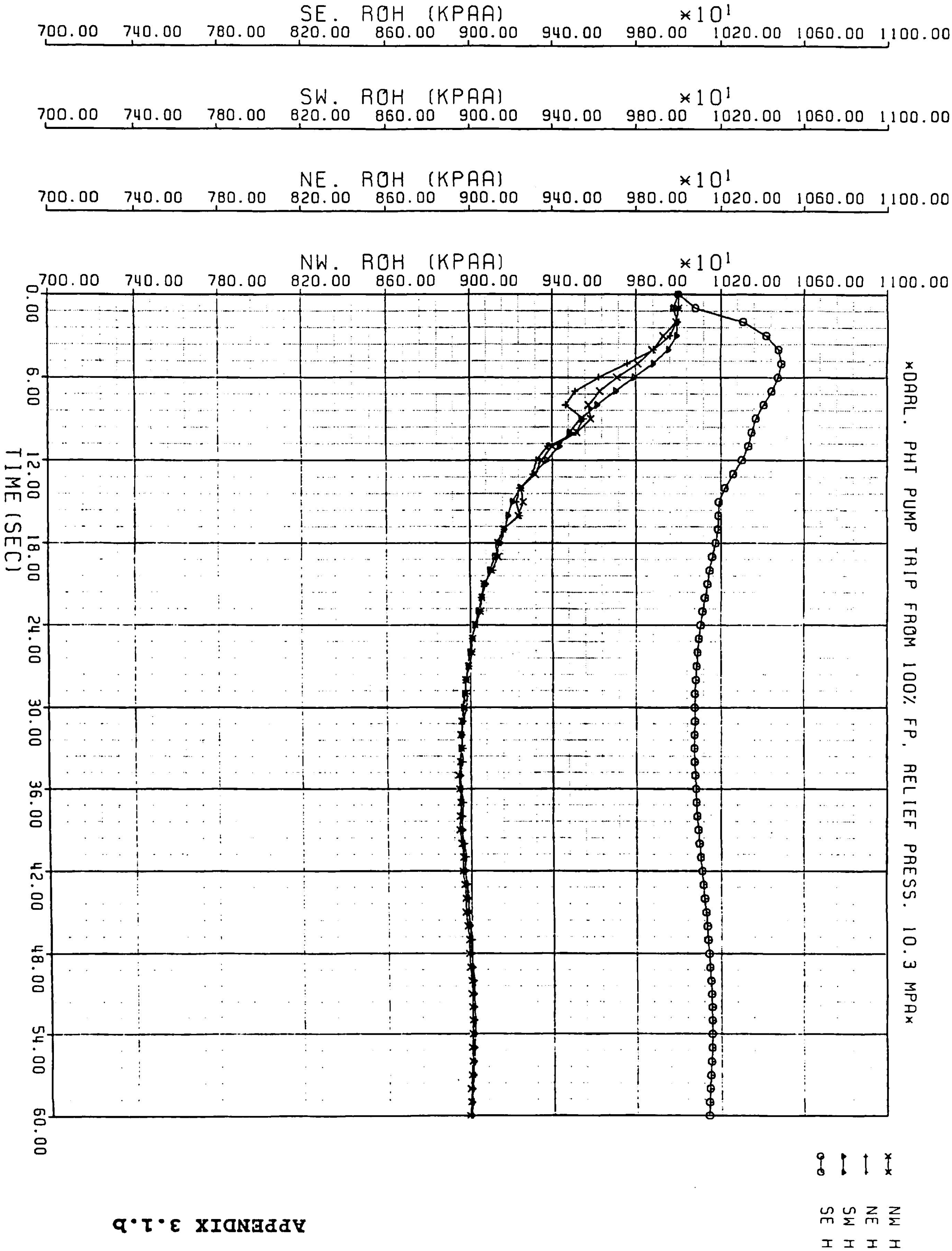
APPENDIX 3.1.d



APPENDIX 3.1.b