HYDRO-ELECTRIC POWER STATIONS

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APPENDIX III

STANDARD TESTING CODE FOR HYDRAULIC TURBINES

THE following Code has been prepared by a Committee of the Hydraulic Turbine Manufacturers to assist in avoiding misunderstandings in regard to stipulated performances of hydraulic turbines. It is subject to such revision from time to time as will be required by any new developments in turbine testing methods. The reader is also referred to the draft of the American Society for Mechanical Engineers' Code, published in *Mechanical Engineering*, for April, 1922.

INTRODUCTION

1. Intended Scope. Hydraulic turbine tests are of two distinct kinds: First, acceptance tests on completed turbines after installation in the power plant; second, experimental tests either on full-sized turbines or models, carried out at manufacturers' laboratories or at a testing flume. Tests of the first kind are for the purpose of determining the fulfillment or nonfulfillment of contracts between the turbine builders and the purchasers. Tests of the second kind are carried out for the purpose of obtaining experimental data on which the design of an installation may be based; for scientific research work; or for the investigation of special problems. This code is intended to apply only to tests of the first kind. When tests of the second kind are used for determining the performance of a full-sized installation, this application should be made only in accordance with principles which will be stated in section 10, below.

2. Principal Factors, Meaning and Intent of Terms Used. 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 transformers, 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.

For the purpose of computing the plant efficiency the total or gross head acting on the plant is to be used, and is to be taken as the difference in elevation between the equivalent still-water surface before the water has passed through the racks, to 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 actual elevation of the water surface shall be increased by the amount of this velocity head. The same process shall apply to the point of measurement in the tailrace; that is, the velocity head at the point of measurement in the tailrace shall be added to the actual elevation of the surface, the sum being considered the equivalent still-water elevation.

Except where specifically stated herein, 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 the turbine, the losses through the racks, in the intake to the penstocks, and in the penstocks shall not be charged against the turbine; nor shall the head necessary to set up the velocity required to discharge the water from the end of the draft tube be charged against the turbine. The net or effective head acting on the turbine shall be measured from a point near the intake to the turbine casing in turbines equipped with casings, or from a point immediately over the turbine in turbines having an open-flume setting, to a point in the tailrace in the manner set forth below under the heading "Measurement of Head." Since the turbine cannot develop power without discharging water, a correction for the velocity head required to discharge the water into the tailrace shall be added to the tailwater elevation; and a similar correction applied at the intake to encased turbines, as called for under the heading "Measurement of Head." The power developed by the turbine shall be taken as the mechanical power delivered on the turbine shaft and transmitted by the turbine shaft to the generator or other driven machine or system.

In drawing up a general code it is recognized that under particular circumstances sometimes occurring, methods of measuring or computing certain factors entering into the test different from those specified, may appear possible and reasonable; it is, however, the intent of this code that the meaning of the terms efficiency, effective head, etc., shall be the efficiency, effective head, etc., determined as herein specified, and that such terms shall be understood only as thus defined.

General

3. Inspection. Careful inspection should be made before, during, and after the tests to insure the proper operation of the turbine and conditions of measurement.

The turbine runner, guide vanes, and casing should be inspected before and after test to guard against obstructions clogging the vanes. Any change in performance during a test should be investigated.

4. Operating Conditions During Test. Apparatus installed for the purpose of the test shall not affect the performance of the turbine during the test. When any doubt exists regarding this point, a special experiment shall be carried out to detect any effect of removing and replacing the apparatus in question, other conditions being maintained constant.

The unit shall be in normal operating condition throughout the test, and shall have been operated under load for an aggregate time of at least three days prior to the test.

4. (*a*) **Leakage.** Care should be taken that all air inlets into the draft tube are closed, and that leakage of air into the tube or drawing of air into the penstock intake is not taking place, as indicated by excessive amounts of air in the discharge, or presence of vortices in the intake. Precautions against leakage of water from penstock or turbine casing should be taken, particularly through drain valves, relief valves or other connections. The rate of fall of the standing water surface in the turbine casing below the point of intake through the turbine gates should be observed during shutdown as an indication of possible leakage.

(*b*) **Unsteady Conditions.** Tests should not be made under conditions of changing head, load or speed. Variations of load during an individual run shall not exceed 3 per cent above or 3 per cent below the average load, and variations of head shall not exceed 2 per cent above or 2 per cent below the average head, and variations of speed shall not exceed 1 per cent above or 1 per cent below the average speed. Instrument calibrations and correction curves should be prepared in advance of the test, and measures taken to enable results to be computed as quickly as possible during the course of the test or before the work of testing shall be considered to have been completed.

5. Calibration of Instruments. Important instruments shall be installed in duplicate and all instruments shall be calibrated both before and after the test. Only the readings of those instruments in which the two calibrations agree shall be used in computing the results. Where results are appreciably altered by reason of instrument calibrations made after the test disagreeing with those made before, the test shall be repeated.

6. Conduct of Test. Both parties to the contract shall be represented and shall have equal rights in determining the methods and conduct of the test.

All points of disagreement shall be settled to the satisfaction of both parties, and the results of the test be agreed on as acceptable, before the test shall be considered terminated or the test equipment removed.

The measurement of the various quantities entering into the computation of turbine power and efficiency shall be in accordance with the following regulations:

Measurement of Power Output

7. (*a*) **By Electrical Measurement of Generator Output and Generator Losses.** In turbines direct-connected to electrical generators the power output of the turbine may be measured as provided below.

The intent of the provisions contained herein is that the power output of the turbine shall be taken as the power output of the generator plus all losses supplied by the turbine up to the point of measurement.

The generator may be tested for efficiency either in the shops of the builder or after installation, the losses being determined either by direct measurement of input and output or by the separate-loss method; the electrical measurements being carried out in accordance with the Standardization Rules of the American Institute of Electrical Engineers of September, 1916, but subject to the provisions contained herein.

The generator losses and efficiency as herein defined are for the generator considered as a dynamometer, and are independent of the performance guarantees of the generator which are not within the scope of this code. The generator efficiency shall be determined for the values of load, power factor, temperature or other conditions existing during the turbine test. When the generator is run during the turbine test at speeds different from that used in the generator test, the generator efficiency shall be corrected for the changes in speed.

When practicable, the generator is to be separately excited during both generator and turbine tests, and the excitation loss is not to be included in computing generator efficiency, and is therefore also to be omitted in computing turbine output during the turbine test.

When determined by the separate-loss method, the generator efficiency in the case of polyphase alternators when separately excited is to be taken as

$$= \frac{\text{(Kilowatt Output at Generator Terminals)}}{\left\{\begin{matrix}\text{Kilowatt}\\\text{Output}\end{matrix}\right\} + \left\{\begin{matrix}I^2R\text{ ar-}\\\text{mature}\end{matrix}\right\} + \left\{\begin{matrix}\text{Open cir-}\\\text{cuit core}\\\text{loss}\end{matrix}\right\} + \left\{\begin{matrix}\text{Stray Load-}\\\text{Losses}\end{matrix}\right\} + \left\{\begin{matrix}\text{Generator}\\\text{windage}\\\text{and friction}\end{matrix}\right\}}$$

all losses being expressed in kilowatts.

The stray load-losses are to be determined, in accordance with Paragraph 458 of the above Standardization Rules of the A.I.E.E., by operating the generator on short-circuit and at the current corresponding to the load to be used in turbine test. This, after deducting the windage and friction and I^2R loss, gives the stray load-loss, the total amount of the loss so determined being included in the above formula, in place of $\frac{1}{2}$ or $\frac{1}{3}$ of this value as sometimes used in former practice. It is, however, understood that whenever under the special conditions of an installation other losses exist, these are to be added, in accordance with the second paragraph of this subdivision, to the stray load losses determined as here given.

The value of generator windage and friction should be directly measured in the shop, or after installation. In units containing direct-connected exciters, the windage and friction may be measured by driving the generator by the exciter run as a motor. When the windage and friction cannot be directly measured, it is to be taken either from shop tests of generators of similar design or from a retardation test made after installation. When possible more than one method should be used in order to obtain a check.

In making such a retardation test, the turbine shaft and runner, or the turbine runner, are to be disconnected when practicable from the generator shaft, in order to enable the windage and friction of the generator alone to be computed. When the turbine shaft or runner cannot be disconnected, the generator windage and friction are to be computed by deducting from the total windage and friction that of the turbine, which for this purpose may be found with sufficient accuracy from the formula:

Turbine windage and friction in kw. $= KBD^4N^3$, in which

B = height of distributor in feet;
D = entrance diameter of runner in feet;
N = revolutions per second;
K = an empirical coefficient which may be taken as 0.000115 as determined from available test data.

In computing the turbine output in the turbine test, this is to be taken as the kilowatt output of generator divided by the generator efficiency as computed above, the result being converted from kilowatts to horse-power.

If an exciter generator is also mounted on the unit shaft and is used to excite the unit under test, then to the output of the main generator computed as above without reference to excitation there is to be added the kilowatt output of exciter divided by the exciter efficiency, this converted to horse-power. It is recommended, however, for simplicity that when possible the exciter shall be run without load and the unit separately excited.

It is recommended to avoid retests and to provide a reliable check, that the electrical instruments used in all tests be installed in duplicate. These instruments, together with the instrument transformers, shall be calibrated both before and after the tests in the same condition as used in the tests. When tests are made under slightly fluctuating loads, the output shall be determined both by indicating wattmeters, read at short intervals, and by recording watt-hour meters. During the turbine test the speed of the unit shall be observed by accurately calibrated tachometer or by revolution counter.

(*b*) **By Absorption Dynamometer.** When a dynamometer, either of the Prony brake, friction disc, or other type, is used, the dynamometer is to be so arranged as to avoid imposing either end thrust or side thrust on the turbine shaft and bearings, or to avoid adding any friction load which is not measured.

The brake must be capable of operating with the weighing beam floating free of the stops during the entire duration of a run. A dash pot or equivalent device may be used to assist this action if so arranged that the accuracy of measuring the actual torque acting on the turbine shaft is not impaired.

The dynamometer must be so constructed that the lengths of all lever arms used for transmitting and reducing the loads can be accurately measured. The zero load of the dynamometer must be capable of accurate measurement and should not be large in comparison with the net load to be measured.

When power is determined by dynamometer, particular care is to be used in obtaining accurate measurement of the speed of the shaft. If tachometers are used these are to be frequently calibrated by counting the revolutions over an ample length of time. Under usual conditions it is recommended that the speed be directly measured by revolution counter, a tachometer being also used as a check and to indicate variations in speed during a run.

Measurement of Power Input or Water Horse-power

8. Measurement of Head. The intent of the provisions contained herein for the measurement of head is the true determination of the difference between the total energy contained in the water immediately before its entrance into the turbine, and its total energy immediately after its discharge from the draft tube.

The turbine shall be tested if possible under the effective head stated in the contract, and at the speed specified in the contract. If during the test, however, the effective head shall differ from the specified head by an amount not exceeding 10 per cent of the latter, the speed of operation of the turbine shall be adjusted to correspond to the head under which the test is made. The principle is recognized and accepted that if the speed is changed in proportion to the square root of the head, the horse-power output will change in proportion to the three-halves power of the head, and the turbine efficiency will remain the same; that is, when the head differs from the value specified in the contract, the contract guarantees shall be considered to apply if the hydraulic equivalents of the power and speed of the turbines are substituted for the power and speed enumerated in the contract. The hydraulic equivalent of the speed is equal to the specified speed multiplied by the square root of the ratio of the effective head existing during the test to the specified effective head. The hydraulic equivalent of the horse-power is equal to the specified horse-power, multiplied by the three-halves power of the ratio of the effective head existing during the test to the specified effective head.

The test shall not be carried out if the head differs from the contract value by more than 10 per cent either above or below, or if, due to an excess of the head above the contract value, or to a reduction in tailwater elevation, the total draft head approaches within 5 feet of the limiting value corresponding to the barometric height. By total draft head is meant the height of the centerline of the distributor of vertical turbines, or of the highest point of the discharge space of the runner of horizontal turbines above tailwater, added to the velocity head at the point of minimum internal diameter of the runner band.

If during the test it is not practicable to adjust the speed, or if the final calculation should show the speed to have been incorrectly adjusted to suit the head, provided that the discrepancy in speed does not exceed 2 per cent either way from the correct value, the values of power and efficiency shown by the test shall be corrected on the basis of the test curves, of the same or a homologous turbine, made at a testing flume or on a wheel tested in place according to the methods of this code, when such curves are available.

(*a*) **Encased Turbines.** In turbines having closed casings the head is to be measured by at least two, and when possible not less than four piezometers located in a straight portion of the penstock near the turbine casing intake, and by two or more rod or float gauges in the tailrace, placed at points reasonably free from local disturbances.

Such board, rod or float gauges are to be free of velocity effects, and if this is not obtainable when the gauges are set in the open channel, they shall be placed in properly arranged stilling boxes.

All piezometers shall be connected to separate gauges. The conditions of measurement, including velocity distribution, length of straight run of penstock, and conditions of piezometer orifices shall be such that no piezometer shall vary in its readings by more than 20 per cent of the velocity head from the average of all the piezometers in the section of measurement. The piezometer orifices shall be flush with the surface of the penstock wall, the passages shall be normal to the wall, and the wall shall be smooth and parallel with the flow in the vicinity of the orifices. The piezometer orifices shall be approximately $\frac{1}{4}$ inch in diameter. If any piezometer shall be obviously in error due to some local cause or other condition, as indicated by its reading, after the addition of the velocity head, giving a head in excess of the initial available head corresponding to the elevation of the surface of headwater, the source of the discrepancy shall be found and removed, or the piezometer eliminated.

When stilling boxes are used in the tailrace the communication between the box and channel shall consist of one or more piezometer openings in a plane surface parallel to the flow, in order to avoid velocity effects. When board gauges are used at the side of the channel, they shall be flush with the wall surface.

The effective head on the turbine is to be taken as the difference between the elevation corresponding to the pressure in the penstock near the entrance to the turbine casing, and the elevation of the tailwater at the highest point attained by the discharge from the unit under test, the above difference being corrected by adding the velocity head in the penstock at the point of measurement and subtracting the residual velocity head at the end of the draft tube. The velocity head in the penstock shall be taken as the square of the mean velocity at the point of measurement, divided by $2g$; the mean velocity being equal to the quantity of water flowing in cubic feet per second, divided by the cross-sectional area of the penstock at the point of measurement in square feet. The residual velocity head at the end of the draft tube shall be taken as the square of the mean velocity at the end of the draft tube, divided by $2g$, the mean velocity being equal to the quantity flowing in cubic feet per second, divided by the final cross-sectional discharge area of the closed or submerged portion of the draft tube in square feet.

(*b*) **Open Flume Setting.** In the case of turbines set in open flumes, the head is to be measured by board, rod or float gauges located immediately above the center of the turbine, and by board, rod or float gauges in the tailrace, all gauges being placed at points reasonably free from local disturbances, and not less than two gauges being installed in the flume and not less than two in the tailrace.

Such gauges are to be free of velocity effects, and if this is not obtainable when the gauges are set in the open channel, they shall be placed in properly arranged stilling boxes. When stilling boxes are used, the communication between the box and channel shall consist of one or more piezometer openings in a plane surface parallel to the flow, in order to avoid velocity effects. When board gauges are used at the side of the channel, they shall be flush with the wall surface.

The effective head on the turbine is to be taken as the difference between the elevation of the free water surface immediately above the center of the turbine, and the elevation of the tailwater at the highest point attained by the discharge from the unit under test, the above difference being corrected by subtracting the residual velocity head at the end of the draft tube. The residual velocity head at the end of the draft tube shall be taken as the square of the mean velocity at the end of the draft tube, divided by $2g$; the mean velocity being equal to the quantity flowing in cubic feet per second, divided by the final cross-sectional discharge area of the closed or submerged portion of the draft tube, in square feet.

Measurement of Quantity of Water

9. The quantity of water discharged from the turbine is to be measured by one of the following methods. It is recommended that whenever possible more than one of these methods be used, the quantity being taken as the average of the results of two or more simultaneous measurements.

(*a*) **By Weir.** When the quantity of water is measured by weir, weirs with suppressed end contractions shall be used.

The weir or weirs shall if possible be located on the tailrace side of the turbine, and care shall be taken that smooth flow, free from eddies, surface disturbances or the presence of considerable quantities of air in suspension exists in the channel of approach. To insure this condition the weir should not be located too close to the end of the draft tube, and stilling racks and booms should be used when required. The channel of approach should be straight, of uniform cross-section and should be unobstructed by racks and booms, for a length of at least 25 feet from the crest. The racks should be arranged to give approximately uniform velocity across the channel of approach. The uniformity of velocity should be verified by current meter or otherwise.

The head on the weir should be observed by hook gauges placed in stilling boxes communicating through orifices approximately 1 inch in diameter in the sides of the channel of approach, approximately 1 foot below the level of the crest and a distance of not less than 5 or more than 10 times the head upstream therefrom, the head being observed independently at both sides of the channel. In measuring quantities of water corresponding to the loads on which the turbine guarantees are based, the head on the crest shall not be more than two (2) feet or less than one (1) foot, and the velocity of approach shall not be greater than 1 foot per second.

TABLE OF VALUES OF C FOR VARIOUS HEADS AND HEIGHTS OF CREST P

Head h in Feet.	Height of Crest P.										
	4	5	6	7	8	9	10	12	14	16	20
1.0	3.376	3.356	3.344	3.335	3.329	3.325	3.322	3.317	3.314	3.311	3.308
1.2	3.391	3.366	3.350	3.339	3.332	3.326	3.322	3.316	3.311	3.308	3.305
1.4	...	3.379	3.359	3.346	3.336	3.330	3.324	3.316	3.311	3.307	3.303
1.6	...	...	3.370	3.354	3.343	3.334	3.328	3.319	3.312	3.308	3.302
1.8	...	...	...	3.363	3.350	3.340	3.333	3.322	3.315	3.309	3.303
2.0	...	...	...	...	3.358	3.347	3.338	3.325	3.317	3.311	3.304

The discharge shall be computed by the Francis formula in the form given below, using the accompanying table of coefficients. These coefficients are believed to represent the best available information. The values of turbine efficiency resulting from weir tests made in accordance with this code are understood to be efficiencies computed by the use of the formula and coefficients here given.

$$Q = CLh^{3/2},$$

where Q = quantity in cubic feet per second;
L = length of weir in feet;
h = observed head above crest in feet.

P is the height of the crest above the bottom of the channel of approach in feet.

To facilitate computations, all corrections for velocity of approach have been included within the coefficients as given; these are therefore to be used in the formula stated above, the observed head being used without modification.

Note: The above coefficients are the averages of values computed by the following three formulas:

(1) Bazin,

$$Q = \left(0.405 + \frac{0.00984}{h}\right)\left[1 + 0.55\,\frac{h^2}{(p+h)^2}\right]\sqrt{2g}\,Lh^{3/2};$$

(2) Rehbock,

$$Q = \left[0.605 + \frac{1}{320h - 3} + 0.08\,\frac{h}{p}\right]\frac{2}{3}\sqrt{2g}\,Lh^{3/2};$$

(3) Fteley-Stearns,

$$Q = 3.31L(h + 1.5h_v)^{3/2} + 0.007L,$$

in which h_v = head due to velocity of approach.

The weir shall be sharp crested, with smooth, vertical crest wall, complete crest contraction, and free overfall. Complete aeration of the nappe shall be secured and observation of the crest conditions and form of nappe shall be made during the test to avoid defective conditions such as adhering nappe, disturbed or turbulent flow, or surging. The sidewalls of the channel shall be smooth and parallel and shall extend downstream beyond the overfall above the level of the crest.

Weirs of a length exceeding approximately twenty times the head (excepting in cases where the velocity of approach is extremely low); or weirs of moderate crest length having high velocities of approach; or those in which the velocity of approach is irregularly distributed, or in which the leading channel is subject to action of the wind, should either be subdivided into a number of sections or the head should be observed not only at both sides but also at intermediate points across the channel of approach. The elevation of the crest should be measured at short intervals of its length in determining the zero readings of the hook gauges.

(*b*) **By Current Meter.** When the discharge is measured by current meter, observations shall be taken by two different types of meter, one type having preferably such characteristics that it will slightly over-register under conditions of turbulent or oblique flow, and the other type having characteristics such that it will under-register under similar conditions. The true velocity obtained by reducing the meter readings on the basis of their still-water ratings may then be taken as a weighted mean between the two series of observations.

As a basis for arriving at the proper weighting of diverging meter results, the instruments in question should, in addition to their regular still-water ratings, be given simultaneous oscillation or angularity tests at several velocities near those which will probably be experienced during tests. By means of the resulting data, curves showing the over- and under-registering characteristics of each meter may be plotted for varying degrees of obliquity or velocities of oscillation. The total deviation of the two meters may then be noted for any obliquity or lateral velocity. When the relative deviation of the two meters is observed in the field, the curves will then indicate the proportions in which the total deviation should be divided to give the proper correction for each meter.

The point method of observation shall be used and sufficient points shall be obtained to enable both vertical and horizontal velocity curves to be plotted for all portions of the section of measurement. The average velocity shall be determined from these curves by planimeter.

The section of measurement shall be rectangular and smooth flow conditions shall be obtained. It is recommended that in order to avoid abnormally long durations of run a number of meters of each type be used simultaneously. The elevation of water shall be continuously observed during the current meter measurement by stilling boxes, piezometers, or other reliable means. If the supporting rods for the meters are in the same plane as the meters, the area of these rods shall be subtracted from the wetted area of the flume in calculating the quantity. The meter should preferably be supported by rods placed a sufficient distance behind them to avoid any obstructive effect. When a heavy mast or supporting frame is used, it should be designed to offer a minimum disturbance, and should be located several feet downstream from the meters.

(*c*) **By Pitot Tube.** When the Pitot tube method is used, the Pitot tube shall be located in a straight run of penstock or conduit, at a distance equal to at least ten pipe diameters from any upstream bend and at least five diameters from a downstream bend. When the observation is made in a circular pipe or penstock, at least two Pitot tubes shall be arranged to traverse two relatively perpendicular diameters, but in the case of very large penstocks or those having unsymmetrical flow, Pitot tubes shall be arranged to traverse completely or partially the intermediate diameters, giving traverses at forty-five degree intervals.

In determining the velocity in the penstock by the Pitot tubes the static pressure over the cross-section shall be measured by from four to eight carefully constructed piezometers equally spaced around the wall of the penstock at a section 1 foot in advance of the Pitot tube section to avoid the effect of the Pitot tube supporting structure, the penstock being of uniform cross-section between the piezometers and the points of the Pitot tubes. All piezometers shall be connected to separate gauges. The conditions of measurement, including velocity distribution, length of straight run of penstock, and condition of piezometer orifices shall be such that no piezometer shall vary in its readings by more than 10 per cent of the velocity head from the average of all the piezometers. The piezometer orifices shall be flush with the inside surface of the penstock wall, the passages shall be normal to the wall, and the wall shall be smooth and parallel with the flow in the vicinity of the orifices. The orifices shall be $\frac{1}{8}$ inch in diameter.

The velocity at each point in the penstock shall be computed by the formula $V = \sqrt{2gh}$, in which h represents the difference in feet between the total dynamic pressure recorded by the Pitot tube at that point and the average static pressure recorded by the piezometers. The velocities so determined shall be plotted as ordinates against values of the areas of the sections of the penstock corresponding to the points of measurement as abscissas, a smooth curve being drawn through the points obtained. The mean velocity in the penstock will then be taken as the mean ordinate of the above curve multiplied by 0.976. This coefficient is based on the average of various comparative tests, and is required to correct for oblique or sinuous flow under the usual conditions in straight penstocks.

When the length of straight run of penstock is insufficient or when the flow is disturbed by a severe bend or obstruction upstream from the tube or when the average velocity is less than 5 feet per second, the above coefficient will not apply correctly, the correct value being considerably lower in such cases, which do not, therefore, come within the scope of this code. The coefficient corresponds to a tube, the point of which is $\frac{3}{8}$ inch in diameter with a $\frac{1}{8}$ inch hole, the face being normal to the axis, and at least 3 inches from the nearest surface of the supporting pipe.

(*d*) **By the Screen or Diaphragm Method.** When the screen method is used a sufficient length of straight flume of uniform cross-section shall be constructed with a close-fitting screen filling the cross-section. Provision shall be made for accurately observing the velocity of the screen, preferably by electric contacts and chronograph. The length of run of the screen shall be sufficiently in excess of the portion used for measurement to provide ample space for starting and stopping the screen, so as to insure uniform conditions over the measured portion of the run. In determining the discharge the velocity of the screen shall be multiplied by an area intermediate between the net immersed area of the moving screen and the average area of stream cross-section of the portion of the channel traversed. The variation of the level in the flume shall be observed during the course of the run and the average elevation shall be used in determining the area.

(*e*) **By Titration or Chemical Method.** When the chemical method is used in measuring discharge, care shall be taken to insure that at the point of introducing the dosing solution no portion of the solution shall be carried off by back currents and shall therefore fail to pass to the sampling station, and that the sampling station shall be so placed that no pollution shall be caused by reverse currents, causing fresh water to pass the station from downstream. When necessary, owing to a short length of mixing passage or lack of sufficient disturbance to cause thorough mixing, the dosing pipes shall be so placed that an equal degree of concentration over the entire section of the sampling station shall be obtained. Samples shall be taken from points distributed over the entire sampling section. All necessary precautions shall be observed in taking samples, and in observing the end-point of the reaction during titration.

In short tests, care shall be taken to preserve a uniform rate of introduction of the dosing solution. Preliminary observations shall be made to determine the time required after the dosing is started for uniform conditions to become established at the sampling station; and in the actual tests the dosing shall be continued for double this time before sampling is begun. Uniformity of dilution of samples both with respect to location in the section and the time of taking shall be considered essential for an acceptable test.

Power Tests of Turbine Supplemented by Efficiency Tests of a Model

10. When the conditions of an installation are such as to involve serious difficulty or expense in the application of any of the above methods of water measurement, the tests of the installed turbine may be made when acceptable to both parties without measuring the quantity of water, a homologous model of the turbine being constructed and tested at the expense of the purchaser, and the power delivered by the installed turbine compared with that computed from the model tests.

This method must not be confused with the practice, which has sometimes been followed, of comparing a turbine with a model having a homologous runner, but dissimilar with respect to setting, draft tube or other parts. The runner, guide vanes, draft tube, casing, or other adjacent water passages should be geometrically similar in the turbine and model; and when so constructed, the power stepped up from the model tests for the hydraulic equivalent of the speed gives a reliable basis of comparison with the power actually obtained from the installed unit.

The power of the model when operating at the hydraulic equivalent of the speed of the large unit in the tests of the latter, at the same proportional gate opening, is to be multiplied by the ratio of the area of the discharge orifices of the large turbine runner to that of the model, and by the three-halves power of the ratio of the head existing in the tests of the large unit to the head in the model tests. When the power so computed agrees exactly with that obtained from the installed unit, the efficiency of the large unit shall be considered to be identical with that of the model; and when the power of the large unit exceeds that thus computed from the model, the efficiency of the large unit shall be considered to be in excess of that of the model. In measuring the gate opening the actual opening of the gates shall be determined, and care shall be taken to avoid errors due to the effect of the pressure on the vanes.

Appendix

11. Special Methods of Water Measurement. The following methods of water measurements may sometimes be applied; these are, however, subject to limitations, and are available only under special conditions. They have not as a rule been in sufficiently general use in turbine testing to permit full reliance to be placed on them until opportunities are afforded for checking them against the methods already given.

(*a*) **By the Bulk or Volumetric Method.** Water measurement by weight or volume is not usually available; the former is limited to laboratory use, which is outside the scope of this code. The bulk method is applicable only when there is available a reservoir of regular form, the volume of which up to various water levels may be accurately measured, and when the following conditions may be observed:

The draw-down or filling of the reservoir must not cause a variation in head on the turbine during a run exceeding the limits specified under section 4 (*b*), namely, a total of 4 per cent of the head. It must be possible to shut off completely all inflow into or outflow from the reservoir. The tightness of the gates and reservoir walls must be tested by closing all gates, and observing over a time of several hours the rate of rise or fall of water level in the reservoir throughout the full range of variation of level which will be used in the turbine test. At the same time any leakage through the turbine head gates is to be measured. The surface elevation in the reservoir is not to be so affected by velocity or wind effects as to cause local variations in level of more than 5 per cent of the total draw-down used in the turbine tests. This variation is to be observed by gauges distributed over the whole reservoir, which are to be read simultaneously at short intervals throughout the test. The effect of surface evaporation shall be investigated and corrections applied to cover it when local conditions are such that it becomes appreciable.

(*b*) **By Venturi Meter.** When it is possible to install a Venturi meter not exceeding in dimensions or differing in conditions from meters whose coefficients have previously been determined in accurate tests, the Venturi meter may be used. The meter shall be similar in proportions to meter previously tested.

(*c*) **By Color Velocity Method.** When the water used by the turbine passes through a conduit suited to the purpose, the color method of quantity determination may be used, depending upon the time of passage between two points of a mass of color injected into the stream. The distance between the two points where the passage of the color is observed must be sufficiently great to render the interval between the times of passage of the color at the two stations large compared to the time required for all the color to pass either station. The conduit must be of sufficiently regular form to permit its cross-sectional areas to be accurately measured at all points between the stations.

(*d*) **By Brine Velocity Method.** A method similar to 11 (*c*) adapted to closed conduits has been used, consisting in the injection of a mass of brine, the time of passage of which is detected by the variation in electrical resistance between two contacts placed in the stream. A pair of such contacts is placed at each station, and the time of passage of the brine between the stations is chronographically recorded by a specially arranged wattmeter. The stations should be arranged as under 11 (*c*).

(*e*) **By Color Density Method.** The coloration or color density may also be employed for approximate tests, this method depending on the use of a colored dosing solution in place of a salt solution in a manner similar to the chemical method of 9 (*e*), observation of the color density replacing the titration.

(*f*) **By Resistance of Salt Solution.** A method which has been used experimentally is similar to the chemical method of 9 (*e*), except that the amount of chemical (salt) in solution is determined by measurement of the electrical resistance of the solution instead of by titration. Care is required to guard against changes in resistance due to small temperature variations.

12. Measurement of Water Horse-power in Plants Containing a Fall Increaser. In case of an installation including a fall increaser or other device utilizing an auxiliary flow for increasing the effective head, the following provisions shall be observed: In determining the efficiency of the turbine proper, considered separately from the fall increaser, the fall increaser shall be closed, and precautions shall be taken that no water except that passing through the turbine shall enter the system between the points at which the head is measured.

In order to determine the performance of the combined hydraulic installation, including both turbine and fall increaser, the total water horse-power shall be computed from the sum of the turbine discharge multiplied by the head on the turbine, and the auxiliary discharge multiplied by the head on the fall increaser. The head on the turbine shall be measured from a point immediately in advance of the point of intake to the turbine proper, as above provided, and the head on the fall increaser shall be measured from a point immediately in advance of the intake gates of the increaser, the head in each case being measured to a point below the junction of the two streams at the outflow from the plant. For the computation of water horse-power it will be necessary to determine the division of the total discharge between the turbine and fall increaser. This may be done when practicable by separately measuring the water admitted to the turbine during the operation of the fall increaser.

If, owing to the arrangement of the fall increaser, it is impracticable to separate the water horse-power of the turbine from that of the fall increaser, the gross efficiency of the combined installation may be determined by measuring the combined total flow, and the total head from a point common to the two flows before entering the plant to a point after they are reunited below the final point of discharge.