

ASME PTC 18-2011
(Revision of ASME PTC 18-2002)

Hydraulic Turbines and Pump-Turbines

Performance Test Codes

AN INTERNATIONAL CODE



**The American Society of
Mechanical Engineers**

Copyright © 2011 by the American Society of Mechanical Engineers.
No reproduction may be made of this material without written consent of ASME.



INTENTIONALLY LEFT BLANK



ASME PTC 18-2011
(Revision of ASME PTC 18-2002)

Hydraulic Turbines and Pump-Turbines

Performance Test Codes

AN INTERNATIONAL CODE



**The American Society of
Mechanical Engineers**

Three Park Avenue • New York, NY • 10016 USA

Copyright © 2011 by the American Society of Mechanical Engineers.
No reproduction may be made of this material without written consent of ASME.



Date of Issuance: June 10, 2011

The next edition of this Code is scheduled for publication in 2016. There will be no addenda issued to this edition.

ASME issues written replies to inquiries concerning interpretations of technical aspects of this Code. Interpretations are published on the ASME Web site under the Committee Pages at <http://cstools.asme.org> as they are issued.

ASME is the registered trademark of The American Society of Mechanical Engineers.

This code or standard was developed under procedures accredited as meeting the criteria for American National Standards. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment that provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not approve, rate, or endorse any item, construction, proprietary device, or activity.

ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of any applicable letters patent, nor assumes any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations of this document issued in accordance with the established ASME procedures and policies, which precludes the issuance of interpretations by individuals.

No part of this document may be reproduced in any form,
in an electronic retrieval system or otherwise,
without the prior written permission of the publisher.

The American Society of Mechanical Engineers
Three Park Avenue, New York, NY 10016-5990

Copyright © 2011 by
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
All rights reserved
Printed in U.S.A.

Copyright © 2011 by the American Society of Mechanical Engineers.
No reproduction may be made of this material without written consent of ASME.



CONTENTS

Notice	v
Foreword	vi
Committee Roster	viii
Correspondence With the PTC 18 Committee	ix
Section 1 Object and Scope	1
1-1 Object	1
1-2 Scope	1
1-3 Uncertainties	1
Section 2 Definitions and Descriptions of Terms	2
2-1 Definitions	2
2-2 International System of Units (SI)	2
2-3 Tables and Figures	2
2-4 Reference Elevation, Z_c	2
2-5 Centrifugal Pumps	2
2-6 Subscripts Used Throughout the Code	3
Section 3 Guiding Principles	26
3-1 General	26
3-2 Preparations for Testing	26
3-3 Tests	28
3-4 Instruments	29
3-5 Operating Conditions	29
3-6 Data Records	29
Section 4 Instruments and Methods of Measurement	32
4-1 General	32
4-2 Electronic Data Acquisition	32
4-3 Head and Pressure Measurement	33
4-4 Flow Measurement	37
4-5 Power Measurement	58
4-6 Speed Measurement	62
4-7 Time Measurement	63
Section 5 Computation of Results	64
5-1 Measured Values: Data Reduction	64
5-2 Conversion of Test Results to Specified Conditions	64
5-3 Evaluation of Uncertainty	65
5-4 Comparison With Guarantees	65
Section 6 Final Report	67
6-1 Responsibility of Chief of Test	67
6-2 Parties to the Test	67
6-3 Acceptance Tests	67
Figures	
2-3-1 Head Definition, Measurement and Calibration, Vertical Shaft Machine With Spiral Case and Pressure Conduit	20
2-3-2 Head Definition, Measurement and Calibration, Vertical Shaft Machine With Semi-Spiral Case	21
2-3-3 Head Definition, Measurement and Calibration, Bulb Machine	22
2-3-4 Head Definition, Measurement and Calibration, Horizontal Shaft Impulse Turbine (One or Two Jets)	23



2-3-5	Head Definition, Measurement and Calibration, Vertical Shaft Impulse Turbine.....	24
2-4-1	Reference Elevation, Z_c , of Turbines and Pump-Turbines.....	25
3-5.3-1	Limits of Permissible Deviations From Specified Operating Conditions in Turbine Mode.....	30
3-5.3-2	Limits of Permissible Deviations From Specified Operating Conditions in Pump Mode.....	31
4-3.14-1	Pressure Tap.....	35
4-3.15-1	Calibration Connections for Pressure Gages or Pressure Transducers.....	36
4-4.3.4-1	Example of Digital Pressure–Time Signal.....	41
4-4.4.1-1	Ultrasonic Method: Diagram to Illustrate Principle.....	43
4-4.4.1-2	Ultrasonic Method: Typical Arrangement of Transducers for an 8-Path Flowmeter in a Circular Conduit.....	44
4-4.4.3-1	Ultrasonic Method: Typical Arrangement of Transducers.....	46
4-4.4.4-1	Distortion of the Velocity Profile Caused by Protruding Transducers.....	47
4-4.4.6-1	Ultrasonic Method: Typical Arrangement of Transducers for an 18-Path Flowmeter in a Circular Conduit.....	49
4-4.4.6-2	Ultrasonic Method: Typical Arrangement of Transducers for an 18-Path Flowmeter in a Rectangular Conduit.....	50
4-4.4.11-1	Locations for Measurements of D	52
4-4.5.1-1	Schematic Representation of Dye Dilution Technique.....	54
4-4.5.2.1-1	Experimental Results: Allowable Variation in Tracer Concentration.....	55
4-4.5.5-1	Typical Chart Recording During Sampling.....	57
4-5.1-1	Three-Wattmeter Connection Diagram.....	59
4-5.1-2	Two-Wattmeter Connection Diagram.....	60
4-5.1-3	Measuring Instrument Burden.....	61
Tables		
2-2-1	Conversion Factors Between SI Units and U.S. Customary Units of Measure.....	3
2-3-1	Letter Symbols and Definitions.....	4
2-3-2M	Acceleration of Gravity as a Function of Latitude and Elevation, SI Units (m/s^2).....	10
2-3-2	Acceleration of Gravity as a Function of Latitude and Elevation, U.S. Customary Units (ft/sec^2).....	11
2-3-3M	Vapor Pressure of Distilled Water as a Function of Temperature, SI Units (kPa).....	11
2-3-3	Vapor Pressure of Distilled Water as a Function of Temperature, U.S. Customary Units ($lbf/in.^2$).....	12
2-3-4M	Density of Water as a Function of Temperature and Pressure, SI Units (kg/m^3).....	13
2-3-4	Density of Water as a Function of Temperature and Pressure, U.S. Customary Units ($slug/ft^3$).....	14
2-3-5	Coefficients I_i , J_i , and n_i	15
2-3-6M	Density of Dry Air, SI Units (kg/m^3).....	16
2-3-6	Density of Dry Air, U.S. Customary Units ($slug/ft^3$).....	16
2-3-7M	Density of Mercury, SI Units (kg/m^3).....	17
2-3-7	Density of Mercury, U.S. Customary Units ($slugs/ft^3$).....	18
2-3-8M	Atmospheric Pressure, SI Units (kPa).....	19
2-3-8	Atmospheric Pressure, U.S. Customary Units ($lbf/in.^2$).....	19
4-4.4.2-1	Integration Parameters for Ultrasonic Method: Four Paths in One Plane or Eight Paths in Two Planes.....	45
4-4.4.6-1	Integration Parameters for Ultrasonic Method: 18 Paths in Two Planes.....	51
Nonmandatory Appendices		
A	Typical Values of Uncertainty.....	69
B	Uncertainty Analysis.....	70
C	Outliers.....	74
D	Relative Flow Measurement–Index Test.....	75
E	Derivation of the Pressure–Time Flow Integral.....	81



NOTICE

All Performance Test Codes **MUST** adhere to the requirements of **PTC 1, GENERAL INSTRUCTIONS**. The following information is based on that document and is included here for emphasis and for the convenience of the user of this Code. It is expected that the Code user is fully cognizant of Parts I and III of PTC 1 and has read them prior to applying this Code.

ASME Performance Test Codes provide test procedures which yield results of the highest level of accuracy consistent with the best engineering knowledge and practice currently available. They were developed by balanced committees representing all concerned interests. They specify procedures, instrumentation, equipment operating requirements, calculation methods, and uncertainty analysis.

When tests are run in accordance with a Code, the test results themselves, without adjustment for uncertainty, yield the best available indication of the actual performance of the tested equipment. ASME Performance Test Codes do not specify means to compare those results to contractual guarantees. Therefore, it is recommended that the parties to a commercial test agree before starting the test and preferably before signing the contract on the method to be used for comparing the test results to the contractual guarantees. It is beyond the scope of any Code to determine or interpret how such comparisons shall be made.



FOREWORD

The “Rules for Conducting Tests of Waterwheels” was one of a group of ten test codes published by the ASME in 1915. The Pelton Water Wheel Company published a testing code for hydraulic turbines, which was approved by the Machinery Builders’ Society on October 11, 1917. This code included the brine velocity method of measuring flow wherein the time of passage of an injection of brine was detected by electrical resistance. Also in October 1917, the Council of the ASME authorized the appointment of a joint committee to undertake the task of revising the “Rules for Conducting Tests of Waterwheels.” The joint committee consisted of thirteen members, four from the ASME and three each from ASCE, AIEE, and NELA (National Electric Light Association). The code was printed in the April 1922 issue of *Mechanical Engineering* in preliminary form. It was approved in the final revised form at the June 1923 meeting of the Main Committee and was later approved and adopted by the ASME Council as a standard practice of the Society.

Within three years the 1923 revised edition was out of print and a second revision was ordered by the Main Committee. In November 1925, the ASME Council appointed a new committee, the Power Test Codes Individual Committee No. 18 on Hydraulic Power Plants. This committee organized itself quickly and completed a redraft of the code in time for a discussion with the advisory on Prime Movers of the IEC at the New York meeting later in April 1926. The code was redrafted in line with this discussion and was approved by the Main Committee in March 1927. It was approved and adopted by the ASME Council as the standard practice of the Society on April 14, 1927.

In October 1931 the ASME Council approved personnel for a newly organized committee, Power Test Codes Individual Committee No. 18 on Hydraulic Prime Movers, to undertake revision of the 1927 test code. The committee completed the drafting of the revised code in 1937. The Main Committee approved the revised code on April 4, 1938. The code was then approved and adopted by the Council as standard practice of the Society on June 6, 1938. The term “Hydraulic Prime Movers” is defined as reaction and impulse turbines, both of which are included in the term “hydraulic turbines.” A revision of this Code was approved by the Power Test Codes Committee and by the Council of ASME in August 1942. Additional revisions were authorized by Performance Test Code Committee No. 18 (PTC 18) in December 1947. Another revision was adopted in December 1948. It was also voted to recommend the reissue of the 1938 Code to incorporate all of the approved revisions as a 1949 edition. A complete rewriting of the Code was not considered necessary, because the 1938 edition had been successful and was in general use. A supplement was prepared to cover index testing. The revised Code including index testing was approved on April 8, 1949, by the Power Test Codes Committee and was approved and adopted by the Council of ASME by action of the Board on Codes and Standards on May 6, 1949.

The members of the 1938 to 1949 committees included C. M. Allen, who further developed the Salt Velocity Method of flow rate measurement; N. R. Gibson, who devised the Pressure-Time Method of flow rate measurement; L. F. Moody, who developed a method for estimating prototype efficiency from model tests; S. Logan Kerr, successful consultant on pressure rise and surge; T. H. Hogg, who developed a graphical solution for pressure rise; G. R. Rich, who wrote a book on pressure rise; as well as other well known hydro engineers.

In 1963, Hydraulic Prime Movers Test Code Committee, PTC 18, was charged with the preparation of a Test Code for the Pumping Mode/Pump Turbines. The Code for the pumping mode was approved by the Performance Test Codes Supervisory Committee on January 23, 1978, and was then approved as an American National Standard by the ANSI Board of Standards Review on July 17, 1978.

The PTC 18 Committee then proceeded to review and revise the 1949 Hydraulic Prime Movers Code as a Test Code for Hydraulic Turbines. The result of that effort was the publication of PTC 18-1992 Hydraulic Turbines.

Since two separate but similar Codes now existed, the PTC 18 Committee proceeded to consolidate them into a single Code encompassing both the turbine and pump modes of Pump/Turbines. The consolidation also provided the opportunity to improve upon the clarity of the preceding Codes, as well as to introduce newer technologies such as automated data-acquisition and computation techniques, and the dye-dilution method. Concurrently, the flow methods of salt velocity, pitot tubes and weirs, which had become rarely used, were removed from the 2002 Edition. However, detailed descriptions of these methods remain in previous versions of PTC 18 and PTC 18.1

Following the publication of the 2002 Revision of PTC 18, the PTC 18 Committee began work on the next Revision to further modernize and increase the accuracy of measuring techniques and to improve clarity. The 2011 Revision is characterized by the following features: increased harmonization of text with other ASME Performance Test Codes according to PTC 1 General Instructions; improvement of text and illustrations; modernization of techniques with increased guidance on electronic data acquisition systems and — in the case of the Ultrasonic Method — increasing ultrasonic flow-measurement accuracy with additional paths; deletion from this Code of the seldom used Venturi, volumetric and pressure-time Gibson flow-measurement methods; deletion from this Code of the seldom practical



direct method of power measurement; and removal of the Relative Flow Measurement–Index Test from the main text of the Code to a nonmandatory Appendix.

The methods of measuring flow rate included in this Code meet the criteria of the PTC 18 Committee for soundness of principle, have acceptable limits of accuracy, and have demonstrated application under laboratory and field conditions. There are other methods of measuring flow rate under consideration for inclusion in the Code at a later date.

This Code was approved by the Board on Standardization and Testing on March 3, 2011, and approved as an American National Standard by the ANSI Board of Standards Review on April 25, 2011.



ASME PTC COMMITTEE

Performance Test Codes

(The following is the roster of the Committee at the time of approval of this Code.)

STANDARDS COMMITTEE OFFICERS

J. R. Friedman, *Chair*
J. W. Milton, *Vice Chair*
J. H. Karian, *Secretary*

STANDARDS COMMITTEE PERSONNEL

P. G. Albert, General Electric Co.	R. R. Priestley, Consultant
R. P. Allen, Consultant	J. A. Silvaggio, Siemens Demag Delaval, Inc.
J. M. Burns, Burns Engineering, Inc.	W. G. Steele, Mississippi State University
W. C. Campbell, Southern Company Services, Inc.	T. L. Toburen, T2E3, Inc.
M. J. Dooley, Alstom Power, Inc.	G. E. Weber, Midwest Generation EME LLC
J. R. Friedman, Siemens Energy, Inc.	J. C. Westcott, Mustan Corp.
G. J. Gerber, Consultant	W. C. Wood, Duke Energy, Inc.
P. M. Gerhart, University of Evansville	T. K. Kirpatrick, <i>Alternate</i> , McHale & Associates, Inc.
T. C. Heil, Consultant	S. A. Scavuzzo, <i>Alternate</i> , Babcock & Wilcox Com.
R. A. Henry, Sargent & Lundy, Inc.	R. L. Bannister, <i>Honorary Member</i> , Consultant
J. H. Karian, The American Society of Mechanical Engineers	W. O. Hays, <i>Honorary Member</i> , Consultant
D. R. Keyser, Survice Engineering	R. Jorgensen, <i>Honorary Member</i> , Consultant
S. J. Korellis, Electric Power Research Institute	F. H. Light, <i>Honorary Member</i> , Consultant
M. P. McHale, McHale & Associates, Inc.	G. H. Mittendorf, Jr., <i>Honorary Member</i> , Consultant
P. M. McHale, McHale & Associates, Inc.	J. W. Siegmund, <i>Honorary Member</i> , Consultant
J. W. Milton, RRI Energy, Inc.	R. E. Sommerlad, <i>Honorary Member</i> , Consultant
S. P. Nuspl, Consultant	

PTC 18 COMMITTEE — HYDRAULIC PRIME MOVERS

W. W. Watson, <i>Chair</i>	L. L. Pruitt, Stanley Consultants, Inc.
R. I. Munro, <i>Vice Chair</i>	D. E. Ramirez, US Army Corps of Engineers
G. Osolso, <i>Secretary</i>	P. R. Rodrigue, Hatch Acres, Inc.
C. W. Almquist, Principia Research Corporation	G. J. Russell, Weir American Hydro
M. Byrne, Voith Hydro, Inc.	J. W. Taylor, BC Hydro, Inc.
J. J. Hron, MWH Americas, Inc.	J. T. Walsh, Rennasonic, Inc.
D. O. Hulse, US Bureau of Reclamation	W. W. Watson, Watson Engineering Consultants, Inc.
J. Kirejczyk, Toshiba International Corp.	Z. Zrinyi, Manitoba Hydro, Inc.
D. D. Lemon, ASL Environmental Sciences, Inc.	A. Adamkowski, <i>Contributing Member</i> , Szewalski Institute of Fluid Flow Machinery
A. B. Lewey, Consultant	C. Deschenes, <i>Contributing Member</i> , Laval University
P. W. Ludwig, New York Power Authority	V. Djelic, <i>Contributing Member</i> , Turboinstitut D. D.
P. A. March, Hydro Performance Processes, Inc.	S. Durham, <i>Contributing Member</i> , U.S. Bureau of Reclamation
C. Marchand, Andritz Hydro, Ltd.	G. H. Mittendorf, <i>Contributing Member</i> , Consultant
R. I. Munro, R.I. Munro Consulting	T. Staubli, <i>Contributing Member</i> , Hochschule Luzern
G. Osolso, The American Society of Mechanical Engineers	L. F. Henry, <i>Honorary Member</i> , Consultant
B. Papillon, Alstom Hydro Canada, Inc.	A. E. Rickett, <i>Honorary Member</i> , Consultant
G. Proulx, Hydro Quebec, Inc.	

DEDICATION

This Revision of PTC 18, Hydraulic Prime Movers, is dedicated to the memory of Norman Latimer, who passed away while this revision was in progress: Mr. Latimer was an outstanding engineer who significantly promoted the importance of hydro power-plant performance activities, a faithful Member of the Committee, and a major contributor to the content of this Code.



CORRESPONDENCE WITH THE PTC 18 COMMITTEE

General. ASME Codes are developed and maintained with the intent to represent the consensus of concerned interests. As such, users of this Code may interact with the Committee by requesting interpretations, proposing revisions, and attending Committee meetings. Correspondence should be addressed to:

Secretary, PTC 18 Committee
The American Society of Mechanical Engineers
Three Park Avenue
New York, NY 10016-5990 USA

Proposing Revisions. Revisions are made periodically to the Code to incorporate changes which appear necessary or desirable, as demonstrated by the experience gained from the application of the Code. Approved revisions will be published periodically.

The Committee welcomes proposals for revisions to this Code. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal including any pertinent documentation.

Interpretations. Upon request, the PTC 18 Committee will render an interpretation of any requirement of the Code. Interpretations can only be rendered in response to a written request sent to the Secretary of the PTC 18 Committee.

The request for interpretation should be clear and unambiguous. It is further recommended that the inquirer submit his request in the following format:

- Subject:** Cite the applicable paragraph number(s) and a concise description.
- Edition:** Cite the applicable edition of the Code for which the interpretation is being requested.
- Question:** Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation. The inquirer may also include any plans or drawings, which are necessary to explain the question; however, they should not contain proprietary names or information.

Requests that are not in this format will be rewritten in this format by the Committee prior to being answered, which may inadvertently change the intent of the original request.

ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME Committee. ASME does not “approve,” “certify,” “rate,” or “endorse” any item, construction, proprietary device, or activity.

Attending Committee Meetings. The PTC 18 Committee holds meetings or telephone conferences, which are open to the public. Persons wishing to attend any meeting or telephone conference should contact the Secretary of the PTC 18 Committee or check our Web site <http://www.asme.org/codes/>.



INTENTIONALLY LEFT BLANK



HYDRAULIC TURBINES AND PUMP-TURBINES

Section 1 Object and Scope

1-1 OBJECT

This Code defines procedures for field performance and acceptance testing of hydraulic turbines and pump-turbines operating with water in either the turbine or pump mode.

1-2 SCOPE

This Code applies to all sizes and types of hydraulic turbines or pump-turbines. It defines methods for ascertaining performance by measuring flow rate (discharge), head, and power, from which efficiency may be determined. Requirements are included for pretest arrangements, types of instrumentation, methods of measurement, testing procedures, methods of calculation, and contents of test reports. This Code also contains recommended procedures for

index testing and describes the purposes for which index tests may be used.

1-3 UNCERTAINTIES

The test procedures specified herein and the limitations placed on measurement methods and instrumentation are capable of providing uncertainties, calculated in accordance with the procedures of PTC 19.1 and this Code of not more than the following:

- (a) Head: $\pm 0.40\%$
- (b) Power: $\pm 0.90\%$
- (c) Flow rate: $\pm 1.75\%$
- (d) Efficiency: $\pm 2.00\%$

Where favorable measurement conditions exist and the best methods can be used, smaller uncertainties should result. Any test with an efficiency uncertainty greater than the above value does not meet the requirements of this Code.

