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Manual of Petroleum Measurement Standards Chapter 22.1

General Guidelines for Developing Testing Protocols for Devices Used in the Measurement of Hydrocarbon Fluids

SECONDEDITION, AUGUST 2015

ADDENDUM 1, NOVEMBER 2018

ADDENDUM 2, XXXX 202X



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Introduction

Various sections of API *MPMS* Chapter 22 provide testing protocols for devices used in the measurement of hydrocarbon fluids. This Chapter (22.1) is the general guideline for developing the other sections of API *MPMS* Chapter 22. A testing protocol may address the performance of the devices classified by the technology used (e.g. thermocouple, thermistor element, RTD, etc.) or by the measured parameter (e.g. temperature), irrespective of the technology used. The purpose of a testing protocol is to define appropriate methods for measuring and reporting the performance characteristics of equipment performing similar tasks; thus providing a means to highlight the relative performance advantages and disadvantages of competing devices.

General Guidelines for Developing Testing Protocols for Devices Used in the Measurement of Hydrocarbon Fluids

1 Scope

This document is for the development of testing protocols and to serve as a guideline to document performance characteristics of hydrocarbon fluid measurement related devices.

2 Normative References

No other document is identified as indispensable or required for the application of this document.

Individual sections of this API *MPMS* Chapter may include a list of important and relevant publications available in the public domain that may describe or address the technology or technique used by the device or instrument for which the testing protocol is developed. If such a list is included, it should be comprehensive and should serve only as an additional information source for the user of the respective testing protocol document.

If the testing protocol document requires a specific test method described in a national or international standard or document (e.g. ASTM, ISO, OIML, etc.), the relevant section or sections of the reference document shall be specified and the title and year of publication of that referenced standard or document shall be listed under Normative References.

3 Terms and Definitions

All symbols and/or terms listed under the Terms and Definitions section should be consistent with API *MPMS* Chapter 1. Any symbol used in the equations, or a term used in sections of API *MPMS* Chapter 22 that is not defined in API *MPMS* Chapter 1 shall be defined under the Terms and Definitions section of the document. If a symbol or definition of a term in the document is different from that in API *MPMS* Chapter 1, the specific reason for the change shall be explained in the document.

4 Field of Application

The field of application of testing protocols developed under this chapter should be limited to devices that are used in the measurement of hydrocarbon fluids in the petroleum, energy, and petrochemical industries.

5 Parameter Variations Affecting Device Performance

The manufacturer shall define the meter installation requirements, operating range, limits of fluid properties, and environmental conditions for which the device is designed and/or is intended to be used. The range of conditions over which the device is to be tested shall be defined before the test is performed, because extrapolation of the process variable is not permitted for fiscal measurement beyond the range over which the performance of the device is tested. Each section of Chapter 22 developed for a specific type or class of instrument or device should define the parameters that are important for the performance evaluation of the device or instrument and list the parameters and information that should be documented in the test report.

Listed below are some of the parameters which may influence the performance of the device to be tested. For certain devices or instruments, some of the parameters listed in this section may have no influence, while there could be other parameters not listed in this section that may influence the performance of the device to be tested. If such parameters can be identified, the testing protocol should define them.

The various conditions which may affect the performance of the device may include and are not limited to:

— fluid property conditions: fluid density, viscosity, lubricity, abrasiveness, phase, phase fractions, composition, etc.;

- operating conditions: flow rate, temperature, and pressure;
- installation conditions: nature and location of flow disturbances, flow conditioners, pulsations, vibrations, and length of time in service;
- environmental conditions: ambient pressure, temperature, humidity, insulation, etc.
- effects on performance inherent to the device/technology being evaluated.

6 Mandatory Tests

6.1 Test Conditions

Identify the important test condition variables which should be measured and recorded before, during, and/or after each test and document that its value did not vary beyond the allowable limits.

Due to limitations of the test facility, it may not be possible to evaluate the influence of certain parameters over the entire range specified for the device. The testing protocol should specify that the test report include a list of those parameters which may affect the performance of the device but were not tested. The manufacturer shall specify performances within the range that the equipment was tested.

6.2 Test Installation

If applicable, the testing protocol should define the type of test installation needed to evaluate the effects of the important test condition variables on device performance. For critical measurements, the test protocol should define the allowable precision limit of the test equipment and which measuring devices should be required to record and document the traceability to a national standard (e.g. NIST).

6.3 Test Results

The parameter(s) defining the performance of the device (i.e. test results) shall be recorded during and after each test. Additional recording requirements shall be specified in the individual sections of the testing protocols as needed.

6.4 Baseline (Ideal Condition) Testing

In order to identify the influence of certain parameters or changes to the operating condition, ideal or baseline test(s) are necessary. The testing protocol should define the test conditions which may be considered as the ideal or baseline test(s).

The document should define, if applicable, the type and frequency of baseline testing needed to verify the reproducibility of the tested device.

NOTE The test facility uncertainty should be considered for calculations of acceptable reproducibility.

6.5 Non-ideal Condition Testing

Testing of the device for non-ideal conditions shall be defined, such as testing with variations in parameters that may affect the performance of the device. The format of the report section for the influence of non-ideal conditions should be defined in the document. In addition, the document may define how deviations from the baseline data for the non-ideal tests are to be reported. Non-ideal conditions likely to be experienced in real-world applications should receive a high priority when developing non-ideal test parameters.

6.6 Special Testing

Special tests may be defined where the combined effect of variations in multiple factors may be tested to reduce the cost of performance testing of the device. Whenever possible, tests should be designed to produce results to reflect the influence of one well-defined variable at a time.

6.7 Testing Documentation

All data used to calculate the final or intermediate result shall be recorded, attested, and/or certified by the test facility. If tests are performed at a third party facility, results shall be retained for future reference. These test results shall be retained for the period of time defined by the document. If a specific test report is not published in the public domain and is not available for verification of the performance claim, the associated claim will be deemed unverifiable.

6.8 Testing Procedure

The document shall describe in detail how the tests are to be conducted or reference other published procedure(s) for similar type tests, if type testing is permitted for the device.

7 Test Facility Requirements

7.1 Audit Process

To assure adherence to the testing protocols defined in this chapter, the laboratory or testing facility performing the tests shall provide documentation that the tests are performed in accordance with the standard. This documentation shall be provided at the request of any user of the facility. The user of the facility can request an audit of the laboratory or the testing facility to ensure the validity of the tests. The depth of the audit is determined by the user of the facility and shall be consistent with relevant national and/or international standards. The user of the facility may require the laboratory or testing facility to be traceable to national or international standards of weights and measures. The laboratory or testing facility shall provide documentation of how it estimates the uncertainty of its systems and procedures and how that uncertainty is maintained throughout the testing process under this protocol. A user of the facility wanting a detailed analysis of the performance of the lab/facility, may request to review its applicable procedures and processes.

7.2 Lab/Facility Qualification

The testing procedure defined in the standard may require a lab/facility to meet minimum performance criteria in order to demonstrate that the facility can successfully perform the test with acceptable precision. This is not an audit of the lab/facility, but may be necessary to ensure that the intent of the testing protocol is being followed. This also allows manufacturers to perform testing at their own facility, provided the facility can meet the qualification requirements of the testing protocol and the requirements of the user.

8 Uncertainty Analysis & Calculation

8.1 Types of Uncertainty

8.1.1 General

The testing protocol shall clearly define any specific uncertainty terms and how the value is determined. For example, pressure devices typically have values for linearity, hysteresis, and repeatability, ambient temperature effects, stability, and static pressure effects. If terms such as these are to be used in any section of the testing protocol, the protocol shall establish precise definitions, test procedures, and calculation methodologies for each. The testing protocol should also describe how overall device uncertainty is affected by the various operational effects. In the presentation of uncertainty, the results of each test should be separated.

8.1.2 Test Facility Uncertainty

Each testing protocol shall define a methodology to determine the uncertainty of the parameters applied by the test facility to the device being tested. Such parameters may include flow rate, pressure, temperature, frequency, and electrical values (milliamps, millivolts, Farads, etc.). A test facility may supply a national certification statement to validate the facility uncertainty.

The test facility shall define and state the system uncertainty for the device being tested and if requested by the user of the facility or the user of the device, shall provide the documentation of the method and calculation procedure used to establish the measurement uncertainty of the test. If the test facility does not provide the requested verifiable documentation used to establish and determine the measurement uncertainty of the tests, test results of that facility shall not be accepted in defining the measurement uncertainty of the device.

8.1.3 Device Uncertainty

Each testing protocol shall define a methodology to be used for the determination of uncertainty of the device being tested. The basis of the methodology should be a comparison of the parameter applied by the test facility with the output of the device as it is used in real-world operating conditions. Uncertainty may be given as a single value or a function of an operating condition, for example: Reynolds number, pressure, temperature, flow rate, etc. The uncertainty is only valid for the range of operating conditions tested (see Section 5 for the parameters that affect the performance of the device). Additional testing to quantify the uncertainty effects of operating conditions should be defined in a similar manner.

8.1.4 Significance Determination

The testing protocol should describe a methodology to determine the significance of a specific non-ideal operating condition that causes a statistically significant shift in the output of the device when compared to the baseline test as defined by the testing protocol. If a number of different methodologies could apply, the testing protocol should clearly describe the intent of the calculation and set general guidelines. If a specific method of determination of statistically significant level of influence is desired, the preferred method should be specified. Whenever possible, sample calculations should be included.

The testing protocol should require that all acquired data be reported in the database, without removing any outliers. If the cause of the outliers is known or can be defined, it should be stated in the reported data. Any industry accepted statistical method may be employed to improve the statistical inference of the database and the testing protocol should define how the statistical method of handling the outliers is to be reported or referenced in the test report.

8.2 How to Calculate Uncertainty

Each testing protocol shall describe a method or methods for the calculation of uncertainties in 8.1. The calculation methods should comply with standard or accepted industry practice such as the *Guide to the Expression of Uncertainty in Measurement (GUM)*. If different statistical methodology is permitted by the testing protocol to the acquired data, the testing protocol should clearly describe the intent of the calculation. Sample calculations defining the necessary steps of the calculation procedure should be provided.

All uncertainty results shall be reported at a 95 % confidence level, along with the number of measurements used in the determination of the uncertainty calculation.

If the testing protocol includes tests to determine the operating limits of a device (see 8.1.4), then a methodology for determining statistical significance should also be defined. The methodology should be designed to compare baseline testing with tests for different operating conditions, in order to determine if a statistically significant difference exists between the two data sets.

8.3 Presentation of Uncertainty

Each protocol should describe the preferred method of presenting the uncertainty determinations. For test facility uncertainty (see 8.1.2), it is recommended that each source of uncertainty and corresponding sensitivity coefficient be identified in tabulated format.

For device uncertainty (see 8.1.3), it is recommended that a graph of test facility input versus device output be included for each condition tested, along with the calculated uncertainty bands.

If operating limit determinations are required by the protocol (see Section 9), graphs of baseline testing along with specific operating conditions should also be included.

9 Test Report

The intent of the testing protocol is not to define a level of performance that a device being tested shall meet. Instead, the intent is to allow users to compare relative performance characteristics of similar devices, under the same operating conditions, as a function of parameters that are important in selecting the device for measurement. For certain applications, a user may be looking for a device that excels in one aspect, while not being concerned about another aspect. For example, some users may be primarily concerned with cost, and are willing to sacrifice some accuracy, for their particular application.

Each section of the testing protocol should define the reporting format of the test results in order to provide the user with the ability to determine which devices best fit their application. The test data reporting format should consider and address the typical selection criteria considered by the user for the selection of the type of instrument or device. The intent of specifying a format is not to require identical reports from all test facilities, but to ensure that the user is provided with a sufficient level of pertinent information on the testing that was performed. The format should be such that a side by side comparison of results can easily be made, regardless of where the tests were conducted. It is also recommended that a test summary, in a checklist format, be developed to document that tests were performed in compliance with the applicable section under this chapter.

As a minimum, the test report should contain the following sections:

- Summary;
- Description of Device Tested;
- Identification Information of the Device: make and model, line flow rate limits, etc.;
- Parameters Affecting Device Performance.

To quantify the effect of different parameters, the testing protocol should define the minimum acceptable limits of different test variables; e.g. tolerance of performance variables, limits of performance variables, etc.

- description or name of the test facility;
- tests performed;
- test results;
- uncertainty analysis;
- discussion of test results;

- conclusions;
- appendices.

Additional informative and relevant information should be defined in the appendices of the document. Those may typically include descriptive literature, sales literature, specification sheets, installation and operation manuals, service manual, parts lists, photographs, and drawings/sketches. If used, published procedures or test protocols should also be provided in the appendices section of the Test Report.

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Annex A (normative)

Type Testing

A.1 Introduction

This annex provides guidance specific to type testing of measurement devices governed by the individual sections of API MPMS Chapter 22. If type testing is applicable, ~~each then the specific~~ section of API MPMS Chapter 22 ~~shall~~ include an annex detailing the requirements for type testing of the devices covered by that section. This annex also provides guidelines for the development of these type testing annexes.

Users of devices for measuring hydrocarbon fluids may choose to test the performance of single or multiple instruments of the same brand, model, and measurement range, or to test single or multiple instruments with identical hardware and software features critical to performance. These approaches are commonly called “type testing,” where “type” refers to the brand and model of instrument or to the set of characteristics (such as size, geometric dimensions, instrumentation, software version, or operating range) common to the instruments being tested. The devices under test are subjected to similar-identical test conditions and compared to the performance requirements. After examining the results of the device(s) and evaluating the variations in performance, the user may approve the instrument type for its measurement applications. This approach avoids the need to test all instruments of that type by evaluating only a representative sample of the instruments instead, which results in confidence in the off-the-shelf performance of a device. ~~Government agencies may also require type testing of instruments used by petroleum and natural gas companies. By reviewing and approving the results of type tests, the agencies can approve instruments by type and eliminate the burden of reviewing test results for all instruments in their jurisdiction.~~

A.2 Identifying Type Testing Requirements

A.2.1 Type Testing Definitions

For the purposes of type testing, a “test item” or a “test unit” shall be defined as a complete instrument or piece of equipment that can be removed from a measurement system and replaced by another instrument or piece of equipment:

- of the same manufacturer and design; and/or
- having identical-similar characteristics affecting performance and measurement accuracy uncertainty.
- Examples of a test item include a single pressure transmitter, a single flow computer, or a single gas chromatograph.

“Device type” shall refer to the common characteristics of a group of units undergoing type tests. A device type shall be defined by brand and model, or by a set of characteristics affecting performance and accuracy. Characteristics of a device type shall be listed or defined in the applicable type testing annex. Acceptable variations among tested units of the defined device type shall also be identified within the type testing annex.

A.2.2 Selection of Test Items

Each type testing annex shall define the minimum number of test units sufficient for type testing, based on a statistical method described in an accepted standard. An informative list of example standards with guidance on selecting the minimum number of test units can be found in the bibliography. Each type testing annex shall also give other appropriate guidance for selecting test items, such that each unit chosen for type testing shall be representative of the device type being evaluated. The number of items tested [and if applicable, the size(s) of the test items] shall represent the range of devices and equipment available from the manufacturer that are included in the device type

and are applicable to the type tests. The number of test units and the selection method shall be agreed to by the manufacturer, the test facility, and the end user before type testing begins. The method of selection shall be documented in the type testing report.

Test items may have both hardware and software components. If the hardware and software are only available as an integrated unit from a single manufacturer, they shall be tested together as an integral unit.

The type testing annex shall also describe changes in device characteristics that will require new type testing of the device type. These shall include changes that affect device measurements, calculation results, and device performance (as quantified by accuracy, precision, operating range, etc.). Changes in critical dimensions, sensors, electronics, and software are examples of device changes that may require new type testing. Manufacturers, end users, and other interested parties may use quality assurance documentation to determine whether reduction of tests may be appropriate or when modifications to a device require new type tests.

~~Test items may have both hardware and software components. If the hardware and software are only available as an integrated unit from a single manufacturer, they shall be tested together as an integral unit.~~

A.2.3 Test Facility Requirements

In addition to complying with the facility audit and qualification requirements in the main body of this document (API MPMS Chapter 22.1), the test facility shall meet the requirements of the appropriate section of API MPMS Chapter 22. Type testing may be performed at a third-party laboratory or at a manufacturer's facility that meets the appropriate requirements and may include previously obtained test results. The facility should be capable of testing the required number of test items under ~~identical~~ similar conditions.

The uncertainty of the test facility for the relevant calibration shall be reported. The reported value shall either be validated through accreditation, or the uncertainty calculation methodology shall be available for evaluation by the user of the facility.

When performing type testing, the overall uncertainty of the reported value from the reference standard and its associated sources of error determines the minimum value when defining the uncertainty of the tested device. If the device uncertainty is claimed to be less than the claimed uncertainty of the device under test is defined by the test results and can be no less than the square root of two multiplied by the uncertainty of the test facility used for the calibration at 95 % confidence interval then, the claimed uncertainty of the test can be estimated at twice the uncertainty of the test facility used for the calibration at 95 % confidence interval unless evidence is shall be provided to substantiate a the lower uncertainty value.

All references used to establish the measurement uncertainty or performance of the device type shall be traceable to nationally or internationally recognized standards. The test facility system uncertainty and the uncertainty of each measured variable included in the type testing report shall include the measurement uncertainty at the 95 % confidence level.

A.2.4 Test Conditions and Test Requirements

The test conditions and test parameters required for units undergoing type testing shall be defined in the type test annex of the applicable section of API MPMS Chapter 22. End-user requirements for the items being tested should be considered in selecting test conditions, and in selecting characteristics of the test items, such as size or measurement span and range.

At a minimum, type testing under the appropriate section of API MPMS Chapter 22 shall require the following:

- the mandatory baseline and non-ideal testing outlined in Sections 6.4 and 6.5 of Chapter 22.1; and
- the performance tests outlined in Section 6.

The type testing annex may specify any additional testing required to determine any long-term changes in the performance of the test item(s).

Uniformity of the test conditions and of device treatment among all the test items is critical for valid type testing. If possible, tests should be performed on all test units in the same location, using ~~the same~~ similar test fluids, the same power supply, the same installation configurations, and ~~identical the same~~ values of all other conditions. This will help ensure that all test items are treated uniformly and are not subjected to variations that could affect performance.

Variables not being tested should also be held as consistent as possible to minimize their effect on the test results.

If it is not practical or feasible to test all items simultaneously using the same test fluids or at the same conditions, the variations between test items and test conditions shall be quantified and noted in the type testing report (see Section A.4).

A.3 Uncertainty Analysis and Calculation for Type Testing

Each test protocol in API *MPMS* Chapter 22 defines the methodologies for calculating uncertainties in the test facility, for calculating uncertainties in measurements by individual test items, and for determining non-ideal operating conditions that cause statistically significant shifts in device performance. The end users should choose acceptance criteria for all test items of the device type based on their own applications and requirements, since the test protocols of API *MPMS* Chapter 22 do not establish acceptance criteria.

Any test method not defined by the applicable test protocol shall be documented. Any statistical methodology for calculating and assigning measurement uncertainties shall be documented in the type testing report. The method should comply with standard or accepted industry practice, such as the ISO *Guide to the Expression of Uncertainty in Measurement (GUM)*. An example of a methodology that may be adapted to type testing can be found in *GUM* Annex H.5.

A.4 Type Testing Report

In addition to meeting the reporting requirements of the applicable API *MPMS* Chapter 22 test protocol for individual test items, reports for type tests shall include the following:

- test date(s);
- information on test units:
 - method for selecting units to be tested and selection criteria;
 - model numbers of units tested and quantity of each model tested;
 - serial numbers of units tested;
 - manufacturing location(s) of units tested;
 - software or firmware revision of units tested;
 - any certification dates and/or expiration dates of units tested;
 - dimensional drawings of each unit tested for which dimensions can affect performance (such as flow meters);

- verification of dynamic similarity for tested flow measurement primary devices.
- information on test facility:
 - lab certification documents;
 - for hardware testing, traceability and calibration information on test equipment and calibration references.
- information on type test conditions:
 - test setup drawings and/or descriptions;
 - dimensional drawings of pipework (if included as part of the test);
 - detailed description of the complete test matrix;
 - environmental conditions during tests or other uncontrolled factors that may impact test results.
- information on test results:
 - a comparison of predicted results for each test point (if available) to actual test results;
 - for software testing, sources of expected calculation results or verification or validation data;
 - required uncertainty calculation for facility reference values;
 - measurement uncertainties of individual test units based on the test results and the calculation method discussed in Section A.3.

Variations in test parameters or environmental conditions between test items and estimated effects on type test results.

Bibliography

- [1] BIPM, ¹ *Evaluation of measurement data — Guide to the expression of uncertainty in measurement (GUM)*

Examples of Standards for Selecting the Number of Test Units in a Type Test

Note that guidance in these standards on accepting test results may not apply to API MPMS Chapter 22 type testing protocols.

- [2] ANSI/ASQ Z1.4, ² *Sampling Procedures and Tables for Inspection by Attributes*

- [3] ISO 2859-1, ³ *Sampling procedures for inspection by attributes – Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection*

- [4] NCWM Publication 14, ⁴ *Measuring Devices*

Example of Standard for Calculating and Assigning Measurement Uncertainties

- [5] ISO *Guide to the Expression of Uncertainty in Measurement (ISO GUM)*

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² American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, New York 10036, www.ansi.org.

³ International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, www.iso.org.

⁴ National Conference on Weights and Measures, 1135 M Street, Suite 110, Lincoln, Nebraska 68508, www.ncwm.net.



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