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JAPANESE INDUSTRIAL STANDARD

**Methods for Model Tests of
Hydraulic Turbine and
Reversible Pump-turbine**

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Methods for Model Tests of Hydraulic Turbine and Reversible Pump-turbine B 8103-1989

1. Scope

This Japanese Industrial Standard specifies methods for efficiency tests and cavitation tests of model hydraulic turbine and model reversible pump-turbine corresponding to single stage prototype hydraulic turbine and prototype reversible pump turbine.

Further, the complete characteristic test method and temporary pressure pulsation test method are shown in Reference.

In case where the specific speed is particularly low and therefore this Standard is difficult to apply, this Standard may be applied with adoption, rejection or supplement.

- Remarks 1. This Standard applies also to the case where acceptance of hydraulic turbine and reversible pump turbine by model test instead of working site efficiency test is carried out.
2. This Standard applies also to storage pump to be set in pumped storage power plant of multi-stage reversible pump-turbine, separate type and tandem type, as appropriate by adoption, rejection or supplement according to agreement between the parties concerned with delivery.
 3. In the cavitation test of reversible pump-turbine, mainly the pump cavitation test specified in 9.13 (2) is carried out and in hydraulic turbine cavitation test specified in 9.13 (1) is carried out in the test range preliminarily agreed upon between the parties concerned on delivery.
 4. Depending upon agreement between the parties concerned with delivery, the test to examine the influence of cavitation on runaway speed is carried out. In this case, the test method and test conditions should preferably be agreed upon.
 5. Models mean respectively the model hydraulic turbine and model reversible pump-turbine, and prototype hydraulic turbine and prototype reversible pump turbine.

Applicable Standards, Corresponding International Standards and Reference Standard: See page 80.

2. Definitions

For the purpose of this Standard, main definitions are in accordance with JIS B 0119 and for others following definitions apply:

- (1) efficiency test The test to examine the performance of model in the state receiving no influence of cavitation. In the case of reversible pump-turbine the test consists of turbine efficiency test and pump efficiency test, and the turbine efficiency test includes runaway speed test.
- (2) cavitation test The test to examine the influence of cavitation relative to the performance of reaction water turbine. In the case of reversible pump-turbine, the test consists of turbine cavitation test and pump cavitation test.
- (3) inlet, outlet and upstream, downstream The inlet (usually the casing inlet) and outlet (usually the draft tube outlet).

Further, the upstream and downstream is defined by the direction of flowing water in the case of operating as hydraulic turbine.
- (4) effective head The total head to be utilized in turbine operation. The sum of pressure head, velocity head and potential head at the inlet subtracted by their sum at the outlet (Refer to Attached Figs. 4.1 to 4.3).
- (5) total head The total head made by pumping operation. The sum of pressure head, velocity head and potential head at the inlet subtracted by their sum at the outlet (Refer to Attached Figs. 4.2 and 4.3).
- (6) rate of flow The volume of water passing through hydraulic turbine or reversible pump-turbine in 1 sec. during generating operation.
- (7) pump discharge The volume of pumping water of reversible pump-turbine in 1 sec. during pumping operation.
- (8) turbine output The effective mechanical power transmitted from hydraulic turbine or reversible pump-turbine during generating operation.
- (9) pump input The effective mechanical power transmitted to the reversible pump-turbine shaft during pumping operation.
- (10) normal rotational speed The rotational speed of model corresponding to normal effective head at prototype generating operation and rated rotational speed.
- (11) normal output The model turbine output corresponding to normal output at prototype generating operation.
- (12) normal opening The opening of model corresponding to the opening to pass normal rate of flow (guide vane opening or needle opening) of prototype at normal effective head.

- (13) specific speed The specific speed of model hydraulic turbine is expressed by specific speed of rate of flow at highest efficiency point.

$$n_{sQopt} = n_{11opt} \cdot Q_{11opt}^{\frac{1}{2}}$$

where n_{11opt} : unit rotational speed at the highest efficiency point

Q_{11opt} : unit rate of flow at the highest efficiency point

The specific speed of model reversible pump turbine is expressed by specific speed of rate of flow at the highest efficiency point of pump.

The specific speed of prototype hydraulic turbine is expressed by using the value at the maximum output at the normal effective head.

$$n_s = n \cdot P^{\frac{1}{2}} / H^{\frac{5}{4}}$$

where n : rated rotational speed (min^{-1})

P : output (kW)

H : normal effective head (m)

The specific speed of prototype reversible pump-turbine means the specific speed of pump, and, unless specially designated, is expressed by using the value at the point where the efficiency is highest in such operating condition as to give the maximum pump discharge in the specification range.

$$n_{sQ} = n \cdot Q^{\frac{1}{2}} / H^{\frac{5}{4}}$$

where n : rated rotational speed (min^{-1})

Q : pump discharge (m^3/s)

H : net pump head (m)

- (14) draft height The pressure head of model outlet at the designated position of model. However, the pressure not higher than atmospheric pressure is taken as positive (Refer to Attached Fig. 10).
- (15) plant cavitation factor The cavitation factor in prototype operating condition. Unless specially designated, the cavitation factor when the prototype becomes at the worst conditions relative to the cavitation in the range defined in the specification is employed.

Remark: This factor is called, in same cases, to be plant sigma.

- (16) critical cavitation factor The cavitation factor at the time of beginning of lowering of efficiency due to generation of cavitation (Refer to Attached Fig. 11).

Remark: The critical cavitation factor is called, in some cases, to be critical sigma.

- (17) pump-test rotational speed The rotational speed of model reversible pump-turbine selected as the normal when carrying out the pump performance test and cavitation test.
- (18) operation NPSH The effective suction head (NPSH) in pump-test rotational speed of model reversible pump-turbine corresponding to operating cavitation factor.

Remark: Relating to NPSH, refer to 9.11.3 (2).

- (19) critical NPSH The effective suction head (NPSH) in pump-test rotational speed of model reversible pump turbine corresponding to critical cavitation factor.
- (20) representative dimensions The representative dimensions of model mean the following dimensions (Refer to Attached Figs. 1.1 to 1.6).

Pelton turbine	Diameter of tangential circle of jet central line (D_1)
Francis turbine	Runner outlet diameter (D_2)
Diagonal flow turbine	Runner normal diameter (D_1) ⁽¹⁾
Propeller turbine	Runner outer diameter (D_1) ⁽¹⁾
Francis type reversible pump turbine	Runner outlet diameter (D_2)
Diagonal flow type reversible pump turbine	Runner normal diameter (D_1) ⁽¹⁾
Propeller type reversible pump turbine	Runner outer diameter (D_1) ⁽¹⁾

Note ⁽¹⁾ The bore of fixed part opposing to this may be employed.

3. Mutual Relation of Models for Turbine Efficiency Test, Pump Efficiency Test, Turbine Cavitation Test and Pump Cavitation Test and the Measuring Instrument

The mutual relation of models for turbine efficiency test, pump efficiency test, turbine cavitation test and pump cavitation test and the measuring instrument shall be as follows:

- (1) As to the turbine efficiency test, pump efficiency test, turbine cavitation test and pump cavitation test, as a rule, the same model shall be used.

- (2) As to the turbine efficiency test and pump efficiency test, as a rule, the measuring instrument calibrated by the same reference device shall be used.

4. Measuring Items

The measurement shall be carried out on the following items:

- (1) Turbine Efficiency Test The effective head, rate of flow, rotational speed (including runaway speed), turbine output and turbine efficiency.
- (2) Pump Efficiency Test The net pump head, pump discharge, rotational speed, pump input and pump efficiency.
- (3) Turbine Cavitation Test The effective head, rate of flow, rotational speed, turbine output, turbine efficiency, cavitation factor.
- (4) Pump Cavitation Test The net pump head, pump discharge, rotational speed, pump input, pump efficiency, cavitation factor.

5. Water for Test

For test, the clean water at not higher than 35°C shall be used.

6. Calibration of Measuring Instrument

The measuring instrument to be used for test, prior to test, shall be calibrated on the whole measuring range of generating operation and pumping operation of model.

7. Models

7.1 Resembling Range of Models Models shall be resembled with the prototype in the following parts:

- (1) Pelton Turbine The casing, nozzle pipe, nozzle tip, needle, runner, housing, etc.
- (2) Reaction Hydraulic Turbine and Reversible Pump-Turbine The casing speed ring, guide vane, runner, discharging, draft tube, balance pipe, balance hole, etc.

Remarks 1. The deflector, backside of bucket of Pelton turbine, upper cover, lower cover, runner seal gap, balance pipe, balance hole of reaction turbine and reversible pump-turbine, stay vane, check shaft, etc. of valve turbine and s type tubular turbine, may not be made resembled according to agreement between the parties concerned with delivery. However, the runner gap shall not be made smaller than the dimension resembled to the prototype. The total sum of areas of balance pipe and balance hole shall not be made smaller than the dimension resembled to the prototype.

2. The resembling range of casing inlet and draft tube outlet shall be in accordance with agreement between the parties concerned with delivery. The range of casing inlet to be resembled should preferably be so agreed that it does not become the distance not more than two times the runner outlet diameter with measuring from the turbine center.

7.2 Dimensions of Models Dimensions of models shall be as follows:

- (1) The representative dimensions of models shall be as follows:

Pelton turbine	Diameter of tangential circle of jet center line	350 mm min.
Francis turbine	Runner outlet diameter	350 mm min.
Diagonal flow turbine	Runner reference diameter	350 mm min.
Propeller turbine	Runner outer diameter	350 mm min.
Francis type reversible pump-turbine	Runner outlet diameter	250 mm min.
Diagonal flow type reversible pump-turbine	Runner reference diameter	350 mm min.
Propeller type reversible pump turbine	Runner outer diameter	300 mm min.

Remark: In the case where the specific speed is specially low or high and it is difficult to satisfy the above dimension from the relation of capacity of test apparatus, the representative dimension may be varied depending upon agreement between the parties concerned with delivery.

- (2) As to the model, the dimension inspection shall be carried out by contrasting with its design drawing.

The permissible deviations on model dimensions shall be in accordance with Tables 1 to 4.

Remarks 1. As to dimension inspection parts in Tables 1 to 4, refer to Attached Figs. 1.1 to 1.6.

2. The inspection on sectional shape of runner vane shall, as a rule, be carried out relating to 3 to 5 sections (refer to Attached Figs 1.4 and 1.5).
3. The inspection for sectional shape of runner vane of Francis turbine, and Francis type reversible pump-turbine shall, as a rule, be carried out by preparing a profile gauge of conical section or conical tangential place and by setting this at a regular angle. The error of angle shall be so made that it is capable of

being measured as profile error. Depending upon the shape of runner, it is in some cases more convenient to use a profile gauge of horizontal section (Refer to Attached Fig. 1.4.).

4. For measurement of sectional shapes of guide vane and runner vane, by direct measurement of coordinates of sectional shape instead of using a profile gauge, the difference from the drawing dimension may be obtained.
5. Seal gap means 1/2 of sum of gaps on both sides on a diameter.

Table 1. Dimensional Permissible Deviations on Pelton Turbine

Item		Permissible deviations %	Remark	
Casing	Inlet internal diameter (D_s)	± 1	From turbine center up to the internal wall	
	Shape dimensions (A, B, C, D)	± 2		
	Offset (R)	± 2		
	Inlet length (L)	± 2		
Housing	Shape dimensions ($L_1, L_2, L_3, L_4, L_5, L_6, L_7$)	± 2	-	
Nozzle pipe	Bore (D_p)	± 2	-	
	Outer diameter of needle-stem protective tube (D_l)	± 10		
Nozzle tip	Bore (D_n)	± 0.5	Ratio to tip bore	
	Internal surface shape (C_n)	± 1		
Needle	Maximum outer diameter of head (D_m)	± 0.3	Ratio to the maximum outer diameter	
	Shape (C_m)	± 1		
Runner	Bucket	Inner width (B_1)	± 1	At design maximum width position
		Notch width (B_2)	± 1	
		Thickness (T)	± 20	
		Length (L_b)	± 1	
		Depth (H_b)	± 0.5	Ratio to inner width
		Shape (C_b)	± 0.5	Ratio to inner width (outlet is 0.2%)
		Drip tip diameter (D_2)	± 0.5	
		Pitch (P)	± 2	Ratio to mean value
		Offset (R_b)	± 1	Ratio to diameter of tangential circle of jet center line
		Runout of bucket drip in axial direction from jet center line (E)	± 1	Ratio to inner width
Jet center line	Diameter of tangential circle (D_1)	± 0.2	-	

Remark: For symbols in parentheses in respective items, refer to Attached Figs. 1.1 and 1.2.

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Table 2. Dimensional Permissible Deviations on Francis Turbine and Francis Type Reversible Pump Turbine

Item		Permissible deviations %	Remark
Casing	Inlet internal diameter (D_s)	± 1	From turbine center up to inner wall
	Shape dimensions (A, B, C, D)	± 2	
	Offset (R)	± 2	
	Inlet length (L)	± 2	
Speed ring	Outlet passage width (B_s)	± 2	—
	Internal diameter (D_i)	± 2	
Guide vane	Passage width (B_g)	± 0.3	When B_g is 50 mm min. When B_g is less than 50 mm Ratio to maximum thickness
	Section shape (C_g)	± 0.15 (mm)	
	Pitch circle diameter (D_g)	± 3	Ratio to its average value at 100 % opening
	Outlet opening (A_g)	± 0.2	
Runner	Inlet diameter (D_1)	± 0.15	Position at 1/2 of inlet height Lower end of runner band When B_1 is 50 mm min. When B_1 is less than 50 mm
	Outlet diameter (D_2)	± 0.15	
	Inlet height (B_1)	± 0.3	
	Runner-band height (H)	± 0.15 (mm)	
	Seal gap (G)	± 0.5 $+ 100$ 0	As G , a calculation value from other measured value may be used.
	Runner vane	Section shape (C_r)	
		Thickness (T)	
		Inlet pitch (P_1)	
Outlet opening	Outlet opening	Outlet opening (A_2)	—
		Average of outlet opening ($\bar{A}_2$)	
Draft tube	Inlet bore (D_s)	± 1	For W_2, W_4 , ratios relative to respective W_1, W_3 As H_4 , other measured value may be used.
	Others ($L_1, L_2, H_1, H_2, H_3, H_4, W_1, W_2, W_3, W_4$)	± 5	
Balance hole Balance pipe	Total area (A_b)	$+ 100$ 0	—

Remark: For symbols in parentheses in respective items, refer to Attached Figs. 1.3 and 1.4.

Table 3. Dimensional Permissible Deviations on Diagonal Flow Type and Propeller Type Turbines and Reversible Pump-Turbines

Item		Permissible deviations %	Remark	
Casing	Inlet internal diameter (D_s)	± 1	From turbine center up to inner wall	
	Shape dimensions (A, B, C, D)	± 2		
	Offset (R)	± 2		
	Inlet length (L)	± 2		
Speed ring	Outlet passage width (B_s)	± 2	—	
	Internal diameter (D_i)	± 2		
Guide vane	Passage width (B_g)	± 0.3	When B_g is 50 mm min. When B_g is less than 50 mm Ratio to maximum thickness At 100 % opening, the ratio to its average value	
	Sectional shape (C_g)	± 0.15 (mm)		
	Pitch circle diameter (D_g)	± 3		
	Outlet opening (A_g)	± 0.2		
Runner	Reference diameter (diagonal flow) (D_1)	± 0.1	As G , a calculated value from other measured value may be used.	
	Outer diameter (propeller) (D_1)	± 0.1		
	Boss diameter (diagonal flow) (D_b)	± 0.2		
	Boss diameter (propeller) (D_b)	± 0.2		
	Diagonal flow angle (diagonal flow) (ϕ)	± 15 (min)		
	Vane end gap (G)	+ 100 0		
	Runner vane	Sectional shape (C_r)		± 0.1
		Thickness (T)		± 5
		Length (L_r)		+ 0.5 - 1
		Pitch (P)		± 1
Mounting angle (θ)		± 15 (min)		
Discharge ring throat diameter (D_4)		± 0.3	—	
Discharge ring diameter (D_3)		± 0.2	Average value of perpendicularly intersecting two diameters	
Draft tube	Inlet bore (D_5)	± 1	Relating to W_2, W_4 , the ratio to respective W_1, W_3 As H_4 , calculated value from other measured value may be used.	
	Others ($L_1, L_2, H_1, H_2, H_3, H_4, W_1, W_2, W_3, W_4$)	± 5		
Balance pipe	Total area (A_b)	+ 100 0	—	

Remark: For symbols in parentheses in respective items, refer to Attached Figs. 1.3 and 1.5.

Table 4. Dimensional Permissible Deviations on Valve Turbine and S Type Tubular Turbine

Item		Permissible deviations %	Remark	
Passage	Inner wall surface dimensions (<i>A, B, C</i>)	± 2	In the case where <i>A, B</i> are not circular shape, the measurement may be carried out according to longitudinal and lateral representative dimensions.	
	Valve outer wall surface dimensions (<i>E, F, G</i>)	± 2	Requirement of inspection on valve support members shall be subjected to agreement between the parties concerned with delivery. In the case where these become non resemble from restriction of structure of model hydraulic turbine, it should preferably be agreed preliminarily.	
Guide vane	Inside pitch circle diameter (<i>D_{g1}</i>)	± 0.2	Ratio to the maximum thickness At 100 % opening, the ratio to its average value	
	Outside pitch circle diameter (<i>D_{g2}</i>)	± 0.2		
	Sectional shape (<i>C_g</i>)	± 3		
	Passage width (<i>B_g</i>)	± 0.3		
	Outlet opening (<i>A_g</i>)	± 2		
Runner	Boss diameter (<i>D_b</i>)	± 0.2	As <i>G</i> , a calculated value from other measured value may be used.	
	Outer diameter (<i>D₁</i>)	± 0.1		
	Vane end gap (<i>G</i>)	+ 100 0		
	Runner vane	Sectional shape (<i>C_r</i>)	± 0.1	Ratio to outer diameter Ratio to maximum value of each section (at design maximum thickness point)
		Thickness (<i>T</i>)	± 5	
		Length (<i>L_r</i>)	+ 0.5 - 1	
		Pitch (<i>P</i>)	± 1	
Mounting angle (<i>θ</i>)		± 15. (min)		
Discharge ring	Discharge ring diameter (<i>D₃</i>)	± 0.2	Average value of perpendicularly intersecting two diameters	
	Throat diameter (<i>D₄</i>)	± 0.3		
	Total length (<i>L_d</i>)	± 2	Ratio to total length <i>L_d</i> Ratio to total length <i>L_d</i>	
	Upper part length (<i>L_{d1}</i>)	± 2		
	Lower part length (<i>L_{d2}</i>)	± 2		
Draft tube	Draft tube inlet bore (<i>D₅</i>)	± 1	—	
	Others (<i>L₁, L₂, H₁, H₂, H₃, W₁, W₂</i>)	± 5		

Remark: For symbols in parentheses in respective items, refer to Attached Figs. 1.3, 1.5 and 1.6.

7.3 Finishing of Water-Flow Surface of Model The finishing degree of water-flow surface of model shall be, as a rule, in accordance with Table 5.

Table 5. Finishing Degree of Water-Flow Surface

Pelton turbine	Reaction turbine	Finishing degree
Inner surface of nozzle tip Surface of needle head Range near 2/3 of outer periphery of bucket inner surface	Negative pressure side of runner vane outlet of diagonal flow turbine, propeller turbine, and propeller reversible pump-turbine Negative pressure side of outlets of runner vanes of Francis turbine, Francis reversible pump-turbine	Within 0.8 μmRa
Parts of bucket inner surface other than the above-described	Parts of runner other than the above-described, negative pressure side of guide vane, upper cover and lower cover	Within 1.6 μmRa
—	Parts to contact with flowing water such as stay vane, pressure side of guide vane, discharge ring, etc.	Within 3.2 μmRa

Remarks 1. The finishing degree herein means that according to specifications of JIS B 0601.

2. The finishing range of runner vane is shown in Attached Fig. 2.

3. Painting may be applied to the water-flow surface.

8. Efficiency Test Methods

8.1 Test Effective Head and Test Net-Pump Head The efficiency test shall be carried out at as high test effective head or test net-pump head as possible and the model test effective head or test net-pump head corresponding to normal effective head or normal net-pump head of prototype shall be not less than the value of Table 6.

Table 6. Test Effective Head and Net-Pump Head

Unit: m

Propeller turbine	Diagonal flow turbine	Francis type reversible pump-turbine	Pelton turbine
Propeller type reversible pump-turbine	Francis turbine Diagonal flow type reversible pump-turbine		
3	10	20	30

8.2 Test Apparatus The test apparatus shall be as follows:

- (1) The test apparatus shall be provided with devices to give the model the stabilized pressure and water flow such as upper tank, lower tank, penstock, pump-discharge adjusting valve, etc., effective head (or net pump head) measuring device, rotational speed measuring device, output (or input) measuring device and flow-rate (or pump discharge) measuring device having capacity and accuracy capable of measuring accurately the performance of model. The arrangement examples of test apparatus are shown in Attached Figs. 3.1 and 3.2.

- (2) The upper tank of measuring apparatus for turbine efficiency test and the lower tank of measuring apparatus for pump efficiency test shall have such capacity as to satisfy the test conditions of 8.3.

Further, the inlet of pipe line from these tanks to the model shall be provided at a position not to suck-in air from water surface.

- (3) The pipe line before and after the model shall be little in bending.
- (4) Relating to the shape of connecting part of draft tube and lower tank of model, cares should preferably be so taken that a large exfoliation loss relative to the flow in pump direction or the like is not generated.
- (5) The lower tank of test apparatus for efficiency test of reaction hydraulic turbine or reversible pump turbine shall have such capacity and length that it has no influence to the flow from draft tube of model.

Further, the lower tank shall be capable of keeping the water surface at such a position that the upper end of draft tube outlet is not exposed.

- (6) Between the model and the flow-rate measuring device, water leakage, air leakage or water-pouring and air-feeding shall be made not to exist. If water leakage from shaft sealing part of model exists or the device to pour water into the shaft sealing part is used, its rate of flow shall be corrected.
- (7) The effective head (or net pump head) measuring device differential pressure type flow-rate (or pump discharge) measuring device, piping reaching them, etc. shall be provided with no throttling device. However, in case where the pulsation is excessively large in operating condition apart from the highest efficiency point or the like and therefore the measuring is difficult, a suitable throttling device may be entered in the measuring device or in the midway of piping. In this case, the throttling effects in both positive and reverse directions of variation shall be so made as to be equal.

Further, in case where the liquid column difference of manometer is separated by air, the throttling effects in the midways of pipings to reach both high and low liquid columns shall be made to be equal.

8.3 Test Conditions Test conditions shall be as follows:

- (1) In hydraulic turbine operation and pump operation, the speed distribution of approaching flow to model shall be uniform as far as possible.
- (2) In the case of reaction turbine or reversible pump-turbine, the disturbance of water level of lower tank shall be made small.
- (3) In the turbine efficiency test, even though the rate of flow is varied by changing the opening of guide vane or needle, the variation of test head corresponding to an effective head of prototype shall be within $\pm 10 \%$.

- (4) In the pump efficiency test, the variation of rotational speed of model following the variation of pump discharge shall be within $\pm 5\%$ of pump test rotational speed.

Remark: In the case where in a diagonal flow type reversible pump turbine, the runner vane angle is small, depending upon agreement between the parties concerned with delivery, the test may be carried out by raising the test rotational speed.

- (5) In turbine and pump efficiency test, the measurement shall be carried out after confirming that the operating condition of model is at ordinary condition.

Remark: The ordinary condition means the condition, when the measurements of effective head or net pump head and rotational speed are carried out not less than 5 times over before and after measuring of flow-rate torque, where the difference between the maximum value and the minimum value of their measured values is within the following limits:

Effective head or net pump head:

$$\Delta H' = \epsilon_H H' \times \frac{1}{100} \quad \epsilon_H = 0.5\%$$

$$\text{Rotational speed: } \Delta n' = \epsilon_n n' \times \frac{1}{100} \quad \epsilon_n = 0.25\%$$

where $\Delta H'$: variation permissible limit of measured value of effective head or net pump head (m)

H' : a measured value of effective head or net pump head (m)

$\Delta n'$: variation permissible limit of measured value of rotational speed (min^{-1})

n' : a measured value of rotational speed (min^{-1})

The measurements of effective head or net pump head and rotational speed for confirming the ordinary condition should preferably be carried out at equal time interval of about 10 sec.

8.4 Measuring Methods as well as Measuring Appliances for Effective Head and Net Pump Head

8.4.1 Measuring Methods for Effective Head and Net Pump Head

The measuring method for effective head and net pump head shall be as follows:

- (1) The effective head or net pump head, in the reaction turbine and reversible pump turbine, shall be obtained by pressure head difference between the model inlet and the model outlet with correcting by velocity head. In the Pelton turbine, it shall be obtained by pressure head at model inlet with correcting by velocity head.
- (2) In the reaction turbine and reversible pump-turbine, the pressure head difference between the model inlet and the model outlet shall be obtained by measuring respectively pressure head at inlet side measuring position and outlet side measuring position shown in 8.4.2 (1) and by calculation, or by measuring directly the pressure head difference between the inlet side measuring position and the outlet measuring position.
- (3) For measurement of pressure heads of model inlet and model outlet as well as the pressure head difference between the model inlet and the model outlet, either one of the following methods shall be used:
 - (a) The method to measure as the water level with taking the designated position of model as the reference and to express by the head.
 - (b) The method to measure as the pressure with adding the correction by elevation difference between the reference position of pressure measuring device and the designated position of model shown in 8.4.4 (1) and to convert to the head at designated position of model. However, in the case where the pressure measuring device is calibrated by other pressure reference device, it shall be corrected by elevation difference between the reference position of pressure reference device and the designated position of model.
 - (c) The method to measure as the differential pressure and to convert to head difference.
- (4) The velocity at the inlet side shall be obtained from the sectional average rate of flow at pressure-head measuring position and at the outlet side it, obtained from the average rate of flow of section shown in 8.4.4 (2) (b).

The average rate of flow shall be obtained by dividing the rate of flow by sectional area at its position.

Remark: In case where in reaction turbine and reversible pump-turbine, the position of draft tube outlet is not clear, it shall be decided preliminarily by agreement between the parties concerned with delivery.

- (5) The pressure head shall be read out to the nearest 0.1 % of test effective head or test net pump head.
- (6) In the case where the pressure is measured by using a pressure measuring device to obtain the pressure head, the elevation difference between the reference position of pressure reference

device used for pressure measuring device or for calibration of pressure measuring device and the designated position of model shown in 8.4.4 (1) shall be read out to the nearest 0.1 % of test effective head or test net pump head.

8.4.2 Measuring Position and Shape of Measuring Hole The measuring position and shape of measuring hole shall be as follows:

- (1) The measuring position of effective head or net pump head shall be, at inlet of model, the tube wall of straight tube part near the model, and for both turbine efficiency test and pump efficiency test, the same measuring hole, be used.

Further, the measuring hole at inlet of model of valve turbine, or S type tubular turbine shall be provided at the upstream side from the valve.

The measuring position of outlet side of model in reaction hydraulic turbine or reversible pump-turbine shall be the tube wall of draft tube near the outlet of draft tube, and both for turbine efficiency test and pump efficiency test, the same measuring position, be used. However, in the case where the velocity head at outlet of draft tube is not more than 0.5 % of effective head, the measurement may be carried out at side wall of lower part tank. In the case where measured at tube wall of draft tube near the outlet of draft tube, the sectional area of measuring section shall not be different in a large amount from the sectional area of outlet of draft tube.

- (2) The diameter of pressure measuring hole at model inlet shall be 2 to 4 mm. In the case where the inlet straight tube is of circular section, not less than four pieces shall be provided on one section in uniform arrangement. In the case where the inlet straight tube part is of rectangle section, the number of pressure measuring holes shall be at least four pieces and, provided at the middle of each side. However, in valve turbine or the like, the straight tube part can not be taken at inlet, and at upper and lower walls of passage bendings exist, at least two pieces shall be provided respectively in right and left walls (Refer to Attached Fig. 3.3).
- (3) In the case of reaction turbine or reversible pump-turbine, the diameter of pressure measuring hole at model outlet shall be 2 to 4 mm, and in the case of measuring at side wall of lower tank, two pieces in side wall in opposite shall be provided and in the case of measuring at tube wall of draft tube, four pieces for each passage on one section, provided (Refer to Attached Fig. 3.3).
- (4) Reading-out values relating to respective measuring holes on a sectional surface shall have not deviation exceeding ± 0.2 % from the average value of measured values of effective head or net pump head.
- (5) The lengths of pipings from the pressure measuring hole up to the measuring instrument shall be so made that resistances of respective pipings become equal.

Further, those shall be so arranged that air is difficult to be accumulated in the midway of piping.

- (6) The wall surface in the range of 100 mm in radius from the pressure measuring hole shall be smooth and the edge of hole, free from burrs.
- (7) Though the outlet pressure head becomes negative pressure in many cases, in this case, the following cares shall be taken for piping from the measuring hole up to the measuring instrument.
 - (a) In piping, water or air is filled completely.
 - (b) In the case of filling air, cares shall be so taken that water does not penetrate into piping.
 - (c) In the case of filling water, the water in piping is exchanged at times and the bubbles generated by negative pressure shall be removed.
 - (d) The connecting part, valves, etc. shall be made free from water leakage, and air leakage.

8.4.3 Measuring Appliances for Effective Head and Net Pump Head

Measuring appliances for effective head and net pump head shall be as follows:

- (1) For measuring appliances, the following are used:
 - (a) In the case of measuring water level:
Water column manometer, float gauge
 - (b) In the case of measuring pressure or differential pressure:
Mercury manometer, Bourdon tube pressure gauge, weight type pressure gauge, electric type pressure converter
- (2) The water column manometer and mercury manometer shall be as follows:
 - (a) The bore of glass tube of manometer shall be not less than 6 mm and uniform in thickness.
 - (b) In the case of using U type or reverse U type manometer, both high and low liquid columns shall be read-out at the same time.
 - (c) In the case of obtaining differential pressure by using U type or reverse U type manometer, it shall be converted to correct pressure by taking into consideration the density of using liquid.

Water density, mercury density and acceleration of free fall are shown in Reference Tables 1, 2 and 3.
 - (d) In a single-tube type manometer, the correction shall be carried out by taking into consideration the variation of liquid surface of liquid storing tank. The internal diameter of liquid storage tank shall be not less than 10 times the bore of glass tube.

- (e) The scale to be used for reading of liquid column shall be of mm-unit and of having received verification.

Reference Table 1. Density of Water

Water temperature °C	Density kg/m ³	Water temperature °C	Density kg/m ³	Water temperature °C	Density kg/m ³
0	999.8	12	999.5	24	997.3
1	999.9	13	999.4	25	997.0
2	999.9	14	999.2	26	996.8
3	1 000.0	15	999.1	27	996.5
4	1 000.0	16	998.9	28	996.2
5	1 000.0	17	998.8	29	995.9
6	999.9	18	998.6	30	995.7
7	999.9	19	998.4	31	995.3
8	999.9	20	998.2	32	995.0
9	999.8	21	998.0	33	994.7
10	999.7	22	997.8	34	994.4
11	999.6	23	997.5	35	994.0

Remark: Values between the water temperatures shown in the table, shall be obtained according to linear interpolation.

Reference Table 2. Density of Mercury

Temperature °C	0	5	10	15	20	25	30	35
Density of mercury kg/m ³	13 595	13 582	13 570	13 558	13 546	13 533	13 521	13 509

- Remarks 1. Values between the temperatures shown in the table shall be obtained according to the following formula:

$$\rho_{Hg} = 13\,595 - 2.46 \times T$$

2. The formula and table described in IEC 4 (CO) 48 are shown, but the difference is small, and therefore either of them may be used.

Reference Table 3. Acceleration of Free Fall

Unit: m/s^2

Latitude ϕ (degrees)	Elevation Z (m)				
	0 (on the sea level)	1 000	2 000	3 000	4 000
0	9.780	9.777	9.774	9.771	9.768
10	9.782	9.779	9.776	9.773	9.770
20	9.786	9.783	9.780	9.777	9.774
30	9.793	9.790	9.787	9.784	9.781
40	9.802	9.799	9.796	9.792	9.789
50	9.811	9.808	9.804	9.801	9.798
60	9.819	9.816	9.813	9.810	9.807
70	9.826	9.823	9.820	9.817	9.814

Remarks 1. Values between the latitudes or elevations shown in the table shall be obtained according to the following formula:

$$g = 9.7803 \times (1 + 0.0053 \sin^2 \phi) - 3 \times 10^{-6} Z$$

2. The value of standard gravitational acceleration ($= 9.80665 \text{ m/s}^2$) corresponds to the value on the sea level at approximately 45 degrees in latitude.

3. Values of Reference Table 3 and the above-mentioned formula are in accordance with IEC 4 (CO) 48.

(3) Weight type pressure gauge shall be as follows:

- (a) The weight type pressure gauge shall be calibrated by using a pressure reference device.
- (b) The lowering speed of piston of weight type pressure gauge shall be not more than 3 mm/min.
- (c) In order to remove the influence due to friction of piston and cylinder, the measurement shall be carried out with the piston rotating at 30 min^{-1} .

(4) Bourdon-tube pressure gauge shall be as follows:

- (a) The Bourdon-tube pressure gauge may be used according to agreement between the parties concerned with delivery exclusively in the case where it is confirmed that it has the accuracy required in 8.8 (1).

- (b) At the time of use, it shall be calibrated relative to the increasing and decreasing direction of pressure.
- (5) The float gauge shall be as follows:
 - (a) The float gauge of which actuation is confirmed that it is secure and which can be calibrated may be used.
 - (b) The diameter of float shall be not less than 150 mm.

Further, though the float is given with variation under the condition of a definite water level, it shall be capable of returning to the original state within reading of 1 mm.

- (c) The diameter of water reservoir storing the float shall be not less than 200 mm.
- (6) Electric type pressure converter shall be as follows:
 - (a) Electric type pressure converters such as feed-back balance type pressure converter, diaphragm type manometer, vibration type pressure converter, etc. may be used according to agreement between the parties concerned.
 - (b) At the time of use, it shall be calibrated relative to the increasing and decreasing direction of pressure.

8.4.4 Calculation of Effective Head and Net Pump Head The calculation of effective head and net pump head shall be in accordance with the following:

- (1) The conversion of pressure at the pressure measuring section of inlet and outlet of model to be pressure head at the designated position of model shall be in accordance with the following:

$$h_p = \frac{p}{\rho' g'} + Z$$

where h_p : pressure head at the designated position of model (m)

p : measured value of pressure (Pa)

ρ' : density of water (kg/m³)

g' : acceleration of free fall at measuring position (m/s²)

Z : elevation difference between the reference position of pressure reference device used for pressure measuring device or its calibration and the designated position of model. Take the case where the reference position is higher than the designated position of model as positive.

Herein, the designated position of model means, in the reaction turbine and reversible pump-turbine, the elevation shown in Attached Fig. 10, in vertical shaft Pelton turbine, the elevation at runner center, and in lateral shaft Pelton turbine, the average elevation at contact points of runner pitch circle with the jet central line (Refer to Attached Fig.4.1).

- (2) The effective head and net pump head shall be obtained according to the following formulae:

- (a) Pelton turbine (Refer to Attached Fig. 4.1)

$$H' = H_p' + H_{v1}'$$

where H' : effective head of model (m)

H_p' : pressure head at measuring section of inlet side of model (conversion to designated position of model) (m)

H_{v1}' : velocity head at measuring section of inlet side of model (m)

- (b) The reaction turbine and reversible pump-turbine (Refer to Attached Figs. 4.2 and 4.3)

$$\begin{aligned} H' &= H_{st}' + H_{v1}' - H_{v2}' \\ &= H_p' - H_d' + H_{v1}' - H_{v2}' \end{aligned}$$

where H' : effective head or net pump head of model (m)

H_{st}' : pressure head difference between the inlet and the outlet of model (m) $H_{st}' = H_p' - H_d'$

H_p' : pressure head at measuring section of inlet side of model (conversion to designated position of model) (m)

H_d' : pressure head at measuring section of outlet side of model (conversion to designated position of model) (m)

H_{v1}' : velocity head at measuring section of inlet side of model (m)

H_{v2}' : velocity head at measuring section of outlet side of model (m)

8.5 Measuring Methods of Rotational Speeds and Measuring Appliances

8.5.1 Measuring Methods of Rotational Speeds The measuring methods of rotational speeds shall be as follows:

- (1) The rotational speed shall be obtained by counting, for a definite time, the signals generated by rotation of main shaft of model or of the dynamometer shaft connected directly therewith.
- (2) The rotational speed, at the turbine efficiency test, shall be read out to the nearest 0.1 % of reference rotational speed and, at the reversible pump-turbine test, to the nearest 0.1 % of test rotational speed.
- (3) In the runaway speed test, the rotational speed, when the torque becomes zero by separating the dynamometer or by operating the directly connected dynamometer as the electric motor, shall be measured.

Remark: The runaway speed herein means the rotational speed of model at no load, at a certain effective head, opening and static suction head.

8.5.2 Measuring Appliances of Rotational Speed Measuring appliances of rotational speed shall be as follows:

- (1) As to the counting part of measuring appliance of rotational speed, such a digital counter that it is able to set the time to count the input signal at an error not more than 10^{-4} shall be used.
- (2) The appliance to measure rotational speed of which the driving power shall be so small that it is negligible in comparison with the turbine output or pump input.
- (3) In the case where a detector of rotational speed is connected with the rotational shaft, a deflection joint shall not be used.
- (4) The method to take out the rotational speed by applying belt shall not be used.

8.5.3 Calculation of Rotational Speed The rotational speed of model shall be obtained according to the following formula:

$$n' = \frac{60 R}{fT}$$

where n' : rotational speed of model (min^{-1})

R : number of integrating pulses in T sec.

f : number of pulses per one revolution of model

T : integrating time (s)

8.6 Measuring Methods and Measuring Appliances for Turbine Output and Pump Input

8.6.1 Measuring Methods for Turbine Output and Pump Input The measuring methods of turbine output and pump input shall be as follows:

- (1) The turbine output and pump input shall be obtained by measuring braking force on the arm of dynamometer or driving reaction force and the rotational speed.
- (2) The sensitivity of a dynamometer during using, in the turbine efficiency test, shall be not more than 0.1 % of weighing amount at reference output time of model, and in the pump efficiency test, not more than 0.1 % of weighing amount at the maximum input of model specification.
- (3) The variation of braking force or driving reaction force at the time of measuring shall be within ± 1.0 % of weighing amount of (2).
- (4) The braking force or driving reaction force shall be read out to the nearest 0.2 % of weighing amount of (2).
- (5) Cares shall be so taken that the air resistance of rotational part of dynamometer does not generate the error of braking force or driving reaction force.
- (6) In the case where according to the structure of measuring apparatus a part of turbine output or pump input is not indicated on the dynamometer, as far as the correct actual measurement is possible, the turbine output or pump input may be corrected by this. However, this correction amount shall not exceed the value corresponding to 0.2 % of weighing amount of (2).

Further, relating to the actual measuring method and calibration method, agreement between the parties concerned with delivery shall be conducted preliminarily.

- (7) The electrical wiring of electric dynamometer shall be connected with taking cares so that the measuring value of braking force or driving reaction force is not influenced.

8.6.2 Measuring Appliances of Turbine Output and Pump Input

The measuring appliances of turbine output and pump input shall be as follows:

- (1) For measuring appliances of turbine output and pump input, a dynamometer shall be used. In that case, it is preferable to use an electric dynamometer capable of being operated as generator and electric motor.
- (2) As to the measuring apparatus of braking force of dynamometer and driving reaction force, as a rule, a mechanical balance or pressure balance shall be used. However, in the case of valve turbine or the like which is difficult to transmit correctly the turbine output to dynamometer, the shaft torque may be measured by attaching a rotary type torque converter between the model and the dynamometer. In either cases, the measuring device of braking force or driving reaction force shall be capable of reading out to the nearest 0.2 % of weighing amount of 8.6.1 (2).
- (3) Pivots, knife edges, bearings, etc. of mechanical balance shall be as small as possible in friction. The piston of pressure balance shall be revolved at not less than 30 min^{-1} in order to remove the influence of friction.

- (4) In the case of using a mercury manometer, Bourdon tube type pressure gauge for display of braking force, those in accordance with 8.4.3, as appropriate shall be used.
- (5) The rotary type torque converter shall be as follows:
 - (a) The rotary type torque converter may be used only in the case where it is confirmed that it has the accuracy required in 8.8 (2).
 - (b) At the time of use, it shall be calibrated relative to both increasing and decreasing directions of braking force or driving force.
- (6) The dynamometer shall be able to brake or to drive in the variation range of rotational speed shown in 8.3 (5).
- (7) In the case where a shock absorber is put into a measuring apparatus, it shall actuate similarly in both increasing and decreasing directions of force, and, the measuring apparatus, indicate the correct average value.
- (8) The length of effective arm of dynamometer shall be measured at an accuracy of ± 0.05 % of its length.
- (9) As to the dynamometer containing a mechanism to convert the braking force or driving reaction force in horizontal direction to the vertical direction, cares shall be so taken that its mechanism is free from friction.

Further, its lever ratio shall be measured at an accuracy of ± 0.05 %.
- (10) The dynamometer, including the measuring apparatus of braking force or driving reaction force, shall be calibrated by using a weight verified in a condition near the measuring condition relative to the increasing and decreasing directions of braking force or driving reaction force.

8.6.3 Calculation of Turbine Output and Pump Input The turbine output and pump input of model shall be obtained according to the following formula:

$$P' = \frac{2\pi n' Wl}{6 \times 10^4} \pm P_t = \frac{n' Wl}{9549} \pm P_t$$

where + : when calculating turbine output

- : when calculating pump input

P' : turbine output or pump input of model (kW)

n' : rotational speed of model (min^{-1})

W : braking force or driving reaction force measured by dynamometer (N)

l : length of arm of dynamometer (m)

P_t : a part of turbine output or pump input not measured by dynamometer (kW) [Refer to 8.8 (2)]