TURBINE TESTING
BY THE
GIBSON AND INDEX METHODS

134

Prepared by
U. S. Army Engineer District, Portland
Corps of Engineers
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PREFACE

This manual is the result of the accumulated experience of persons involved in and responsible for conducting turbine tests in the Portland District and the North Pacific Division, and the compilation of data from various technical papers and articles.

A manual entitled "Index Testing of Hydraulic Turbines by the Winter-Kennedy Method" was published by the Portland District, 1 September 1961, to standardize testing procedures within the District. Its acceptance for use in other districts warranted preparation of a revised manual. During the process of revision it was concluded that the subject of Index Testing could be combined with that of Gibson Testing, for which a manual was also being prepared, to avoid extensive duplication of material which would be required by both manuals.

This combined manual is designed to provide the information necessary to conduct the subject tests under normal conditions. Actual field conditions may necessitate digressing from the material presented in this manual. Forms required for the tests are printed on reproducible paper and may be removed from the manual.

TABLE OF CONTENTS

TABLE OF CONTENTS (Contd)

FIGURES

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TURBINE TESTING

By The

GIBSON AND INDEX METHODS

SECTION 1 - INTRODUCTION

1.01 General. - For the testing of hydraulic turbines, the Portland District uses both the Gibson and Index Methods. The Gibson Method is used as an acceptance test at those plants which have penstocks and the Index Method is used to supplement Gibson data as well as provide performance data for plants which do not have penstocks.

The first use of the Gibson Method of hydraulic turbine testing, by the Portland District, was the acceptance test on Unit Number 2, Detroit Dam, made on 5 November 1953. To date, Gibson tests have also been made in the Portland District on the unit at Big Cliff Reregulating Dam, Unit Number 2 at Lookout Point Dam and Unit Number 1 at Hills Creek Dam.

Index Testing of Hydraulic Turbines by the Winter-Kennedy Method has been used by the Portland District since 5 May 1954, when the first Index Test was conducted on Unit Number 2 at Detroit Dam. One or more power units at each of six completed plants in the Portland District have been tested by this method, resulting in 32 tests at various heads on 15 units of both the Francis- and Kaplan-types.

1.02 Purpose of manual. - This manual provides a ready reference of testing theories and procedures to insure adequate and consistent use of these methods in future tests.

For explanations beyond the scope of this manual, reference in the text, to published articles is by the use of numbers in parentheses. These numbers, in parentheses, refer to the number and page of the publication in the "Selected Reference" list which follows the table of contents.

SECTION 2 - GENERAL

2.01 Preparation prior to and during construction. - During construction, it is necessary to install piezometer taps at the net head and scroll-case sections for use with both the Gibson and Winter-Kennedy Methods and also at the penstock test sections for use with the Gibson Method.

a. Orifice installation. - The piezometer taps are installed flush with the surface of the wall. The orifice bore must be normal to the wall and uniform for a depth of at least two diameters from the wall face.

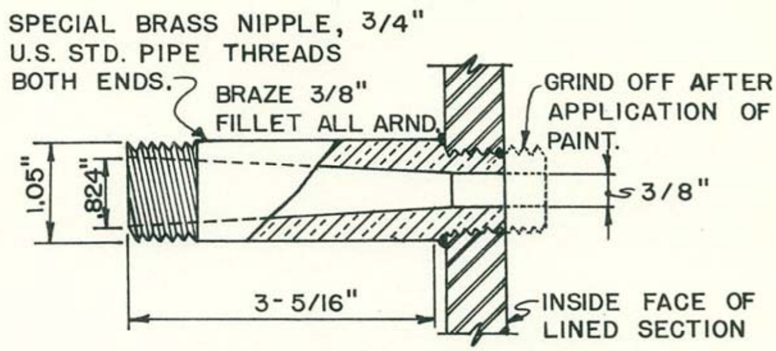
b. Finish. - The wall should be smooth and parallel with the flow for a minimum distance of 18-inches upstream and 6-inches downstream from each tap.

c. Sizes. - The piezometer orifices should be from 1/8th-inch to 3/8th-inch in diameter and the edge should be free from burrs or irregularities. Figure 2.1 illustrates the installations of orifices for lined and unlined scroll case, net head and penstock sections.

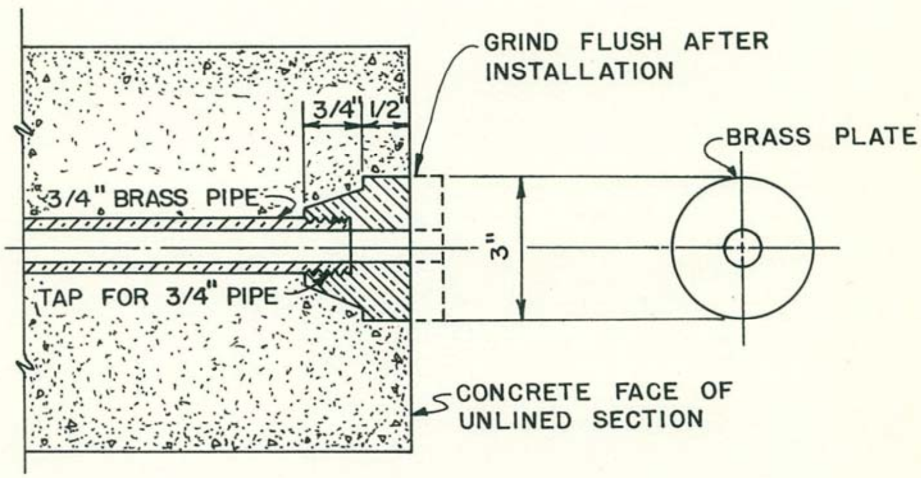
d. Piping. - All pipe connections should be tight against leakage. Piping should be embedded with a slope of not less than 1/4 inch per foot between the piezometer and the measuring instrument. The piping should be sloped continuously so that no possibility exists for trapping air. Means should be provided for eliminating any entrained air.

e. Protection. - The orifices should be plugged and/or otherwise protected during construction to prevent damage and stoppage.

f. Scroll-case piezometers. - Two or more piezometer taps should be located at the measuring section in the scroll-case, one at the outer radius of the scroll-case and one at the inner radius near the stay ring. The location of the piezometer at the inner radius should preferably be such that the differential pressure reading between the outer piezometer and the inner piezometer exceeds 1.5 feet of water at maximum turbine discharge and rated head (1:4). A method of computing the probable maximum manometer deflection is given in Appendix C of this manual.



WITH STEEL LINER

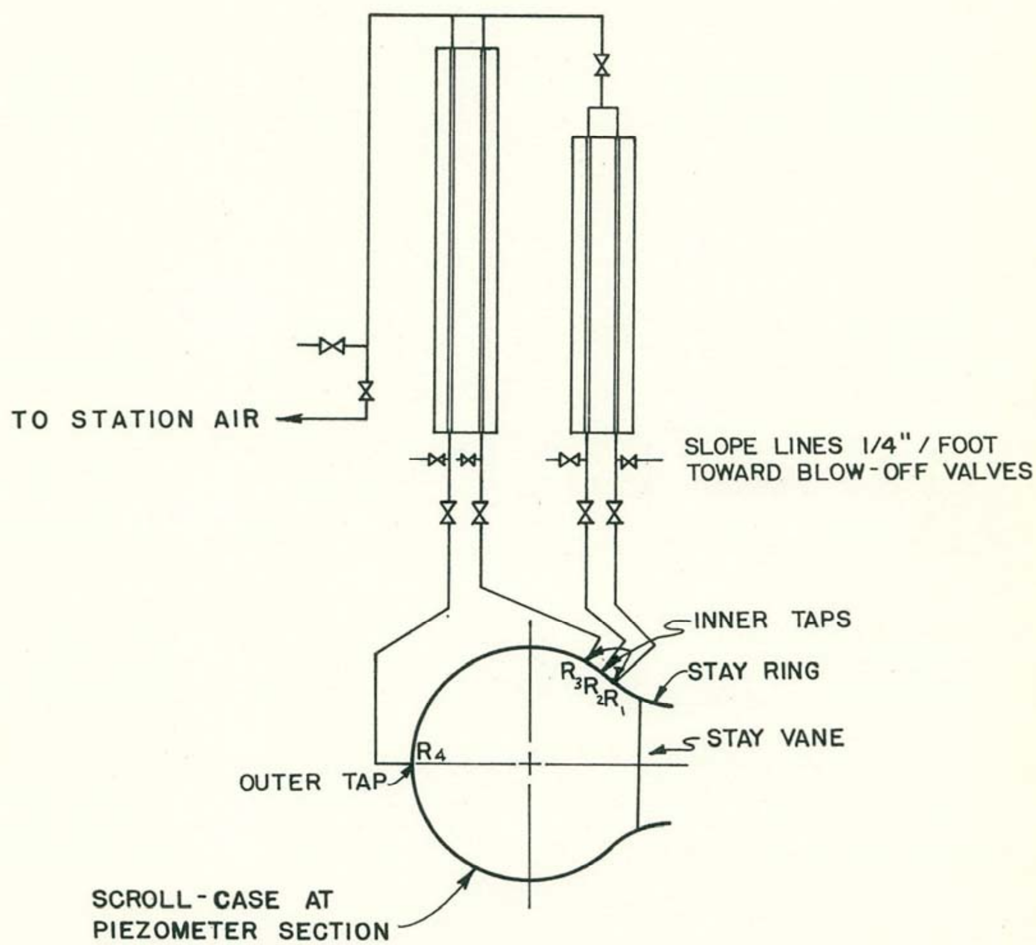


WITHOUT STEEL LINER

RECOMMENDED PIEZOMETER DESIGNS

FIGURE 2.1

In the Portland District, it has been customary to provide one outer tap and two or three taps in the region of the inner radius. One or two inner taps are selected for use, at the time of the test, to obtain the optimum combination of pressure differentials between the inner and outer taps. See Figure 2.2 below.



TYPICAL SCROLL CASE PIEZOMETER INSTALLATION

FIGURE 2.2

g. Net head piezometers. - A minimum of 4 net head taps should be located immediately upstream of the scroll case inlet, in pairs, on diameters equally spaced around the section.

h. Penstock Gibson piezometers. - During construction, it is necessary to provide piezometer openings in the penstock of the unit to be tested and to install the necessary piping from the penstock taps to the powerhouse.

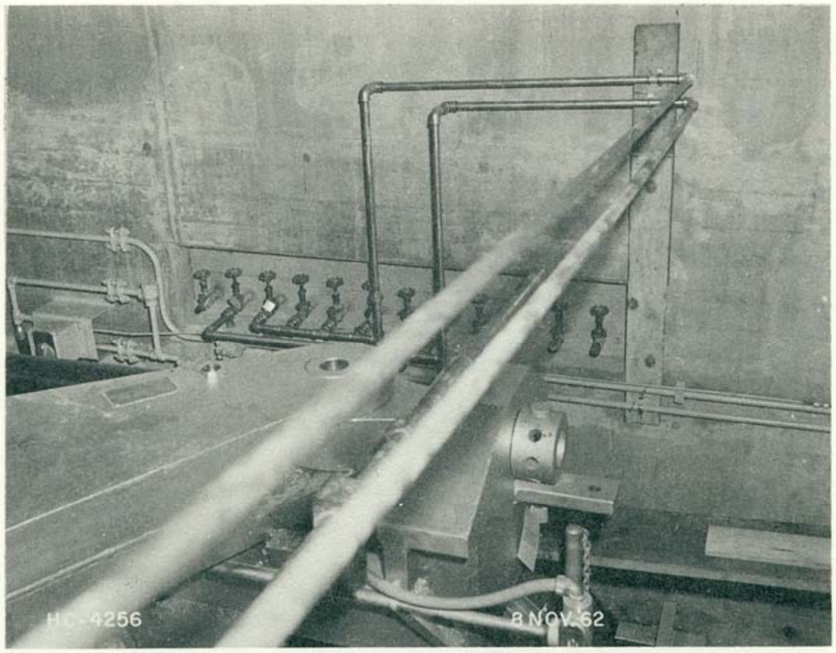
Approval of the design and location of the penstock piezometers will be furnished on request, without charge, from Norman R. Gibson, P. O. Box 244, Niagara Falls, New York. Recommended piezometer tap designs are shown in Figure 2.1. For the differential application of the Gibson Method two piezometer sections are required in the penstock. These sections should be located at appropriate points which are free from local distrubances and a suitable distance apart. The minimum distance between test sections is given in paragraphs 120 and 121 of the ASME Power Test Code. See Figure A-2, Appendix A of this manual.

2.02 Piping and manometers. - All hydraulic equipment should be connected to their respective piezometers through suitable systems of valves and manifolds.

All piezometer lines should slope continuously at not less than 1/4 inch per foot toward blow-off valves which should be operated frequently (bled) throughout the tests to emit any air accumulations. Discharge from the blow-off valves should be disposed of through hoses clamped to the valve outlets.

Provisions should be made for connecting compressed air to the piezometer manifolds so that air can be blown through the lines for their identification. The piezometer taps at each penstock and net head station are identified by station (i.e. upper, lower, etc.) and are numbered in a clockwise direction, facing downstream, starting at the uppermost right-hand piezometer. The scroll-case piezometers are numbered beginning with the tap located nearest to the turbine runner. Each piezometer number is used as a subscript to an identifying letter as follows: Penstock Gibson taps - G, Net Head taps - N, and Scroll-case taps - R.

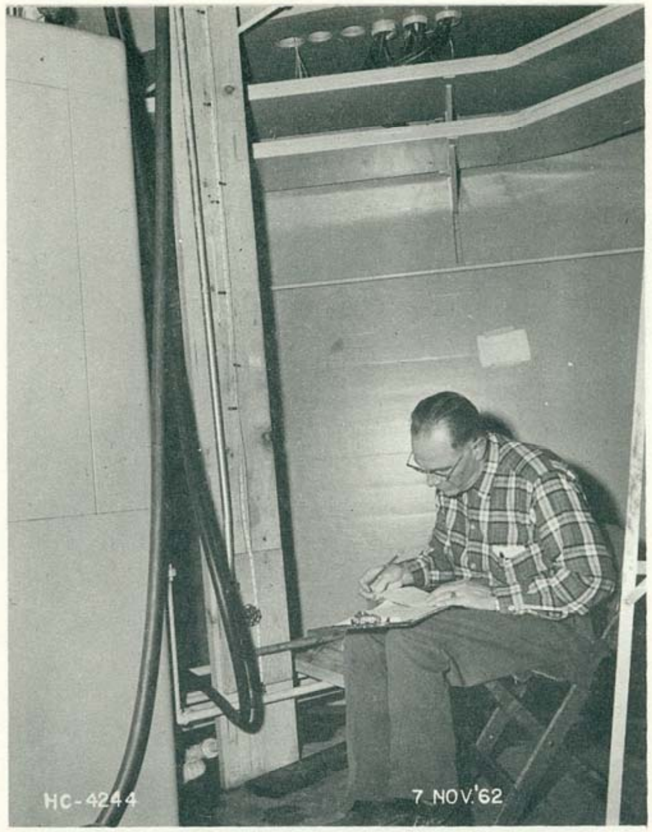
a. Piping to Gibson Apparatus. - Exposed piping to the Gibson Apparatus should be new 3/4" ID galvanized iron or brass pipe and should be free from oil or grease. For sealing threaded joints, glyptal or a piping tape (not white lead) is recommended. Fittings required adjacent to the Gibson Apparatus include 2 tees, 6 ells, 2 unions, and 2 gate valves. Gibson furnishes bleeder valves and bushings to 3/4" pipe for bleeding air adjacent to the Apparatus. Manifolds, with provisions for flushing, are required to connect piezometers from each Gibson section to corresponding sides of the Gibson Apparatus. (See Figure 2.3). Usually, the Gibson Apparatus is located as near the manifolds as layout permits and if possible, within view of the net head manometer.



PIPING TO GIBSON APPARATUS

FIGURE 2.3

b. Piping to Net Head Manometer. - A manifold, with flushing connection, is required at the termination of the embedded piezometer piping. Piping to a manometer of 1/4" plastic tubing should be either 3/8" copper tubing or the same as the piping to the Gibson Apparatus. Fittings required adjacent to the 1/4" manometer include a gate valve, tee and union and a 1/4" bleeder valve. Galvanized 1/4" iron pipe is used for the manometer connection.



NET HEAD MERCURY MANOMETER

LOWER LEG

FIGURE 2.4

The Net Head Manometer should be mounted rigidly on a well supported board. The supporting board should be at least 8 inches wide when 1/4" plastic tubing is used for the manometer. (See Figure 2.4). The height of the supporting board is about 6 feet greater than the height of the required mercury column. The mercury column height is equal to the difference between the forbay elevation and the floor elevation at the manometer divided by 13.5. Tests conducted at high heads will probably require provision for an observer near the top of the manometer.

Often times the manometer is located at the nearest stairwell or at a hatchway if suitable support for the board can be provided. It is desirable to have the lower portion of the manometer visible from the Gibson Apparatus during Gibson tests. The elevations of both manometer legs should be determined by precise levels.

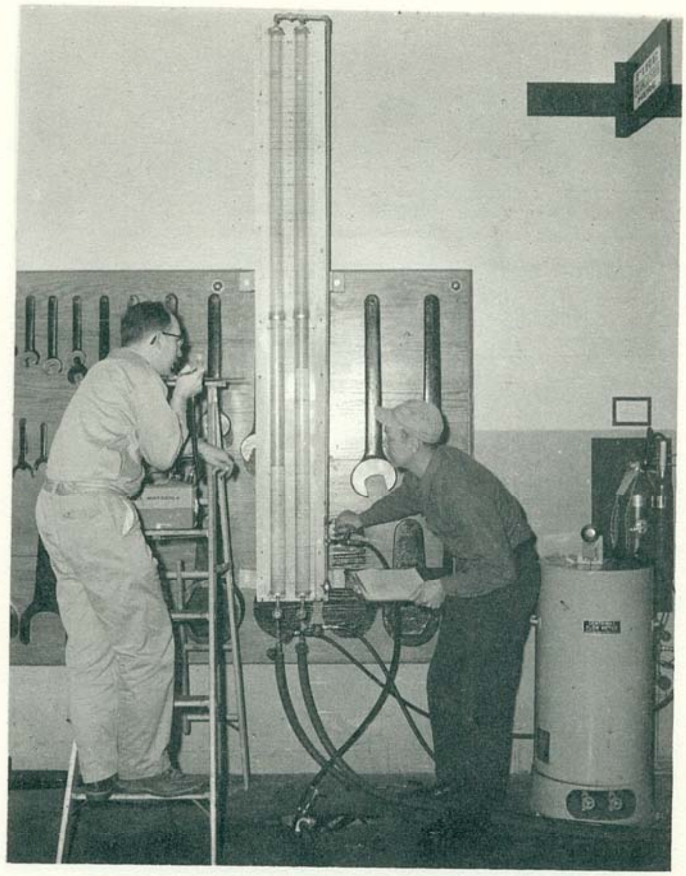
c. Scroll-case Manometer. - The scroll case manometer is connected to the scroll-case piezometers through a suitable system of valves and manifold. The manometer should have one tube for each piezometer and may use either water or mercury depending upon the maximum probable deflection. (See Figure 2.5). The maximum deflection of a water manometer generally does not exceed ten percent of the test head. Approximately two feet is added to the computed maximum for a safety factor. The theory for determining the probable manometer deflection is found in Appendix C of this manual.

The manometer should be mounted in a true vertical position near the scroll case piezometer terminals. Because of possible restricted ceiling heights it may be necessary to install the manometer beneath a hatchway. The scale zero of each manometer scale should be set at the same elevation by a line of precise levels. Further details may be found in paragraph 4.05 f of this manual.

2.03 Gross Head Measurements. - The forebay and tailwater gages are located as outlined below and should be set to a common datum by a line of precise levels.

a. Forebay gage. - The forebay gage should be located so as to measure the equivalent still water surface before the water has passed through the trashracks. (See Figure 2.6). When this is not possible and the water in the forebay flows with sufficient velocity to make the velocity head an appreciable quantity, with respect to the test head, the equivalent still water surface is the actual elevation of the water surface increased by the amount of the velocity head.

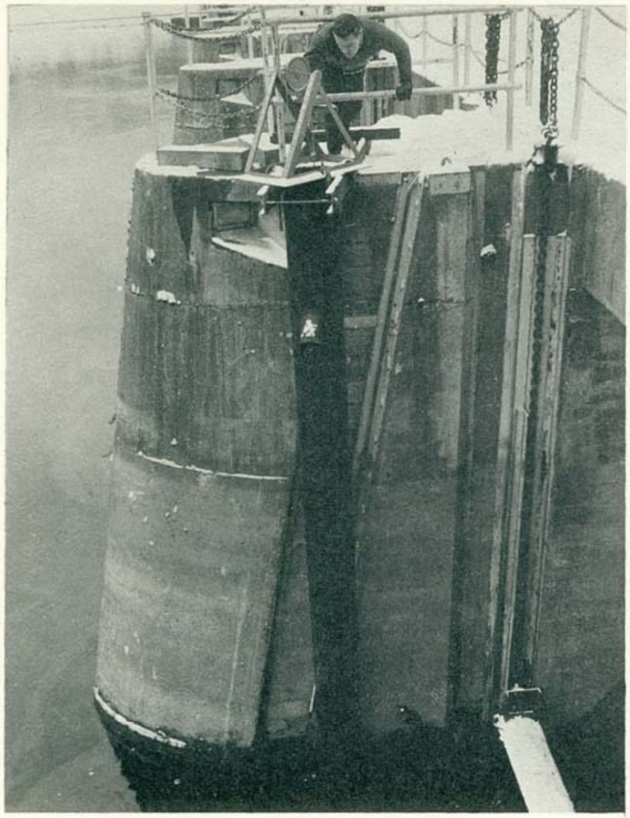
b. Tailwater gage. - The tailwater gage is located at the point of highest average elevation attained by the discharge from the unit under test, but in general not closer to the draft tube outlet than a distance equal to the width of the outlet. (See Figure 2.7). In determining the correction for velocity head in the tailrace for the unit under test, that part of the tailrace channel should be used which may reasonably be charged to that unit alone. In general, for units discharging in parallel into a common tailrace the width of channel is equal to the unit spacing or the width of draft tube outlet plus thickness of pier between adjacent units. The bottom elevation of the tailrace may be obtained from contract or "as constructed" drawings or from actual



WINTER-KENNEDY MANOMETER

FIGURE 2.5

soundings. As the Test Code conditions are somewhat rigid it is possible that the tailwater elevation at a single location for a plant containing several units would not be considered satisfactory. A carefully located staff gage, or float gage, may be required for each unit tested.



FOREBAY FLOAT GAGE

FIGURE 2.6

TAILWATER FLOAT GAGE

FIGURE 2.7

It is important that the tailwater measurements be accurate, especially at lower-head plants where the percent of error becomes critical.

The occurrence of cavitation in the turbine is closely related to tailwater elevation. Since cavitation is often accompanied by a measurable change in turbine performance it is essential that the tailwater during the test not drop below the guaranteed minimum. It is also advisable to insure that the plant sigma under actual test conditions falls within design limits.

c. Inspection. - Before making measurements of head it is good practice to inspect the trashracks to insure that the head loss is not excessive as a result of a collection of debris, ice or other obstructions.

d. Velocity head corrections. - Velocity head corrections for Index Tests may be made using the estimated quantities of water. Corrections in Gibson Tests use the actual quantities of water.

2.04 Calibration. - Flow through the water passages of a hydraulic turbine installation with the unit operating at a constant head and speed is controlled by the position of the turbine wicket-gates and the area of the runner vent. This data, as well as the blade-angle measurements of Kaplan-type turbines, should be determined to obtain complete characteristics of the unit being tested.

a. Runner-vent. - The relation between the total orifice area of the wicket-gate opening and the servomotor piston stroke is readily determined by calibration with the casing empty and the machined servomotor-piston-spacers or adjustable stop-nuts in position. This calibration makes it possible to accurately translate the servomotor-piston stroke in inches to orifice area in square feet. The total orifice area of the runner vent can then be determined with a high degree of accuracy by calibration in the shop, or if necessary, after installation.

The purpose of the calibration is to permit the interpolation or extrapolation of the measured performance of one unit for comparison with several units of like design in a given plant. Interpretation of the effects of the difference in areas of runner vents for similar turbines involves indeterminate factors and for this reason it is desirable to specify turbines of like design to have vent areas within 1 percent in a group of identical units. This degree of accuracy may be questioned, but it is not necessary to obtain final dimensions in the original castings, as minor chipping of high places and building up of low spots by welding makes it feasible to obtain values within these limits. With like runner-vent area, it may be concluded that the discharge values between identical units when stated in terms of the coefficient of discharge of the wicket-gates will give results within 1 percent of comparable values (30:495).

b. Wicket-gate. - With the unit unwatered, the clearances both top and bottom of the wicket-gates should be measured with feeler gauges and recorded.

A check for leakage is made with the gates tightly closed. Any gates that do not close completely should be adjusted by means of eccentric gate pins.

After the test for leakage and necessary adjustments are made, the gates are set at approximately 75 percent of full opening and the openings between each pair of gates are determined. The average of the above openings is determined and the average pair of gates selected. The opening between the average pair of gates should then be calibrated against governor servomotor stroke from 0 to 100 percent stroke at each 10 percent stroke. A sample calibration form is shown by Figure 2.8.

c. Blade-angle. - On a Kaplan turbine, the blade-angle indicator may be calibrated against the blade-angle indications on the runner hub, however, due to the possibility of having to duplicate the blade-angle positions in future tests, the travel of the upper end of the inner oil pipe, relative to a fixed point on the oil-head, should be measured, as shown in Figure 2.9. This measurement is referred to as the "oil-head reference" and is designated "Y". A sample calibration form is shown by Figure 2.10.

Published papers state that this oil-head reading should be made so that the blade-angle can be reproduced for check readings at a later date. Exception has been taken to this idea by the Tennessee Valley Authority as they have found that it is practically impossible to reproduce a blade-angle (26:493). Tests made by the Portland District further support the TVA conclusion. Should it be considered necessary to obtain additional readings at a particular blade-angle after the blade-angle has been changed, it is recommended that the old readings be discarded and only the new ones considered.

CALIBRATION OF TURBINE GATE OPENINGS

Project ____________ Unit ____________ Inspector ____________ Date ____________

Recommended Procedure:
1. Set servomotor stop nut at 75% gate opening, as indicated on the (gate ring, stop nut)[1] scale
2. Record data in columns (1) through (5) and select average pair of gates.
3. Record data in columns (9) through (13) using gates selected in 2.
4. Record data in columns (6) through (8)

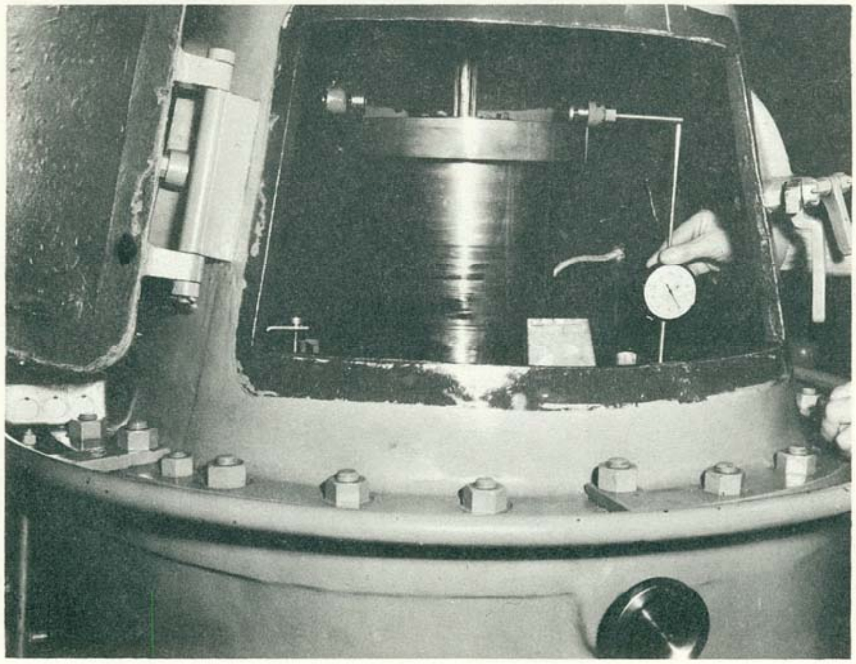
Gate Openings	Distributor Height inches (1)	Minimum Openings inches Top (2)	Center (3)	Bottom (4)	Area (5)	Gates Closed Clearances between gates and facing plates Top (6)	Bottom (7)	Area (8)	(Gate Ring)[1] (Stop Nut)[1] Indicated Opening %	Piston Stroke inches (9)	Minimum Opening-inches Average pair of gates Top (10)	Center (11)	Bottom (12)	Area (13)
									0[2]					
									10					
									20					
									30					
									40					
									50					
									60					
									70					
									80					
									90					
									100					
Total area														
Average area														
Indicate average pair of gates														

Design data from manufacturer's drawings:
100% gate opening= inches
Dia guide vane circle= inches
Dia guide vane stems {= inches(top)
{= inches(bottom)

Notes: 1. Indicate reference scale.
2. Indicate servomotor pressure in closed position ________ psi.

Remarks:

FIGURE 2.8



KAPLAN OIL-HEAD READING

FIGURE 2.9

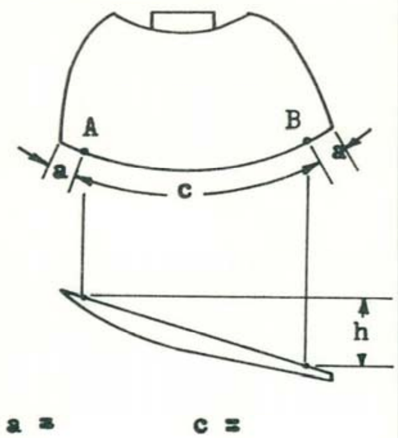
In setting the runner blades care should be taken to always approach the desired setting from the same direction so that all lost motion due to clearances is taken up in the same direction. This procedure insures consistency in results. Recommended also, is bleeding of the oil head chambers prior to the test to remove any entrapped air at these points.

During the test, the cam controlling the blade-angle is removed from the control valve and the blade positions are set manually at a minimum of five fixed blade-angles. See Figure 2.11.

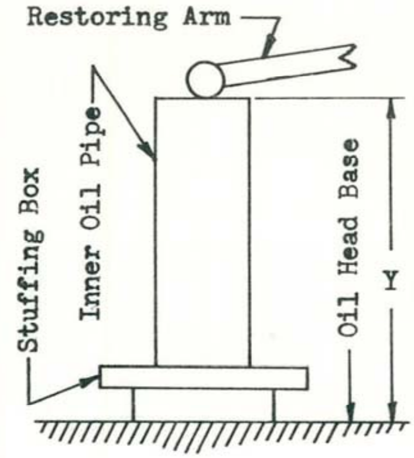
It is also desirable to determine the clearances at the periphery of each blade at the centerline of blade rotation.

CALIBRATION OF BLADE POSITIONS

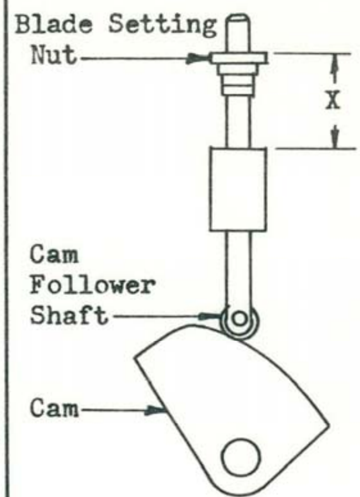
______________Powerhouse Unit No.____ Inspector______ Date______



Runner Blade Measurement



Oil Head Measurement



Cam Follower Measurement

PROCEDURE

1. Establish reference points A and B along the peripheral edge on the top of the master blade at a distance, a, from the leading and trailing edges, where a = runner throat diameter / 48. Measure and record dimension, c.

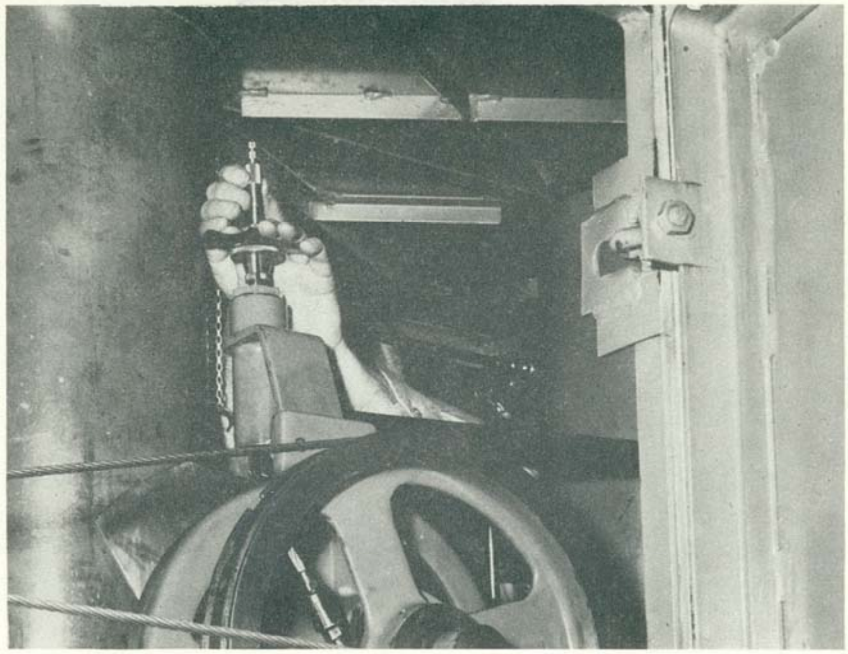
2. Establish a reference horizontal plane, above or below the blade (the surface of the lower facing plates may be used), to determine the difference in elevation, h, between reference points A and B.

3. Position the blades by means of the hub scale for the master blade and record dimensions h, X and Y obtained at each graduation on the hub scale. Also record the chordal distance, b, between each graduation.

4. True blade angle is referred to the developed profile at the periphery of the blade and is defined as the angle subtended by the chord, c, of the developed profile.

Hub Scale		Vertical distance between ref. pts and ref. plane - ft		h	True B.A. - Deg ArcSine $\frac{h}{c}$	X	Y
Indicated B.A.-Deg.	b inches	A	B	Feet		inches	inches

FIGURE 2.10



USING DEPTH GAGE TO DETERMINE

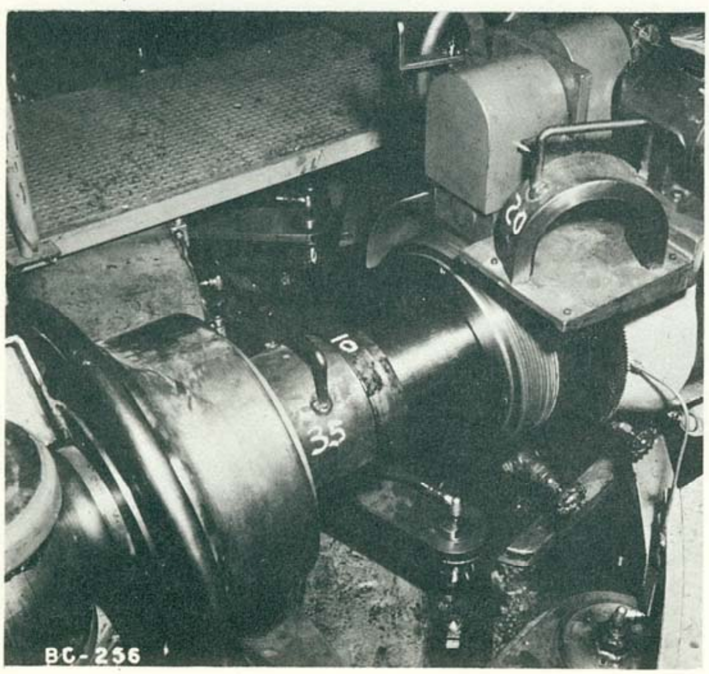
POSITION OF CAM FOLLOWER

FIGURE 2.11

2.05 Servomotor Piston Stroke. - The desired wicket gate opening is usually obtained by blocking the gate servomotor against the adjustable stop-nut or especially machined spacer blocks. (See Figures 2.12 and 2.13). The adjustable stop-nut may be used provided it gives positive control and does not allow the stroke to change during the test run. When spacer blocks are used, they are usually machined to provide increments of the total servomotor stroke, and, by means of a suitable combination of spacer blocks of various thicknesses, it is possible to obtain a complete traverse of the turbine performance with relatively few blocks. A machinist's scale, graduated to 1/64th inch, should be mounted on the servomotor restoring cable conduit with a pointer clamped to the restoring cable conduit in such a manner that the full range of piston stroke can be accurately measured and observed on the scale. (See Figure 2.12).

GATE SERVOMOTOR STROKE
MEASUREMENT USING MACHINIST'S
SCALE WITH POINTER CLAMPED
TO RESTORING CABLE MECHANISM

FIGURE 2.12



PISTON SPACER BLOCKS
USED ON TURBINE GATE
SERVOMOTOR (35% and 10%
SPACERS SHOWN IN PLACE)

FIGURE 2.13

SECTION 3 - GIBSON METHOD

3.01 General. - The Gibson Method of hydraulic turbine testing is presently used by the Portland District for acceptance testing of newly installed turbines. These tests are performed for the Portland District, under contract with Norman R. Gibson, Consulting Engineer, Niagara Falls, New York, whose representative supervises the test, operates the Gibson Apparatus and prepares the report. The responsibility of the Portland District includes coordinating interested parties, i.e., turbine manufacturer, generator manufacturer, etc., providing assistance during the test and assuring proper correlation of the final test results with data obtained from other sources to obtain the most efficient operation of the plant.

The Gibson Method uses load rejection with its corresponding water hammer to establish the rate of flow through the turbine immediately prior to shutting the turbine gates. The Gibson Method has been generally accepted world-wide as an accurate method of acceptance testing and is included in the ASME Power Test Code for Hydraulic Prime Movers.

3.02 History. - The Gibson inertia-pressure method of flow measurement was developed about 1920 by Mr. Norman R. Gibson, then Hydraulic Engineer with the Niagara Falls Power Company, Niagara Falls, New York.

The first official water measurements by this method were made during July and August 1920 at Station 3B of the Niagara Falls Power Company. During the 35-year period from 1920-55 this method was used to conduct 310 tests at various plants throughout the world. In addition, 16 sets of Gibson Apparatus have been manufactured for the use of others (7:455-6).

The units tested during the 35-year period have ranged in size from 750 to 165,000 horsepower under heads of 46 to 2,500 feet. The discharges have ranged from 5 cfs to 9,000 cfs. Maximum turbine efficiencies have ranged from 68% to 94.5%. The length of the penstock test sections have been as short as 18 feet for a differential diagram and as long as 3,953 feet for a simple diagram (7:456-7).

3.03 Principles. - The Gibson Method of flow determination is presently the only method of turbine testing which involves load rejection. It has a peculiar feature in that it takes advantage of the water hammer caused by load rejection, usually considered unfavorable in hydraulic engineering.

Basically, the Gibson Method is used to establish the initial rate of flow through a turbine from a diagram on which is recorded the variation in pressure occurring in a penstock during the shutting down of the unit in a known time. This method reverses the usual procedure used to calculate the degree of water hammer occurring in pressure pipe in that the discharge is determined from pressure measurements taken during the period in which the regulating gear is closed.

The pressure-time diagrams may be of either the simple or differential type. With simple diagrams the changes of pressure at one piezometer section in the penstock are recorded while with the differential diagrams the difference between the changes of pressure at two piezometer sections in the penstock is recorded. This manual deals only with the differential application which is used exclusively in the Portland District.

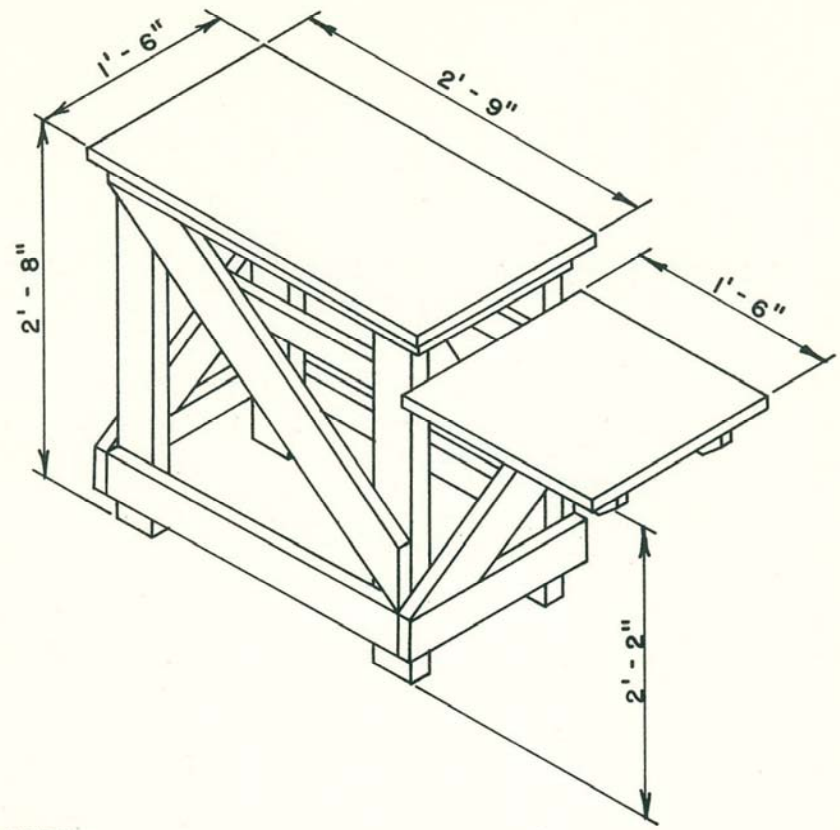
Basically, the Gibson test consists of setting the turbine wicket gates at the desired opening, bringing the unit up to load at 1.0 power factor, taking readings at the various test stations to determine the head, output, etc., starting the Gibson Apparatus and closing the turbine wicket gates completely to obtain the pressure-time diagram. This procedure is repeated for each of a minimum of 30 test runs covering the operating range of the turbine. Data thus obtained is then converted to performance characteristics at the test head.

3.04 Responsibilities of the Government for the test. - In addition to the items listed under Section 2 of this manual the Government furnishes the following materials and services:

a. Table. - A small table for the Gibson Apparatus, as shown in Figure 3.1, and the necessary location for setting up the test apparatus.

b. Signalling system. - The wiring and signalling system with components physically located at or audible at the forebay gage (if required), governor, switchboard, location of electrical meters, tailwater gage, turbine pit, net head manometer, scroll case manometer (if required) and Gibson Apparatus. This signalling system may be a separate bell or buzzer system, powerhouse klaxon or siren on an adjacent unit. The push button for this signalling system should be located at the Gibson Apparatus table.

c. Generator output. - Obtain and set up, in conjunction with the generator manufacturer, all necessary electrical equipment, such as accurately calibrated indicating wattmeters, specially calibrated current and potential transformers, voltmeters, ammeters, etc., required to determine the power output, current, voltage and power



NOTE:
1. LEGS ARE 2 X 4'S.
2. TOP AND BRACING IS 1" MAT'L.

GIBSON APPARATUS TABLE

FIGURE 3.1

factor of the main generator, and the power, current and voltage of the exciter. The 3-wattmeter method of measuring the 3-phase power output of the generator is recommended. (See ASME Power Test Code for Hydraulic Prime Movers - 1949 and Appendix A of this manual.) It may also be necessary for the Government to aid the generator manufacturer by providing personnel to assist in reading the electrical meters and in making computations to determine the power output of both the generator and the turbine.

d. Penstock measurements. - Accurate field measurements of the physical dimensions (lengths and inside diameters) of the penstocks between the piezometer stations. The allowable tolerance for the length is ± 0.05 foot and for diameters is ± 0.01 foot. An example calibration form is shown in Figure 3.2.

e. Staff. - A competent staff of operators to operate the power plant equipment during the tests and to be responsible for the safety of the plant and personnel.

f. Darkroom. - A suitable and conveniently located darkroom equipped with a photographic red light for handling the 11" x 18" films without exposure to light during the test.

g. Power and lighting. - One hundred and ten volts, 1250 watts, alternating current for the lamp of the Gibson Apparatus. Special lighting, if required, should be installed at the observing stations.

3.05 Responsibilities of Gibson. - If the test is made under contract with Gibson, he will furnish the pressure-time apparatus required, together with the necessary lighting equipment for the apparatus, the services of one engineer to direct the tests and operate the Gibson Apparatus, and the results from the diagrams and test data.

The report submitted by Gibson will include:

a. Compilation of test data.

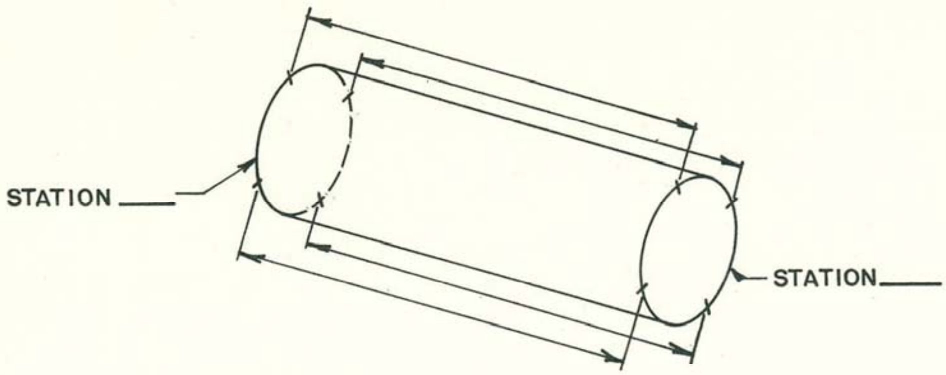
b. Tabulated results of test.

c. Curve sheets showing relation of turbine and unit efficiency, power output, turbine discharge and gate opening.

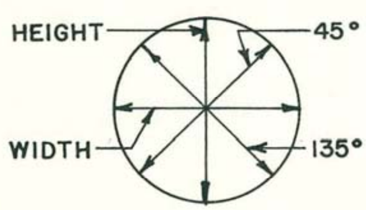
d. Conduit loss of head.

e. Calibration of scroll case manometer, if any.

f. Any other information obtained from the test.



STA.	HEIGHT	WIDTH	45°	135°	DIST. BETWEEN STATIONS	
					TOP	BOTTOM
NET HD. TAPS						



SECTION THRU STATIONS LOOKING U/S

EXAMPLE PENSTOCK CALIBRATION FORM

FIGURE 3.2

3.06 Responsibilities of the Generator Manufacturer. - Turbine power output for each test run will be determined from the generator output and losses. This work will be under the direction of the generator manufacturer in accordance with the generator specifications. The Government will provide observers if requested. The generator manufacturer or Government will later submit a report to Gibson showing in tabular form the turbine output for each test run.

3.07 Test procedure.

a. Inspection. - Prior to the test, the turbine is carefully inspected to see that the runner and wheelcase are free from debris and that the various parts are in good mechanical condition.

b. Leakage test. - The leakage test is made after the penstock has been inspected and filled with water. With the unit operating as a motor at its rated speed, the penstock headgate is lowered to seal. Following the instant of closure, observations of scroll case pressures are recorded at approximately five-second intervals until the water level in the penstock air vent has dropped to the top of the penstock. The rate of fall at a given instant, multiplied by the cross-sectional area of the air vent, will give the leakage at the prevailing head.

If the leakage cannot be determined in the above manner an alternative method is to measure the turbine gate clearances and apply a discharge coefficient to the leakage orifice area.

c. Piezometer traverse. - The accuracy of the net head piezometers is checked before the test while the turbine is operating at approximately rated load. Each of the piezometers is read both individually and in diametrically opposite pairs on the net head manometer by proper setting of the manifold valves. Each piezometer should not vary in its reading by more than 20 percent of the velocity head from the average of all the piezometers in the section, and the average of any pair of diametrically opposite piezometers should not vary from the other pair by more than 10 percent of the velocity head.

d. Gate closure time. - Prior to the tests, the cushion is removed from the servomotor closing stroke. The governor is then adjusted so that the time of full gate closure is as requested by the Gibson engineer to obtain a suitable pressure-time diagram and still remain within the limits specified in the governor contract.

e. Auxiliary connections. - Care should be taken that all auxiliary water connections to the scroll case and penstock; except lubrication water for the turbine wearing plates, are closed during the acceptance tests and during the leakage test. All air inlets into the draft tube are closed except those intended for use during normal operation.

f. Test procedure. - A complete test by this method consists of a minimum of 30 test runs lasting approximately 8 hours. During the test the other units in the plant are either controlled so that the combined output of the units remain approximately constant at all times or are shut down completely. The system dispatcher should be informed of the nature of the tests and arrangements made for the power system to absorb any abrupt fluctuations. While the test is in progress readings are taken of the switchboard watt-hour meter to calibrate that instrument with the generator output as determined by the three watt-meter method.

Prior to each run, the turbine wicket gates of the test unit are opened to the desired setting against gate blocks placed on the servomotor piston or the adjustable stopnut. See paragraph 2.05 of this manual.

After the flow has stabilized and everything is in readiness a warning signal is given on the signalling system. The first reading signal is given ten seconds later, at which time all observers read and record the instantaneous readings of their respective gages. A total of five such readings are taken at 30-second intervals for each run.

Shortly after the last reading, a signal is given for gate closure. The Gibson apparatus is started and the governor operator closes the turbine gates at their previously adjusted maximum rate. The piston stroke observer times the closure by stop watch as the Gibson diagram is being made. Static readings of net head, tailwater, and piston stroke are taken between each run. Preparations then proceed for the following run.

g. Practice run. - A practice run precedes the first authentic run to acquaint all participants with the routine of the tests and to assure that all equipment is functioning properly. All procedures of an authentic run, including the recording of data, are duplicated during the practice run except that no diagram is made on the Gibson apparatus.

h. Personnel. - The following Government personnel are required during the running of the test:

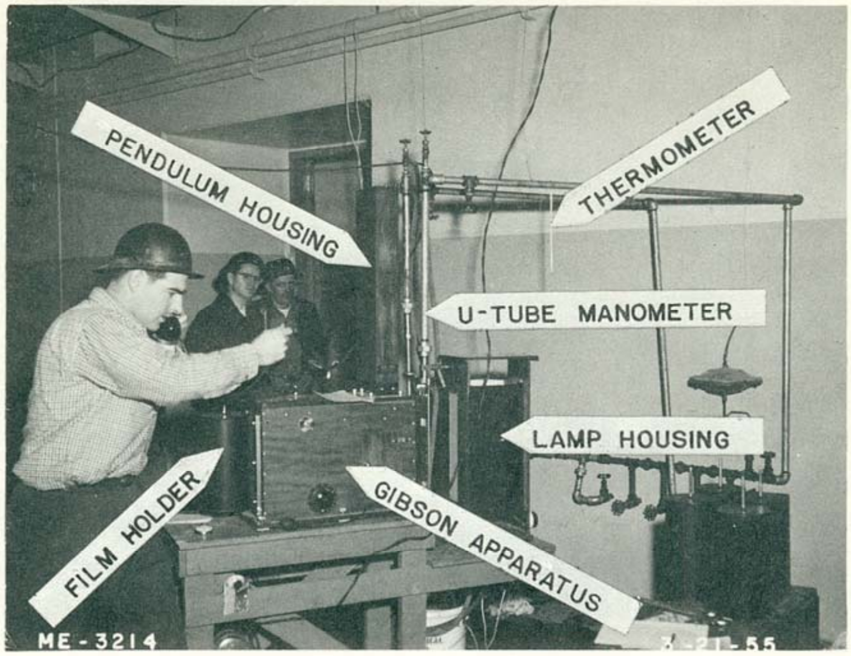
Coordinating Center	1 Coordinator
Coordinating Center	1 Computer
Governor - Test Unit	1 Operator
Governor - Other Units	1 Operator
Servomotor stroke	1 Observer
Forebay gage	1 Observer
Tailwater gage	1 Observer
Net head gage	2 Observers
Scroll case gages	4 Observers
Switchboard watt-hour meter	2 Observers
Reload Gibson film	1 Photographer
Develop diagrams	1 Photographer
Service men	2 Pipe fitters
Service man	1 Electrician
Power output	3 Engineers (estimated requirements of generator contractor)

During the two days preceding the test a levelman, rodman, pipe fitters, and electrician are required to set up the apparatus.

i. Materials. - The equipment and materials required for the Gibson test are essentially the same as those listed for the Index Test, paragraph 4.05 b. An additional requirement is the table for the Gibson apparatus as shown in Figure 3.1 and one additional stop-watch for the servomotor stroke observer.

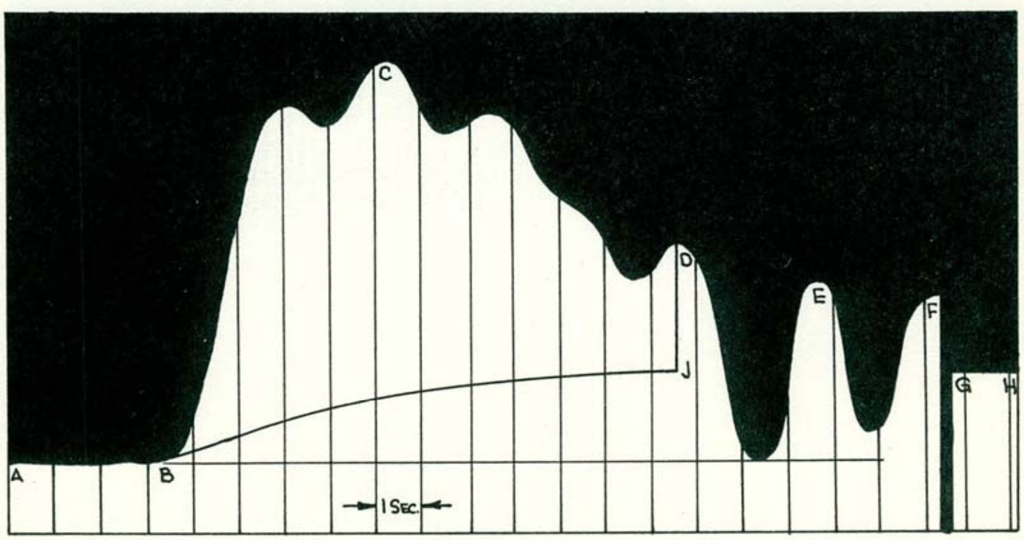
3.08 Gibson Apparatus and Diagram. - The pressure-time diagram recorded by the apparatus shown in Figure 3.3 is a photograph of the movement of a mercury column in a calibrated U-tube manometer connected to the conduit by one or both legs, according to the application, i.e., simple or differential. The movements are photographed on photographic film wound onto a mechanically or electrically driven drum. A pendulum swinging between the camera lens and the mercury manometer marks time signals on the film by interrupting the beam of light from the light source. These time signals appear as vertical lines on the final print.

The Gibson Method of measuring the quantity of water flowing through a hydraulic turbine is based on a simple principle of physics. If the mass "M" of a moving body is known, and if the average pressure "P" required to bring it to rest in a known time "t" can be measured, the velocity "v" at the moment the pressure was first applied can be computed by Newton's second law of motion which may be stated in the form $Mv = Pt$ or $v = Pt/M$. The measurement of the product of average pressure and time required to destroy the momentum in a given mass of fluid is accomplished by the Gibson Method. The measurement is actually made by the Gibson apparatus, a photographic device, Figure 3.3, that records the change in pressure and the time required to bring a known mass of fluid in motion to rest.



GIBSON APPARATUS

FIGURE 3.3



EXAMPLE PRESSURE-TIME DIAGRAM

FIGURE 3.4

The vertical motion of the top of the mercury column as obtained in the photographic record is caused by the differential pressure exerted in the two legs of the U-tube manometer connected to the Gibson apparatus. The horizontal distance between each of the vertical lines on the diagram, Figure 3.4, represents one second of time. These lines are produced by a pendulum that blocks the light once each second as it swings past the lens. The location of the pendulum housing of the Gibson apparatus is shown in Figure 3.3.

The exposure from A to B, Figure 3.4, called the running line of the diagram, shows the movement of the mercury column a few seconds before the turbine gates start to close. During this period, and for several minutes earlier, the turbine gates are held at a fixed gate opening so that both the flow of water through the turbine and the power output are relatively stable. About two minutes before the turbine gates start to close, observers measure the hydraulic head, servomotor piston stroke, and power output of the generator and other auxiliary electrical equipment. The power measurements are used to determine the power input to the generator shaft from the turbine.

At point B, the turbine gates start to close. The displacement of the mercury column along the wavy line BCD is caused by the change of pressure in the penstock between the upstream and downstream piezometer sections as the velocity of the water in the conduit is gradually destroyed. The instant the turbine gates reach the closed position (point D), the flow of water in the penstock ceases, except for the relatively small amount of water that leaks through the closed gates. Immediately after the turbine gates reach the closed position, the only forces acting on the mercury column are gravity and the dampening effect of friction in the hydraulic system between the two piezometer sections through the piping to the Gibson apparatus. This section of the diagram is commonly known as the afterwaves, and the mercury oscillates to a position of rest in a dampened harmonic wave motion (DEF).

The photographic record is continuous from A to F. The exposure of the film is interrupted at F after a few afterwaves have been photographed. As soon as the mercury column has come to rest (usually from one to two minutes after the gate closure), a photographic record is made of the top of the mercury column in that position (GH). This final record of the position of the mercury at rest is the so-called static line. The vertical distance between the average position of the running line (AB extended horizontally) and the static line GH represents a measure of the recovery of friction and velocity head in the conduit between the two piezometer sections as a result of the destruction of the velocity of the water.

The reverse curved line drawn between points B and J represents the gradual recovery of the friction and velocity head during the period of gate closure. The position of the line BJ is determined by trial and error. A trial line is drawn and the area on the diagram is divided into vertical strips, the areas of which are added up in succession from the beginning of the diagram. An imaginary area proportional to the leakage through the turbine gates is then added to the final sum to make a total area that would correspond to the initial flow.

Since friction and velocity heads are proportional to the square of velocity, the remainder is squared and multiplied by the distance from the static line down to the running line at the beginning of the diagram. The resulting lengths are marked off from the static line downwards on the respective verticals separating one strip from the next. The smooth curve through the ends is the resulting recovery line. The heads recovered are represented by the differences between these lengths and the distance between the static line and the running line at the beginning of the diagram. If this recovery differs from the trial line, the procedure is repeated until the correct recovery line is found. Finally, the area of the diagram is measured and the net area is obtained by allowing corrections for the effect of the drum slot.

The film is marked with gage points before exposure. The ordinates represent retarding pressure head in feet of water to a scale given by calibration of the manometer and the time scale is given by the intervals recorded on the diagram by the pendulum.

The area (BCDJB) in square inches, measured by a precision planimeter, is the pressure-time area of the diagram, and represents a measure of the product of (a) the average pressure required to bring the mass of water in the test section of the penstock to rest and (b) the time in seconds the average pressure was applied. Hence, the area is a measure of Pt in the formula: $v = Pt/M$, where "v" is velocity of the water in feet per second, "P" is differential pressure in pounds, "t" is time in seconds, and "M" is total mass of water in pounds per foot per second.

The Gibson apparatus is calibrated in the laboratory to provide the values of its constants so that the area BCDJB in square inches is therefore readily translated into the product of average pressure expressed in feet of water and time in seconds. Hence, having thus measured the value of Pt and knowing the mass of the water in the test section of the conduit, the average velocity of the water in the conduit at the instant the turbine gates started to close may be computed. The quantity of water Q in cubic feet per second flowing at that instant is equal to the average cross-sectional area of the test section of the conduit in square feet multiplied by the average velocity in feet per second, or $Q = Av$. Any loss due to leakage is then added to give the total stopped rate of flow.

3.09 Advantages and Disadvantages. - The Gibson Method requires relatively little apparatus and, apart from the tappings into the penstock, its application does not require extensive preliminary work and the conduit does not have to be opened. However, since it involves load rejection, normal power station operation during the tests is impossible and the penstock, turbine regulating gear, and the turbine itself are subjected to very considerable stresses. In addition, evaluation of the results is a somewhat long and arduous process.

Various improvements to the recording apparatus have been devised since this method of measurement was originally conceived and it is now generally accepted as an accurate and reliable means of measuring turbine water flow (17:54-56).

SECTION 4 - INDEX TESTING

4.01 Definition. - An Index Test of a hydro-electric unit is a means of determining the efficiency of the unit over its full operating range of gate-opening and output. It may be used when a direct measure of discharge is not available, the discharge being a relative determination. The efficiency determined is relative to an actual or estimated peak efficiency.

Index Testing is presently the only method available to the Portland District for testing of hydro-electric power plants which are not equipped for acceptance testing. Until such time as a method of determining the absolute values of discharge and efficiency for plants without penstocks is provided, this method must suffice.

4.02 Limitation. - The ASME Power Test Code imposes the restriction on Index Testing that it "shall not be used as an acceptance test of a hydraulic turbine to determine whether it (the turbine) meets the contract guarantees . . ."

4.03 Application. - Index Testing may be used to:

a. Determine the characteristics of a turbine for efficient operation in cases where an acceptance test is not made.

b. Supplement data obtained from an acceptance test.

c. Determine the proper cam relationship between wicket gate and runner-blade setting for Kaplan turbines.

d. Determine changes in efficiency or output of a unit due to wear, erosion, alteration or any other change.

4.04 Inspection. - Prior to beginning an Index Test the unit is unwatered, inspected and calibrated. During inspection the water passages of the turbine should be examined for any signs of pitting, corrosion, erosion or defects which might have an adverse effect upon the performance of the unit. All debris should be removed from the turbine, intake passages and trashracks. The piezometer orifices should be inspected, the plates ground smooth, and the plugs removed.

4.05 Conduct of test. - A test of this type which involves unusually costly equipment should be under the direct supervision of a qualified engineer who must assume full responsibility as to methods and results.

Since field conditions do not always lend themselves to the requirements of an Index Test, it is usually desirable for the test engineer to arrive on the site a day or so prior to the date scheduled for the test. This will allow time for observation as well as for inspection of gages, tubing and instruments, and recommendation of any possible alterations or additions. This will also insure that the necessary materials are available before the test.

a. Personnel. - The total number of persons required for the test may be as high as 17, including the construction and operating personnel assigned from the project to aid during the test. The number and assignments of the individuals for a typical test are listed in the following tabulation.

ASSIGNMENT OF TEST PERSONNEL

Number Required	Position Title	Duty Location
1	Computer	Coordinating Center
1	Coordinator	Coordinating Center
1	Operator	Governor
1	Operator	Switchboard
1	Observer	Turbine Pit
1	Assistant	Turbine Pit
2	Observers	Scroll-case Manometer
1	Observer	Forebay Gage
1	Observer	Tailwater Gage
2	Observers	Net Head Manometer
2	Observers	Watt-hour Meter
1	Machinist	Governor
2	Alternates	As assigned
17		

Prior to the test the personnel should be thoroughly briefed on the general procedure and an opportunity should be provided for individual instructions. It is particularly essential that specific instructions be given regarding the manner of taking and recording data at the various stations and reporting observations without delay.

b. Materials. - The materials required for a typical Index Test are listed as follows:

MATERIALS AND EQUIPMENT REQUIRED FOR INDEX TEST

Item	Number required	Remarks
Large table and chairs		Seating for 5 persons at coordinating and computation center.
Desk calculator	1	At coordinating center table.
Clip boards	12	For observers and coordinator.
Graph paper and drafting supplies		For computing staff.
Reproducible data sheets and pencils		For each observer.
Decimal equivalent chart		See Appendix D of this manual.
Stop watches	2	For watt-hour meter observers.
Communication system		Radio or telephone at each station.
Signal system		Bell or buzzer at each station.
Scroll-case manometer board	1 or 2*	Equipped with U-tube. See para. 2.02 c and Appendix C.
Ladder	1	To read high side of manometer.
Forebay Gage with stilling well	1	See para. 2.03 a.
Tailwater Gage with stilling well	1	See para. 2.03 b.
Net head manometer	1	See para. 2.02 b.
Machinist's scale	1	To measure gate stroke. See para. 2.05.
Gate servomotor piston blocks (if required)		See para. 2.05 and Figure 2.13.
Measuring instruments		To measure the oil-head reference and cam position with micrometer accuracy. See Figures 2.9 and 2.11.
Feeler gages	1 set	For wicket gate clearance.
Survey equipment		For levels and soundings.

Note: All observers should be equipped with watches.

* Depending on number of scroll-case piezometers used.

c. Time required. - As many test runs should be made as are required to define accurately the performance characteristics of the unit. This number will vary depending upon the judgment of the computer and the coordinator, the consistency of the plotted points, and the type of turbine being tested. The ASME Power Test Code lists the minimum number required. See paragraph 43, Appendix B.

The over-all time required for the test may vary from three to four hours for a Francis turbine up to eight or ten hours for a Kaplan-type turbine. For Kaplan-type turbines another two or three hours of testing time may be required to confirm the final cam profile. Longer over-all time will be required if it is not possible to obtain clearance from the power system dispatcher for a period sufficient to complete the entire test in one attempt. (8:491).

Each test run should last long enough to allow the observers sufficient time to obtain as many readings as will result in a reliable average. A typical run usually lasts two to five minutes during which time ten periodically spaced readings of all fluctuating values are taken.

The time required to make the actual test runs, exclusive of meals and set-up time, based upon actual tests made by the Portland District, is tabulated below. It should be noted that the time required to set-up manometer boards, gages, etc., has not been included as this is usually accomplished the day before the test is scheduled to begin.

d. Communication system. - The problem of correlating the measurements of the participating personnel located at various stations throughout the plant may be solved by a combination of a bell or buzzer system for signalling and radio or telephone for voice communication.

e. Variation in test conditions. - When the actual test conditions for this method do not agree with the limits suggested by the Power Test Code, agreement as to the allowable variation may be agreed upon by both the representative of the manufacturer and the test coordinator.

TABULATION OF PORTLAND DISTRICT INDEX TESTS

Project Name	Turbine Type	Unit No.	Head in Feet	Date of Test	Approx. Time Hours*	No. Test Runs	Approx Runs Per Hour
Detroit	Francis	2	250	20Jun54	3	13	4
			316	20Oct54	3	20	7
			360	5May54	3	16	5
Big Cliff	Kaplan	-	91	4Jun54	8	48	6
			85	5Jun54	4	35	9
			79	6Jun54	3½	32	9
			73	6Jun54	4	32	8
Lookout Point	Francis	2	134	12Jan56	3	22	7
			159	3Nov55	2½	21	8
			206	6Oct55	2½	18	7
			230	3Jun55	3	21	7
Dexter	Kaplan	-	44	18Apr57	4½	43	10
			54	27Jul55	6½	49	8
The Dalles	Kaplan	F-2	81.4	20Nov57	5½	35	6
			73	8May58	6	39	6
			64.5	20May58	4½	36	8
			56	6Jun57	6½	55	8
		2	85.5	5Dec57	5	34	7
			78	1Jul58	4½	39	9
			71	17Jun58	5½	41	7
			63	5Jun58	4½	38	8
		1	85.6	21Oct58	4	27	7
		3	84.6	22Oct58	3	21	7
		4	84.4	22Oct58	2	20	10
		5	84.5	23Oct58	2	22	11
		6	84.0	8Mar60	2½	21	8
		7	83.5	9Mar60	3	27	9
		8	83.5	9Mar60	3	25	8
		9	84.0	10Mar60	3½	26	7
Bonneville	Kaplan	5	62.5	14Jan60	4½	32	7
			54	15Apr59	5	39	8
			45.5	10Jun59	5	42	8

* Actual test time only, excluding meals and rounded to nearest half-hour.

f. Relative discharge measurement. - Relative discharge measurements consist of obtaining the average of fluctuating manometer readings, the manometers being connected to carefully installed piezometer taps which measure an arbitrary differential head theoretically proportional to the square of the discharge (23:448).

It is not necessary that the differential-pressure taps be installed in the turbine casing, during construction, to be able to conduct a satisfactory Index Test involving the measurement of flow of water through the turbine. Many satisfactory installations of scroll-case differential-pressure taps have been made by inserting the high-pressure piezometer line through the casing from within the turbine pit and tack-welding or clipping the pipe line around the casing to the outside horizontal center-line where the high-pressure orifice is located. The inner or low-pressure connection can be installed from within the turbine pit by drilling and tapping the pressure orifice in the exposed portion of the speed ring.

For turbines whose intakes are designed along conventional lines and whose relative-discharge taps are located according to the Winter-Kennedy Method, the minimum manometer deflection at full gate and rated head must be 1.5 feet (1:4). The maximum deflection in feet of water will probably not exceed 10 percent of the actual head during the test (23:488). The theory for computing the probable maximum deflection is given in Appendix C. A margin of at least 2 feet of water over the maximum computed deflection is recommended in determining the size of the manometer board to allow for fluctuations, displacement resulting from air leakage, and safety margin.

When the head on the plant is such that a water manometer would be so large that it is not practical, recourse is made to the use of mercury as a measuring liquid. The manometer in this case may then be a simple U-tube.

Whenever feasible, the manometer should be located at an elevation low enough to insure maximum ease of manipulation and reliability of measured data. In the event the manometer stations has been located too near pool level a less reliable means of flushing, such as circulating water through the tubing and out by the orifice opening, may be used.

Rapid fluctuation of the manometer column is a frequent characteristic of this type of measurement. In order to reduce the rapid fluctuation and to facilitate making the required observations, valves are sometimes used in the individual piezometer lines to throttle the free surging of the measuring liquid. Undue throttling of a manometer line may cause an error in a set of readings.

A recommended method which eliminates possible error and at the same time increases greatly the ease of making observations is the use of a simple foot-operated clamping device. The hoses connecting the manometers to the piezometers may be threaded through the clamp in such a manner that at any desired instant the circulation and therefore the fluctuations can be totally eliminated instantaneously in each line. The only precaution is to design the clamp so that the same volumetric change takes place in each tube when pinched. This is easily checked, when the turbine gates are closed, by making certain that the slight meniscus rise resulting from the operation of the clamp is equal in each tube (23:489).

The piping from the piezometer to the inverted U-tube manometer should be arranged so that the water level can be depressed an equal distance for both legs of the manometer, by the use of compressed air, to a level convenient for reading. This procedure is permissible as only the differential reading is required for Index Testing.

The manometer board should be furnished with a glass or plastic tube (preferably backed with cross-section paper) for each piezometer, with the lower ends connected to individual taps and the upper ends to a horizontal manifold which constitutes the top side of the inverted "U". One end of this manifold should be connected to a drain for thorough and periodic flushing of all air pockets, and the other end to an air-pressure supply for depressing the water-column levels to the desired elevation. Extreme care should be taken to insure that all the air is removed from the tubing by bleeding the manometers prior to the tests and periodically during the tests.

Ten pairs of readings of the manometer should be taken at approximately 15-second intervals during each run. Since there is usually a slight fluctuation in the two legs of the manometer it is important that each leg be read simultaneously.

The average differential manometer reading, "D", is computed for each run and "$\sqrt{D}$", uncorrected for head, is plotted against wicket gate servomotor stroke as the test proceeds. Any irregular points caused by air in the manometer tubing or other erroneous readings could be noticed and the condition causing them eliminated. After the test is completed, the $\sqrt{D}$ is corrected to a common head, Hc, by the ratio of $\sqrt{Hc/H}$ and the discharge is determined as a straight line function of $\sqrt{D}$. Discharge is given by the relation $Q = C \sqrt{D}$ where "C" is the piezometer calibration constant and $\sqrt{D}$ is the relative discharge.

g. Power output. - The watt-hour meter method of determining power output consists of accurately timing, by means of a stop watch, the number of whole revolutions of the revolving meter disk for a period of approximately two minutes.

The watt-hour meter should be calibrated with a rotating standard prior to the tests.

The power output is then computed from the relationship

KW = "K" x revolutions per second

where "K" = $\frac{3600}{1000}$ x PT ratio x CT ratio x meter constant

PT - Potential Transformer
CT - Current Transformer
Meter Constant - stamped on meter.

Power-factor observations should also be made and the actual power-factor held as close to unity as possible during the test.

To the generator output should be added the generator losses, including exciter losses, either as calculated or guaranteed by the generator manufacturer. The generator input should then be converted to turbine output in horsepower.

4.06 Tabulation of test data. - During the Index Test, the test data is recorded on individual data sheets as shown in Apprndix E. After recording the individual data it is relayed to the computer's table where the necessary computations are made and curves drawn in accordance with Appendix F.

Appendix A

EXCERPTS FROM

ASME POWER TEST CODE FOR HYDRAULIC PRIME MOVERS

PTC 18-1949

Section 1 - Object and Scope

1. This code is directed specifically to the formulation of standard and approved practices for the testing of an individual reaction or impulse turbine of any type. For the purposes of this code the term "prime movers" will include both reaction turbines and impulse water wheels; and the term "hydraulic turbines" when used in a general sense, also includes both types.

3. Where the actual test conditions for the method of measurement to be used do not fall within the limits set by this code, agreement as to the allowable variation from the quantities measured shall be reached by conference between representatives of both parties to the contract before the test is begun.

4. In cases where the turbine setting or physical conditions of the installation preclude the complete field application of this code, a laboratory test on a model turbine and its complete setting including approach conduit, casing, and draft tube, truly homologous with the actual unit, may be used as a basis for the determination of efficiency. The method of allowing for the scale effect shall be agreed upon by the representatives of both parties to the contract. Any laboratory tests shall be conducted in accordance with this code. Water measuring devices and all instruments used for the acceptance test shall be calibrated in advance.

Section 2 - Description and Definition of Terms

5. In computing the efficiency of an installation a distinction must be made between the efficiency of the plant and the efficiency of the turbine. The efficiency of the plant may include all losses of energy up to any stated point of delivery, such as the delivery of electric power from the transformer, at the switchboard or at the generator terminals, or may be confined to the total efficiency of the hydraulic installation for which purpose the power is to be computed as that delivered by the turbine to the generator shaft.

6. This code shall be understood to apply to tests of the turbine proper, and the terms, power, efficiency, effective head, etc., are to be taken as referring to the turbine. In computing the efficiency of a turbine, the losses through the racks, in the intake to the penstock, in the penstock and through any penstock valves shall not be charged against the turbine; nor in the case of a reaction turbine shall the head necessary to set up the velocity required in the tailrace to discharge the water be charged against the turbine. The net or effective head acting on the turbine shall be measured from a section near the inlet of the turbine casing when turbines are equipped with casings, to a section in the tailrace in the manner set forth under "Head". Since the turbine cannot develop power without discharging water, a correction for the velocity head required to discharge the water in the tailrace shall be added to the tailwater elevation; and a similar correction shall be applied to the intake of the casing, as called for under "Head". The power developed by the turbine shall be taken as the mechanical power delivered at the turbine shaft and transmitted by the turbine shaft to the generator or other driven machine or system.

Term	Symbol	Description	Unit
Area of cross section	A	The area of the cross section of any conduit or the channel used for measuring water flow	sq ft
Whole net area (Gibson method)	A_d	The whole net area of the Gibson pressure-time diagram	sq in
Area of diagram (Gibson method)	a	The area of the Gibson pressure-time diagram measured to a given point	sq in
Blade depth	B_p	The distance measured from inlet edge to discharge edge of a propeller type turbine runner blade at its outer periphery and parallel with the axis of the runner	ft
Distributor height	B_r	The distance between faces of the distributor passage measured parallel with the axis of the runner	ft

Term	Symbol	Description	Unit
Total friction and velocity heads (Gibson method)	c	The sum of the friction and velocity heads recorded on the pressure-time diagram in the Gibson method	in. of mercury
Impulse wheel diameter	D	The outside diameter of impulse bucket wheel	ft
Propeller runner diameter	D_p	The outside diameter of a propeller type turbine runner	ft
Reaction runner diameter	Dr	The entrance diameter of a reaction turbine runner measured at the center of the distributor height	ft
Conduit constant (Gibson method)	F	The pipe factor used in the Gibson method for determining the rate of flow through or discharge from the conduit	
Leakage (Gibson method)	G	The leakage past the turbine gates or other device used to create the pressure rise	cfs
Acceleration of gravity	g	Local value of acceleration due to gravity. The standard value of acceleration due to gravity, at 45 deg. N latitude and at sea level = 32.174 fps^2	fps^2
Effective head	H	The total net height of the water column effective on the turbine runner when generating power	ft

Term	Symbol	Description	Unit
Water barometric height	H_b	The height of a water column corresponding to the pressure of atmosphere, minus the vapor pressure of the water	ft
Velocity head	H_v	The square of the mean velocity of flow divided by twice the acceleration of gravity	ft
Static draft head	Hs	The measured height of the runner above the tail-water surface	ft
Calibration constant (Gibson method)	K_g	A calibration constant of the recording apparatus used in the Gibson method of water measurement	
Length between measuring points (Gibson method)	L	The distance between the piezometer section and the forebay for simple diagrams or between the two piezometer sections for differential diagrams measured along the center line of flow	ft
Conduit length (Gibson method)	l	A length along the conduit used in determining the pipe factor where the conduit is of nonuniform cross section	ft
Number of blades	Np	The number of blades on a propeller turbine runner	
Net output (Mechanical)	Pc	The output of the turbine measured by the brake, dynamometer, or other loading, at coupling or on shaft 1 bhp or 1 hp or 1 shp = 550 ft-lb per sec = 0.74566 kw	bhp hp shp

Term	Symbol	Description	Unit
Windage (Turbine runner)	P_w	The power required to drive an impulse, reaction or propeller turbine runner at a given speed of rotation in air	kw
Resistance loss in Generator windings	P_1	The power absorbed by the resistance of generator winding	kw
Water flow quantity rate	Q	Rate of water discharge or flow	cfs
Area ratio (Gibson method)	r	The quotient of the area of the Gibson diagram measured to a given point divided by the whole net area of the diagram	
Time constant (Gibson method)	S	The horizontal length of the Gibson diagram Corresponding to one second of time	in
Velocity	V	The rate of water flow at any point in a conduit or channel	fps
Average or mean velocity	Va	Average or mean rate of water flow in any conduit or channel	fps
Flywheel effect	WR^2	The flywheel effect of the rotating element	$lb\text{-}ft^2$
Weight of water	w	The weight unit of the water that generates power in the prime mover	lb per cu ft
Height constant (Gibson method)	y	The vertical height on the Gibson diagram corresponding to one foot of pressure change in the conduit	in

Term	Symbol	Description	Unit
Cavitation factor	σ	A function of water barometric height, static draft head, and effective head indicating liability of turbine runners to cavitation	

8. Efficiency. - Performance guarantees involve the relation between efficiency and horsepower.

$$\text{Turbine efficiency} = \frac{550\ Pc}{QwH}$$

where Pc = output of turbine in horsepower as determined by Par. 74
Q = water quantity in cubic feet per second
w = weight of a cubic foot of water. (This may be taken from the following table.) When the water contains an abnormal quantity of solids, gas or air in solution or suspension w shall be obtained by direct weight or by specific gravity determination
H = effect head in feet

Weight of a Cubic Foot of Water

in Air

Temp. deg F	lb per cu ft	Temp. deg F	lb per cu ft
32	62.350	62	62.292
34	62.354	64	62.280
36	62.357	66	62.267
38	62.359	68	62.253
40	62.360	70	62.239
42	62.358	72	62.224
44	62.356	74	62.208
46	62.353	76	62.191
48	62.348	78	62.173
50	62.344	80	62.155

Weight of a Cubic Foot of Water

in Air

Temp. deg F	lb per cu ft	Temp. deg F	lb per cu ft
52	62.337	82	62.136
54	62.329	84	62.116
56	62.322	86	62.096
58	62.312	88	62.075
60	62.302	90	62.053

Section 4 - Instruments and Methods of Measurement

32. Electrical Measurement of Generator Output and Generator Losses. When the turbine is direct connected to an electric generator the output of the turbine is to be measured as herein provided. (See Fig. A-1.)

33. The turbine output shall be taken as the power output of the generator plus all generator losses supplied by the turbine plus the input to all auxiliary drives supplied by the turbine. Generator windage shall be considered a generator loss and turbine windage a turbine loss.

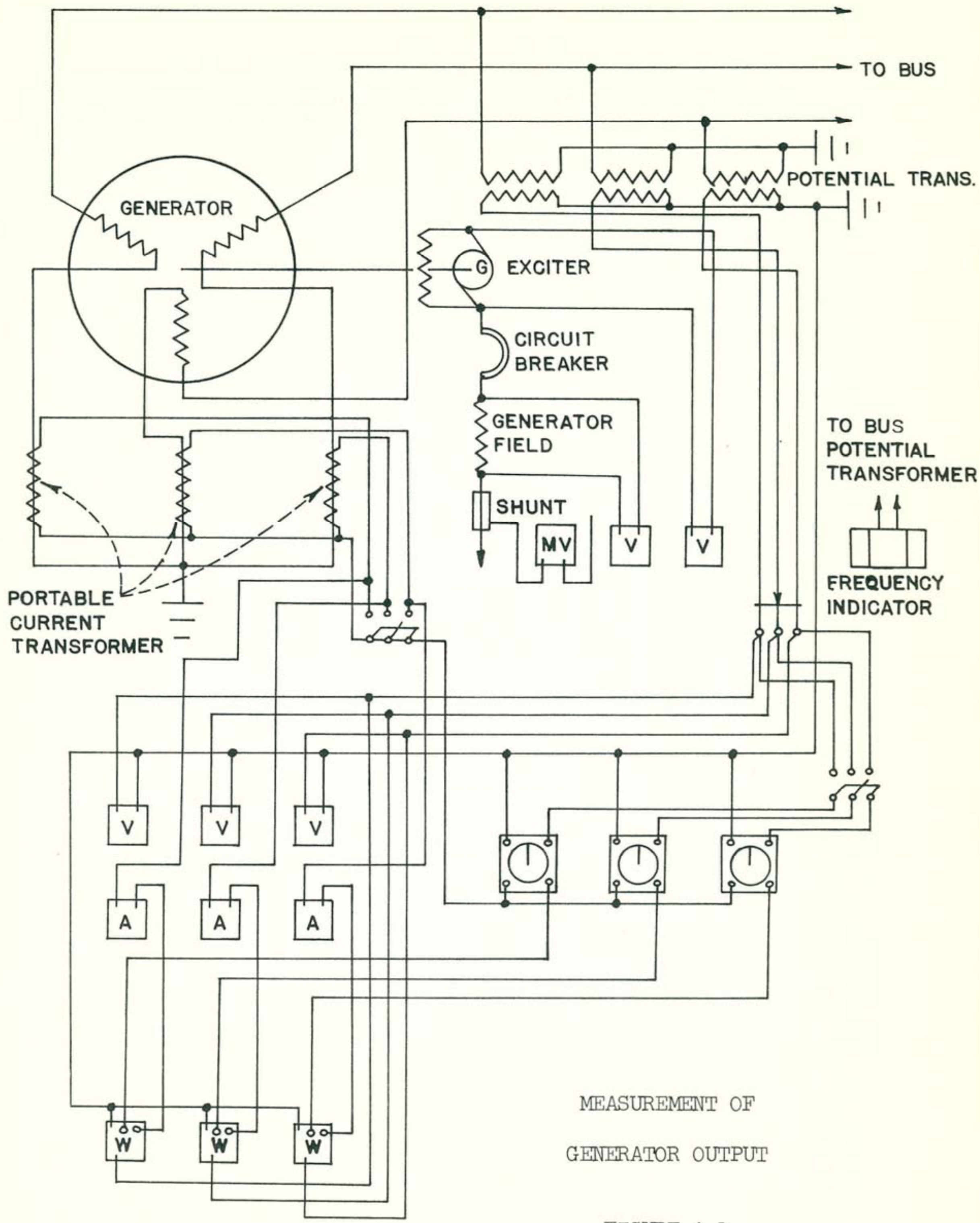
34. Generator loss tests shall be made either in the shops of the builder or after installation by the separate loss method ....

62. Instrument Calibrations and Corrections. All instruments, instrument transformers, etc., used for the test shall be calibrated by comparison with standards acceptable to both parties.

63. All instrument transformers shall be corrected for ratio and phase angle for the burdens imposed under actual test conditions.

64. Generator Output. During the turbine test the generator shall be operated as near to rated voltage and unity power factor as operating conditions will permit. Should the power factor be below unity, suitable corrections in the computation of the core loss shall be made.

65. Output may be measured by indicating wattmeters or by integrating watthour meters of the rotating standard type. The three-wattmeter method of measuring three-phase power output of the generator is recommended.



MEASUREMENT OF

GENERATOR OUTPUT

FIGURE A-1

REF: ASME PTC 18-1949, FIG. 3

74. Turbine Output. The total turbine output shall be taken as the sum of the following:

Generator output
Armature I^2R loss
Generator windage and friction
Stray load loss
Core loss
Exciter input (if direct driven)
Input to auxiliaries when the motive power is furnished by the turbine.

Measurement of Head

75. Distinction shall be made between the total or gross operating head on the plant and the net or effective head on the turbines. Total operating head on the plant is the difference in elevation of the forebay and tailrace levels, both corrected for velocity heads. In computing the efficiency and other factors of turbine performance, the net or effective head shall be used.

76. When possible the effective head shall be checked by comparison with the total operating head on the plant, to see that the difference is consistent with reasonable values of the conduit losses.

79. The total or gross head acting on the plant shall be taken as the difference in elevation between the equivalent still water surface before the water has passed through the racks, and the equivalent still water surface in the tailrace after discharge from the draft tube. When the water in the forebay in advance of the racks flows with sufficient velocity to make its velocity head an appreciable quantity, the elevation of the equivalent still water is the actual elevation of the water surface increased by the amount of this velocity head. The same process shall apply to the section of measurement in the tailrace, that is: the velocity head at the section of measurement in the tailrace shall be added to the actual elevation of the surface, the sum being considered the equivalent still water elevation.

80. Incased Turbine. For turbines having closed casings the effective head is to be measured by at least four piezometers located in pairs on diameters equally spaced around the pipe, in a straight portion of the penstock at the turbine casing intake, and by two or more board, piezometer, hook, rod or float gages in the tailrace, placed at points reasonably free from local disturbances. To avoid air, preferably no piezometer shall be located at or near the top of the penstock. Such gages shall be free of velocity effects, and if this condition is not obtainable when the gages are set in the open channel, they shall be placed in properly arranged stilling boxes.

81. All piezometers shall be so connected with individual valves that they may be read separately.

82. The gages shall, when practicable, be water columns or manometers; and for high pressures shall be mercury manometers, dead-weight gage testers, or calibrated bourdon gages ..... All gage connections shall be tight against leakage ..... If during the test, any piezometer shall be obviously in error due to some local cause or other condition, as indicated by the reading after the addition of the velocity head, showing a total head in excess of the initial available head corresponding to the elevation of the surface of headwater, the source of discrepancy shall be found and removed, or the piezometer shall be eliminated.

84. The effective head on the turbine shall be taken as the difference between the elevation corresponding to the pressure head in the penstock at the entrance to the turbine casing and the elevation of tailwater, the above difference being corrected by adding the velocity head in the penstock at the section of measurement and subtracting the residual velocity head at the section of measurement in the tailrace. The velocity head in each of the above cases shall be taken as the square of the mean velocity at the section of measurement divided by 2g; the mean velocity being equal to the quantity of water flowing divided by the cross-sectional area of the section of flow.

Methods of Measurement of Quantity of Water

117. Gibson Method of Measurement. This method for measuring the flow of water is applicable where the water to be measured flows through a closed conduit, of either uniform or varying cross section.

118. It is based upon two fundamental principles, the first is Newton's Second Law of Motion known as the Equation of Impulse and Momentum, and the second, a corollary of the first, which gives the relation between change of pressure and change of velocity of a column of water expressed in terms of the pressure waves propagated during the change. No empirical coefficients are used.

119. The method makes use of pressure-time diagrams of either the simple or differential type. With simple diagrams the changes of pressure at one piezometer section in the conduit are recorded while with differential diagrams the difference between the changes of pressure at two piezometer sections in the conduit is recorded.

120. The length of conduit upstream from the piezometer section for simple diagrams or the length between the two piezometer sections for differential diagrams shall be not less than 30 feet nor less than twice the maximum dimension of the conduit cross section.

121. The product of L and Va shall be not less than 200 where Va is the mean velocity in the conduit when the unit is carrying rated full load and L is the length of the conduit used for the test.

(See Figure A-2 for minimum length of test section)

122. The leakage past the turbine gates or other device used in producing the pressure rise shall, in the closed position, not be greater than 5 percent of full gate discharge and the leakage shall be determined within an error of two-tenths of one percent of such discharge.

123. The physical dimensions of the interior of the conduit shall be measured in the field with sufficient precision to determine the pipe factor F within an error of two-tenths of one percent ..... Construction drawings should be used only as a check on the field measurements.

124. Two or more piezometers shall be installed at each piezometer section. They shall be installed in positions diametrically opposed in a plane normal to the flow at the section, and shall be connected to a common header. Pipes leading from the headers of the two piezometer sections are to be connected, one to each side of the recorder U-tube manometer.

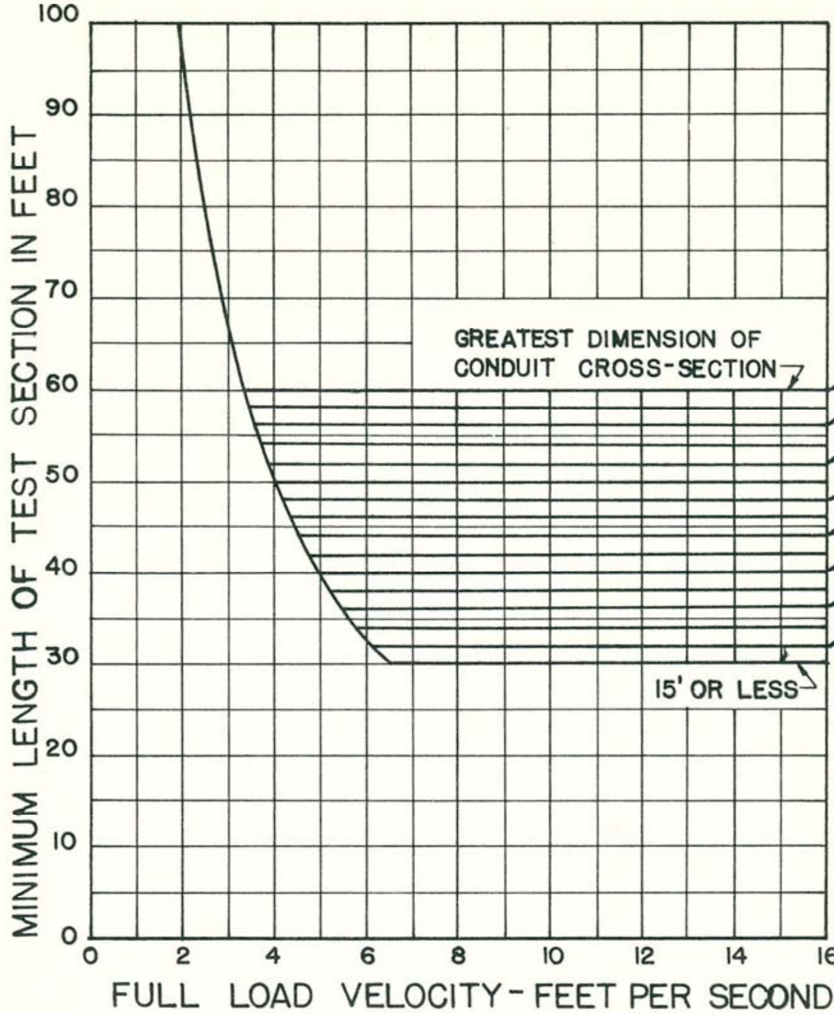
125. All piezometers shall be installed in accordance with Paragraphs 81 and 82 as specified for incased turbines.

126. Immediately before a test all the piezometers shall be inspected and tested and any that remain faulty, disconnected. No less than two piezometers per section shall be available for the test.

127. When simple diagrams are made, an accurate record of the changes of water level in the forebay at the entrance to the conduit for a period of about one minute before and after the flow is stopped shall be made in order that a correction may be applied to the pressure-time diagram to allow for any surge which may have taken place in the forebay during the recording of the diagram.

128. The rate of flow which is to be measured in the conduit shall be established by fixing the gate opening of the turbine in the required position.

129. A pressure-time diagram shall be obtained by gradually closing the control gates in one continuous movement and graphically recording the resultant change in pressure on the chart of a recording device such



TO USE:

1. SELECT CURVE FOR GREATEST DIMENSION OF CONDUIT CROSS-SECTION.
2. FOLLOW CURVE TO PROPER VELOCITY.
3. READ ACROSS TO MINIMUM LENGTH.

MIMIMUM LENGTH OF TEST SECTION

FIGURE A-2

as the Gibson apparatus which photographs on a sensitized film moving at a uniform rate, the movement caused by the pressure change of the top surface of a column of mercury in a U-tube manometer.

130. The recovery of friction and velocity heads on the diagram shall be eliminated by dividing the diagram into several parts and by trial and error determining the friction and velocity heads destroyed. At any time during the closing period the ratio of any part of the net area from the beginning of the diagram to the whole net area is equal to the ratio of the velocity destroyed up to that time to the initial velocity.

131. That part of the gross area of the diagram produced by the recovery of friction and velocity heads shall therefore be eliminated by considering that the value of the friction and velocity heads remaining is equal to

$$c(1 - r)^2$$

where $r = \frac{a}{A}$

a = the area of diagram measured to a given point
A = the whole net area of the diagram, and
c = the sum of the friction and velocity heads recorded on the pressure-time diagram

132. Rate of Flow. The rate of flow through or discharge from the conduit shall be computed by the equation:

$$Q = \frac{Kg\ Ad}{SF} + G$$

where Q = discharge in cubic feet per second
Kg = calibration constant of the recording apparatus = $\frac{g}{y}$

g = acceleration of gravity
y = vertical height in inches on the diagram corresponding to 1 foot of pressure change in the conduit. This calibration constant is constant for any particular set of apparatus
Ad = net area in square inches of the pressure-time diagram
S = time constant of the diagram. It is the horizontal length in inches corresponding to 1 sec of time
F = constant of the conduit called the pipe factor If the pipe is of uniform cross section $F = \frac{L}{A}$

133. If the conduit be of nonuniform cross section F is the integration of length divided by area.

$$F = \int \frac{1}{A} \, d\ell$$

where ℓ = length along the conduit in feet

L = distance in feet between the piezometer section and the forebay for simple diagrams or between the two piezometer sections for differential diagrams measured along the center line of flow

A = cross-sectional area of the conduit in square feet

G = leakage past the turbine gates or other device used to create the pressure rise, in cubic feet per second. This leakage shall be measured under the same conditions of closure of the device attained during the test.

134. This method shall be applied only by men trained and experienced in its use.

Appendix B

EXCERPTS FROM

SUPPLEMENT TO

ASME POWER TEST CODE FOR HYDRAULIC PRIME MOVERS

PTC 18-1949

INDEX METHOD OF TESTING

Section 1 - Object and Scope

1. This Code is directed specifically to the formulation of standard and approved practices for making Index Tests on an individual reaction or impulse turbine unit of any type. For the purposes of this code the term "prime movers" will include both reaction turbines and impulse water wheels, and the term "hydraulic turbines" when used in a general sense, also includes both types.

2. This Code is intended to apply only to the Index Method of testing hydraulic turbines, which consists of making a test in which the values of power output and head are measured and in which the quantities of water and velocity head are not measured but are determined relatively for various gate settings and heads as outlined herein.

3. Where the actual test conditions for the method of measurement to be used do not fall within the limits suggested by this code, agreement as to allowable variation from the quantities measured may be reached by conference between representatives of both the purchaser and the manufacturer of the equipment.

Section 2 - Limitations

4. The Index Method of testing shall not be used as an acceptance test of a hydraulic turbine to determine whether it meets the contract guarantees, but may be used for the following:

(a) To determine the characteristics of a turbine for efficient operation in cases where an acceptance test is not made.

(b) To supplement the data obtained from an acceptance test.

(c) To determine the proper cam relationship between wicket gate and runner blade setting of a Kaplan turbine.

(d) To determine the change in efficiency or output of a unit due to wear, erosion, alteration or any other change.

Section 3 - Methods

Turbine Gate Setting

5. The turbine wicket gates shall preferably be blocked at the desired settings during the tests by one of the following methods:

(a) By blocking the governor by means of a load limit.

(b) By blocking the movement of the servomotor pistons with mechanical stops.

(c) By putting the governor on manual control.

The servomotor stroke, or the gate setting as indicated on the governor dial during the test should be recorded.

Water Quantity Determination

6. The relative discharge of the turbine may be determined by one of the following methods at a location where the flow conditions are relatively stable. In all of these methods a coefficient shall preferably be used to estimate the water quantity such that the maximum efficiency of the turbine as calculated using this quantity will be equal to the maximum expected efficiency.

24. Winter-Kennedy Method. The Winter-Kennedy Method or a modification thereof may be used to determine relative discharge if the turbine is encased in a spiral case or a semi-spiral case.

25. Two or more piezometer taps should be located at the measuring section, one at the outer radius of the spiral case and one at an inner radius near the stay ring. The location of the piezometer at the inner radius shall preferably be such that the differential pressure reading between the outer piezometer and the inner piezometer exceeds 1.5 feet of water at maximum turbine discharge at rated head.

26. The piezometer taps shall preferably be installed in accordance with Par. 82 as specified for encased turbines.

27. The discharge shall be taken as a straight line function of the square root of the differential reading.

Head Determination

32. For turbines having closed casings the pressure head may be obtained by use of a calibrated pressure gage connected to a single piezometer in the inlet conduit or by any of the methods under the section of the test code entitled "Measurement of Head".

34. The tailrace elevation may be obtained by reading the tail-water level on a gage board located at some convenient point in the tailrace, or by any of the methods specified under "Measurement of Head" section of the test code.

35. Velocity head corrections may be made using the estimated quantities of water.

Section 4 - Calculation of Results

38. Where Index tests are made before or after an accurate determination of the quantity of water has been made for a limited number of conditions of operation, the method of quantity of water determination used during the Index test shall preferably be calibrated by the accurate water measurements and the coefficients determined by this test may be applied to the water measurements.

39. Where no accurate determination of the quantity of water is made, the Index test method may apply a coefficient to the water measurement such that the maximum turbine efficiency as determined by the Index test corresponds to the maximum expected efficiency of the turbine at best point.

40. Turbine discharge and power output, as determined by the test, may be plotted against the gate setting, and final values of discharge and power output shall preferably be taken from smooth curves drawn through the test points.

(b) To supplement the data obtained from an acceptance test.

(c) To determine the proper cam relationship between wicket gate and runner blade setting of a Kaplan turbine.

(d) To determine the change in efficiency or output of a unit due to wear, erosion, alteration or any other change.

Section 3 - Methods

Turbine Gate Setting

5. The turbine wicket gates shall preferably be blocked at the desired settings during the tests by one of the following methods:

(a) By blocking the governor by means of a load limit.

(b) By blocking the movement of the servomotor pistons with mechanical stops.

(c) By putting the governor on manual control.

The servomotor stroke, or the gate setting as indicated on the governor dial during the test should be recorded.

Water Quantity Determination

6. The relative discharge of the turbine may be determined by one of the following methods at a location where the flow conditions are relatively stable. In all of these methods a coefficient shall preferably be used to estimate the water quantity such that the maximum efficiency of the turbine as calculated using this quantity will be equal to the maximum expected efficiency.

24. Winter-Kennedy Method. The Winter-Kennedy Method or a modification thereof may be used to determine relative discharge if the turbine is encased in a spiral case or a semi-spiral case.

25. Two or more piezometer taps should be located at the measuring section, one at the outer radius of the spiral case and one at an inner radius near the stay ring. The location of the piezometer at the inner radius shall preferably be such that the differential pressure reading between the outer piezometer and the inner piezometer exceeds 1.5 feet of water at maximum turbine discharge at rated head.

26. The piezometer taps shall preferably be installed in accordance with Par. 82 as specified for encased turbines.

27. The discharge shall be taken as a straight line function of the square root of the differential reading.

Head Determination

32. For turbines having closed casings the pressure head may be obtained by use of a calibrated pressure gage connected to a single piezometer in the inlet conduit or by any of the methods under the section of the test code entitled "Measurement of Head".

34. The tailrace elevation may be obtained by reading the tail-water level on a gage board located at some convenient point in the tailrace, or by any of the methods specified under "Measurement of Head" section of the test code.

35. Velocity head corrections may be made using the estimated quantities of water.

Section 4 - Calculation of Results

38. Where Index tests are made before or after an accurate determination of the quantity of water has been made for a limited number of conditions of operation, the method of quantity of water determination used during the Index test shall preferably be calibrated by the accurate water measurements and the coefficients determined by this test may be applied to the water measurements.

39. Where no accurate determination of the quantity of water is made, the Index test method may apply a coefficient to the water measurement such that the maximum turbine efficiency as determined by the Index test corresponds to the maximum expected efficiency of the turbine at best point.

40. Turbine discharge and power output, as determined by the test, may be plotted against the gate setting, and final values of discharge and power output shall preferably be taken from smooth curves drawn through the test points.

Section 5 - Determination of Shape of Cam on Kaplan Turbines

41. The Index Method may be used to determine the proper cam relationship between the wicket gate setting and the setting of the adjustable runner blades of a Kaplan propeller type turbine.

42. The discharge, the power output and the head on the turbine may all be determined in accordance with the methods described under the Index test supplement.

43. Tests shall preferably be made with the runner blades fixed at a minimum of 5 values of tilts. At each of these runner blade settings determination of discharge, power output and head may be made at various wicket gate settings over the range of maximum efficiency for that particular runner blade setting. Not less than five gate settings shall preferably be tested for each blade setting.

44. All tests for a given series of tilts and gate settings shall preferably be made at a constant head, within plus or minus 5%.

Measurement of Head

81. All piezometers shall be so connected with individual valves that they may be read separately.

82. The gages shall, when practicable, be water columns or manometers; and for high pressures shall be mercury manometers, dead-weight gage testers, or calibrated bourdon gages ..... All gage connections shall be tight against leakage ..... If during the test, any piezometer shall be obviously in error due to some local cause or other condition, as indicated by the reading after the addition of the velocity head, showing a total head in excess of the initial available head corresponding to the elevation of the surface of headwater, the source of discrepancy shall be found and removed, or the piezometer shall be eliminated.

Appendix C

EXCERPTS FROM

"IMPROVED TYPE OF FLOW METER FOR HYDRAULIC TURBINES"

By

IREAL A. WINTER

PROCEEDINGS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS,

APRIL 1933

The following notation is used in this appendix:

A = area of scroll case at piezometer section.

C = coefficient of deflection.

D = differential pressure between piezometers.

H = head: H_e = effective pressure head on turbine; H_{v1} = velocity head corresponding to tangential velocity component, V_1; H_{v2} = velocity head corresponding to V_2.

Q = discharge: Q_n = net expected maximum discharge through the piezometer section.

R = a distance measured from the center of the turbine: R_1, R_2, etc. - distances to piezometers; and R_x = distance to center of gravity of piezometer section.

V = velocity: V_1, V_2, etc. - tangential velocity components at piezometers; and V_x = mean velocity at center of gravity of piezometer section.

g = acceleration due to gravity.

k = experimental constant.

m = mass of water flowing at any point in the piezometer section.

n = logarithmic exponent.

The flow lines within the scroll case do not follow definite directions, but are subject to considerable variation. This combination of flows invites an investigation as to their possible effect upon pressures at various points across the section. The following laws of flow are significant:

(a) For radiating currents, the pressure head at any point distance from the center is a function of,

$$R_1V_1 = R_2V_2 \quad \ldots \quad (1)$$

(b) Likewise, for a revolving mass of water in which the stream lines are concentric circles and the total pressure head for each stream line is the same, the pressure head at any distance is a function of Equation (1).

(c) Furthermore, for a revolving mass of water having a radiating flow combined with a circular flow, the pressure head at any distance from the center line of the turbine is a function of Equation (1), for both components of flow, and with positive or negative acceleration.

(d) If no change in direction or relative magnitude of flow takes place within the scroll case, the differential pressure, D, existing between any two points is found to be,

$$D = \frac{V_1^2}{2g} - \frac{V_2^2}{2g} \quad \ldots \quad (2)$$

Therefore, the flow, Q_n, through the scroll at the piezometer section is a function of the square root of the differential pressure, D.

In designing an installation of scroll-case differential-pressure taps, the relation, $R_1V_1 = R_2V_2$, is used as a basis. The velocities, V_1 and V_2, are considered as tangential components of the absolute velocity, and the radii, R_1 and R_2, are their distances from the center of the turbine. This assumption is necessary as the absolute direction of the flow is unknown. Therefore, Equation (2) must take the form of,

$$D = C\left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right) \quad \ldots \quad (3)$$

The coefficient, C, in Equation (3), varies with the ratio of height of scroll case at R_x, the center of gravity of the cross-sectional area, to height of turbine guide vanes - the smaller the ratio, the larger the coefficient. The absolute value of C ranges from 0.75 at the entrance to 1.25 at the last quarter of the scroll.

The quantity of water flowing at the section selected for trial, is determined by assuming the entrance edge of the speed-ring stay-vanes as the orifice of discharge from the scroll case. The total arc of the speed-ring orifice, through which the total discharge, Q, flows, is determined by deducting the thickness of the scroll baffle on a line with the circumference of the stay-vane tip of the speed-ring. The net quantity, Q_n, flowing past the piezometer section is taken as the percentage of orifice circumference past that section. This establishes the net flow to be used in the calculations. The quantity, Q, when used as a basis of design, is always taken as the maximum expected discharge through the turbine. With the net flow and the area of cross-section of the scroll case known, the mean velocity is,

$$V_x = \frac{Q_n}{A} \quad \ldots \quad (4)$$

As shown by the relation, $R_1V_1 = R_2V_2$, the incremental velocities vary inversely as the radii. Hence, the velocity curve from the entrance of the speed-ring to the outer wall of the scroll case takes the form, $y = cx^n$, with the exponent, n, at unity.

For stability of flow, the revolving mass of water must have a common center of gravity. This common center of gravity is assumed to be the center of gravity of the cross-sectional area of the scroll-case section. Then, by the law of constant moment of angular momentum,

$$R_1m\ V_1 = R_2m\ V_2 \quad \ldots \quad (5)$$

the point of mean velocity, R_x, is about the center of gravity of the cross-sectional area. With the point of mean velocity R_x, established, the velocity at any point of the section is determined by the relation of its distance (R_1, R_2, etc.) to the center of the turbine.

Appendix D

Computation Aids

DECIMAL EQUIVALENT CHART

8 THS	16 THS	32 NDS	64 THS	Decimal
			1	.01562
		1		.03125
			3	.04688
	1			.0625
			5	.07812
		3		.09375
			7	.10938
1				.125
			9	.14062
		5		.15625
			11	.17188
	3			.1875
			13	.20312
		7		.21875
			15	.23438
1/4				.25
			17	.26562
		9		.28125
			19	.29688
	5			.3125
			21	.32812
		11		.34375
			23	.35938
3				.375
			25	.39062
		13		.40625
			27	.42188
	7			.4375
			29	.45312
		15		.46875
			31	.48438
1/2				.5
			33	.51562
		17		.53125
			35	.54688
	9			.5625
			37	.57812
		19		.59375
			39	.60938
5				.625
			41	.64062
		21		.65625
			43	.67188
	11			.6875
			45	.70312
		23		.71875
			47	.73438
3/4				.75
			49	.76562
		25		.78125
			51	.79688
	13			.8125
			53	.82812
		27		.84375
			55	.85938
7				.875
			57	.89062
		29		.90625
			59	.92188
	15			.9375
			61	.95312
		31		.96875
			63	.98438
1				1.0

HEAD RATIOS - ONE HALF POWER and THREE HALVES POWER

r	$r^{\frac{1}{2}}$	r 3/2	r	$r^{\frac{1}{2}}$	r 3/2
.950	.9747	.9259	1.000	1.0000	1.0000
.951	.9752	.9274	1.001	1.0005	1.0015
.952	.9757	.9289	1.002	1.0010	1.0030
.953	.9762	.9303	1.003	1.0015	1.0045
.954	.9768	.9318	1.004	1.0020	1.0060
.955	.9773	.9333	1.005	1.0025	1.0075
.956	.9778	.9347	1.006	1.0030	1.0090
.957	.9783	.9362	1.007	1.0035	1.0105
.958	.9788	.9377	1.008	1.0040	1.0120
.959	.9793	.9391	1.009	1.0045	1.0135
.960	.9798	.9406	1.010	1.0050	1.0150
.961	.9804	.9421	1.011	1.0055	1.0165
.962	.9808	.9435	1.012	1.0060	1.0181
.963	.9813	.9450	1.013	1.0065	1.0196
.964	.9819	.9465	1.014	1.0070	1.0211
.965	.9824	.9480	1.015	1.0075	1.0226
.966	.9829	.9494	1.016	1.0080	1.0241
.967	.9834	.9509	1.017	1.0085	1.0256
.968	.9839	.9524	1.018	1.0090	1.0271
.969	.9844	.9539	1.019	1.0095	1.0286
.970	.9849	.9553	1.020	1.0100	1.0301
.971	.9855	.9568	1.021	1.0105	1.0317
.972	.9860	.9583	1.022	1.0110	1.0332
.973	.9865	.9598	1.023	1.0115	1.0347
.974	.9870	.9613	1.024	1.0120	1.0362
.975	.9874	.9627	1.025	1.0125	1.0377
.976	.9879	.9642	1.026	1.0130	1.0393
.977	.9884	.9657	1.027	1.0135	1.0408
.978	.9890	.9672	1.028	1.0140	1.0423
.979	.9895	.9687	1.029	1.0144	1.0438
.980	.9899	.9702	1.030	1.0150	1.0453
.981	.9905	.9716	1.031	1.0154	1.0468
.982	.9910	.9731	1.032	1.0159	1.0484
.983	.9915	.9746	1.033	1.0164	1.0499
.984	.9920	.9761	1.034	1.0169	1.0514
.985	.9925	.9776	1.035	1.0174	1.0530
.986	.9930	.9791	1.036	1.0179	1.0545
.987	.9935	.9806	1.037	1.0184	1.0560
.988	.9940	.9821	1.038	1.0188	1.0575
.989	.9945	.9835	1.039	1.0194	1.0591
.990	.9950	.9850	1.040	1.0200	1.0606
.991	.9955	.9865	1.041	1.0204	1.0622
.992	.9960	.9880	1.042	1.0209	1.0637
.993	.9965	.9895	1.043	1.0213	1.0652
.994	.9970	.9910	1.044	1.0218	1.0667
.995	.9975	.9925	1.045	1.0223	1.0683
.996	.9980	.9940	1.046	1.0228	1.0698
.997	.9985	.9955	1.047	1.0232	1.0713
.998	.9990	.9970	1.048	1.0238	1.0729
.999	.9995	.9985	1.050	1.0247	1.0759

Three-halves Powers of Numbers

No.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
1.0	1.00	1.02	1.03	1.05	1.06	1.08	1.09	1.11	1.12	1.14
1.1	1.15	1.17	1.19	1.20	1.22	1.23	1.25	1.27	1.28	1.30
1.2	1.31	1.33	1.35	1.36	1.38	1.40	1.41	1.43	1.45	1.47
1.3	1.48	1.50	1.52	1.53	1.55	1.57	1.59	1.60	1.62	1.64
1.4	1.66	1.67	1.69	1.71	1.73	1.75	1.76	1.78	1.80	1.82
1.5	1.84	1.86	1.87	1.89	1.91	1.93	1.95	1.97	1.99	2.00
1.6	2.02	2.04	2.06	2.08	2.10	2.12	2.14	2.16	2.18	2.20
1.7	2.22	2.24	2.26	2.28	2.30	2.32	2.34	2.36	2.38	2.40
1.8	2.42	2.44	2.46	2.48	2.50	2.52	2.54	2.56	2.58	2.60
1.9	2.62	2.64	2.66	2.68	2.70	2.72	2.74	2.76	2.79	2.81
2.0	2.83	2.85	2.87	2.89	2.91	2.94	2.96	2.98	3.00	3.02
2.1	3.04	3.06	3.09	3.11	3.13	3.15	3.17	3.20	3.22	3.24
2.2	3.26	3.28	3.31	3.33	3.35	3.38	3.40	3.42	3.44	3.46
2.3	3.49	3.51	3.53	3.56	3.58	3.60	3.63	3.65	3.67	3.70
2.4	3.72	3.74	3.76	3.79	3.81	3.84	3.86	3.88	3.91	3.93
2.5	3.95	3.98	4.00	4.02	4.05	4.07	4.10	4.12	4.14	4.17
2.6	4.19	4.22	4.24	4.27	4.29	4.31	4.34	4.36	4.39	4.41
2.7	4.44	4.46	4.49	4.51	4.54	4.56	4.58	4.61	4.64	4.66
2.8	4.68	4.71	4.74	4.76	4.79	4.81	4.84	4.86	4.89	4.91
2.9	4.94	4.96	4.99	5.02	5.04	5.07	5.09	5.12	5.14	5.17
3.0	5.20	5.22	5.25	5.27	5.30	5.33	5.35	5.38	5.40	5.43
3.1	5.46	5.48	5.51	5.54	5.56	5.59	5.62	5.64	5.67	5.70
3.2	5.72	5.75	5.78	5.80	5.83	5.86	5.89	5.91	5.94	5.97
3.3	6.00	6.02	6.05	6.08	6.10	6.13	6.16	6.19	6.21	6.24
3.4	6.27	6.30	6.32	6.35	6.38	6.41	6.44	6.46	6.49	6.52
3.5	6.55	6.58	6.60	6.63	6.66	6.69	6.72	6.74	6.77	6.80
3.6	6.83	6.86	6.89	6.92	6.94	6.97	7.00	7.03	7.06	7.09
3.7	7.12	7.15	7.18	7.20	7.23	7.26	7.29	7.32	7.35	7.38
3.8	7.41	7.44	7.47	7.50	7.52	7.55	7.58	7.61	7.64	7.67
3.9	7.70	7.73	7.76	7.79	7.82	7.85	7.88	7.91	7.94	7.97

Three-halves Powers of Numbers (Continued)

No.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
4.0	8.00	8.03	8.06	8.09	8.12	8.15	8.18	8.21	8.24	8.27
4.1	8.30	8.33	8.36	8.39	8.42	8.45	8.48	8.52	8.55	8.58
4.2	8.61	8.64	8.67	8.70	8.73	8.76	8.79	8.82	8.86	8.89
4.3	8.92	8.95	8.98	9.01	9.04	9.07	9.10	9.14	9.17	9.20
4.4	9.23	9.26	9.29	9.32	9.36	9.39	9.42	9.45	9.48	9.51
4.5	9.55	9.58	9.61	9.64	9.67	9.71	9.74	9.77	9.80	9.83
4.6	9.87	9.90	9.93	9.96	10.00	10.03	10.06	10.09	10.12	10.16
4.7	10.19	10.22	10.25	10.29	10.32	10.35	10.39	10.42	10.45	10.48
4.8	10.52	10.55	10.58	10.62	10.65	10.68	10.71	10.75	10.78	10.81
4.9	10.85	10.88	10.91	10.95	10.98	11.01	11.05	11.08	11.11	11.15
5.0	11.18	11.21	11.25	11.28	11.31	11.35	11.38	11.42	11.45	11.48
5.1	11.52	11.55	11.59	11.62	11.65	11.69	11.72	11.76	11.79	11.82
5.2	11.86	11.89	11.93	11.96	11.99	12.03	12.06	12.10	12.13	12.17
5.3	12.20	12.24	12.27	12.31	12.34	12.37	12.41	12.44	12.48	12.51
5.4	12.55	12.58	12.62	12.65	12.69	12.72	12.76	12.79	12.83	12.86
5.5	12.90	12.93	12.97	13.00	13.04	13.07	13.11	13.15	13.18	13.22
5.6	13.25	13.29	13.32	13.36	13.39	13.43	13.47	13.50	13.54	13.57
5.7	13.61	13.64	13.68	13.72	13.75	13.79	13.82	13.86	13.90	13.93
5.8	13.97	14.00	14.04	14.08	14.11	14.15	14.19	14.22	14.26	14.29
5.9	14.33	14.37	14.40	14.44	14.48	14.51	14.55	14.59	14.62	14.66
6.0	14.70	14.73	14.77	14.81	14.84	14.88	14.92	14.95	14.99	15.03
6.1	15.07	15.10	15.14	15.18	15.21	15.25	15.29	15.33	15.36	15.40
6.2	15.44	15.48	15.51	15.55	15.59	15.62	15.66	15.70	15.74	15.78
6.3	15.81	15.85	15.89	15.93	15.96	16.00	16.04	16.08	16.12	16.15
6.4	16.19	16.23	16.27	16.30	16.34	16.38	16.42	16.46	16.50	16.53
6.5	16.57	16.61	16.65	16.69	16.72	16.76	16.80	16.84	16.88	16.92
6.6	16.96	16.99	17.03	17.07	17.11	17.15	17.19	17.22	17.26	17.30
6.7	17.34	17.38	17.42	17.46	17.50	17.54	17.58	17.62	17.65	17.69
6.8	17.73	17.77	17.81	17.85	17.89	17.93	17.97	18.01	18.05	18.09
6.9	18.12	18.16	18.20	18.24	18.28	18.32	18.36	18.40	18.44	18.48

Three-halves Powers of Numbers (Continued)

No.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
7.0	18.52	18.56	18.60	18.64	18.68	18.72	18.76	18.80	18.84	18.88
7.1	18.92	18.96	19.00	19.04	19.08	19.12	19.16	19.20	19.24	19.28
7.2	19.32	19.36	19.40	19.44	19.48	19.52	19.56	19.60	19.64	19.68
7.3	19.72	19.76	19.80	19.85	19.89	19.93	19.97	20.01	20.05	20.09
7.4	20.13	20.17	20.21	20.25	20.29	20.33	20.38	20.42	20.46	20.50
7.5	20.54	20.58	20.62	20.66	20.70	20.75	20.79	20.83	20.87	20.91
7.6	20.95	20.99	21.03	21.08	21.12	21.16	21.20	21.24	21.28	21.32
7.7	21.37	21.41	21.45	21.49	21.53	21.58	21.62	21.66	21.70	21.74
7.8	21.78	21.83	21.87	21.91	21.95	21.99	22.04	22.08	22.12	22.16
7.9	22.20	22.25	22.29	22.33	22.37	22.42	22.46	22.50	22.54	22.58
8.0	22.63	22.67	22.71	22.75	22.80	22.84	22.88	22.93	22.97	23.01
8.1	23.05	23.10	23.14	23.18	23.22	23.27	23.31	23.35	23.40	23.44
8.2	23.48	23.52	23.57	23.61	23.65	23.70	23.74	23.78	23.83	23.87
8.3	23.91	23.96	24.00	24.04	24.09	24.13	24.17	24.22	24.26	24.30
8.4	24.35	24.39	24.43	24.48	24.52	24.56	24.61	24.65	24.69	24.74
8.5	24.78	24.83	24.87	24.91	24.96	25.00	25.04	25.09	25.13	25.18
8.6	25.22	25.26	25.31	25.35	25.40	25.44	25.48	25.53	25.57	25.62
8.7	25.66	25.71	25.75	25.79	25.84	25.88	25.93	25.97	26.02	26.06
8.8	26.10	26.15	26.19	26.24	26.28	26.33	26.37	26.42	26.46	26.51
8.9	26.55	26.60	26.64	26.69	26.73	26.78	26.82	26.87	26.91	26.96
9.0	27.00	27.04	27.09	27.14	27.18	27.23	27.27	27.32	27.36	27.41
9.1	27.45	27.50	27.54	27.59	27.63	27.68	27.72	27.77	27.81	27.86
9.2	27.90	27.95	28.00	28.04	28.09	28.13	28.18	28.22	28.27	28.32
9.3	28.36	28.41	28.45	28.50	28.54	28.59	28.64	28.68	28.73	28.77
9.4	28.82	28.87	28.91	28.96	29.00	29.05	29.10	29.14	29.19	29.23
9.5	29.28	29.33	29.37	29.42	29.47	29.51	29.56	29.61	29.65	29.70
9.6	29.74	29.79	29.84	29.88	29.93	29.98	30.02	30.07	30.12	30.16
9.7	30.21	30.26	30.30	30.35	30.40	30.44	30.49	30.54	30.58	30.63
9.8	30.68	30.73	30.77	30.82	30.87	30.91	30.96	31.01	31.06	31.10
9.9	31.15	31.20	31.24	31.29	31.34	31.38	31.43	31.48	31.53	31.58

<u>Three-halves Powers of Numbers</u> (<u>Continued</u>)

No.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
10.0	31.62	31.67	31.72	31.77	31.81	31.86	31.91	31.96	32.00	32.05
10.1	32.10	32.15	32.19	32.24	32.29	32.34	32.38	32.43	32.48	32.53
10.2	32.58	32.62	32.67	32.72	32.77	32.82	32.86	32.91	32.96	33.01
10.3	33.06	33.10	33.15	33.20	33.25	33.30	33.35	33.39	33.44	33.49
10.4	33.54	33.59	33.64	33.68	33.73	33.78	33.83	33.88	33.93	33.98
10.5	34.02	34.07	34.12	34.17	34.22	34.27	34.32	34.36	34.41	34.46
10.6	34.51	34.56	34.61	34.66	34.71	34.76	34.80	34.85	34.90	34.95
10.7	35.00	35.05	35.10	35.15	35.20	35.25	35.30	35.24	35.39	35.44
10.8	35.49	35.54	35.59	35.64	35.69	35.74	35.79	35.84	35.89	35.94
10.9	35.99	36.04	36,09	36.14	36.18	36.23	36.28	36.33	36.38	36.43
11.0	36.48	36.53	36.58	36.63	36.68	36.73	36.78	36.83	36.88	36.93
11.1	36.98	37.03	37.08	37.13	37.18	37.23	37.28	37.33	37.38	37.43
11.2	37.48	37.53	37.58	37.63	37.68	37.73	37.78	37.83	37.88	37.94
11.3	37.99	38.04	38.09	38.14	38.19	38.24	38.29	38.34	38.39	38.44
11.4	38.49	38.54	38.59	38.64	38.69	38.74	38.80	38.85	38.90	38.95
11.5	39.00	39.05	39.10	39.15	39.20	39.25	39.30	39.36	39.41	39.46
11.6	39.51	39.56	39.61	39.66	39.71	39.76	39.82	39.87	39.92	39.97
11.7	40.02	40.07	40.12	40.17	40.23	40.28	40.33	40.38	40.43	40.48
11.8	40.53	40.59	40.64	40.69	40.74	40.79	40.84	40.90	40.95	41.00
11.9	41.05	41.10	41.15	41.21	41.26	41.31	41.36	41.41	41.47	41.52
12.0	41.57	41.62	41.67	41.72	41.78	41.83	41.88	41.93	41.99	42.04
12.1	42.09	42.14	42.19	42.25	42.30	42.35	42.40	42.45	42.51	42.56
12.2	42.61	42.66	42.72	42.77	42.82	42.87	42.93	42.98	43.03	43.09
12.3	43.14	43.19	43.24	43.30	43.35	43.40	43.45	43.51	43.56	43.61
12.4	43.66	43.72	43.77	43.82	43.88	43.93	43.98	44.04	44.09	44.14
12.5	44.19	44.25	44.30	44.35	44.41	44.46	44.51	44.56	44.62	44.67
12.6	44.73	44.78	44.83	44.89	44.94	44.99	45.05	45.10	45.15	45.21
12.7	45.26	45.31	45.37	45.42	45.47	45.53	45.58	45.63	45.69	45.74
12.8	45.79	45.85	45.90	45.96	46.01	46.06	46.12	46.17	46.22	46.28
12.9	46.33	46.39	46.44	46.49	46.55	46.60	46.66	46.71	46.76	46.82

Three-halves Powers of Numbers (Continued)

No.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
13.0	46.87	46.93	46.98	47.03	47.09	47.14	47.20	47.25	47.31	47.36
13.1	47.41	47.47	47.52	47.58	47.63	47.69	47.74	47.79	47.85	47.90
13.2	47.96	48.01	48.07	48.12	48.18	48.23	48.28	48.34	48.39	48.45
13.3	48.50	48.56	48.61	48.67	48.72	48.78	48.83	48.89	48.94	49.00
13.4	49.05	49.11	49.16	49.22	49.27	49.33	49.38	49.44	49.49	49.55
13.5	49.60	49.66	49.71	49.77	49.82	49.88	49.93	49.99	50.04	50.10
13.6	50.15	50.21	50.26	50.32	50.37	50.43	50.48	50.54	50.59	50.65
13.7	50.71	50.76	50.82	50.87	50.93	50.99	51.04	51.10	51.15	51.21
13.8	51.26	51.32	51.38	51.43	51.49	51.54	51.60	51.66	51.71	51.77
13.9	51.82	51.88	51.93	51.99	52.05	52.10	52.16	52.21	52.27	52.33
14.0	52.38	52.44	52.50	52.55	52.61	52.66	52.72	52.78	52.83	52.89
14.1	52.95	53.00	53.06	53.11	53.17	53.23	53.28	53.34	53.40	53.45
14.2	53.51	53.57	53.63	53.68	53.74	53.79	53.85	53.91	53.96	54.02
14.3	54.08	54.13	54.19	54.25	54.30	54.36	54.42	54.47	54.53	54.59
14.4	54.64	54.70	54.76	54.81	54.87	54.93	54.98	55.04	55.10	55.16
14.5	55.21	55.27	55.33	55.39	55.44	55.50	55.56	55.61	55.67	55.73
14.6	55.79	55.84	55.90	55.96	56.02	56.07	56.13	56.19	56.25	56.30
14.7	56.36	56.42	56.48	56.53	56.59	56.65	56.71	56.76	56.82	56.88
14.8	56.94	56.99	57.05	57.11	57.17	57.23	57.28	57.34	57.40	57.46
14.9	57.51	57.57	57.63	57.69	57.75	57.80	57.86	57.92	57.98	58.04
15.0	58.09	58.15	58.21	58.27	58.33	58.38	58.44	58.50	58.56	58.62
15.1	58.68	58.73	58.79	58.85	58.91	58.97	59.03	59.09	59.14	59.20
15.2	59.26	59.32	59.38	59.44	59.49	59.55	59.61	59.67	59.73	59.79
15.3	59.85	59.90	59.96	60.02	60.08	60.14	60.20	60.26	60.32	60.38
15.4	60.43	60.49	60.55	60.61	60.67	60.73	60.79	60.85	60.91	60.96
15.5	61.02	61.08	61.14	61.20	61.26	61.32	61.38	61.44	61.50	61.56
15.6	61.62	61.67	61.73	61.79	61.85	61.91	61.97	62.03	62.09	62.15
15.7	62.21	62.27	62.33	62.39	62.45	62.51	62.57	62.62	62.68	62.74
15.8	62.80	62.86	62.92	62.98	63.04	63.10	63.16	63.22	63.28	63.34
15.9	63.40	63.46	63.52	63.58	63.64	63.70	63.76	63.82	63.88	63.94

Three-halves Powers of Numbers (Continued)

No.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
16.0	64.00	64.06	64.12	64.18	64.24	64.30	64.36	64.42	64.48	64.54
16.1	64.60	64.66	64.72	64.78	64.84	64.90	64.96	65.02	65.08	65.14
16.2	65.20	65.26	65.32	65.38	65.45	65.51	65.57	65.63	65.69	65.75
16.3	65.81	65.87	65.93	65.99	66.05	66.11	66.17	66.23	66.29	66.35
16.4	66.41	66.48	66.54	66.60	66.66	66.72	66.78	66.84	66.90	66.96
16.5	67.02	67.08	67.15	67.21	67.27	67.33	67.39	67.45	67.51	67.57
16.6	67.63	67.69	67.76	67.82	67.88	67.94	68.00	68.06	68.12	68.18
16.7	68.25	68.31	68.37	68.43	68.49	68.55	68.61	68.67	68.74	68.80
16.8	68.86	68.92	68.98	69.04	69.11	69.17	69.23	69.29	69.35	69.41
16.9	69.48	69.54	69.60	69.66	69.72	69.78	69.85	69.91	69.97	70.03
17.0	70.09	70.15	70.22	70.28	70.34	70.40	70.46	70.53	70.59	70.65
17.1	70.71	70.77	70.84	70.90	70.96	71.02	71.08	71.15	71.21	71.27
17.2	71.33	71.40	71.46	71.52	71.58	71.64	71.71	71.77	71.83	71.89
17.3	71.96	72.02	72.08	72.14	72.21	72.27	72.33	72.39	72.46	72.52
17.4	72.58	72.64	72.71	72.77	72.83	72.89	72.96	73.02	73.08	73.14
17.5	73.21	73.27	73.33	73.40	73.46	73.52	73.58	73.65	73.71	73.77
17.6	73.84	73.90	73.96	74.03	74.09	74.15	74.21	74.28	74.34	74.40
17.7	74.47	74.53	74.59	74.66	74.72	74.78	74.85	74.91	74.97	75.04
17.8	75.10	75.16	75.22	75.29	75.35	75.41	75.48	75.54	75.60	75.67
17.9	75.73	75.80	75.86	75.92	75.99	76.05	76.11	76.18	76.24	76.30
18.0	76.37	76.43	76.49	76.56	76.62	76.69	76.75	76.81	76.88	76.94
18.1	77.00	77.07	77.13	77.20	77.26	77.32	77.39	77.45	77.52	77.58
18.2	77.64	77.71	77.77	77.84	77.90	77.96	78.03	78.09	78.16	78.22
18.3	78.28	78.35	78.41	78.48	78.54	78.61	78.67	78.73	78.80	78.86
18.4	78.93	78.99	79.06	79.12	79.18	79.25	79.31	79.38	79.44	79.51
18.5	79.57	79.64	79.70	79.77	79.83	79.89	79.96	80.02	80.09	80.15
18.6	80.22	80.28	80.35	80.41	80.48	80.54	80.61	80.67	80.74	80.80
18.7	80.87	80.93	81.00	81.06	81.13	81.19	81.26	81.32	81.39	81.45
18.8	81.51	81.58	81.64	81.71	81.78	81.84	81.91	81.97	82.04	82.10
18.9	82.17	82.23	82.30	82.36	82.43	82.49	82.56	82.62	82.69	82.75

Three-halves Powers of Numbers (Continued)

No.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
15	58.1	58.7	59.3	59.8	60.4	61.0	61.6	62.2	62.8	63.4
16	64.0	64.6	65.2	65.8	66.4	67.0	67.6	68.2	68.9	69.5
17	70.1	70.7	71.3	72.0	72.6	73.2	73.8	74.5	75.1	75.7
18	76.4	77.0	77.6	78.3	78.9	79.6	80.2	81.0	81.5	82.2
19	82.8	83.5	84.1	84.8	85.4	86.1	86.8	87.4	88.1	88.8
20	89.4	90.1	90.8	91.5	92.1	92.8	93.5	94.2	94.9	95.6
21	96.2	96.9	97.6	98.3	99.0	99.7	100.4	101.1	101.8	102.5
22	103.2	103.9	104.6	105.3	106.0	106.7	107.4	108.2	108.9	109.6
23	110.3	111.0	111.8	112.5	113.2	113.9	114.6	115.4	116.1	116.8
24	117.6	118.3	119.0	119.8	120.5	121.3	122.0	122.8	123.5	124.3
25	125.0	125.8	126.5	127.3	128.0	128.8	129.5	130.3	131.0	131.8
26	132.6	133.3	134.1	134.8	135.6	136.4	137.2	138.0	138.7	139.5
27	140.3	141.1	141.8	142.6	143.4	144.2	145.0	145.8	146.6	147.4
28	148.2	149.0	149.8	150.6	151.4	152.2	153.0	153.8	154.6	155.4
29	156.2	157.0	157.8	158.6	159.4	160.2	161.0	161.9	162.7	163.5
30	164.3	165.1	166.0	166.8	167.6	168.4	169.3	170.1	170.9	171.8
31	172.6	173.4	174.3	175.1	176.0	176.8	177.6	178.5	179.3	180.2
32	181.0	181.9	182.7	183.6	184.4	185.3	186.1	187.0	187.8	188.7
33	189.6	190.4	191.3	192.2	193.0	193.9	194.8	195.6	196.5	197.4
34	198.2	199.1	200.0	200.9	201.8	202.6	203.5	204.4	205.3	206.2
35	207.1	208.0	208.8	209.7	210.6	211.5	212.4	213.3	214.2	215.1
36	216.0	216.9	217.8	218.7	219.6	220.5	221.4	222.3	223.2	224.2
37	225.1	226.0	226.9	227.8	228.7	229.6	230.5	231.5	232.4	233.3
38	234.2	235.2	236.1	237.0	238.0	238.9	239.8	240.7	241.7	242.6
39	243.5	244.4	245.4	246.4	247.3	248.3	249.2	250.1	251.1	252.0
40	253.0	253.9	254.9	255.8	256.8	257.7	258.7	259.6	260.6	261.6
41	262.5	263.5	264.5	265.4	266.4	267.3	268.3	269.3	270.2	271.2
42	272.2	273.2	274.1	275.1	276.1	277.1	278.0	279.0	280.0	281.0
43	282.0	283.0	283.9	284.9	285.9	286.9	287.9	288.9	289.9	290.9
44	291.9	292.9	293.9	294.9	295.9	296.9	297.9	298.9	299.9	300.9

Three-halves Powers of Numbers (Continued)

No.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
45	301.9	302.9	303.9	304.9	305.9	306.9	307.9	308.9	310.0	311.0
46	312.0	313.0	314.0	315.0	316.1	317.1	318.1	319.1	320.2	321.2
47	322.2	323.2	324.3	325.3	326.3	327.4	328.4	329.4	330.5	331.5
48	332.6	333.6	334.6	335.7	336.7	337.8	338.8	339.9	340.9	342.0
49	343.0	344.1	345.1	346.2	347.2	348.3	349.3	350.4	351.4	352.5
50	353.6	354.6	355.7	356.7	357.8	358.8	359.9	361.0	362.1	363.1
51	364.2	365.3	366.4	367.4	368.5	369.6	370.7	371.7	372.8	373.9
52	375.0	376.1	377.1	378.2	379.3	380.4	381.5	382.6	383.7	384.8
53	385.8	386.9	388.0	389.1	390.2	391.3	392.4	393.5	394.6	395.7
54	396.8	397.9	399.0	400.1	401.2	402.3	403.4	404.6	405.7	406.8
55	407.9	409.0	410.1	411.2	412.4	413.5	414.6	415.7	416.8	417.9
56	419.1	420.2	421.3	422.4	423.6	424.7	425.8	426.9	428.1	429.2
57	430.3	431.5	432.6	433.7	434.9	436.0	437.2	438.3	439.4	440.6
58	441.7	442.9	444.0	445.1	446.3	447.4	448.6	449.7	450.9	452.0
59	453.2	454.3	455.5	456.6	457.8	459.0	460.1	461.3	462.4	463.6
60	464.8	465.9	467.1	468.3	469.4	470.6	471.7	472.9	474.1	475.3
61	476.4	477.6	478.8	479.9	481.1	482.3	483.5	484.7	485.8	487.0
62	488.2	489.4	490.6	491.7	492.9	494.1	495.3	496.5	497.7	498.9
63	500.0	501.2	502.4	503.6	504.8	506.0	507.2	508.4	509.6	510.8
64	512.0	513.2	514.4	515.6	516.8	518.0	519.2	520.4	521.6	522.8
65	524.0	525.3	526.5	527.7	528.9	530.1	531.3	532.5	533.8	535.0
66	536.2	537.4	538.6	539.8	541.1	542.3	543.5	544.7	546.0	547.2
67	548.4	549.6	550.9	552.1	553.3	554.6	555.8	557.0	558.2	559.5
68	560.7	562.0	563.2	564.5	565.7	566.9	568.2	569.4	570.7	571.9
69	573.2	574.4	575.7	576.9	578.2	579.4	580.7	581.9	583.2	584.4
70	585.7	586.9	588.2	589.4	590.7	591.9	593.2	594.5	595.7	597.0
71	598.3	599.5	600.8	602.1	603.3	604.6	605.9	607.1	608.4	609.7
72	610.9	612.2	613.5	614.8	616.0	617.3	618.6	619.9	621.2	622.4
73	623.7	625.0	626.3	627.6	628.8	630.1	631.4	632.7	634.0	635.3
74	636.6	637.9	639.2	640.4	641.7	643.0	644.3	645.6	646.9	648.2

Three-halves Powers of Numbers (Continued)

No.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
75	649.5	650.8	652.1	653.4	654.7	656.0	657.3	658.6	659.9	661.2
76	662.6	663.9	665.2	666.5	667.8	669.1	670.4	671.7	673.0	674.4
77	675.7	677.0	678.3	679.6	680.9	682.3	683.6	684.9	686.2	687.6
78	688.9	690.2	691.5	692.9	694.2	695.5	696.8	698.2	699.5	700.8
79	702.2	703.5	704.8	706.2	707.5	708.8	710.2	711.5	712.9	714.2
80	715.5	716.9	718.2	719.6	720.9	722.3	723.6	725.0	726.3	727.7
81	729.0	730.4	731.7	733.1	734.4	735.8	737.1	738.5	739.8	741.2
82	742.5	743.9	734.3	746.6	748.0	749.3	750.7	752.0	753.4	754.8
83	756.2	757.5	758.9	760.3	761.7	763.0	764.4	765.8	767.1	768.5
84	769.9	771.2	772.6	774.0	775.4	776.8	778.1	779.5	780.9	782.3
85	783.7	785.0	786.4	787.8	789.2	790.6	792.0	793.4	794.8	796.1
86	797.5	798.9	800.3	801.7	803.1	804.5	805.9	807.3	808.7	810.1
87	811.5	812.9	814.3	815.7	817.1	818.5	819.9	821.3	822.7	824.1
88	825.5	826.9	828.3	829.7	831.1	832.6	834.0	835.4	836.8	838.2
89	839.6	841.0	842.5	843.9	845.3	846.7	848.1	849.5	851.0	852.4
90	853.8	855.2	856.7	858.1	859.5	860.9	862.4	863.8	865.2	866.7
91	868.1	869.5	870.9	872.4	873.8	875.2	876.7	878.1	879.6	881.0
92	882.4	883.9	885.3	886.8	888.2	889.6	891.1	892.5	894.0	895.4
93	896.9	898.3	899.7	901.2	902.6	904.1	905.6	907.0	908.5	909.9
94	911.4	912.8	914.3	915.7	917.2	918.6	920.1	921.6	923.0	924.5
95	925.9	927.4	928.9	930.3	931.8	933.2	934.7	936.2	937.7	939.1
96	940.6	942.1	943.5	945.0	946.5	948.0	949.4	950.9	952.4	953.9
97	955.3	956.8	958.3	959.8	961.3	962.7	964.2	965.7	967.2	968.7
98	970.2	971.6	973.1	974.6	976.1	977.6	979.1	980.6	982.1	983.5
99	985.0	986.5	988.0	989.5	991.0	992.5	994.0	995.5	997.0	998.5
100	1000.0	1001.5	1003.0	1004.5	1006.0	1007.5	1009.0	1010.5	1012.0	1013.5
101	1015.0	1016.5	1018.1	1019.6	1021.1	1022.6	1024.1	1025.6	1027.1	1028.6
102	1030.1	1031.7	1033.2	1034.7	1036.2	1037.7	1039.3	1040.8	1042.3	1043.8
103	1045.3	1046.9	1048.4	1049.9	1051.4	1053.0	1054.5	1056.0	1057.5	1059.1
104	1060.6	1062.1	1063.7	1065.2	1066.7	1068.3	1069.8	1071.3	1072.9	1074.4

Three-halves Powers of Numbers (Continued)

No.	0	1	2	3	4	5	6	7	8	9
100	1000	1015	1030	1045	1061	1076	1091	1107	1122	1138
110	1154	1170	1185	1201	1217	1233	1249	1266	1282	1298
120	1315	1331	1348	1364	1381	1398	1414	1431	1448	1465
130	1482	1499	1517	1534	1551	1569	1586	1604	1621	1639
140	1657	1674	1692	1710	1728	1746	1764	1782	1800	1819
150	1837	1856	1874	1893	1911	1930	1948	1967	1986	2005
160	2024	2043	2062	2081	2100	2119	2139	2158	2178	2197
170	2217	2236	2256	2275	2295	2315	2335	2355	2375	2395
180	2415	2435	2455	2476	2496	2516	2537	2557	2578	2598
190	2619	2640	2660	2681	2702	2723	2744	2765	2786	2807
200	2828	2850	2871	2893	2914	2935	2957	2978	3000	3021
210	3043	3065	3087	3109	3131	3153	3175	3197	3219	3241
220	3263	3285	3308	3330	3353	3375	3398	3420	3443	3465
230	3488	3511	3534	3557	3580	3603	3626	3649	3672	3695
240	3718	3741	3765	3788	3811	3835	3858	3882	3906	3929
250	3953	3977	4000	4024	4048	4072	4096	4120	4144	4168
260	4192	4217	4241	4265	4289	4314	4338	4363	4387	4412
270	4437	4461	4486	4511	4536	4560	4585	4610	4635	4660
280	4685	4710	4736	4761	4786	4811	4837	4862	4888	4913
290	4939	4964	4990	5015	5041	5067	5093	5118	5144	5170
300	5196	5222	5248	5274	5300	5327	5353	5379	5405	5432
310	5458	5485	5511	5538	5564	5591	5617	5644	5671	5698
320	5724	5751	5778	5805	5832	5859	5886	5913	5940	5968
330	5995	6022	6049	6077	6104	6132	6159	6186	6214	6242
340	6269	6297	6325	6352	6380	6408	6436	6464	6492	6520
350	6548	6576	6604	6632	6660	6689	6717	6745	6774	6802
360	6831	6859	6888	6916	6945	6973	7002	7031	7059	7088
370	7117	7146	7175	7204	7233	7262	7291	7320	7349	7378
380	7408	7437	7466	7495	7525	7554	7584	7613	7643	7672
390	7702	7732	7761	7791	7821	7850	7880	7910	7940	7970

Three-halves Powers of Numbers (Continued)

No.	0	1	2	3	4	5	6	7	8	9
400	8000	8030	8060	8090	8120	8150	8181	8211	8241	8272
410	8302	8332	8363	8393	8424	8454	8485	8516	8546	8577
420	8608	8638	8669	8700	8731	8762	8793	8824	8855	8886
430	8917	8948	8979	9010	9041	9073	9104	9135	9167	9198
440	9230	9261	9293	9324	9356	9387	9419	9451	9482	9514
450	9546	9578	9610	9642	9674	9705	9737	9770	9802	9834
460	9866	9898	9930	9963	9995	10027	10060	10092	10124	10157
470	10189	10222	10254	10287	10320	10352	10385	10418	10451	10483
480	10516	10549	10582	10615	10648	10681	10714	10747	10780	10813
490	10847	10880	10913	10946	10980	11013	11046	11080	11113	11147
500	11180	11214	11247	11281	11315	11348	11382	11416	11450	11484
510	11517	11551	11585	11619	11653	11687	11721	11755	11789	11824
520	11858	11892	11926	11961	11995	12029	12064	12098	12133	12167
530	12202	12236	12271	12305	12340	12375	12409	12444	12479	12514
540	12548	12583	12618	12653	12688	12723	12758	12793	12828	12863
550	12899	12934	12969	13004	13040	13075	13110	13146	13181	13217
560	13252	13288	13323	13359	13394	13430	13466	13501	13537	13573
570	13609	13644	13680	13716	13752	13788	13824	13860	13896	13932
580	13968	14004	14041	14077	14113	14149	14186	14222	14258	14295
590	14331	14368	14404	14440	14477	14514	14550	14587	14624	14660

Appendix E

INDEX TEST DATA SHEETS

TITLE AND PURPOSE OF INDEX TEST DATA SHEETS

Title	Purpose
"Differential Manometer Data"	Tabulation of readings obtained from a given leg of the differential manometer used during index test.
"Differential Manometer Data-Summary Sheet"	Tabulation of the readings obtained from the high pressure leg of the differential manometer and tabulation of the average reading of the low pressure leg and differential pressure where only one combination of spiral case piezometer is used during a turbine index test.
"Generator Output Data"	Tabulation of pertinent data obtained from watt-hour meter on the generator switchboard to determine the generator output during a turbine index test.
"Electrical Data"	Tabulation of electrical data for determination of the total electrical losses during a turbine index test.
"Blade Angle Measurement"	Tabulation of oil head reading "Y" for determination of the blade angle during a particular test run.
"Gate Servomotor Stroke"	Tabulation of wicket gate servomotor stroke to determine the gate opening for the particular test run.
"Forebay Elevation"	Tabulation of pool elevation during each test run.

Title	Purpose
"Tailwater Elevation"	Tabulation of tailwater elevation during each test run.
"Net Head Manometer"	Tabulation of net head data to determine head loss.
"Summary Sheet"	Summary of pertinent data obtained during a turbine index test to facilitate computations.

TURBINE INDEX TEST DATA

__________Powerhouse Unit No.______ ______Head Test

Differential Manometer Data - Low Pressure Piezometer No.____

Date________ Observer__________ Sheet____ of ____

Run No.										
Time										
Averages										
Run No.										
Time										
Averages										
Run No.										
Time										
Averages										

TURBINE INDEX TEST DATA

__________________Powerhouse Unit No.________ ______Head Test

Differential Manometer Data - Summary Sheet - High Pressure Piezometer No.____

Date__________ Observer______________ Sheet____ of ____

Run No.										
Averages										
Differential										
Run No.										
Averages										
Differential										
Run No.										
Averages										
Differential										

TURBINE INDEX TEST DATA

_________________Powerhouse   Unit No.________   ______Head Test

Generator Output Data

Date_________   Observer_____________   Sheet____ of ____

$$KW = \quad\quad \times \frac{\text{No. of Revs.}}{\text{Sec.}}$$

Run No.	Time	No. of Revs.	Time Secs	Output KW	Run No.	Time	No. of Revs.	Time Secs	Output KW

TURBINE INDEX TEST DATA

_______________ Powerhouse   Unit No. _______   ______ Head Test

Electrical Data

Date ________   Observer ____________   Sheet ___ of ___

Run No.	Time	Generator						Main Exciter			Total Losses
		Indicated			Calculated			Indicated		Losses	
		KV	Amps	KW	KVA	PF	Loss KW	Volts	Amps	KW	KW

TURBINE INDEX TEST DATA

________________Powerhouse Unit No._______ _____Head Test

Blade Angle Measurement

Date________ Observer_____________ Sheet___ of ___

Run No.	Time	Oil Head "Y"	Run No.	Time	Oil Head "Y"	Run No.	Time	Oil Head "Y"

TURBINE INDEX TEST DATA

___________________Powerhouse Unit No.________ ______Head Test

Gate Servomotor Stroke

Date_________ Observer______________ Sheet____ of ____

Run No.	Time	Scale Inches	Stroke Inches	Stroke Decimal Inches	Run No.	Time	Scale Inches	Stroke Inches	Stroke Decimal Inches

TURBINE INDEX TEST DATA

_______________ Powerhouse   Unit No. _______   _____ Head Test

Forebay Elevation

Date _______   Observer ___________   Sheet ___ of ___

Run No.	Time	Gage Reading	Pool Elev	Run No.	Time	Gage Reading	Pool Elev

TURBINE INDEX TEST DATA

________________ Powerhouse Unit No. _______ ______ Head Test

Tailwater Elevation

Date ________ Observer _____________ Sheet ____ of ____

Run No.	Time	Gage Reading	T.W. Elev.	Run No.	Time	Gage Reading	T.W. Elev.

TURBINE INDEX TEST DATA

______________Powerhouse Unit No.________ _____Head Test

Net Head Manometer

Date_______ Observer____________ Sheet___ of ___

Run No.	Time	Gage Reading	Elev Feet	Run No.	Time	Gage Reading	Elev Feet

TURBINE INDEX TEST DATA

_______________Powerhouse   Unit No._______________   ________Head Test

Summary Sheet

Date____________   (Francis, Kaplan Turbine)   Sheet____ of ____

Run No.	Time	Blade Angle Deg	% Gate Stroke	Elevations		Head		Generator Output			"D" Ft. of Water
				Pool Ft msl	T.W. Ft msl	Gross Ft	Net Ft	Revs	Secs	KW	

Appendix F

INDEX TESTING

COMPUTATIONS AND CURVES

INSTRUCTIONS

Step 1	Compile test data on computation form. See example - "Computations"
Step 2	Compute $\sqrt{D}$, square root of Column (5), and enter in Column (6).
Step 3	Compute KW/H, Column (7) divided by Column (4) and enter in Column (8).
Step 4	Compute $KW/H\sqrt{D}$, Column (8) divided by Column (6) and enter in Column (9).
Step 5	Compute $\sqrt{H}$, square root of Column (4). Enter in Column (10).
Step 6	Compute $\sqrt{D/H}$. Column (6) divided by Column (10) and enter in Column (11).
Step 7	Determine $H^{3/2}$ and enter in Column (12). See Appendix D for table of 3/2 powers of numbers.
Step 8	Compute $KW/H^{3/2}$. Divide Column (7) by Column (12) and enter in Column (13). Note: Column (7) is MW.
Step 9	Compute (Hc/Hn) where Hc is common head and Hn is net head during run. Enter in Column (14).
Step 10	Compute $(Hc/Hn)^{1/2}$, square root of Column (14) and enter in Column (15). See Appendix D for table of head ratio powers.
Step 11	Compute $(Hc/Hn)^{3/2}$ and enter in Column (16). See Appendix D for table of head ratio powers.

TURBINE INDEX TEST DATA

__________ Powerhouse Unit No.__________ __________ Head Test

Computations

Date__________ Sheet ____ of ____

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
													Common Head, H_o =				
Run No.	Blade Angles Deg	% Gate Stroke	Net Head H_n Feet	D	$\sqrt{D}$	Gen Output MW	$\frac{KW}{H}$	$\frac{KW}{H\sqrt{D}}$	$\sqrt{H}$	$\sqrt{D/H}$	$H^{3/2}$	$\frac{KW}{H^{3/2}}$	$\frac{H_o}{H_n}$	$\left(\frac{H_o}{H_n}\right)^{\frac{1}{2}}$	$\left(\frac{H_o}{H_n}\right)^{\frac{3}{2}}$	$\sqrt{D}$	MW

Step 12

Compute adjusted relative discharge, $\sqrt{D}$. Multiply Column (6) by Column (15) and enter in Column (17).

Step 13

Compute adjusted generator output. Multiply Column (7) by Column (16) and enter in Column (18).

Step 14

Plot "Relative Efficiency - KW/H $\sqrt{D}$" and "Gate Stroke in Inches" versus Variables as shown below. Each set of curves should be plotted on a separate sheet.

Curve Sheet	Variable
1	Generator Output in MW
2	$\sqrt{D/H}$
3	$KW/H^{3/2}$
4	$\sqrt{D}$

a. Plot the data on each sheet and draw smooth curves for each blade angle. Correlate all curves on a "Correlation Form" as included herein.

b. Draw an envelope curve tangent to the upper set of fixed-blade curves. This curve is the relative efficiency and is the same shape as the actual efficiency curve.

c. Project the points of tangency of the envelope curve and the fixed blade angle curve down to the lower set of curves. Connect these points with a smooth curve to obtain the ideal cam curve, i.e. the cam curve which would give the efficiencies shown by the envelope curve.

d. Check to insure that the corresponding points tabulated on the "Correlation Form" are the same on each curve sheet. If they are not, adjust the curves until they are in agreement.

TURBINE INDEX TEST DATA

____________ Powerhouse   Unit No.______   _____ Head Test

Correlation Form

Date________   Sheet ___ of ___

Maximum Relative Efficiency - $KW/H\sqrt{D}$

Blade Angle	$KW/H\sqrt{D}$ vs			
	Adj. MW	$\sqrt{D/H}$	$KW/H^{3/2}$	$\sqrt{D}$
Envelope Curve				

Point of Tangency of Fixed Blade Angle to Envelope Curve

Blade Angle	$KW/H\sqrt{D}$ vs			
	Adj. MW	$\sqrt{D/H}$	$KW/H^{3/2}$	$\sqrt{D}$

Ideal Gate Stroke in Inches

Blade Angle	$KW/H\sqrt{D}$ vs			
	Adj. MW	$\sqrt{D/H}$	$KW/H^{3/2}$	$\sqrt{D}$

Step 15

From inspection of the curves completed in Step 14 determing the maximum relative efficiency, $KW/H\sqrt{D}$ and the unit power, $KW/H^{3/2}$ at which it occurs. Enter these values on a computation sheet similar to the one titled "Piezometer Calibration Constant - 'C'."

Step 16

Determine the value of "C" in accordance with the steps listed on the computation sheet.

Step 17

Determine efficiencies and discharges on computation form similar to example.

a. Enter head in feet in Column (1).

b. Select values of Generator Output at which efficiencies and discharges are desired and enter in Column (2).

c. Determine $KW/H\sqrt{D}$ from Curve Sheet 4 and enter in Column (3).

d. Determine overall efficiency. Multiply Column (3) by 11.82/C (a constant).

e. Add generator loss to Column (2) and enter in Column (5).

f. Determine turbine output in horsepower. Multiply Column (5) by 1.34048 and enter in Column (6).

g. Divide Column (5) by Column (2) and enter in Column (7).

h. Determine turbine efficiency. Multiply Column (4) by Column (7) and enter in Column (8).

i. Multiply Column (1) by Column (3) and enter in Column (9).

j. Determine relative discharge. Divide Column (2) by Column (9) and enter in Column (10).

k. Determine discharge. Multiply Column (10) by "C" and enter in Column (11).

TURBINE INDEX TEST DATA

__________ Powerhouse   Unit No. ______   _____ Head Test

Piezometer Calibration Constant - "C"

Date ________   Sheet ___ of ___

Head, H = ________ $H^{3/2}$ = ________

Maximum $KW/H\sqrt{D}$ = ________ at $KW/H^{3/2}$ = ________

Maximum Turbine Efficiency, E_t = [ ]

Generator Output in KW = $\left(\frac{KW}{H^{3/2}}\right)\left(H^{3/2}\right)$ = ________

Generator Loss, L_g = ________

$KW + L_g$ = [ ]

Head Loss, L_p = ________

$H - L_p$ = [ ]

Relative Discharge, $\sqrt{D} = \left(\frac{KW}{H}\right)\left(\frac{H\sqrt{D}}{KW}\right)$ = [ ]

$$"C" = \frac{11.82\,(KW + L_g)}{E_t\,(H-L_p)\,\sqrt{D}}$$

$$= \frac{11.82\,(\qquad\qquad)}{(\qquad)(\qquad)(\qquad)}$$

= __________

TURBINE INDEX TEST DATA

__________ Powerhouse   Unit No. __________   ______ Head Test

Efficiencies and Discharges

Date__________   Sheet ____ of ____   "C" = ________   11.82/"C" = ________

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Head	KW	$\frac{KW}{H\sqrt{D}}$	$E_o = \frac{11.82\ KW}{CH\sqrt{D}}$	$KW + L_g$	HP	$\frac{KW + L_g}{KW}$	$E_t = \left(\frac{KW + L_g}{KW}\right)\left(\frac{KW}{H\sqrt{D}}\right)\left(\frac{11.82}{C}\right)$	$H\left(\frac{KW}{H\sqrt{D}}\right)$	$\sqrt{D} = \frac{KW}{H\left(\frac{KW}{H\sqrt{D}}\right)}$	$Q = C\sqrt{D}$

Step 18 — Plot Turbine Efficiency, Overall Efficiency and Power-Discharge curves.

Step 19 — Determine Power and Discharge vs. Gate Opening on computation form similar to example.

a. Enter run number in Column (1).

b. Enter blade angle in Column (2).

c. Enter gate servomotor stroke in Column (3).

d. Enter total stroke in Column (4).

e. Divide Column (3) by Column (4) and enter in Column (5).

f. Enter $\sqrt{D}$ in Column (6).

g. Determine discharge. Multiply Column (6) by "C" and enter in Column (7).

h. Enter generator output in Column (8).

Note: If it is desired that these values be obtained at certain gate strokes such gate strokes should be entered in Column (3) and values of $\sqrt{D}$ and Generator Output determined from appropriate curve sheets and entered in Columns (6) and (8) respectively. Columns (1) and (2) would be left blank.

Step 20 — Plot Power and Discharge vs Gate Opening curves.

FOR KAPLAN-TYPE TURBINES

Step 21 — Plot Optimum Blade - Gate - Head Relationship. This would be a family of curves of "Head in Feet" plotted against "Wicket Gate Servomotor Stroke in Inches" with "Blade Angle" as the parameter.

Step 22 — Plot Cam Curves. This would be a family of curves of "Runner Blade Servomotor Stroke in Inches" plotted against "Wicket Gate Servomotor Stroke in Inches" with "Gross Head" as the parameter.

TURBINE INDEX TEST DATA

________________Powerhouse   Unit No.________   _____Head Test

Power and Discharge vs. Gate Opening

Date________   Sheet ____ of ____

(1) Run Number	(2) Blade Angle	(3) Servo Stroke	(4) Total Stroke	(5) Percent Stroke	(6) $\sqrt{D}$	(7) $Q = C\sqrt{D}$	(8) Gen Output

a. Select the values of head for the cam curves.

b. Determine the gate stroke for the value of head from the curve of Step 21.

c. Determine the runner blade stroke for the blade angle from calibration data.

d. Plot curves.

Step 23

Determine settings for cams.

a. Choose cam and gate opening.

b. Determine gate stroke for particular opening.

c. Determine blade stroke from curve of Step 22.

d. Assume equal overtravel at each end of blade stroke.

(1) Determine difference in "Y" between flat and steep overtravel.

(2) Adjust "Y" by one-half the difference of Step 23 d. (1) above and maximum blade stroke.

e. Determine "Oil Head Reference - Y" for point in question by subtracting the blade stroke in Step 23 c. from the adjusted "Y" for flat overtravel determined from Step 23 d. (2).

f. Determine values at another gate opening as a check on the cam settings.

TURBINE TESTING BY THE GIBSON AND INDEX MET