
Test code for
**Acceptance of
steam turbines**

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- | | |
|---|--|
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Association of Consulting Engineers
Lloyd's Register of Shipping

Power Generating Association, BEAMA
South of Scotland Electricity Board

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steam turbines**

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Foreword

This revision of BS 752:1958 has been prepared under the direction of the Mechanical Engineering Industry Standards Committee and takes into account work in hand by IEC 5 on the revision of IEC Publication 46 'Recommendations for steam turbines', Part 1, 'Acceptance tests' as well as practice in the United Kingdom.

British Standard Test Code for

Acceptance of steam turbines

0. Introduction

The primary object of acceptance tests on a turbine-generator is to demonstrate the fulfilment of contractual obligations in respect of the guaranteed heat rate, the capacity of the set, and the ability of the speed control system to ensure the safety of the machine on sudden loss of full load. This test code describes the methods to be used for the heat rate and capacity test and outlines the requirements for speed responsive tests.

In some cases it may be required to carry out a test at some load or loads different from the guarantee points for the main turbine in order to demonstrate the performance of other items of the plant, e.g. a boiler feed pump driven by a turbine supplied with steam bled from the main turbine.

Section one. General**1. Scope**

This test code specifies test requirements primarily for constant-speed condensing steam turbines driving generators for electric power services. Some of the provisions of this test code are relevant to turbines for applications other than driving electric power generators. This test code does not necessarily apply in all respects to turbines driving small electric generators.

This test code provides for the testing of turbines whether operating with superheated or saturated steam. It includes measurements and procedures required to determine specific enthalpy within the moisture region and describes precautions necessary to permit testing within the requirements of radiological safety where a nuclear plant is involved.

2. References

The titles of the British and International Standards referred to in this standard are listed on the inside back cover.

Section two. Notation, units, definitions**3. Notation and units**

The dimensional quantities that enter into the tests and computations and the symbols used to denote them are shown below. It is envisaged that the units generally employed will be based on the SI system and the relevant units are included below. The code is equally valid for contracts drawn up with any established system of units.

Quantity	Symbol	Unit
Electrical power	P_g	kW
Mass rate of flow	M	kg/s or kg/h
Pressure	p	bar*
Temperature	t	°C
Dryness fraction of wet steam	x	—
Specific enthalpy of steam	H	kJ/kg
Specific enthalpy of water	h	kJ/kg
Rotational speed	n	rev/s
Heat rate		kJ/kW s or kJ/kW h

$$\text{Thermal efficiency \%} = \frac{100K}{\text{heat rate}}$$

NOTE. When heat rate is in kJ/kW s, $K = 1.0$. When heat rate is in kJ/kW h, $K = 3600$. Unless otherwise stated, all pressures are in bar absolute.

* 1 bar = 10^5 N/m² = 100 kPa.

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Number or letter suffixes used with the above symbols refer to the locations shown in figure 1. Those directly appearing in the formula for calculating the heat rate are defined in clause 4.

4. As-run heat rate

For a power station turbine with regenerative feed heating, the heat rate is the significant criterion. Because of the small (almost inevitable) loss of fluid from the system during the test, it is necessary to agree a convention for determining the heat rate formula. It is assumed that any unaccounted for losses occur in the high pressure part of the boiler. Then, if the unaccounted for leakages are kept within the limits recommended in this test code, their effect on the heat rate is negligible. The formula then becomes, for the cycle shown in figure 1:

$$\text{Heat rate} = \frac{M_1 (H_1 - h_f) + M_2 (H_3 - H_2) + M_{1s} (h_f - h_{1s}) + M_{1r} (H_3 - h_{1r})}{P_g}$$

where

M_1 is the steam flow to h.p. turbine stopvalves;

H_1 is the specific enthalpy of steam at h.p. turbine stopvalves;

h_f is the specific enthalpy of final feed-water;

M_2 is the steam flow from h.p. exhaust to reheater;

H_2 is the specific enthalpy of steam at h.p. turbine exhaust;

H_3 is the specific enthalpy of steam at i.p. turbine stopvalves;

M_{1s} is the cooling water flow to superheater;

h_{1s} is the specific enthalpy of cooling water to superheater;

M_{1r} is the cooling water flow to reheater;

h_{1r} is the specific enthalpy of cooling water to reheater;

P_g is the power at generator terminals, less any deduction stipulated in the contract for excitation or for separately driven auxiliaries.

The as-run heat rate is obtained by assigning to the symbols numerical values corresponding to the test conditions and flows after all necessary instrument corrections and adjustments for leakage and changes in stored water have been made in accordance with the principles given in sections four and five.

If there is no reheating, the second and fourth terms vanish.

If there is no feed heating, the third term vanishes.

The formula envisages that no make-up water is supplied during the test. Should the contract guarantee include a specified quantity of make-up for a definite purpose the numerator of the formula may be adjusted by agreement to take account of the corresponding heat added to and rejected from the system.

5. Fully-corrected heat rate

The fully-corrected heat rate is the as-run heat rate corrected to give the heat rate that would have been achieved during the test if the terminal conditions had been as specified and all the plant not covered by the turbine-generator heat rate guarantee had performed exactly in accordance with the specification.

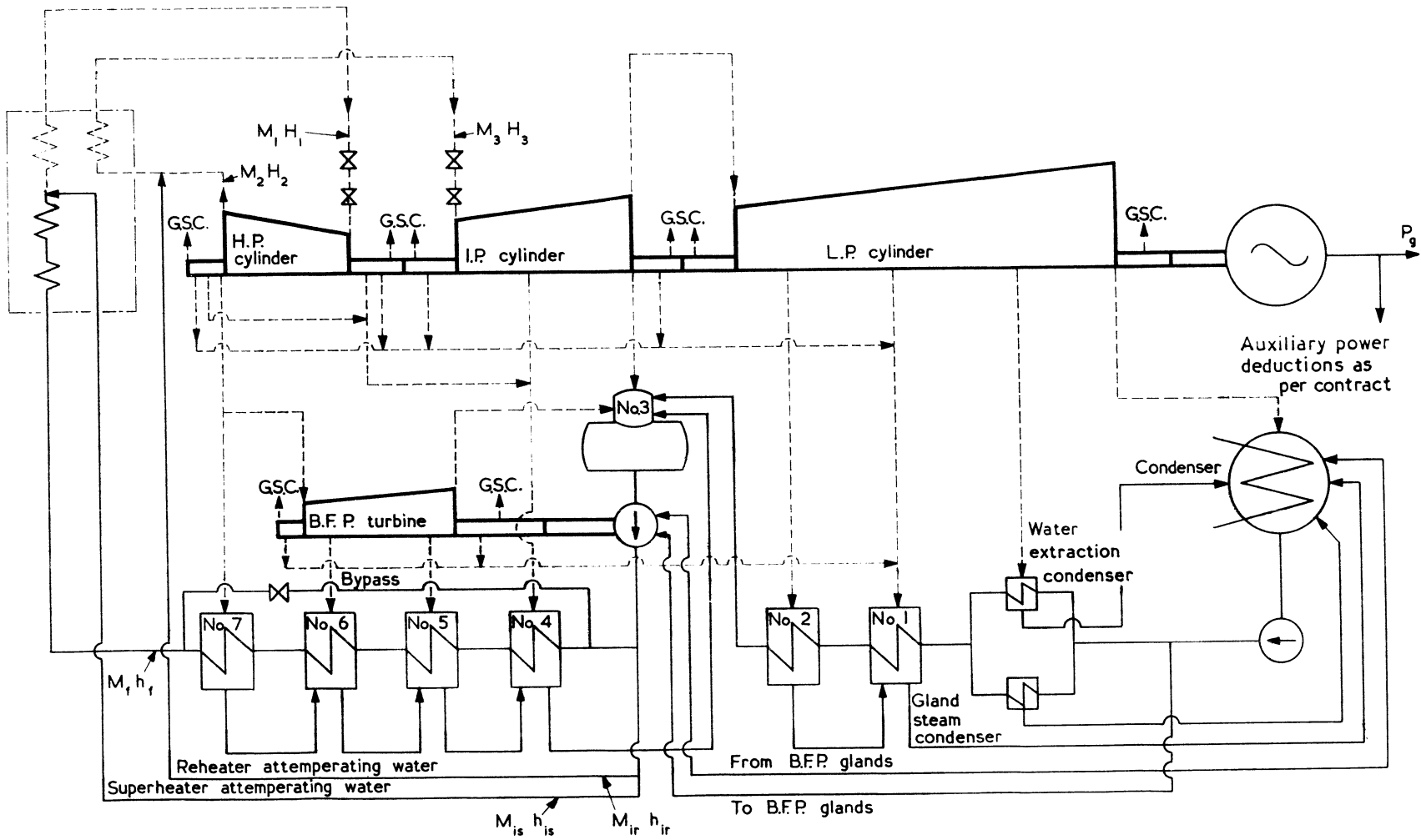
6. Output definitions

Maximum continuous rating (M.C.R.) is the power output assigned to the turbine-generator by the manufacturer at which the turbine may be operated for an unlimited time at the specified terminal conditions. This is the rating which should appear on the nameplate and it will normally carry a guarantee of heat consumption. The governing valves will not necessarily be quite fully open (see clause 15).

Maximum capability is the power output the unit can produce with the governing valves fully open and at the specified terminal conditions.

Maximum overload capability is the maximum power output the unit can produce with valves fully open and with certain other specified conditions, such as by-passed heaters.

NOTE. Specified terminal conditions may include speed, steam inlet pressure and temperature, reheat temperature, feed water heating, exhaust pressure (or condenser cooling water inlet temperature and quantity), pass-in and pass-out pressures and temperatures, and any other relevant factors such as generator power factor and hydrogen pressure.



$$\text{As-run heat rate} = \frac{M_1 (H_1 - h_r) + M_2 (H_3 - H_2) + M_{is} (h_r - h_{is}) + M_{ir} (H_3 - h_{ir})}{P_g}$$

(See clause 4)

Figure 1. Illustration of as-run heat rate for a reheating regenerative condensing turbine with integrated boiler feed pump turbine

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Section three. Guiding principles

7. Items on which it is essential that agreement is reached

As indicated in section one, the overall test programme may have to make provision for performance tests on the condenser, generator, feed pump and feed heaters in addition to tests on the main turbine-generator. Several manufacturers may be involved; it is therefore essential to have a plenary meeting of all parties concerned at an early date to draw up a comprehensive test programme and define the division of duties and the responsibilities of each party.

At the plenary meeting(s) the person in charge of the testing and the person responsible for the operation of the plant during the tests shall be nominated. These two persons shall co-ordinate all aspects of the tests.

Agreement reached at the plenary meeting(s) shall be recorded. Any agreements reached at subsequent meetings at which not all the interested parties are present shall be put in writing and circulated to all parties.

Items which may need discussion and written agreement at these meetings will probably include:

- (a) interpretation of the contractual guarantees;
- (b) location, type and calibration of test instruments;
- (c) means of obtaining steady operating conditions at their specified values;
- (d) means of isolating the plant for test purposes;
- (e) checking for leakage which may cause test error, and the means of eliminating it;
- (f) the dates of the series of acceptance tests;
- (g) the procedure to be followed for calculating the results (including corrections for terminal conditions);
- (h) the production of the official acceptance test report;
- (j) enthalpy drop tests;
- (k) proving runs.

Items (b), (c), (d), (e), (j) and (k) require attention well in advance of the acceptance test dates.

8. Preparation for acceptance tests

The person nominated as having responsibility for the tests shall ensure at an early stage that the plant can be operated under the conditions required for the tests with the test isolation applied. He shall also make sure that the required instrument calibrations have been carried out, that the test instrumentation has been correctly installed and is functioning properly, and that prior to the tests all test personnel are properly instructed in their duties.

9. Time of acceptance tests

The acceptance tests shall follow as closely as practicable the run which classifies the machine as having been commissioned at maximum continuous rating (M.C.R.) load. If there is any delay, the official report shall give the reasons and include a record of the operating regime of the turbine-generator prior to the tests.

10. Depreciation before the acceptance tests

For various reasons extraneous to the turbine-generator, it may not be practicable to conduct full-scale performance tests within a reasonable time after first going on load. Thus it is desirable that the following information, in well-defined conditions of pressure, temperature, valve opening etc., should be recorded from the earliest possible date.

Turbine stage pressures.

Turbine stage temperatures.

Power output.

Opening of governing valves.

Enthalpy drop efficiency, if steam superheated.

Willans line, i.e. graph of steam flow/power output.

Flow of leak-off steam from glands, etc.

The same readings taken in the same conditions just before the test and compared with the original readings will enable any significant changes in the condition of the turbine to be determined.

The parties to the test shall agree on the action to be taken over evidence of deterioration. In some circumstances it may be appropriate that the test should be conducted immediately after the first major

inspection, provided that any deficiencies in the turbine-generator unit affecting performance have been corrected during the inspection period.

11. Steam tables

The steam and compressed water tables and charts upon which the guarantees are based shall be used for the calculation of the test results. The name and edition of the tables and charts employed shall be stated in the report of the tests. The tables used shall be consistent with the International Skeleton Tables established at the sixth International Conference on the Properties of Steam (ICPS) in 1963, and should preferably be based on the 1967 International Formulation Committee (IFC) Formulation for Industrial Use that was approved at the seventh ICPS conference in 1968.

12. Test instrumentation

All test instrumentation shall be of an accuracy acceptable to the parties concerned and within the limits given in section four. The use of unconventional means of making and recording test measurements is permitted, provided that the accuracy and suitability of such methods can be demonstrated to the satisfaction of the parties concerned. The official acceptance test report shall adequately describe the test instrumentation with supporting proof of its accuracy and suitability.

13. Calibration of instruments

Unless otherwise agreed, each instrument shall be calibrated immediately before the acceptance tests. It is important that recalibration after the test, where necessary, be undertaken on an urgent basis so that the test report is not delayed. The test report shall give a summary of all the instrument calibrations whether carried out specifically for the test or not. Facsimile copies of calibration certificates are not required in the official acceptance test report.

14. Proving runs and preliminary tests

It is recommended that some proving runs and preliminary tests be made before the acceptance tests. Should the results of the proving runs be unsatisfactory, the manufacturer shall have the opportunity to examine the turbine and the test equipment. If the preliminary test results are satisfactory they may, if agreed between the parties concerned, be accepted as the official tests.

15. Conduct of tests

15.1 Official guarantee heat rate test. Throttle valve opening, turbine stopvalve (T.S.V.) pressure, T.S.V. temperature, reheat temperature, vacuum and power factor shall be set as closely as possible to their required values at least 30 min before the start of the test. The boiler/turbine unit shall then be operated so that fluctuations in operating conditions are minimized. The cooling water flow rate through the condenser should not be varied in order to maintain specified vacuum unless previous experience has shown that this can be done without causing fluctuations in operation. Conditions will normally be steadier if a gradual change in vacuum due to change in cooling water inlet temperature is accepted.

The official M.C.R. guarantee heat rate test shall be run with the maximum obtainable first stage inlet pressure, subject to the limitation that the power output, when corrected to specified conditions, does not exceed 105% of specified M.C.R. Provided that the corrected power output is between 100% and 105% of M.C.R., no adjustment for load shall be made to the heat rate or power output.

If the output is restricted to a value below 105% of specified M.C.R. by some component outside the turbine-generator manufacturer's contract, then the manufacturer shall have the right to run the test at reduced T.S.V. pressure in order to obtain the throttle opening corresponding to 105% of nominal M.C.R. (which may be full throttle opening), and the test heat rate and power output shall be corrected to what they would have been with the specified terminal conditions.

If the output is restricted to less than 100% of specified M.C.R. by some component outside the turbine-generator manufacturer's contract, the manufacturer shall have the right to postpone the tests until the restriction has been removed.

The official test report shall state if any component outside the turbine-generator manufacturer's contract was restricting output and if the manufacturer opted to run at reduced T.S.V. pressure.

After the governing valves have been set to full throttle or 105%, as the case may be, they shall be maintained in the same position throughout the test. In order to maintain constancy of throttling, the travel of the governing valves, in the opening direction only, shall be limited at the position chosen, and the governor shall be sufficiently overwound to ensure that it does not respond to normal changes in system frequency.

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The official test report shall comment on any change in system frequency affecting the valve opening during the test.

15.2 Maximum overload capability test. If maximum overload capability is specified, it is usually a guaranteed or bona fide figure for a specified duration associated with cycle adjustments such as the isolation of certain feedwater heaters. The specified duration may be short, say one hour, and the settling-down period and the overload test itself will have to be accommodated within this period. In such cases it is essential to have previous experience of operating at overload so that any adjustments to operating conditions such as cooling water flow, hydrogen pressure or steam temperature controls can be correctly made in the short time available after the heaters are isolated. Test readings shall be taken from just before the isolation of the heaters until the unit is returned to normal operation. For the test itself, a period shall be selected during the most stable portion of the run, probably the last half hour for a specified overload duration of one hour. The parties to the test shall mutually decide which period shall be selected for the overload test.

16. Constancy of test conditions; permissible deviations and fluctuations

The variation of any condition which may influence the results of the test, shall be made as constant as possible before the test begins, and shall be so maintained throughout the test within the permissible variations of clause 17.

17. Maximum permissible deviations and fluctuations in operating conditions

Except upon agreement to the contrary by the parties to the test, the maximum permissible deviation of the average test condition for each variable from that specified and the maximum permissible fluctuation of the variable during any one test run, shall not exceed the limit prescribed in table 1.

Table 1. Permissible variations and fluctuations in test conditions

Variable	Maximum permissible deviation of the average of the test from that specified	Maximum permissible rapid fluctuation from the average during any one test run (see Note 1)
Initial steam pressure	$\pm 3\%$ of absolute pressure (see note 2)	$\pm 0.5\%$ of absolute pressure
Initial and reheat steam temperature	superheat $\leq 25 \pm 8^\circ\text{C}$ superheat $\geq 25 \pm 15^\circ\text{C}$ (See note 2)	$\pm 2^\circ\text{C}$ $\pm 4^\circ\text{C}$
Dryness fraction at inlet for turbines supplied with wet steam	0.005	0.001
Exhaust pressures (condensing turbine)	$+ 25\%$ of absolute pressure $- 10\%$ of absolute pressure	$\pm 5\%$
Final feedwater temperature	$\pm 8^\circ\text{C}$ (see note 3)	—
Extraction pressure	See note 4	—
Power	$\pm 5\%$	$\pm 0.25\%$
Voltage	$\pm 5\%$	—
Power factor	May vary between unity and (specified value — 0.05)	—
<i>When the condenser is included in the guarantee</i>		
Cooling water inlet temperature	$\pm 5^\circ\text{C}$	$\pm 1^\circ\text{C}$
Cooling water flow	$\pm 10\%$	—
Air inlet temperature (for air-cooled condensers)	$\pm 10^\circ\text{C}$	$\pm 2^\circ\text{C}$

NOTE 1. A rapid fluctuation is one whose frequency is greater than twice the frequency of the reading.

NOTE 2. In any event the manufacturer's allowable variations in pressure and temperature should not be exceeded. See also IEC Publication 45, clause 19.

NOTE 3. Possible limitations may be specified by the boiler manufacturer or the contractor.

NOTE 4. Deviations of a few per cent in the extraction pressures as compared with the design values normally have a negligible effect on the overall performance. Should there be disproportionately large deviations in the extraction steam flows, suggesting malfunctioning of the heaters, the effect on the overall performance may be serious, and agreement should then be reached on the course to be followed.

18. Duration of tests and frequency of measurements

The requisite test duration is dependent on the steadiness of operating conditions and the speed of acquisition of test data. Accurately measurable changes in level of water stored in the system may be a limiting factor.

The duration of the official guarantee heat rate test shall normally be two hours. During this period, readings of differential pressure flow meters measuring primary flow shall normally be taken every half minute. Readings of electrical power output, if based on indicating wattmeters in the absence of integrating meters, shall be taken at intervals of not more than one minute. Readings of primary pressures and temperatures shall be taken at intervals of five minutes. Fluctuating conditions, especially on flow meter readings, necessitate shorter intervals between readings or a longer test duration in order to achieve a representative average. Contrariwise, the test duration may be shortened to not less than one hour if the parties to the test mutually agree that the data collected in the shorter period adequately represent average conditions.

The duration of the overload test shall comply with the contractual requirements.

19. Reporting acceptance tests

Arrangements shall be made for calculating preliminary test results whilst the tests are proceeding. Simplified methods of calculation may be used for this purpose.

The official acceptance test report may be produced by either party to the tests by mutual agreement or by representatives of the parties working together. If the acceptance test results are capable of being interpreted differently by the parties and they cannot agree, the different interpretations shall be given in the official acceptance test report. If recalibration of some test instruments is essential after the tests, a provisional acceptance test report may be issued and amendment pages circulated later.

The official acceptance test report shall contain the following items, although they need not be in the order shown.

- (a) Objects of test, dates, times and durations.
- (b) Interpretation of the contractual guarantees.
- (c) The division of duties between the parties to the test.
- (d) The steam tables used.
- (e) Schematic diagram of turbine and feed-heating system.
- (f) The results of the leakage checks.
- (g) The results of the enthalpy drop tests.
- (h) The operating regime prior to the acceptance tests.
- (j) The test instrumentation used. Details of any unconventional test equipment and the reason for adopting it. Summary of instrument calibrations (facsimile copies of calibration certificates are not required).
- (k) Variation in system frequency (see clause 15).
- (l) Summaries of the fully corrected test readings.
- (m) The results of the acceptance tests (see section fourteen).

Section four. Test isolation

20. Introduction

The accuracy of the test results depends as much on the isolation of the system as on the accuracy of the instruments. Faulty isolation can lead to two sources of error:

- (a) Extraneous flows, other than those included in the guarantee, will affect the turbine heat rate and cause errors unless the flows and their enthalpies are measured and corrections for them applied to the test results.
- (b) Extraneous flows or flows internal to the turbine cycle, which by-pass or recirculate through a flow measuring device, will cause errors in flow measurement unless they are measured so that the correct flows can be deduced.

21. Flows that have to be isolated

Items of equipment and flows that have to be isolated from the primary turbine feed water cycle include the following.

- (a) Large volume storage tanks.
- (b) Evaporators and allied equipment.
- (c) By-pass systems and auxiliary steam lines for starting.

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- (d) By-pass lines for test flow measuring devices.
 - (e) Turbine exhaust sprays.
 - (f) Drain lines on stop, intercept and control valves.
 - (g) Interconnecting lines to other units.
 - (h) Boiler filling lines.
 - (j) Demineralizing equipment.
 - (k) Chemical feed equipment using condensate.
 - (l) Steam or water lines installed for washing the turbine.
 - (m) Boiler vents.
 - (n) Steam operated soot blowers.
 - (p) Heater by-pass flows.
 - (q) Heater drain by-pass.
 - (r) Heater shell emptying drains.
 - (s) Heater water box vents.
 - (t) Extraction jets for removing incondensable gases.
 - (u) Condenser water box priming jets.
 - (v) Steam or water for station heating.
- Heater steam vents shall be closed if possible; if not, they shall be throttled to a minimum.

22. Flows that have to be measured if not isolated

Flows which may be necessary for the operation of the unit and therefore cannot be isolated shall be measured if they affect the accuracy of the test. Flows which are likely to be in this category are as follows.

- (a) Cooling flows for boiler fire door or slag-tap cooling coils.
- (b) Supply and return flows for gland sealing and cooling on
 - condensate pumps
 - boiler feed pumps
 - boiler water circulating pumps
 - heater drain pumps
 - turbines for turbine-driven pumps
 - control rod seals on nuclear reactors.
- (c) Desuperheating water.
- (d) Boiler feed pump minimum flow lines and balance drain flow.
- (e) Steam for fuel oil atomization and heating.
- (f) Continuous boiler blow-downs.
- (g) Turbine water seal flow.
- (h) Desuperheating water for turbine cooling steam.
- (j) Emergency blow-down valve or turbine gland leakage and sealing system.
- (k) Turbine water seal overflows.
- (l) Steam, other than packing leak-off steam, to the steam seal regulating valve.
- (m) Make-up water.
- (n) Boost steam (such as higher stage extraction at light loads) for low-pressure operation of de-aerator.
- (p) De-aerator overflow line.
- (q) Water leakage into any water-sealed flanges, such as water-sealed vacuum breakers.
- (r) Steam to air pre-heaters.
- (s) Water and steam sampling equipment.
- (t) Pump seal leakage leaving the cycle.
- (u) Automatic extraction steam for industrial uses.

It may be necessary to use calculated values for internal pump leakages, shaft packing, valve stem leakages and internal turbine leakages when it is impossible to measure these flows.

23. Suggested methods of effecting and checking isolation

The following methods are suggested for isolating flows for test purposes.

- (a) Double valves with a telltale in between them.
- (b) Blank flanges or blanks between flanges.

If isolation cannot be effected by the methods (a) or (b), special checks of the leak tightness of corresponding valves shall be made before and after testing. These checks shall be done as follows.

- (c) Removal of a spool piece or the breaking of a joint for visual inspection.
- (d) Visual inspection of steam blowing to atmosphere, e.g. safety valves.
- (e) Installation of a closed valve which has been shown to be leak-proof and which will not be operated during the tests.
- (f) Temperature measurements which will indicate that hot water or steam is not flowing in the line.
- (g) Accurate measurements of levels in any tanks which should be isolated from the system.

24. Test isolation procedure and isolation log sheets

As test isolation is so vital to test accuracy and as there may be special features not covered by clauses 21, 22 and 23, it is recommended that test isolation diagrams should be prepared to show the agreed method of isolating the turbine-generator for test purposes. Isolation log sheets shall then be drawn up so that the isolation can be methodically and thoroughly checked each time the isolation is applied to the plant under test. The isolation procedure shall be rehearsed before the acceptance tests as any effects it may have on the operation of the unit must be known and taken into account before the dates of the tests. The unit shall be fully isolated and running steadily at its test load at least half an hour before the programmed time for the start of each test. Each party to the acceptance tests shall nominate a responsible person to check the isolation and sign the isolation log sheets to signify that they are satisfied that the correct isolation has been applied.

25. Leakage checks

25.1 External leakages. Leakage checks shall be carried out on the boiler/turbine unit sufficiently in advance of the test for any necessary remedial action to be taken.

The total loss of working fluid can be found by measuring the drop in de-aerator level and taking into account other changes in stored water while the plant is isolated from external supplies of make-up. The unaccounted loss of working fluid is the difference between the total loss and the sum of the losses that can be accounted for by measurement or assessment.

If the unaccounted loss found by the leakage check exceeds 0.25% of the throttle flow upon which the full load guarantee has been based, then the parties to the test shall formally decide whether the loss can be further reduced or whether the tests should proceed despite the loss being above the prescribed limit.

If the decision is taken to proceed with the tests, this shall be recorded in the test report which shall contain a derivation of, and comment on, the unaccounted loss.

NOTE. In this connection, it is important to realise that a given percentage of unaccounted for leakage does not denote or imply an equal percentage error in the test heat rate. The heat rate formula in clause 4 is based on the premise that the unaccounted for leakage occurs in the high pressure part of the system, i.e. between the outlet from the main feed heater and the high pressure (H.P.) turbine inlet. If this is in fact where the leakage occurs, the resultant error in the test heat rate is negligible. The unaccounted for loss represents not an error but an uncertainty, since it cannot be proved that all the unaccounted for leakage does occur in the high pressure part of the system. In practice, however, there is always a high probability that the error in the test heat rate associated with a given percentage unaccounted for loss is much smaller than the percentage unaccounted for loss.

The difficulty of achieving such a figure as 0.25% for the unaccounted for loss depends greatly on the size, arrangement and complexity of the plant, the type of construction, the operating conditions and other factors. Should it be anticipated or be found from experience that it is not feasible to keep the unaccounted for leakage below 0.25% without resorting to measures involving unacceptable expense or delay, the parties to the test shall agree on the largest figure that is acceptable in view of all the circumstances prevailing during the test, and bearing in mind the comments in the previous paragraphs.

25.2 Internal leakage. Any internal leakage which by-passes or recirculates through a test flow measuring device shall be prevented or measured so that the correct flows can be deduced.

Feed pump minimum flow leak-offs shall be leak tight. The minimum flow leak-off valves and lines are normally duplicated and isolating valves are provided on both sides of each minimum flow leak-off valve so that one can be removed for maintenance while the other remains in service. To safeguard the feed pump, it is preferable to have the minimum flow leak-off valves serviced and proved leak-tight before the tests rather than to close the isolating valves during the tests.

All H.P. heaters shall be subjected to a leakage check by shutting off the drain and the bled steam while maintaining full water pressure in the tubes. A rise in the gauge glass indicates tube leakage.

A useful method of checking for suspected heater leakage in service is to inject rapidly a small quantity of a water treatment chemical into the condensate line before the feed heater. A check of the conductivity of the heater drain condensate will, if there is a leak, show a sudden rise in conductivity as the chemical passes through. Radioactive tracers may also be used.

Section five. Measurement of power

26. Determination of net power output of turbine-generator

The net power output of a turbine-generator is obtained by deducting from the electrical power of the generator all electrical power used for excitation, control, lubrication, generator cooling and sealing.

Where a motor drive is used for a component such as an exciter, generator cooling fan, lubricating or control pump, or hydrogen seal auxiliary, the power to be debited is the power delivered to the motor(s).

Where excitation is derived from some other source, the power is determined from the product of the current supplied to the generator field and the sum of the voltage drops across the generator field and main rheostats.

When the turbine-generator and condenser are guaranteed as a combined unit, the power requirements of the condenser and feed water heating auxiliaries shall be treated in accordance with the terms of the contract.

27. Methods of measurement of electrical power

For three-phase generators with grounded neutral, the power output of the main unit shall be measured by the three-wattmeter method (see figure 2). For three-phase generators with isolated neutral, the power

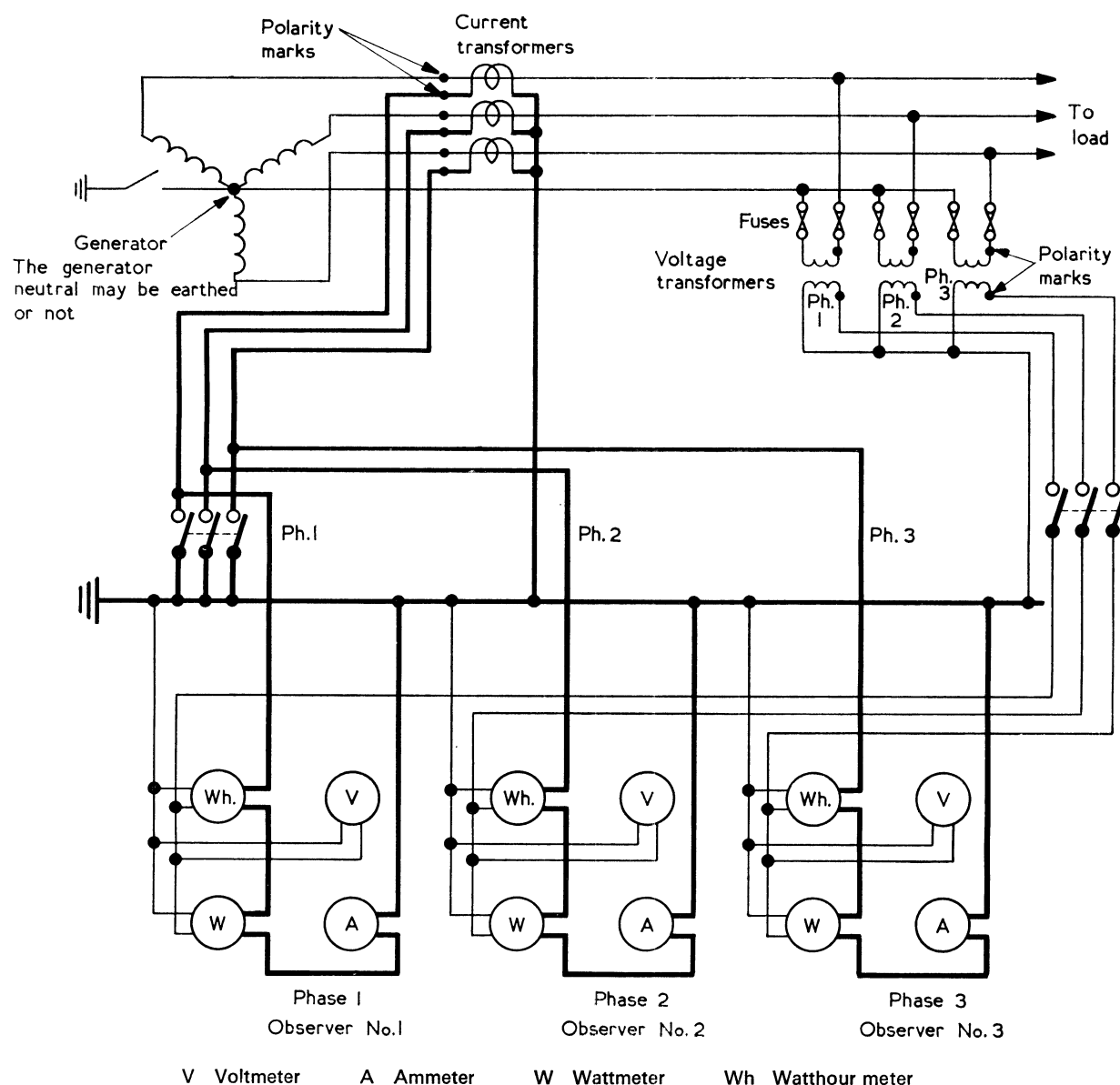


Figure 2. Diagram of connections and table layout for measuring electrical power in a three-phase circuit using three wattmeters

output of the main unit shall be measured either by the two-wattmeter method (see figure 3) or preferably by the three-wattmeter method. The power of single-phase generators shall be measured by the wattmeter method. The power output of d.c. generators shall be measured by the d.c. voltmeter-ammeter method.

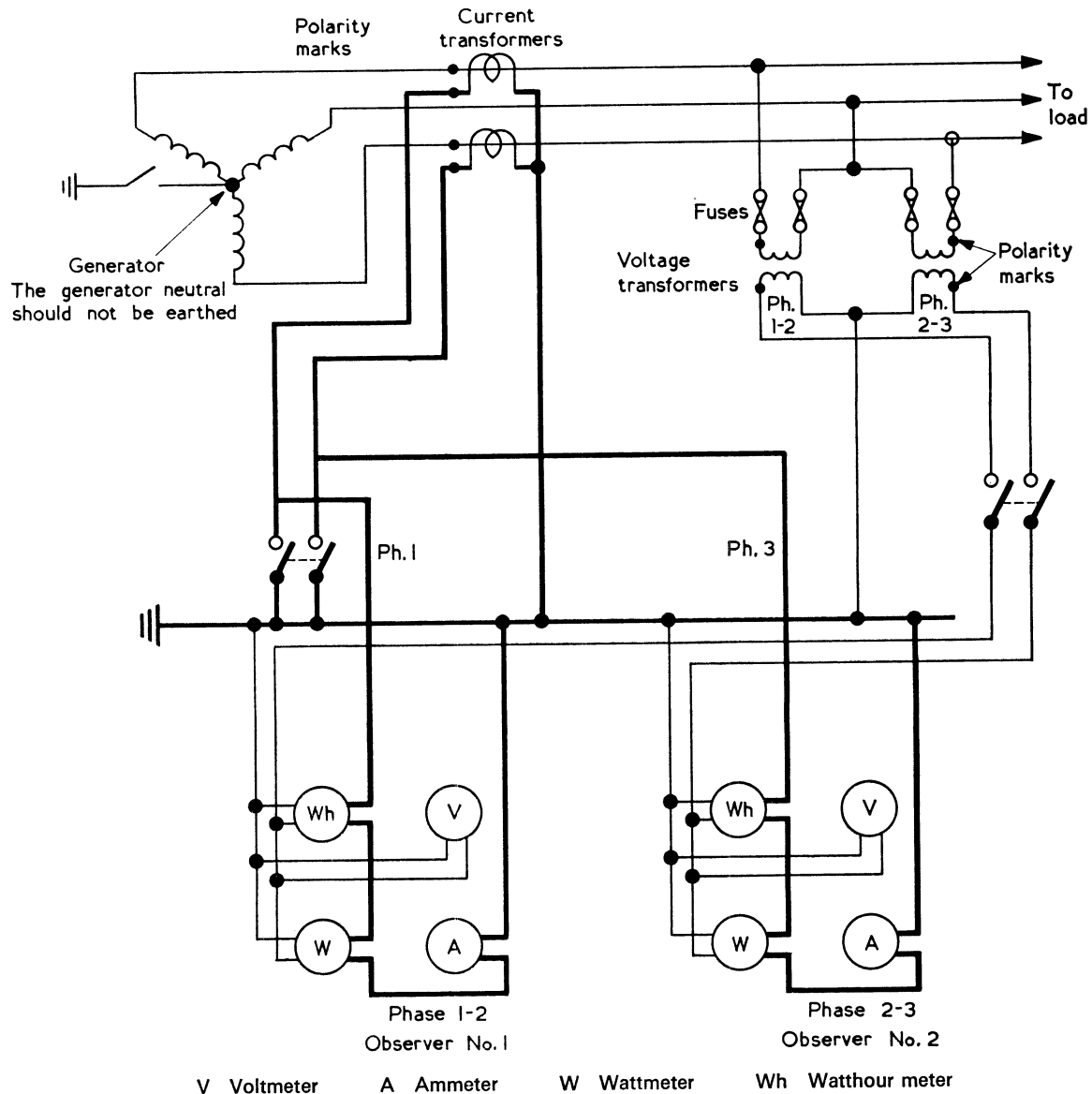


Figure 3. Diagram of connections and table layout for measuring electrical power in a three-phase circuit using two wattmeters

28. Electrical instrument connections

The instruments shall be connected into the lines from the generator as near to the generator terminals as practicable, and on the generator side of any external connections by which power can enter or leave the generator circuit.

Where the generator leads are connected solidly to power transformers, it may be necessary to connect the instruments on the secondary side of the transformers. In such cases, the calculated losses in the transformers and leads shall be added to the transformer output to give the generator output.

If the transformer is included in the guarantees, the output measured at its secondary terminals is the output of the turbine-generator-transformer combination.

The leads to the meters shall be arranged in such a manner that they will not influence the meter readings by reason of inductance or any other like cause. Inductance may be eliminated by braiding the wires of

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each pair of conductors for at least 1 m (3 ft) from the spot where the instruments are located. It is desirable to check the whole arrangement of meters for stray fields, not only from the instrument leads but also from any other source.

29. Electrical instruments

Single-phase or polyphase portable precision watt-hour meters of the highest order of accuracy or precision wattmeters with limits of error over the effective range of not more than 0.2% of full-scale value shall be used, with appropriate current and voltage instrument transformers, for measuring electrical output.

Portable ammeters, voltmeters and wattmeters shall be included in the measuring circuits to establish that the generator load conforms to rated conditions during the tests, and to measure the current, voltage and power factor.

High-grade portable wattmeters and watt-hour meters have, practically speaking, a zero heating error, and such instruments should be used during all tests where maximum accuracy is required.

Instruments which conform with the requirements of this clause are specified in the following British Standards.

Integrating meters, BS 3435; indicating meters, BS 89.

Instruments shall be located and arranged so that they may be read accurately with comfort by the observer.

When watt-hour meters are used for measuring the electrical power output, they shall be calibrated and adjusted in the laboratory so as to have their best operating characteristics in the range of the test values.

30. Instrument transformers

Instrument current and potential transformers of proper rating and accuracy characteristics shall be used. Values of ratio and phase-angle corrections for the conditions of loading equivalent to the test instruments and leads used during the test shall be obtained by a recognized calibration procedure to cover the range of test values of current and voltage. Potential transformers shall be used which have no burden other than that of the test instruments and leads.

Instrument transformers which conform with the requirements of this clause are specified in the following British Standards.

Current transformers, BS 3938, Class AL.

Voltage transformers, BS 3941, Class AL.

Current transformers having a primary rating of 2000 A or more and used under these conditions shall be protected by copper shields or compensating windings to avoid any possibility of local core saturation due to the proximity of heavy current-carrying busbars on other phases, or variation in the centralization of the conductor within the current transformer aperture.

31. Calibration

Instrument transformers, leads and instruments should preferably be calibrated as combined measuring equipment. If this is not practicable, and calibrations of individual transformers and instruments are made instead, then the method of making allowance for the influence of connecting leads shall be agreed.

Calibrations shall be made by a recognized and agreed authority.

The timing of calibrations shall be in accordance with the requirements of clause 13.

32. Measurement of boiler feed pump power

The preferred way of determining the feed pump power is from the rise in specific enthalpy across the pump multiplied by the mass flow.

$$\text{Thus } P = \frac{[(M_d h_d - M_i h_i) + (M_{gd} h_{gd} - M_{gi} h_{gi})]}{K}$$

where

- M_d is the mass flow of water at pump discharge;
- h_d is the specific enthalpy of water at pump discharge;
- M_i is the mass flow at pump inlet;
- h_i is the specific enthalpy of water at pump inlet;
- M_{gd} is the flow of water discharged from glands;

h_{gd} is the specific enthalpy of water discharged from glands;

M_{gi} is the flow of water supplied to glands;

h_{gi} is the specific enthalpy of water supplied to glands.

If M is in kg/h, $K = 3600$.

If M is in kg/s, $K = 1$.

To this power, the equivalent of the heat picked up by the water passing through the pump bearing oil coolers shall be added.

Since the temperature rise across the pump is small, a high degree of precision is required in the temperature measurements. In the absence of precise temperature measurements, the power may be determined by means of a transmission dynamometer interposed between the pump and the driving unit.

When the boiler feed pump is driven by a separate steam turbine without the intervention of a dynamometer, the power input to the pump can be assessed by measuring the steam consumption of the driving turbine and using the efficiency data supplied by the turbine manufacturer.

Failing any of the foregoing methods, the feed pump power may be based on the measured mass flow and head rise across the pump in conjunction with efficiency data supplied by the pump manufacturer. However, unless the data are based on tests over the full range of load, they may be open to question.

Section six. Measurement of fluid flow

33. Introduction

In the determination of a turbine generator heat rate, the flows to be measured can be divided into two categories.

(a) *Main flow*. Flow which is approximately in direct proportion to the power output and has to be measured with a high degree of precision.

(b) *Secondary flows*. Flows which are necessary for the operation of the plant and which have to be taken into account in the adjustment of the measured value of main flow in order to determine the turbine throttle flow and reheated steam flow (see also clause 22).

Actual weighing of water is potentially the most accurate method of measuring flow but it is not economical or practicable for modern large central power station turbines. The same is true of the use of calibrated volume tanks. Main flow measurement is therefore accomplished by means of differential-pressure devices as described in this section.

34. Position in cycle of main flow measurement

Ideally, the best position for the flow-measuring device is in the feedwater line between the final heater and the boiler. In practice, however, in conventional reheat cycles this would introduce difficulties due to the high pressure and high temperature of the water and, in the case of large turbines, high values of Reynolds number well beyond the scope of any available calibration facilities. In these circumstances, it is recommended that the main flow be measured in the low-pressure portion of the feedwater cycle. In saturated steam cycles the pressure after the final heater may be low enough to permit this position.

If there is no de-aerator in the feedwater cycle, the preferred position for the main flow measurement is the nearest position to the extraction pump discharge which would not require heat balances on heaters supplied with wet steam.

If there is an L.P. de-aerator in the cycle, the preferred positions for the main flow measurement, as shown in figures 4 and 6 are:

- (a) between the de-aerator condensate outlet and the boiler feed pump suction;
- (b) between the last L.P. feed heater and the de-aerator inlet.

An appropriate arrangement for a wet steam cycle is shown in figure 5.

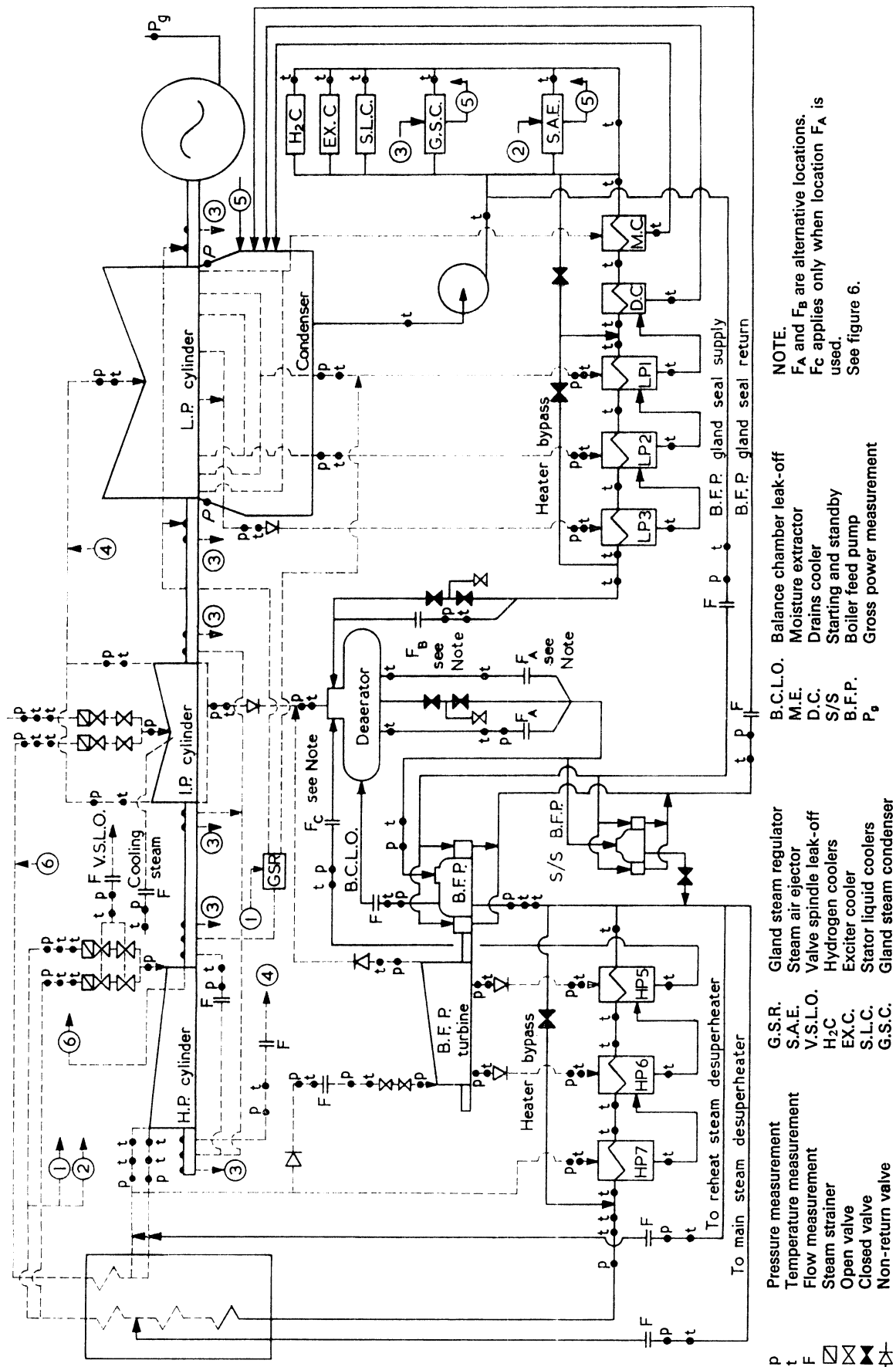
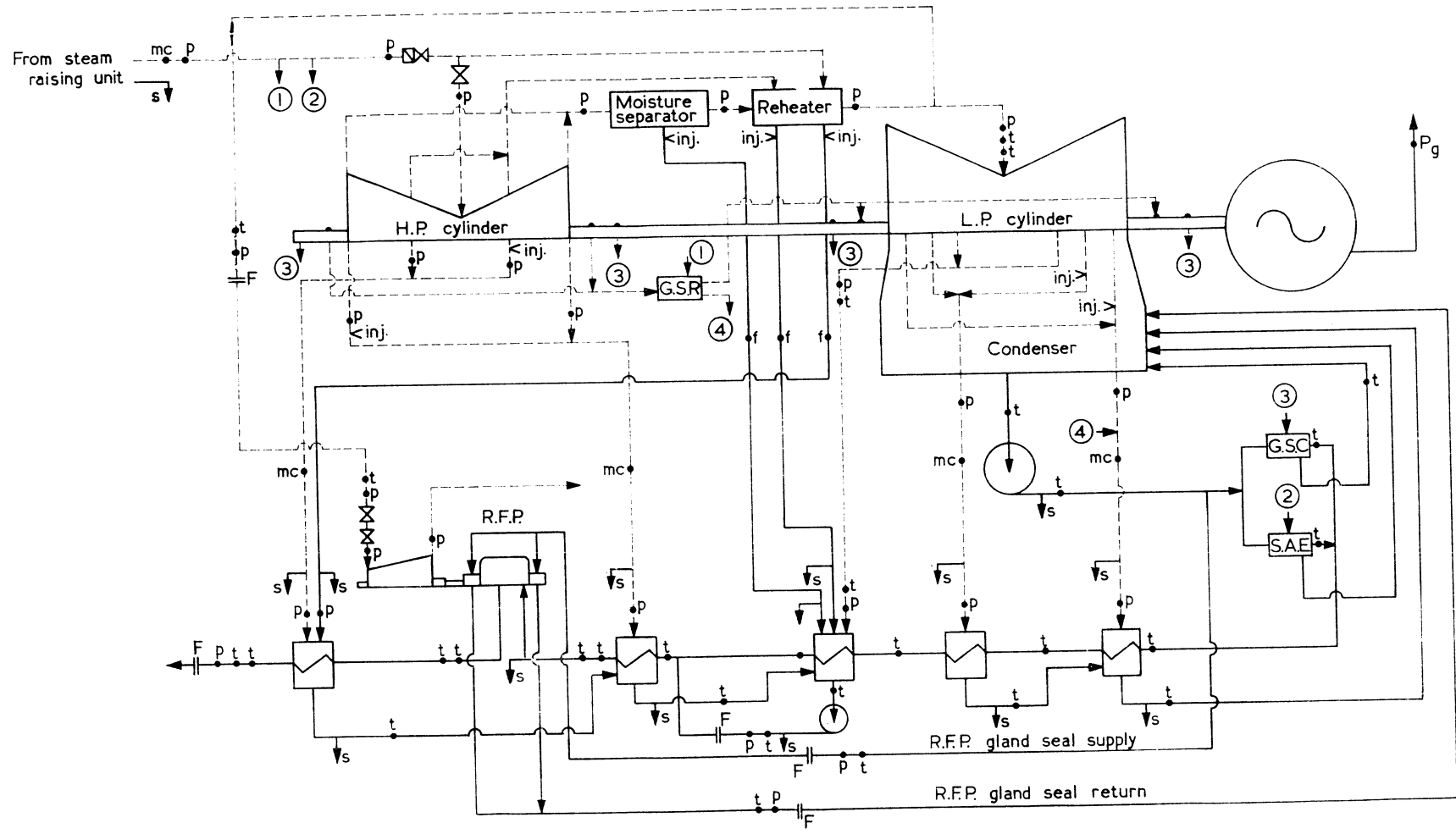


Figure 4. Diagram showing location of test measurements for superheat-reheat cycle



- | | | | |
|----|---|--------|-----------------------|
| p | Pressure measurement | J | Water sample |
| t | Temperature measurement | □ | Steam strainer |
| mc | Moisture content determination (see note) | × | Open valve |
| F | Flow measurement | R.F.P. | Reactor feed pump |
| f | Flow determination by tracer technique | G.S.R. | Gland steam regulator |
| Pg | Gross power | G.S.C. | Gland steam condenser |
| | Tracer injection | S.A.E. | Steam air ejector |

NOTE. Moisture content determined by tracer technique. Throttle steam by condensing method. See section eight clause 55. Bled steam by injection method. See section eight clause 55.

Figure 5. Diagram showing location of test measurements for wet steam cycle