

ASME PTC 19.1-2005
(Revision of ASME PTC 19.1-1998)

Test Uncertainty

AN AMERICAN NATIONAL STANDARD



**The American Society of
Mechanical Engineers**

ASME PTC 19.1-2005
(Revision of ASME PTC 19.1-1998)

Test Uncertainty

AN AMERICAN NATIONAL STANDARD



**The American Society of
Mechanical Engineers**

Date of Issuance: October 13, 2006

The 2005 edition of ASME PTC 19.1 will be revised when the Society approves the issuance of the next edition. There will be no Addenda issued to ASME PTC 19.1-2005.

ASME issues written replies to inquiries as code cases and interpretations of technical aspects of this document. Code cases and interpretations are published on the ASME website under the Committee Pages at <http://www.asme.org/codes/> 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 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 preclude 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 © 2006 by
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
All rights reserved
Printed in U.S.A.

CONTENTS

Notice	vii
Foreword.....	viii
Committee Roster	ix
Section 1 Introduction	1
1-1 General	1
1-2 Harmonization With International Standards	1
1-3 Applications	1
Section 2 Object and Scope	2
2-1 Object	2
2-2 Scope	2
Section 3 Nomenclature and Glossary	3
3-1 Nomenclature	3
3-2 Glossary	3
Section 4 Fundamental Concepts	5
4-1 Assumptions	5
4-2 Measurement Error	5
4-3 Measurement Uncertainty	5
4-4 Pretest and Posttest Uncertainty Analyses	11
Section 5 Defining the Measurement Process	13
5-1 Overview	13
5-2 Selection of the Appropriate “True Value”	13
5-3 Identification of Error Sources	13
5-4 Categorization of Uncertainties	15
5-5 Comparative Versus Absolute Testing	16
Section 6 Uncertainty of a Measurement	17
6-1 Random Standard Uncertainty of the Mean	17
6-2 Systematic Standard Uncertainty of a Measurement	18
6-3 Classification of Uncertainty Sources	19
6-4 Combined Standard and Expanded Uncertainty of a Measurement	19
Section 7 Uncertainty of a Result	22
7-1 Propagation of Measurement Uncertainties Into a Result	22
7-2 Sensitivity	23
7-3 Random Standard Uncertainty of a Result	23
7-4 Systematic Standard Uncertainty of a Result	24
7-5 Combined Standard Uncertainty and Expanded Uncertainty of a Result	24
7-6 Examples of Uncertainty Propagation	24
Section 8 Additional Uncertainty Considerations	28
8-1 Correlated Systematic Standard Uncertainties	28
8-2 Nonsymmetric Systematic Uncertainty	31
8-3 Fossilization of Calibrations	35
8-4 Spatial Variation	36

8-5	Analysis of Redundant Means	36
8-6	Regression Uncertainty	38
Section 9	Step-by-Step Calculation Procedure	41
9-1	General Considerations	41
9-2	Calculation Procedure	41
Section 10	Examples	43
10-1	Flow Measurement Using Pitot Tubes	43
10-2	Flow Rate Uncertainty	47
10-3	Flow Rate Uncertainty Including Nonsymmetrical Systematic Standard Uncertainty	51
10-4	Compressor Performance Uncertainty	61
10-5	Periodic Comparative Testing	62
Section 11	References	69
Section 12	Bibliography	71
Figures		
4-2-1	Illustration of Measurement Errors	6
4-2-2	Measurement Error Components	7
4-3.1	Distribution of Measured Values (Normal Distribution)	8
4-3.3	Uncertainty Interval	11
5-3.1	Generic Measurement Calibration Hierarchy	14
5-4.3	Difference Between “Within” and “Between” Sources of Data Scatter	16
7-6.2	Pareto Chart of Systematic and Random Uncertainty Component Contributions to Combined Standard Uncertainty	27
8-2.1	Schematic Relation Between Parameters Characterizing Nonsymmetric Uncertainty	32
8-2.2	Relation Between Parameter Characterizing Nonsymmetric Uncertainty	34
8-5.1	Three Posttest Cases	37
10-1.1	Traverse Points (Example 10-1)	44
10-2.1	Schematic of a 6 in. \times 4 in. Venturi	48
10-4.1	Typical Pressure and Temperature Locations for Compressor Efficiency Determination	57
10-4.7	The $h-s$ Diagram of the Actual and Isentropic Processes of an Adiabatic Compressor	61
10-5.1-1	Installed Arrangement	63
10-5.1-2	Pump Design Curve With Factory and Field Test Data Shown	64
10-5.1-3	Comparison of Test Results With Independent Control Conditions	64
10-5.2	Comparison of Test Results Using the Initial Field Test as the Control	67
Tables		
6-4-1	Circulating Water Bath Temperature Measurements (Example 6-4.1)	20
6-4-2	Systematic Uncertainty of Average Circulating Water Bath Temperature Measurements (Example 6-4.1)	21
7-6.1-1	Table of Data (Example 7-6.1)	25
7-6.1-2	Summary of Data (Example 7-6.1)	26
7-6.2-1	Table of Data (Example 7-6.2)	26
7-6.2-2	Summary of Data (Example 7-6.2)	27
8-1	Burst Pressures (Example 8-1-1)	29

8-6.4.5	Systematic Standard Uncertainty Components for \hat{Y} Determined from Regression Equation.	40
9-2-1	Table of Data.	42
9-2-2	Summary of Data	42
10-1.2	Average Values (Example 10-1)	44
10-1.3-1	Standard Deviations (Example 10-1)	45
10-1.3-2	Summary of Average Velocity Calculation (Example 10-1)	45
10-1.6	Standard Deviation of Average Velocity (Example 10-1)	46
10-1.9	Uncertainty of Result (Example 10-1)	48
10-2.1-1	Uncalibrated Case (Example 10-2)	48
10-2.1-2	Absolute Sensitivity Coefficients in Example 10-2 (Calculated Numerically)	49
10-2.1-3	Absolute Sensitivity Coefficients in Example 10-2 (Calculated Analytically)	51
10-2.1-4	Absolute Contributions of Uncertainties of Independent Parameters (Example 10-2: Uncalibrated Case).	52
10-2.1-5	Summary: Uncertainties in Absolute Terms (Example 10-2: Uncalibrated Case)	52
10-2.1.1-1	Relative Uncertainty of Measurement (Example 10-2: Uncalibrated Case)	52
10-2.1.1-2	Relative Contributions of Uncertainties of Independent Parameters (Example 10-2: Uncalibrated Case).	53
10-2.1.1-3	Summary: Uncertainties in Relative Terms for the Uncalibrated Case	53
10-2.1.1-4	Relative Uncertainties of Independent Parameters (Example 10-2: Calibrated Case)	53
10-2.1.1-5	Relative Contributions of Uncertainties of Independent Parameters (Example 10-2: Calibrated Case).	54
10-2.1.1-6	Summary: Uncertainties in Relative Terms for the Calibrated Case	54
10-2.1.1-7	Summary: Comparison Between Calibrated and Uncalibrated Cases	54
10-3-1	Absolute Contributions of Uncertainties of Independent Parameters (Example 10-2: Uncalibrated, Nonsymmetrical Systematic Uncertainty Case)	55
10-3-2	Summary: Uncertainties in Absolute Terms (Example 10-3: Uncalibrated, Nonsymmetrical Systematic Uncertainty Case)	56
10-4.1-1	Elemental Random Standard Uncertainties Associated With Error Sources Identified in Para. 10-4.2.	56
10-4.1-2	Independent Parameters.	57
10-4.1-3	Calculated Result	57
10-4.3.2-1	Inlet and Exit Pressure Elemental Systematic Standard Uncertainties	58
10-4.3.2-2	Inlet and Exit Temperature Elemental Systematic Standard Uncertainties	59
10-4.7	Evaluation of Analysis Error	62
10-5.1-1	Pump Design Data ($T_c = 20^\circ\text{C}$)	63
10-5.1-2	Summary of Test Results	63
10-5.2-1	Uncertainty Propagation for Comparison With Independent Control.	66
10-5.2-2	Summary: Uncertainties in Absolute Terms	66
10-5.2-3	Summary of Results for Each Test.	66

10-5.3-1	Uncertainty Propagation for Comparative Uncertainty	68
10-5.3-2	Sensitivity Coefficient Estimates for Comparative Analysis	68
Nonmandatory Appendices		
A	Statistical Considerations	73
B	Uncertainty Analysis Models	84
C	Propagation of Uncertainty Through Taylor Series	87
D	The Central Limit Theorem	92

Currently in preview, click buy full version

NOTICE

All Performance Test Codes must adhere to the requirements of ASME 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 the Supplement. It is expected that the Code user is fully cognizant of Sections 1 and 3 of ASME PTC 1 and has read them prior to applying this Supplement.

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 and 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

In March 1979 the Performance Test Codes Supervisory Committee activated the PTC 19.1 Committee to revise a 1969 draft of a document entitled PTC 19.1 "General Considerations." The PTC 19.1 Committee proceeded to develop a Performance Test Code Instruments and Apparatus Supplement which was published in 1985 as PTC 19.1-1985, "Measurement Uncertainty," and which was intended—along with its subsequent editions—to provide a means of eventual standardization of nomenclature, symbols, and methodology of measurement uncertainty in ASME Performance Test Codes.

Work on the revision of the original 1985 edition began in 1991. The two-fold objective was to improve the usefulness to the reader regarding clarity, conciseness, and technical treatment of the evolving subject matter, as well as harmonization with the ISO "Guide to the Expression of Uncertainty in Measurement." That revision was published as PTC 19.1-1998, "Test Uncertainty," the new title reflecting the appropriate orientation of the document.

The effort to update the 1998 revision began immediately upon completion of that document. This 2005 revision is notable for the following significant departures from the 1998 text:

(a) Nomenclature adopted for this revision is more consistent with the ISO Guide. Uncertainties remain conceptualized as "systematic" (estimate of the effects of fixed error not observed in the data), and "random" (estimate of the limits of the error observed from the scatter of the test data). The new aspect is that both types of uncertainty are defined at the standard-deviation level as "standard uncertainties." The determination of an uncertainty at some level of confidence is based on the root-sum-square of the systematic and random standard uncertainties multiplied times the appropriate expansion factor for the desired level of confidence (usually "2" for 95%). This same approach was used in the 1998 revision but the characterization of uncertainties at the standard-uncertainty level ("standard deviation") was not as explicitly stated. The new nomenclature is expected to render PTC 19.1-2005 more acceptable at the international level.

(b) There is greater discussion of the determination of systematic uncertainties.

(c) There is new text on a simplified approach to determine the uncertainty of straight-line regression.

ASME PTC 19.1-2005 was approved by the PTC Standards Committee on September 13, 2005, and was approved as an American National Standard by the ANSI Board of Standards Review on November 3, 2005.

PERFORMANCE TEST CODE COMMITTEE

19.1 ON TEST UNCERTAINTY

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

OFFICERS

R. H. Dieck, *Chair*
W. G. Steele, *Vice Chair*
G. Osolobe, *Secretary*

COMMITTEE PERSONNEL

J. F. Bernardin, Pratt & Whitney
D. A. Coutts, WSMS
R. H. Dieck, Ron Dieck Associates, Inc.
R. S. Figliola, Clemson University
H. K. Iyer, Colorado State University
J. Maveety, Intel Corp.
J. A. Rabensteine, Environmental Systems Corp.
M. Soltani, Bechtel National Corp.
W. G. Steele, Mississippi State University

PERFORMANCE TEST CODES STANDARDS COMMITTEE

OFFICERS

J. G. Yost, *Chair*
J. R. Friedman, *Vice Chair*
S. D. Weinman, *Secretary*

COMMITTEE PERSONNEL

P. G. Albert
R. P. Allen
J. M. Burns
W. C. Campbell
M. J. Dooley
A. J. Egli
J. R. Friedman
G. J. Gerber
P. M. Gerhart
T. C. Heil
R. A. Johnson
D. R. Keyser
S. J. Korellis

P. M. McHale
M. P. McHale
J. W. Milton
S. P. Nuspl
A. L. Plumley
R. R. Priestley
J. A. Rabensteine
J. W. Siegmund
J. A. Silvaggio
W. G. Steele
J. C. Westcott
W. C. Wood
J. G. Yost

HONORARY MEMBERS

W. O. Hays

F. H. Light

MEMBERS EMERITI

R. L. Bannister
R. Jorgensen

G. H. Mittendorf
R. E. Sommerlad

Section 1

Introduction

1-1 GENERAL

This Supplement has significant additions and Sections that have been rewritten to both add to the available technology for uncertainty analysis and to make it easier for the practicing engineer. Throughout, the intent is to provide a Supplement that can be utilized easily by engineers and scientists whose interest is the objective assessment of data quality, using test uncertainty analysis.

1-2 HARMONIZATION WITH INTERNATIONAL STANDARDS

It is recognized that this Supplement and promulgated international uncertainty standards and/or guides must be in harmony. In rewriting this Supplement, great care was taken to assure continued harmony with the International Organization for Standardization (ISO) *Guide to the Expression of Uncertainty in Measurement* (GUM) [1]. For the practicing engineer, this harmonization means the elimination of such ambiguous terms as bias, precision, bias limit, and precision index. In addition, careful attention was paid to discriminating between errors, the effects of errors, and the estimation of their limits, which is the uncertainty.

The term “bias” is not used in this Supplement. Instead, the combined terms of “systematic error” and “systematic uncertainty” are used. The former describes an error source whose effect is systematic or constant for the duration of a test. The latter describes the limits to which a systematic error may be expected to go with some confidence.

The term “precision” also is not used in this Supplement. Instead the combined terms of “random error” and “random uncertainty” are used. The former describes an error source that causes scatter in test data. The latter describes the limits to which a random error may be expected to reach with some confidence.

Throughout the Supplement, the term “standard” uncertainty has been introduced to improve

harmony with international guidelines and standards. In this Supplement, “standard” uncertainties are always equivalent to a single standard deviation of the average.

The most common confidence level used in this Supplement is 95% although methods for employing alternate confidences are also given. The confidence level of 95% is applied to “expanded” uncertainty. This term, too, was included in this Supplement for improved harmony with international guidelines and standards.

While this Supplement is in harmony with the ISO GUM, this Supplement emphasizes the effects of errors rather than the basis of the information utilized in the estimation of their limits. The ISO GUM utilizes two major classifications for errors and uncertainties. They are “Type A” and “Type B.” Type A uncertainties have data with which to calculate a standard deviation. Type B uncertainties do not have data to calculate a standard deviation and must be estimated by other means.

This Supplement utilizes two major classifications for errors and uncertainties. They are “systematic” and “random.” Random errors (whose effects are estimated with “Random Standard Uncertainties”) cause scatter in test data. Systematic errors (whose effects are estimated with “Systematic Standard Uncertainties”) do not.

Harmonization of this Supplement with the ISO GUM is achieved by encouraging subscripts with each uncertainty estimate to denote the ISO Type, i.e., using subscripts of either “A” or “B.”

1-3 APPLICATIONS

This Supplement is intended to serve as a reference to the various other ASME Instruments and Apparatus Supplements (PTC 19 Series) and to ASME Performance Test Codes and Standards in general. In addition, it is applicable for all known measurement and test uncertainty analyses.

The parameter values and uncertainty levels used throughout the examples are for illustrative purposes only and are not intended to be typical of standard tests.

Section 2

Object and Scope

2-1 OBJECT

The object of this Supplement is to define, describe, and illustrate the various terms and methods used to provide meaningful estimates of the uncertainty in test parameters and methods, and the effects of those uncertainties on derived test results.

Analysis of test measurement and result uncertainty is useful because it

- (a) facilitates communication regarding measurement and test results;
- (b) fosters an understanding of potential error sources in a measurement system and the effects of those potential error sources on test results;
- (c) guides the decision-making process for selecting appropriate and cost-effective measurement systems and methodologies;
- (d) reduces the risk of making erroneous decisions; and

- (e) documents uncertainty for assessing compliance with agreements.

2-2 SCOPE

The scope of this Supplement is to specify procedures for evaluation of uncertainties in test parameters and methods, and for propagation of those uncertainties into the uncertainty of a test result. Depending on the application, uncertainty sources may be classified either by the presumed effect (systematic or random) on the measurement or test result, or by the process in which they may be quantified (Type A or Type B). The various statistical terms involved are defined in the Nomenclature (subsection 3-1) or Glossary (subsection 3-2).

The end result of an uncertainty analysis is a numerical estimate of the test uncertainty with an appropriate confidence level.