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Calibration of Clamp On Flow Meter using Computer Model

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1. Introduction and Summary

Ultrasonic flow meters are used widely in the power industry for feed water flow measurement due to the various failure modes of differential pressure flow devices. Ultrasonic flow meters are subject to changes of the hydraulic conditions inside the pipe. If it is desired to change a configuration upstream of flow measurement locations, the hydraulic conditions can change and thus affect the response of the flow meter. This paper describes a method to accurately determine the effect of the change on the flow meter and thus compensate for any bias introduced.

The purpose of this evaluation is to provide input to calculations to recalibrate an ultrasonic flow meter at a Boiling Water Reactor Generating Station. The ultrasonic meter is a high accuracy Ultrasonic Cross Correlation flow measurement device used to measure the feed flow at the generating station. The ultrasonic measurement is compared to the venturi measured feed flow and a correction factor is developed for input to the core thermal power calculation. The feed water piping employs three strings (18 inch diameter) of heating with a bypass (16 inch diameter). The three heater strings and the bypass join in a common header (30 inch diameter). Two lines branch off the common header to provide feed water to the reactor pressure vessel. The ultrasonic meter is located on the 30 inch diameter common header (see Figure 1). The common header does not have upstream piping configuration conforming to the standard installation. Therefore, a piping configuration correction is required. This correction was determined by locating meters in the 18 inch feed water heater lines at locations meeting the requirements for a standard installation. The initial calculation for the ultrasonic meter assumed a normal plant line up with all three #6 feed water heaters in service. The 6A feed water heater was removed from service by plant personnel due to flow induced vibration of the heater drain line. With the 6A feed water heater removed from service, the original assumptions of the calculation are no longer valid. The changes to the correction factor indicate that the flow velocity profile has changed at the location of the ultrasonic meter. A recalibration of the meter was performed using the existing venturies and thermodynamic modeling software in which a correction from normal operation to current operation was applied to the ultrasonic flow meter. This method relies on the assumption that venturi repeatability are within the requirements of the calculation. Use of thermodynamic modeling software is used to provide analysis of plant data which will support this assumption by showing that the plant responded as expected.

2. Methodology and Inputs

2.1. Assumptions

The methodology of this analysis consists in comparing the changes in plant parameters with the expected changes, given the assumed conditions:

- The change in the ultrasonic correction factor observed is not due to a change in the venturi nozzle discharge coefficient or any other factor associated with the venturi flow measurement.
- The removal of the feed water heater from service is the only significant related plant change that occurred.

If these assumptions are not correct then the expected values of the plant parameters will differ from the actual plant parameters

2.2. Methodology

The following elements were considered in performing this analysis:

- Plant Design Data (PEPSE, Thermal Kit, Balance of Plant Systems)
  The plant design data will provide the basis for determination of plant parameter changes relative to cycle flow changes and the impact of feed water heater configuration

- Feed Flow Instrumentation
  The response of differential pressure calculated feed flow was evaluated to ensure repeatability and correlation with other plant parameters.

- Historical Plant Data
  In conjunction with Plant Design Data perform thermal performance calculations to determine if plant parameter changes correlate with expected values.

- PEPSE Analysis of Plant Data
  Perform analysis of plant data using the PEPSE model to compare observed changes to expected changes.

- Uncertainty Analysis
  The elements included in the uncertainty analysis of the predictability of the plant parameters consist of the following:

  - The statistical uncertainty of the actual plant data taken during the power ascension.
  - The uncertainty of the model to predict changes in plant parameters was calculated based on the statistical uncertainty of the plant parameters. This calculation consisted of calculating the sensitivity of the model based on the plant parameter uncertainty.

  These two uncertainties were combined to determine the overall uncertainty of the model's ability to predict plant conditions and aid in setting power ascension limits.

2.3. Inputs for Evaluation

- P&ID's for BOP Systems
  - Main Feed

  - Main Steam
  - Condensate
  - Extraction Steam
  - Heater Drain
  - Moisture Separator
  - Circulating Water
- Copy of Core Thermal Power Calculation
- Operating Procedures which address maintaining core thermal power.
- Reactor Engineering Procedure for Core Thermal Power
- Any Procedures relating to the Ultrasonic Flow Meter (UFM)
- Isometrics for Feed System, including location of UFM and all upstream piping back to the second highest pressure feed water heater.
- Historical Plant Data (daily snapshot data including all available BOP and Reactor Coolant System Parameters) for the last cycle.
- Most Recent PEPSE Model of the plant
- Vendor Thermal Kit
- Continuous plant data (10 min average) for selected points for the last cycle (per loop as applicable). These are the "heatrate" files:
  - First Extraction Pressure
  - Final Feed water heater outlet temperature
  - Final Feed water heater pressure
  - First Stage Pressure
  - Steam Pressure
  - Feed Temperature
  - Feed Flow(for each loop)
  - Steam Flow
  - Feed Pressure
  - Reactor Water Clean Up (Flow, Inlet Temperature, Outlet Temperature)
  - Control Valve Position
  - Circ Water Inlet & Outlet Temp
  - Condenser Pressure
  - Condenser Hot-well Temperature
  - Gross Generation
  - High Pressure Turbine Exhaust Pressure
  - Nuclear Instrumentation Power
  - (calculated) Feed Flow Correction Factor

3. Correlation of the Venturi Indication with Other Plant Instrumentation

3.1. Summary

Correlation of the venturi indication with other plant instrumentation will provide assurance that the observed plant changes do not affect the uncorrected venturi flow calculation input to the core thermal power calculation. This is a necessary condition to the method proposed whereby the ultrasonic meter will be calibrated to the new conditions based on the venturi flow meter. The result of this analysis indicates good correlation between the plant parameters and the expected response assuming a valid repeatability of the venturi flow measurement. This analysis also provides assurance that there are no other significant plant secondary cycle problems which would alter the plant parameter correlations.

3.2. Isometric Evaluation

The change of the correction factor observed after the removal of the 6A feed water heater from service is assumed to be due to the effect of removing the 6A heater from service. This is a significant change to the upstream geometry. Changes to geometry upstream of the ultrasonic meter will have an effect on the time delay calculated by the ultrasonic meter with respect to the time delay measured during the calibration of the meter. It can be observed from Figure 1 that the removal of the flow of water from the 6A feed water heater discharge piping along with the significant increase of the flow rate from the 6B and 6C feed water heaters (due to all the flow passing through the 6B and 6C heaters) will have a significant impact on the flow velocity distribution in the common header and on the previously calculated correction factor at the point where the ultrasonic meter is currently located. When comparing the location of the ultrasonic meter with respect to the feed flow venturis in Figure 2, it is observed that there are two in-plane elbows and long straight runs of piping downstream of the ultrasonic location which will remove the effects of the profile change. The data evaluation in Section 3.3 supports this conclusion.

3.3. Plant Data Evaluation

The plant data evaluation compares expected values for the plant parameters based on an assumed set of conditions as compared to a normal configuration. In this case, comparing the changes to plant parameters with the 6A feed water heater in service and out of service. Such an evaluation will provide assurance that the observed plant changes do not affect the uncorrected venturi flow calculation input to the core thermal power calculation. In addition, this evaluation provides assurance that no other significant plant secondary cycle problems are present which would alter the plant parameter correlations. Due to the interrelation between various parameters, several effects must be considered when determining the impact of the present configuration on the plant parameters. These are listed below:

- With the ultrasonic meter removed from service the assumption of feed flow accuracy is no longer valid for the appendix K uprate (reduced margin uncertainty). Therefore, reactor power must be reduced by 1.4%.

- Removal of the feed water heater from service reduces final feed water temperature which is an input to the power calculation. If feed temperature is reduced, the enthalpy of the feed water entering the reactor will be reduced. This reduction in enthalpy will cause reactor power to increase at the same feed water flow rate. Therefore, operations will reduce reactor power to maintain the plant within the licensed thermal power limits.

- Corrected feed water flow is determined by multiplying the uncorrected feed water flow by a correction factor derived from the ultrasonic system. In the event that the ultrasonic system is out of service the correction factor is set to 1.0. Setting of the ultrasonic meter correction factor to 1.0 results in an increase of indicated flow. This increase of indicated flow will cause an increase of indicated reactor power and thus operations will reduce power to maintain the licensed thermal power limit with the ultrasonic meter out of service. The 100% power correction factor prior to the removal of the 6A feed water heater from service was approximately 0.985. Therefore the impact on flow is 1 – 0.985 or 0.015 which is equivalent to a 1.5% increase of indicated feed flow and a 1.5% decrease in reactor power.

The overall calculated impact of removing the 6A feed water heater from service on feed water flow is approximately 4.1%. This includes effects of 1.2% due to the reduced feed temperature, 1.4% due to the power reduction resulting from the ultrasonic being removed from service and 1.5% due to the increase in indicated feed water flow resulting from the correction factor being set to 1.0 from an average value of 0.985.

Table 1 displays various plant parameters with 6A feed water heater in service and out of service.

Table 1 Plant Parameters Change Analysis				
Parameter	**Units**	**6A FWH IN**	**6A FWH OUT**	**Plant Change**
Rx Pwr	%	**99.91%**	**98.50%**	1.4%
TPI	%	**99.97%**	**97.96%**	2.0%
First Stage Press	Psig	**697.9**	**670.2**	4.0%
Predicted First Stage Press	Psig	**697.3**	**684.7**	1.8%
Feed Flow Uncorrected B	Mlbm/hr	**7.0972**	**6.8287**	3.8%
Feed Flow Uncorrected A	Mlbm/hr	**7.4975**	**7.1701**	4.4%
Total Feed Flow (uncorrected)	Mlbm/hr	14.5948	13.9988	4.1%
Feed Flow XFLOW	Klbm/hr	**14374.04716**	**13981.02255**	2.7%
Final Feed Temp (DEG F)	Deg F	**424.3**	**415.4**	8.9
xflow Corr F		**0.9849**	**0.9987**	-1.38%
Corrected Gen (CND PRS)	Mwe	**1137.5**	**1099.2**	3.4%
Total Steam Flow	Mlbm/hr	**14.7413**	**14.1405**	4.1%
Heater 6 Shell Press	Psig	**331.1**	**315.4**	4.8%
HP Exhaust Press	Psig	**173.0**	**167.7**	3.1%
Average Heater 5 Shell Press	Psig	**165.3**	**160.3**	3.0%
Average MS Shell Press	Psig	**166.9**	**161.8**	3.1%
3A Heater Drain Flow	Klbm/hr	**1643.8061**	**1278.7956**	22.2%
3B Heater Drain Flow	Klbm/hr	**1574.8869**	**1595.6143**	-1.3%
3C Heater Drain Flow	Klbm/hr	**1624.7511**	**1638.9211**	-0.9%
Heater 6 Temperature Rise	Deg F	**57.4890**	**49.9336**	13.1%
Heater 6 TTD	Deg F	**8.3276**	**12.3861**	4.1
Feed Temp Affect on Flow	%			1.2%
xflow + Power	%			2.9%
Total Flow Reduction	%			4.1%

Table 1 Notes

Predicted First Stage Pressure: Expected first stage pressure for the measured core thermal power.

Feed Flow XFLOW: Feed flow measured by the ultrasonic meter

Corrected Generation: Measured generation corrected for effects of condenser pressure being different than 3 Inches Hga.

Heater 6 TTD: Heater Terminal Temperature Difference is the saturation temperature in the shell of the heater minus the heater outlet temperature. Since to the proximity of the heater outlet temperature instrument to the stratified water exiting the heater can cause possible errors in the outlet temperature measurement, the final feedwater temperature as measured downstream near the venturies is used for this calculation.

It can be observed from Table 1 that the change in the plant parameters corresponds well with the expected change based on percentage power change analysis. The alternate indicators of flow through the cycle and thus thermal power indicate a similar change. First Stage pressure decreased 4.0%; Steam Flow decreased 4.1%; Uncorrected feed water flow decreased 4.1%.

Uncorrected feed water flow change was within 0.1% of the calculated overall power change and the alternate power indicator changes (First Stage Pressure, Steam Flow) which indicates that this flow measured by the plant venturi can provide a reference for the changes associated with the flow profile at the location of the ultrasonic meter.

The extraction pressure to the # 6 heaters decreased 4.8% due to hydraulic and thermodynamic affects of removing the 6A feed water heater from service. Extraction steam flow to the two remaining heaters increased, resulting in a higher pressure drop in the extraction lines due to increased feed water flow through the heater.

The pressures downstream of the extraction point for the # 6 heaters decreased approximately 3%. This is expected as the removal of one heater from the cycle causes an overall decrease in extraction steam supplied to the heaters and the corresponding decrease in pressure downstream in the turbine is less. This can also be observed in Table 2 which compares the secondary computer model changes to plant parameter changes.

4. Computer Model Evaluation

4.1. Summary

The purpose of PEPSE model evaluation is to compare the predicted changes to the plant parameters based on the computer model with actual plant parameter changes. This evaluation provides additional confidence that the observed changes to the plant are due to the assumed causes (removing the 6A feed water heater from service). Additionally this evaluation can be used to predict plant parameters when the proposed calibration of the ultrasonic meter is implemented. Currently, Reactor Engineering provides this guidance for Operations relative to plant parameter expectations and limits.

4.2. Computer Model Changes

PEPSE was used to determine the effects of removing the 6A feed water heater from service and to compare the results with plant parameter changes. This analysis includes effects of removing the ultrasonic meter from service in addition to the feed water heater removal. The current plant configuration was verified by plant personnel to ensure accurate modeling of conditions. Table 2 provides a comparison of calculated plant changes using PEPSE and actual plant parameter changes.

Table 2 PEPSE Comparison to Plant Changes

Parameter	Plant Change	PEPSE Change
First Stage Press	4.0%	4.0%
Total Feed Flow (uncorrected)	4.1%	4.0%
Final Feed Temp (DEG F)	8.9	9.0
Corrected Gen (CND PRS)	3.4%	3.5%
Total Steam Flow	4.1%	4.0%
Heater 6 Shell Press	4.8%	4.4%
HP Exhaust Press	3.1%	2.9%
Heater 5 Shell Press	3.0%	2.9%
MS Shell Press	3.1%	2.9%
3A Heater Drain Flow	22.2%	22.2%
3B Heater Drain Flow	1.3%	1.0%
3C Heater Drain Flow	0.9%	1.0%
Heater 6 Temperature Rise	13.1%	13.2%

As can be observed from Table 2, the plant changes correspond with the changes calculated by the computer model. This analysis provides confidence that the plant conditions are accounted for by the removal of the 6A feed water heater from service, removal of the ultrasonic correction factor and power reduction.

The following changes were made to the model to perform this analysis:

- A baseline model was developed based on plant design inputs (see section 2.3)
- The model was reviewed to insure all schedules which could invalidate anticipated changes were removed.
- The model was compared to the vendor thermal kit to validate its use as a baseline.
- The model was compared to actual plant configuration to ensure all differences between the vendor thermal kit and actual plant configuration were accounted for.
- The model was reconfigured to remove a #6 feed water heater from service. The feed water heaters were placed in design mode which allows the heater performance to be calculated. This analysis provides anticipated plant conditions with the #6 feed water heater removed from service with the plant at 100% power.
- The model was reconfigured to reduce power to 98.6%.
- The model was reconfigured to account for the power change resulting from removing the ultrasonic from service.
- Based on information provided from an analysis of the ultrasonic meter the model was reconfigured to account for the calibration of the ultrasonic meter. This will provide information regarding the expected plant parameters with the current plant conditions and the projected recalibration applied with the ultrasonic meter in service at 100% indicated power.

5. Predicted Plant Values

5.1. Pre-implementation predictions

Utilizing the information from the PEPSE analysis, predicted plant values were determined by combining the changes calculated from the computer model of plant parameters when the 6A feed water heater was out of service. Uncertainties associated with the instrumentation used to measure these parameters were taken into account in order to set limits with respect to 100%

power operation. The plant expected values are based on the calibration values provided by the thermodynamic analysis and the calculated ultrasonic flow meter corrections. The maximum expected values are provided based on the uncertainty of the flow meter which includes conservatism. These data are based on a specific plant data set and the calculated changes are provided to be compared with the plant data at the time of the ultrasonic meter calibration implementation. The primary parameters used to restrict plant operation were First Stage Pressure and Final Feed Temperature. The actual plant parameters at the time of implementation will be dependent on the plant conditions. Table 3 provides the results of this analysis.

Table 3 Expected Plant Parameters

Parameter		6A FWH OUT	Calculate Change: 98.6% Xflow in serv.	98.6% Expected Plant Parameters	Calculated Change: 100%	100% Expected Plant Parameters	Calculated Chage: Maximum	Maximum Expected Plant Parameters
First Stage Press	Psig	**670.2**	9.4	679.6	19.5	689.7	21.3	691.5
Final Feed Temp (DEG F)	Deg F	**415.4**	1.0	416.4	2.1	417.5	2.3	417.7
HP Exhaust Press	Psig	**167.7**	2.5	170.2	5.2	172.9	5.6	173.4
Average Heater 5 Shell Press	Psig	**160.3**	2.4	162.6	4.9	165.2	5.4	165.7
Average MS Shell Press	Psig	**161.8**	2.4	164.2	4.9	166.7	5.4	167.2

6. Implementation Results

After the analysis, the correction factors were installed in the flow meter and the plant increased power to 100% in a stepwise fashion with the suspension limits developed from this analysis for each power plateau. The suspension limits were intentionally set more conservative than the maximum expected plant parameters. If at any plateau the plant data exceeded the suspension criteria values the power ascension was suspended until the cause could be determined. During the implementation no limits were exceeded. Table 4 shows the final results at 100% power.

Table 4 Suspension Criteria and Results

Suspension Criteria and Results					Projected Values	Expected Values	% Difference
Plant Parameter	**Plant Data Value**	**Suspension Criteria**	**A-B**	**C/A**	**A/MCP**	**From Calculations**	**(G-H)/G**
	A	**B**	**C**	**D**	**E**	**F**	**G**
Main Turbine First Stage Pressure (psig)	**689.20**	**690.4**	**-1.20**	**-0.17%**	**689.69**	689.85	-0.02%
Total Feedwater Flow, venturi flow w/o XFCF applied (lbm/hr x 10^6)	**14.3884**	**14.422**	**-0.03**	**-0.23%**	**14.399**	14.41	-0.08%
Average HP Exhaust Press (psig)	**172.56**	**173.1**	**-0.54**	**-0.31%**	**172.7**	172.96	-0.16%
Average MS Shell Press (psig)	**166.43**	**166.9**	**-0.47**	**-0.28%**	**166.5**	166.77	-0.13%
Measured Core Power: MCP	**99.93%**						

Column G indicates the percentage difference from the plant measured data corrected to 100% power and the expected plant parameters at 100% power. The final feed temperature at 100% power was 417.5 which equaled the expected final feed temperature at 100% power of 417.5.

7. Conclusion

This paper shows that a computer model of a power plant can be used to accurately predict plant conditions for changes to actual plant parameters. This information can then be used to provide a correction to the flow meter allowing continued use in an otherwise unusable condition. Other methods could be employed such as in situ calibrations; however, the method described in this evaluation proves to be an accurate and cost effective approach.

Care should be taken to ensure that the use of computer models is combined with an extensive understanding of how the models are developed and how they perform their calculations. The actual data used to tune the model should be chosen carefully and only boundary conditions are used to tune the model.

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List of Figures

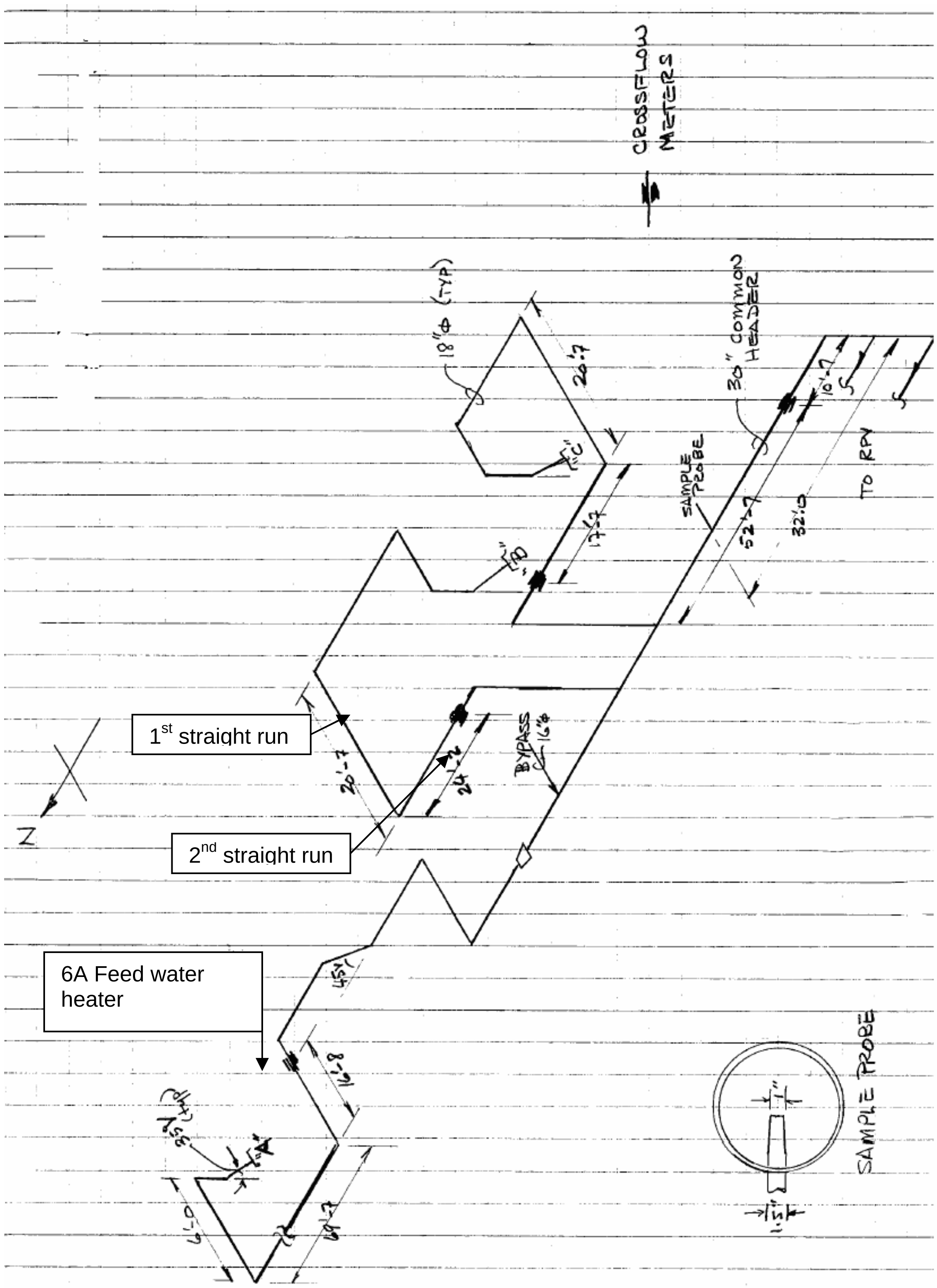
CROSSFLOW METERS
18"Φ (TYP)
30" COMMON HEADER
SAMPLE PROBE
TO RPV
BYPASS 16"Φ
1st straight run
2nd straight run
6A Feed water heater
N
SAMPLE PROBE

FIGURE 1

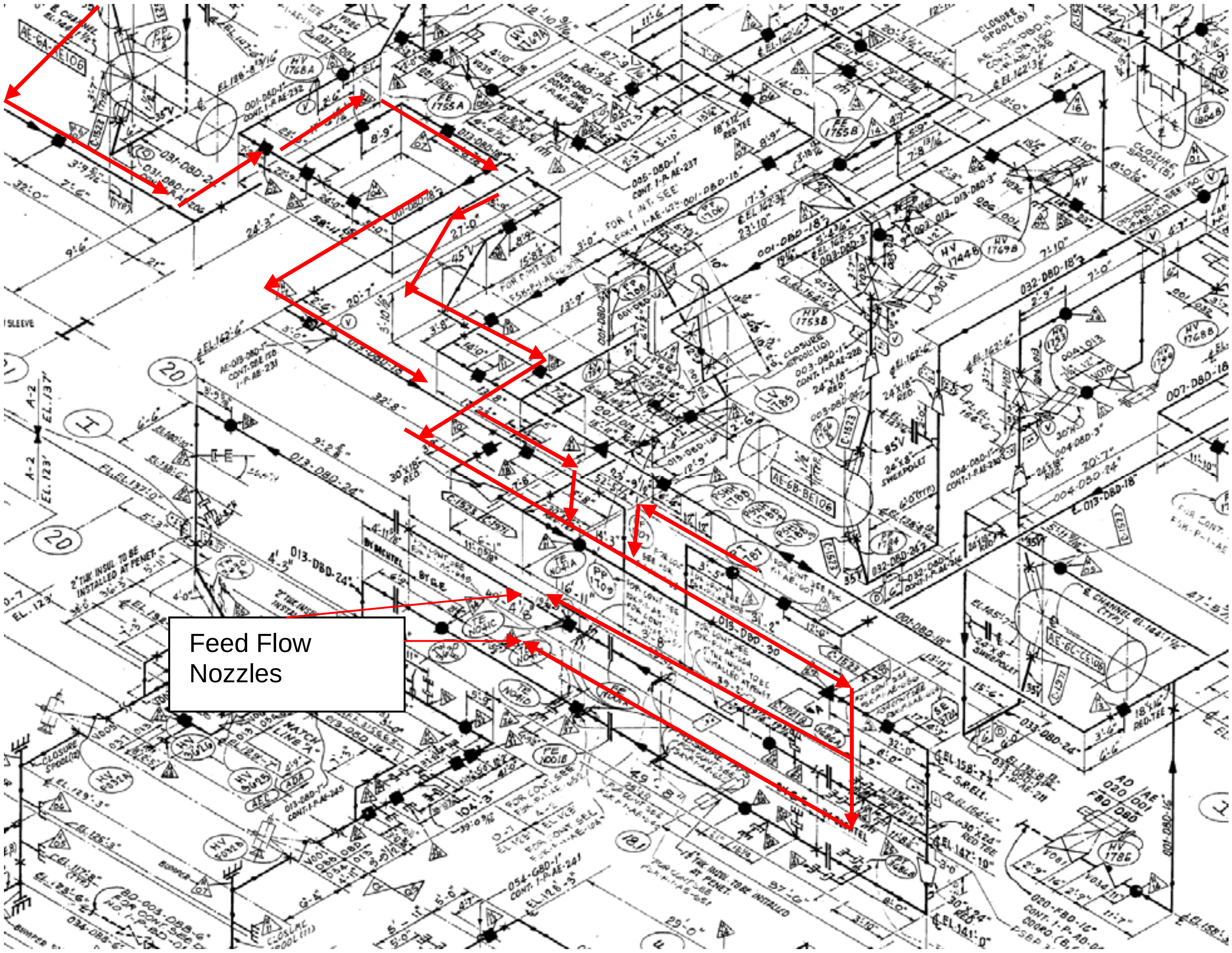

FIGURE 2