A Method for Calculating
Component Performance Deviation

Energy Incorporated
PEPSE User's Group Meeting
November 1 - 2, 1984
New Orleans, Louisiana

Michael Hunt
Louisiana Power & LIght
August 28, 1984

ABSTRACT

Improper utilization of the PEPSE code can result in erroneous conclusions, possibly in the replacement of major equipment which is in perfectly good condition.

This paper will discuss two complementing testing philosophies, trend analysis and analytical testing, their integration in a standardized testing program, and a three step method for calculating component performance deviations.

Michael Hunt
G.O. Fossil Operations
Plant Betterment
Louisiana Power & Light Co.

INTRODUCTION

The purpose of this paper is to provide criteria for standardized testing and calculational methods for the determination of generating unit efficiencies. Standard methods are needed so that accurate, consistent efficiency information is available for evaluating thermal efficiency efforts.

Basically there are two approaches to unit efficiency testing programs, these being the analytical test and the trend analysis study. Proper integration of the two testing philosophies can produce a meaningful testing program.

This paper will discuss testing procedures and the use of the PEPSE code for evaluating component performance deviation.

TEXT

TEST PROCEDURE METHODOLOGY

The accurate determination of the feedwater flow rate is the key to an analytical testing program. An error of 0.1% in feedwater flow will result in a gross turbine heat rate error of 0.1%. The measurement of final feedwater flow eliminates the need to measure pump leakoff flows and heater drain line flows. The possible error associated with feedwater heater tube leaks is also eliminated.

If condensate flow is measured the temperatures and pressures around each heater downstream must be measured accurately. A 0.5 DEG F error in one of these temperature readings will introduce an error in the calculated feedwater flow that exceeds 0.1%. ASME and accepted industry practice is the direct measurement of feedwater flow.

Once feedwater flow has been determined only a few number of high accuracy measurements must be made. These measurements are primarily temperatures and pressures around the H.P. turbine, No. 1 feedwater heater, throttle conditions, hot reheat conditions, and electrical gross power.

Basically the calculation proceeds as follows:

If the feedwater flow is known and the above mentioned parameters are also known the H.P. turbine expansion line slope (section efficiency) is determined. In other words, we now know the electrical power output of this section. This means the balance of the electrical power was generated in the condensing (IP & LP) turbine, thus the condensing turbine expansion line slope (section efficiency) is determined. This is why pressure and temperature measurements associated with the IP and LP turbine, and their respective feedwater heaters, are not as critical.

This procedure closely follows a proposed simplified ASME acceptance test procedure; "A Simplified ASME Acceptance Test Procedure For Steam Turbines", B. Bornstein and K. C. Cotton, EPRI Fossil Plant Heat Rate Improvement Conference and Workshop, 1981.

In the event feedwater flow cannot be accurately measured an alternative calculational approach must be followed. Raw test data will be plotted on a Mollier diagram.

Turbine expansion lines will be constructed, by hand, based upon the judgement of the preformance engineer.

Since the turbine expansion lines and the test gross power are known, a value for feedwater flow can be calculated which satisfies the heat balance. Calculated flow can now be compared to test data flow values. If the value for the calculated flow is not acceptable the turbine expansion lines can be re-drawn and the process repeated. When using this method it is highly desirable to conduct a series of tests so that several heat balances can be calculated and analyzed.

Having followed the above procedure we can accurately calculate the gross turbine heat rate. By having a small amount of additional data boiler efficiency and condenser performance can be calculated.

Having established an analytical testing program a trend analysis program should be initiated. This procedure will be very similar to the analytical program, however the amount and accuracy of test data points is not as rigorous as the analytical procedure. The main goal is test repeatability so that major components efficiencies can be trended in a timely manner.

TEST CALCULATION METHODOLOGY

The PEPSE computer software code will be utilized for test and test/design comparison calculations. The actual mechanics of the PEPSE usage will be explained later, this section serves to explain basic calculational procedures and the assumptions made in these procedures.

ANALYTICAL TEST

Turbine Cycle

Turbine cycle calculations will closely follow ASME PTC 6 "Steam Turbines", 1976., Section 5, Computation of Results.

The main assumptions made will be:

1. Valve stem, gland, and packing leakoff flows will be based upon vendor design values.

2. Feedwater flow will be a calculated value, based upon the turbine expansion lines as constructed by the performance engineer, when accurate feedwater flow measurement equipment is not available.

3. Cycle losses will be based upon hotwell level drop.

The uncorrected raw test turbine heat rate will be corrected to "standard conditions." These are the correction factor curves supplied by the turbine vendor. The items accounted for are primarily variables which affect the turbine performance. Typically these corrections are referred to as "Group 2 Corrections", see ASME PTC 6 "Steam Turbines", 1976.

It should be noted that the test turbine heat rate must be corrected to these "standard conditions" before a valid test/design comparison can be made.

A test/design comparison involves substituting design components for test components and calculating a new heat balance. This procedure can be accomplished easily with the PEPSE code.

Boiler Cycle

Boiler efficiency will be checked by two methods:

1. Input/Output
2. ASME Heat Losses Method

Condenser Cycle

Condenser cleanliness will be calculated using the PEPSE code. The calculation proceeds as follows: From the raw test heat balance we know condenser shell side heating load and the condenser backpressure.

We also know the condenser geometry and the circulating water inlet temperature.

A value of circulating water flow must be assumed. Using standard heat exchanger correlations the U actual/U theoretical (cleanliness factor) can be calculated.

Outlet circulating water temperature is not used for the following reasons:

1. There is a large amount of temperature stratification.
2. A small temperature error will result in a large cleanliness factor error.
3. Ideal thermometer locations are rarely found.

The suggested method for condenser performance calculations will accurately determine tube cleanliness.

TREND ANALYSIS TEST

Turbine Cycle

Turbine cycle calculations will be calculated in the same manner as the analytical test with the following exceptions:

1. A different PEPSE calculational method will be used.
2. L.P. turbine exhaust temperature will be used to determine turbine exhaust pressure.
3. Extraction line pressure drops will be based on analytical test measurements.
4. Makeup, cycle losses, and blowdown flows will be assumed to be design values or values based upon an analytical test.
5. Major pump efficiency calculations will be based on temperature rise.

Boiler Cycle

Boiler efficiency will be calculated by the input/output method.

Condenser Cycle

Condenser cleanliness will be calculated in the same manner as the analytical test.

This procedure will provide an accurate means for trending major equipment performance.

INSTRUMENTATION AND MEASUREMENT UNCERTAINTIES

Instrumentation selection and calibration procedures should provide a total test uncertainty such that meaningful cycle analyses may be performed. An ideal goal of uncertainty for a detailed analytical test would be 0.38% gross turbine heat goal rate error based upon "A Simplified ASME Acceptance Procedure For Steam Turbines", B. Bornstein and K. C. Cotton, EPRI Fossil Plant Heat Rate Improvement Conference and Workshop, 1981.

The ASME, "Guidance for Evaluation of Measurement Uncertainty in Performance Tests of Steam Turbines", PTC-6 Report-1969, should be utilized to evaluate test uncertainties. It is strongly recommended the total test measurement uncertainty be taken into consideration when evaluating component performance deviations.

PEPSE CALCULATIONAL PROCEDURE

STEP 1 - RAW TEST CALCULATION

Averaged test data will be input into one of two PEPSE performance models. The first model utilizes PEPSE special option 3, and is constructed of general turbine sections (type 8). The turbine efficiency solution method is primarily pressure and temperature. After initial data collection, turbine expansion lines are constructed, by hand, on a Mollier diagram. Data from the expansion lines along with other test data is input in the model and option 3 is exercised. Option 3 will adjust throttle steam flow until gross power is matched with test gross power within the user's desired convergence criteria.

This calculated throttle flow should be within the test flow meter's measurement uncertainly limits, if not then the turbine expansion line should be re-drawn and the process repeated.

This method exemplifies the classic heat balance calculation routine and will be the procedure utilized for calculating the detailed analytical test.

The second model utilizes PEPSE option 2. This model is constructed with G.E. turbine sections. Through use of an EFMULT (which mimics option 2), or option 2, the condensing turbine expansion line is "swung" until gross power is achieved. The EFMULT is a multiplier on a turbine efficiency factor. A small amount of input data is required. This method will be utilized for the trend analysis test calculation and the sample test calculation recommended during an analytical test.

STEP 2 - DATA CONVERSION AND CORRECTION TO STANDARD CONDITIONS

After the initial PEPSE run, output data is input into a third performance model. This model is virtually identical to the general turbine option 3 model, however, a flow coefficient, efficiency solution method 3 is now utilized. Use of this solution method now allows us to correct to standard conditions (option 1).

Utilizing PEPSE special option 1 the raw test will be corrected to the following standard conditions:

1) Throttle Temperature and Pressure
2) HRH Temperature
3) Reheater Pressure Drop %
4) Makeup, Cycle losses, and Blowdown flows
5) Generator Hydrogen Pressure and Power Factor
6) Condenser Back Pressure
7) Extraction line pressure drops

STEP 3 - PEFORMANCE ANALYSIS

Two performance analysis models were developed. The first model is for a detailed individual test versus design component analysis. After option 1 is performed individual design components are substituted, one at a time, cumulatively, using stacked cases. Individual component performance deviations are calculated. It is recommended this model be used in conjunction with the special option 3 model in the initial test run.
The second model is virtually identical to the first model. Here, however, major design components are lumped together. Component performance variations are calculated in major groups, such as feedwater heaters, pumps, major turbine sections, etc.

This model was developed as a simplified approach for trend analysis calculations. Use of the option 2 model in the initial test run and use of this model in the analysis run will explain component deviation in major groups.

It should be noted all calculations performed with these models follow ASME TEST CODE, steam turbine, PTC-6, 1976., Section 5, computation of results.

COMMENTS

I. OPTION 3 MODEL

A. Advantages
   1. Most accurate calculational procedure available to the Result engineer.

   2. Best method for detailed component performance analysis.

B. Disadvantages
   1. Large amount of test and input data required.

II. OPTION 2 MODEL

A. Advantages
   1. Small amount of input data required.

   2. Actual total cycle deviation is calculated

3. Major areas of performance deviation will be apparent if the major component deviation model is used.
4. Excellent for trend analysis.

B. Disadvantages

1. Option 2 based on plant flow metering systems.
2. Not applicable for individual component analysis.
3. Not as accurate as Option 3.

III. PEPSE CALCULATIONAL PROCEDURE

A. Advantages

1. Standardization of calculational procedures.
2. Closely follows ASME's recommendations for performance calculations.
3. Allows the Results engineer flexibility in the testing and calculation modes.

B. Disadvantages

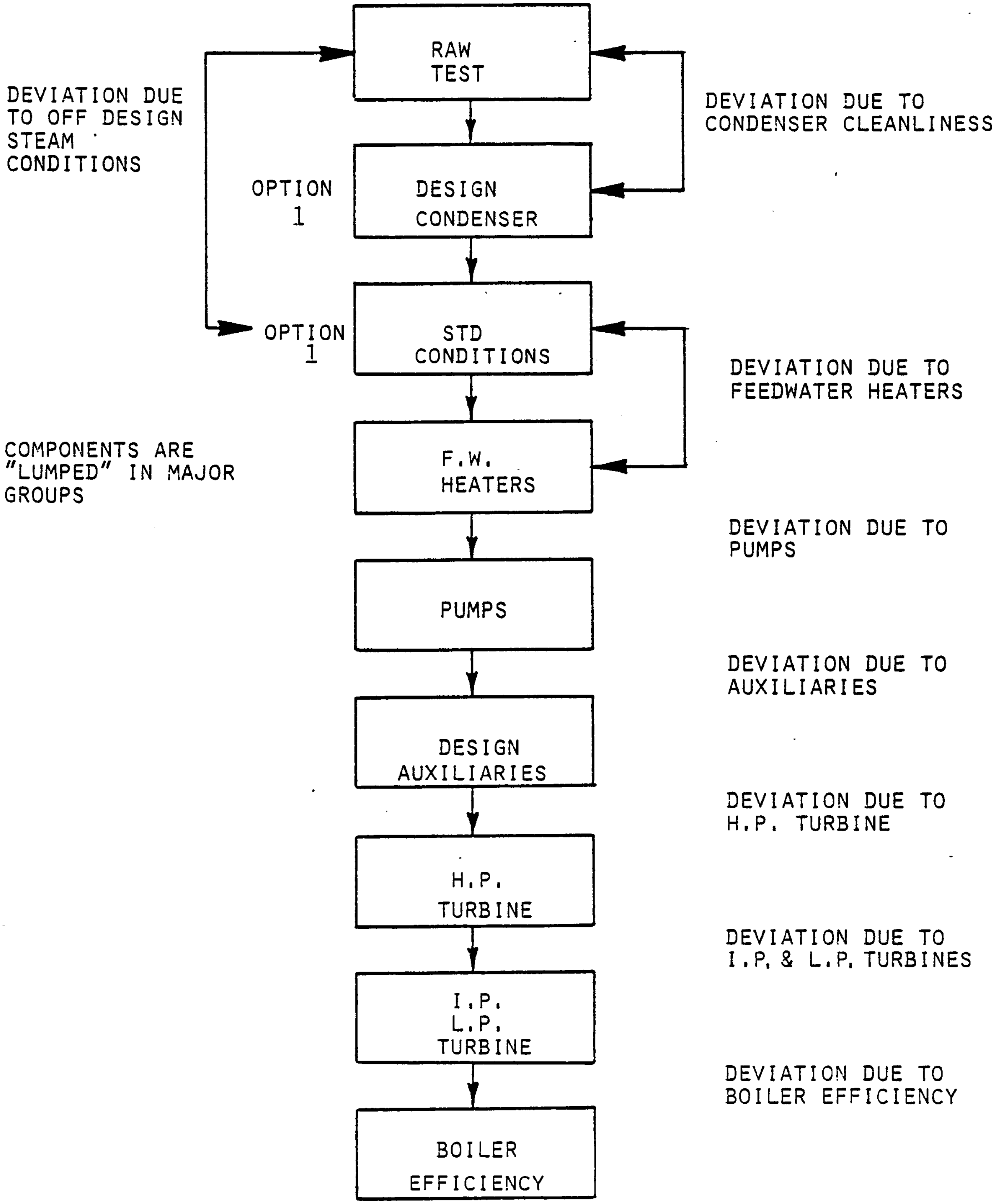
1. Detailed analysis model requires approximately 10-15 minutes CPU time on an IBM 3081 Model K.
2. Major component deviation model requires approximately 5-10 minutes CPU time on an IBM 3081 Model K.
3. Requires development of several PEPSE models prior to system usage.

SUMMARY

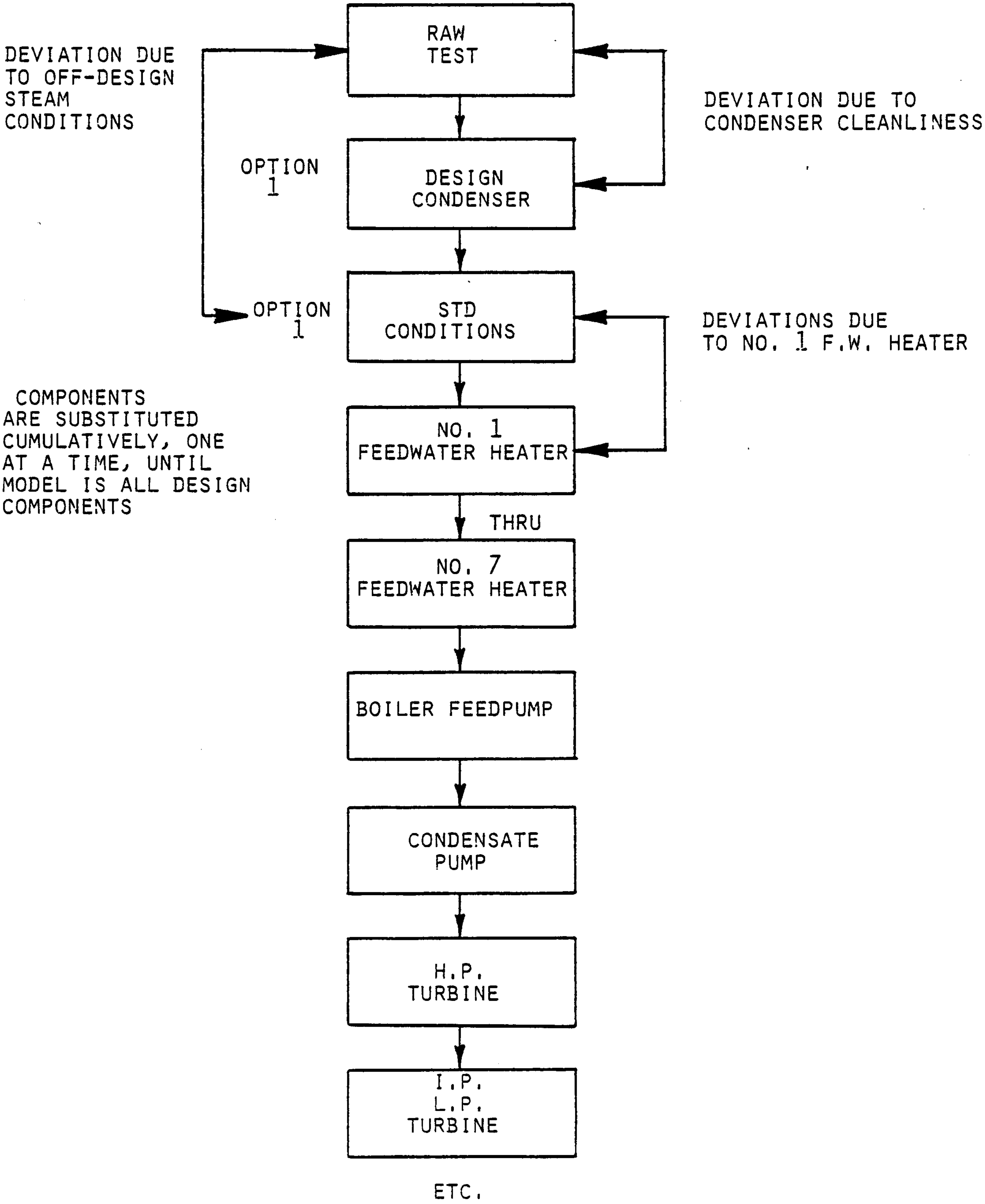
The PEPSE code can play an important role in a performance testing program.

However, the adage "Garbage In - Garbage Out" (GIGO), should be kept in mind when evaluating test data. The quality of PEPSE output is only as good as that of the input data. Standard methods, such as those covered in this paper, should be developed as an integral part of a unit efficiency testing program. Application of these techniques will provide information suitable for meaningful economic analyses.

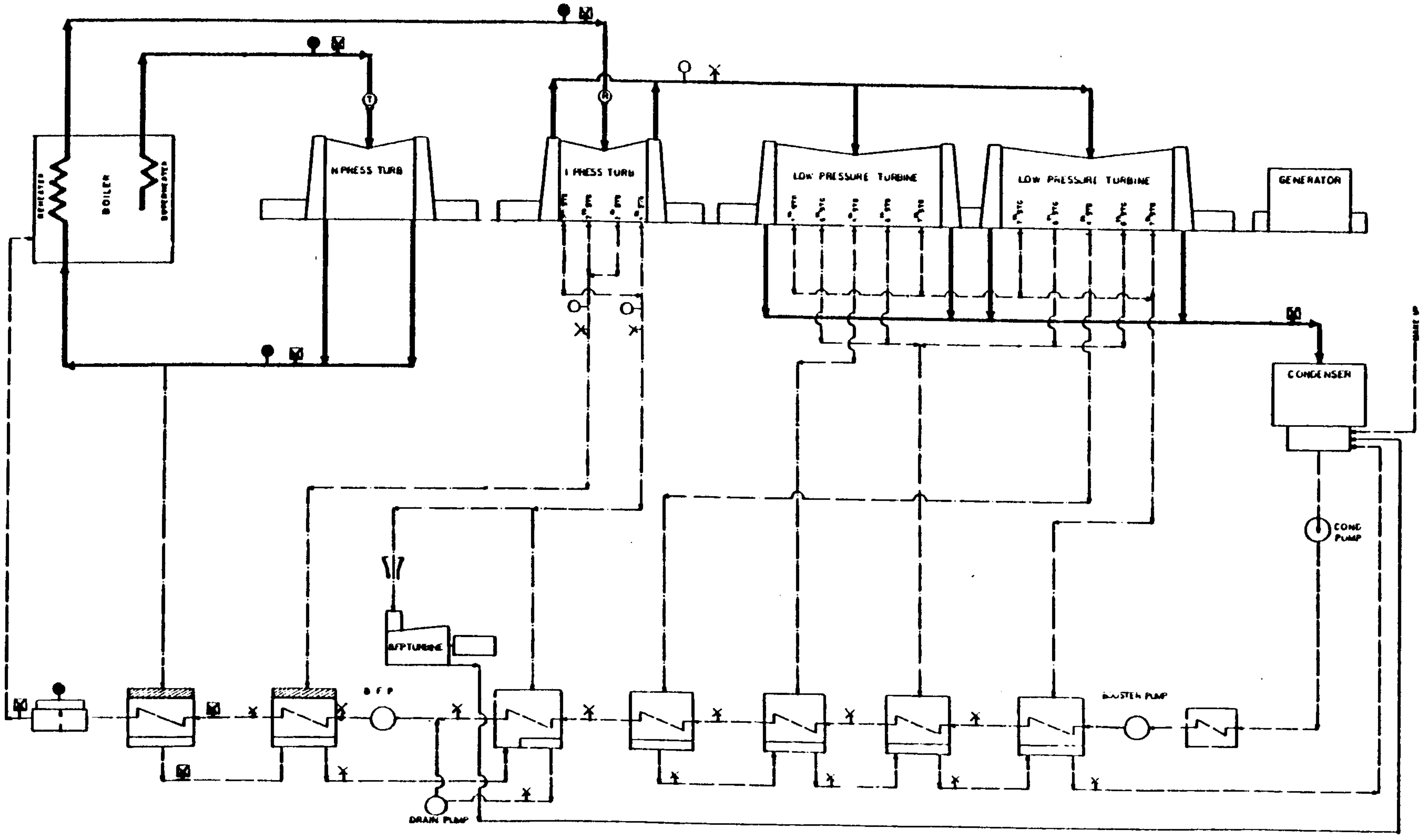
TREND ANALYSIS COMPONENT PERFORMANCE DEVIATION MODEL



ANALYTICAL
COMPONENT PERFORMANCE DEVIATION MODEL



UNIT EFFICIENCY - TREND ANALYSIS TEST INSTRUMENT LIST



LEGEND

- ● CALIBRATED BOURDON GAGE
- ○ STATION GAGE
- ☒ CALIBRATED THERMOCOUPLE
- × STATION THERMOCOUPLE
- ⋛ STATION FLOW DEVICE
- PRECISION PRIMARY FEEDWATER FLOW DEVICE

UNIT EFFICIENCY - TREND ANALYSIS TEST DATA REQUIRED

1) Throttle Pressure - PSIA
2) Throttle Temperature - DEG F
3) HRH Temperature - DEG F
4) HRH Pressure - PSIA
5) H.P. Turbine Exhaust Temperature - DEG F
6) H.P. Turbine Exhaust Pressure - PSIA
7) I.P. Turbine Shell Pressures - PSIA
8) I.P. Turbine Shell Temperatures - DEG F
9) L.P. Turbine Exhaust Hood Temperature - DEG F
10) Feedwater Flow - LB/HR
11) Gross Power - kilowatts
12) Auxiliary Power - kilowatts
13) Generator Hydrogen Pressure - PSIG
14) Generator Reactive Power - kilovars
15) Fuel Input - BTU/HR
16) Circulating Water Inlet Temperature - DEG F
17) Feedwater Heater Inlet, Outlet, and Drain Temperatures - DEG F (Excluding Lowest Pressure Heater Inlet Temperature)

UNIT EFFICIENCY - TREND ANALYSIS TEST GENERIC PROCEDURE

1) TEST WILL BE PERFORMED AT VALVES WIDE OPEN. IN THE EVENT STEAM GENERATOR CAPACITY IS INADEQUATE TO OBTAIN VWO, THROTTLE PRESSURE SHOULD BE REDUCED UNTIL VALVES CAN BE FULLY OPENED.

2) DURATION - ONE HOUR AFTER UNIT IS STABILIZED.

3) TEST TO BE RUN AT NORMAL DESIGN CONDITIONS.

4) USE OF ATTEMPERATING SPRAYS SHOULD BE AVOIDED.

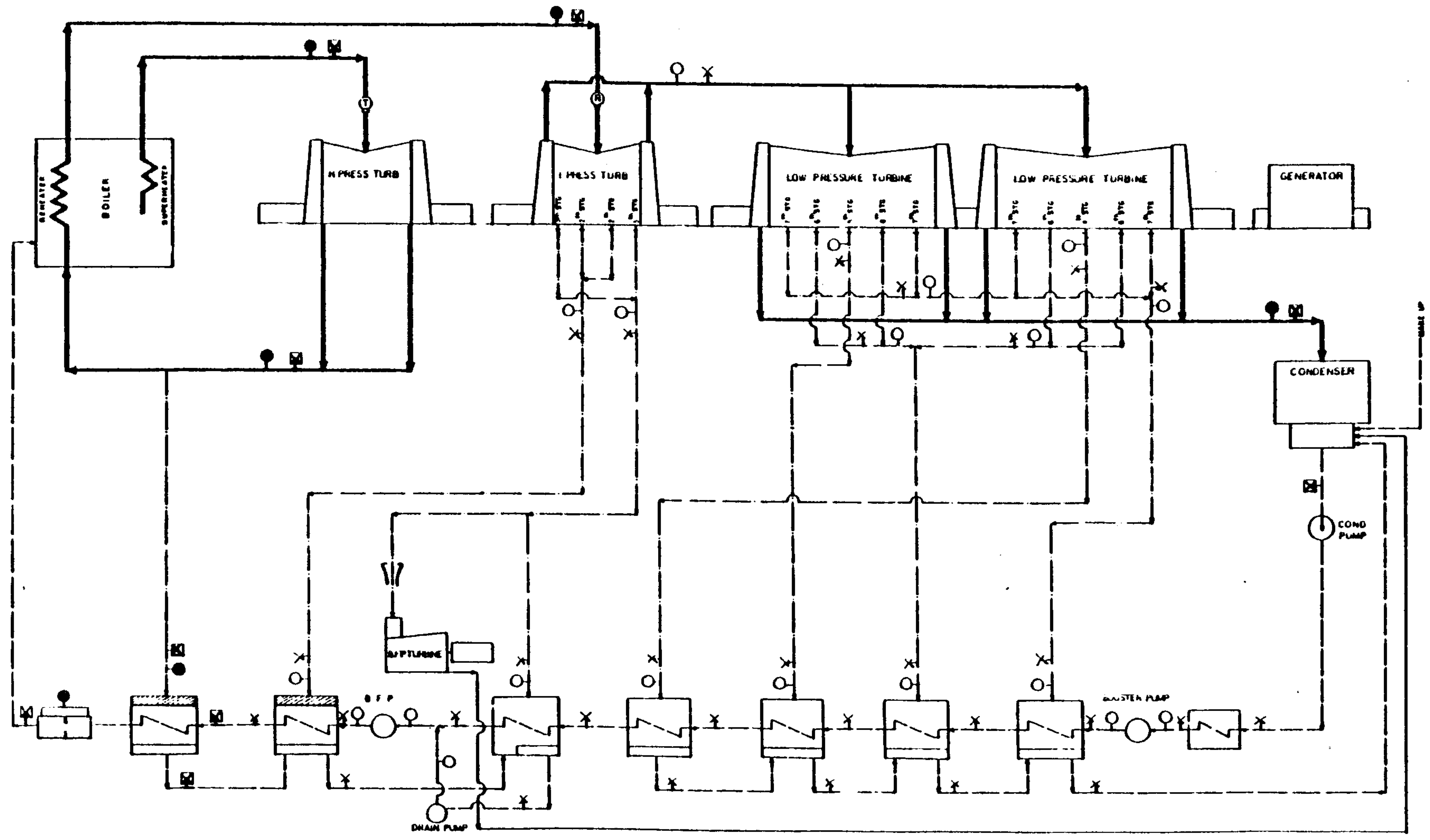
5) MAJOR VALVE LEAKAGES (I.E., BFP RECIRC) SHOULD BE BLOCKED IF POSSIBLE.

6) MAKEUP AND, IF APPLICABLE, BLOWDOWN RATES WILL BE AT NORMAL OPERATING VALUES.

7) FEEDWATER HEATER LEVELS SHOULD BE AT NORMAL OPERATING LEVELS.

8) DATA SHOULD BE COLLECTED EVERY 15 MINUTES.

UNIT EFFICIENCY - ANALYTICAL TEST INSTRUMENT LIST



LEGEND

● PRECISION PRESSURE GAGE

⊃ CALIBRATED FLOW DEVICE

○ CALIBRATED BOURDON GAGE

☒ PRECISION THERMOCOUPLE

X STATION THERMOCOUPLE

PRECISION PRIMARY FEEDWATER FLOW DEVICE

UNIT EFFICIENCY - ANALYTICAL TEST GENERIC DATA REQUIRED

1) THROTTLE PRESSURE - PSIA
2) THROTTLE TEMPERATURE - DEG F
3) HRH TEMPERATURE - DEG F
4) HRH PRESSURE - PSIA
5) H.P. TURBINE EXHAUST TEMPERATURE - DEG F
6) H.P. TURBINE EXHAUST PRESSURE - PSIA
7) I.P. TURBINE SHELL PRESSURES - PSIA
8) I.P. TURBINE SHELL TEMPERATURES - DEG F
9) L.P. TURBINE SHELL PRESSURES - PSIA
10) L.P. TURBINE SHELL TEMPERATURES - DEG F
11) L.P. TURBINE EXHAUST PRESSURE - PSIA
12) L.P. TURBINE EXHAUST HOOD TEMPERATURE - DEG F
13) HOTWELL TEMPERATURE - DEG F
14) HOTWELL LEVEL DROP - INCHES
15) INLET CIRCULATING WATER FLOW - LB/HR (ASSUMED VALUE)
16) INLET CIRCULATING WATER TEMPERATURE - DEG F
17) FEEDWATER HEATERS EXTRACTIONS - INLET TEMPERATURES AND PRESSURES - PSIA AND DEG F
18) FEEDWATER HEATERS INLET, OUTLET, AND DRAIN, TEMPERATURES - DEG F
19) MAJOR PUMPS - SUCTION AND DISCHARGE PRESSURES - PSIA, RPM IF NECESSARY
20) BOILER FEED PUMP TURBINE FLOW - LB/HR
21) FEEDWATER FLOW - LB/HR
22) GROSS POWER - KILOWATTS
23) AUXILIARY POWER - KILOWATTS
24) GENERATOR HYDROGEN PRESSURE - PSIG
25) GENERATOR REACTIVE POWER - KILOVARS
26) FUEL INPUT - BTU/HR
27) ANY OTHER CRITICAL FLOWS, TEMPERATURES, AND PRESSURES UNIQUE TO THE UNIT.

UNIT EFFICIENCY - ANALYTICAL TEST GENERIC PROCEDURE

1) TEST WILL BE PERFORMED AT VALVES WIDE OPEN. IN THE EVENT STEAM GENERATOR CAPACITY IS INADEQUATE TO OBTAIN VWO, THROTTLE PRESSURE SHOULD BE REDUCED UNTIL VALVES CAN BE FULLY OPENED.

2) DURATION - TWO HOURS AFTER UNIT IS STABILIZED.

3) TEST TO BE RUN AT NORMAL DESIGN CONDITIONS.

4) USE OF ATTEMPERATING SPRAYS SHOULD BE AVOIDED.

5) MAJOR VALVE LEAKAGES (I.E., BFP RECIRC, DRAIN LINES, ETC.) SHOULD BE ISOLATED AND BLOCKED.

6) A SAMPLE HEAT BALANCE UTILIZING THE PEPSE CODE WILL BE PERFORMED DURING THE TEST TO INSURE TEST DATA IS ACCEPTABLE.

7) MAKEUP AND BLOWDOWN VALVES WILL BE SECURED. HOTWELL LEVEL DROP WILL BE USED TO CALCULATE CYCLE LOSSES.

8) FEEDWATER HEATER LEVELS SHOULD BE AT THE NORMAL OPERATING LEVEL.

9) DATA SHOULD BE COLLECTED EVERY 15 MINUTES.