The Relevance of Type Testing of Transit Time Ultrasonic Flow Meters

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1 INTRODUCTION

In much of the world one of the major criteria for operators and Weights and Measures organisations is to determine the performance of a meter during operation in some form of "type testing" of the meters. In most cases the standards used are those produced by OIML, R117 for liquids and R137 for gases. There are now available other test protocols, for example API 22.2, although these are not necessarily type testing, but could be used for a basis of a type test. The paper concentrates on the flow measurement aspect of type testing, rather than the auxiliary, functions such as vibration and thermal effects on the components.

The paper discusses the requirements for type testing proposed in OIML B3 "OIML Certificate System for Measuring Instruments", showing how much is left to the discretion of the test authority. For example there is no clear designation for the number of samples and the spread across size that is required for a good "type test".
The paper further discusses the relevance of the standards to USMs, particularly as the OIML standards are general standards and relate to the performance of different types of meter. There is no real discussion of installation requirements, and, for liquids, no real testing for proving, still a major no detailed criteria for custody transfer meters.

A possible impediment to many valid organisations from providing services of certifying meters to OIML standards, is the concept that they have to be authorized by the local Weights and Measures, and that only one organization per category is allowed in a single country. The basic requirement, only allowing one certifying authority for each criterion, goes against the competitive laws and philosophy in many countries.
The API attempt to introduce a performance based standard API chapter 22, currently mainly aimed at differential pressure meters, is discussed and the paper gives an update on the progress
.
Finally the paper lists the recommendations that should be added to the type testing methodologies to make them more practical and useful as criteria for judging the performance of a USM.

2 DO WE NEED TYPE TESTING?

Type testing and standards should have a complimentary function. Both are there to help the user understand the requirements and performance for a particular device, and to guide designers and manufacturers as the appropriate methods to achieve the ends set out by the standard. With flow measurement the need for appropriate standards and type testing is more relevant than for many other devices because of the lack of good theoretical background, requiring that the knowledge of meter performance be determined more by experience than for other devices, such as thermometers and pressure measuring instruments. The range of variables that effect a given flow meter design, whether it be a USM, Coriolis, turbine, positive displacement or orifice meter is large, and generally only available through experimental data, the most economically expensive data available. The consequence is that it takes many years to collect and interpret the data in a way that is useable for non-experts.
Necessarily most standards can only give a set of criteria that should be met by a design, or meter type, it is then left to the designer/manufacturer to provide evidence that their meter conforms to that standard. This can be a chaotic experience, as the presentation of this data can be in many forms, and often heavily influenced by a sales approach, which at best presents the data in the best possible light. A controlled "type testing" is one way in which there can be a standardised presentation of data from all manufactures, hopefully showing

the similarities and distinctions between the products in a clear light. From the manufacturers point of view it should be an opportunity to clearly show that their meters meet the standard.

This paper is concerned with the performance of individual meters. It should be noted that for some countries, the expression "type approval" can be reserved for complete measuring systems. If the system is to be type approved, then there will be a need to type test all of the individual constituent parts, but also it may be necessary to test the complete system, because there may be times when the end result of a system is not equal to the sum of the individual component parts.

3 STANDARDS FOR TYPE TESTING

From the forgoing discussion it should be clear that to achieve satisfactory type testing it needs to be related to a standard. It should also be clear that the standard has to have some quantitative values to define the meter performance. If there are no values to achieve then the only value of type testing is based on qualitative values, leading to defining performance by superlatives, such as superb linearity, and excellent repeatability, when we require numbers, for example 0.2% uncertainty across a 10:1 flow range to be able to compare the meters. Type testing can therefore only be sensibly carried out when used in conjunction with **performance** based standards. Therein, lies the problem, what standards are appropriate, and how far do they go in producing specifications that are useful.

3.1 Liquids

API has, until recently, consistently fought against detailed performance standards for meters. As a consequence the standard for liquid flow meters is really only a very general standard that tells very little about the expected performance of an Ultrasonic flow meter. Also there is minimum discussion about the effects of installation, and how testing should be carried out to determine the performance of a USM under different installation conditions. The API philosophy has been to provide enough to be able to allow company buyers to be able to require conformance to that standard as part of the buying protocol. It is then a contractual issue to work out the numbers. This is seen in many requests to quote, “does the meter conform to API Chapter 5.8?”. The fact that it means nothing, and has no real value is often not a major issue within the bureaucratic parts of a business. The exception to this is the very detailed performance criteria for proving, to which API 5.8 does point the reader. It does not help in those instances, becoming more common, where proving is not part of the operation, neither does it help in defining the general performance.

OIML R117, a standard for measuring liquids other than water, does help with the concept of type testing in that it gives overall guide lines for uncertainty for different levels of measurement. It is classed as a standard for **legal metrology**, implying that it is in effect a government weights and measures standard. It does include range considerations and repeatability within the standard. Throughout the world of USMs, it could be said that it rules as the basis for Type testing. The majority of manufacturers of liquid USMs have used this as a basis for demonstrating the performance of their meters, and yet it is a very loose standard in many terms to use. It says nothing about calibration methods, a word search of the standard failed to show that the word “calibration” appeared even once in the standard. It does go into some detail about the “verification” of conversion equipment, but discusses nothing about the method of flow calibration. With regard to installation the comment is “If the accuracy of the meter is affected by disturbances in the upstream or downstream pipeline, the meter shall be provided with a sufficient number of straight pipe lengths, with or without flow straightening devices, as specified by the manufacturer, so that the indications of the installed measuring system including the meter meet the requirements of 2.4 to 2.6 with respect to the maximum permissible errors and according to the accuracy class of the measuring system” Sections 2.4 to 2.6 refer to the meter conditions for operation.

For OIML type testing the required tests should include:

• Accuracy tests (including repeatability and flow disturbances tests, if applicable),
• Influence factor tests, and
• Electronic disturbance and mechanical tests.

The standard is also not clear as to the method of determining which meters need to be calibrated within the range of sizes, so for example if the range is 4” to 30”, how many meters need to be calibrated to be representative of the range. What method should be used to determine the sizes, or should it be every size? Further, how many meters of each size is truly representative of the meter performance? A classic example of this is with Positive Displacement meters. With one particular design they find that out of the batches of meters produced, one or two meters have a performance that far exceeds the majority. These are sold at a premium price as “super” meters with an uncertainty at least half of the standard meter uncertainty. If these meters were chosen for the type testing then the performance attributed to the standard meters would be false. In fact special effort is often put into ensuring that the meters are as good as they can be for the type testing. The problem is to find a balance between an economically viable number of meters and tests, they are very expensive to conduct and time consuming. They can be seen as “nice little earners” for flow facilities and Weights and Measures organizations, but the point is that the object of type testing is to determine, on behalf of users, commercial and fiscal, the quality of meters produced by different manufacturers and whether they are “fit for purpose” in their application.

To summarise OIML R117 is specifically a legal metrology document aimed at type testing meters generally for fluids other than water. It suffers from the point of view of liquid USMs from not being specific to those meters, and therefore has some eccentricities that are not appropriate, and also misses some features that are particular to USMs. There is no part of the standard that relates to the operation of USMs, or meters with provers, which on custody transfer pipeline measurement is probably a major requirement for small and medium meter sizes.

ISO 12242:2012 specifies requirements and recommendations for ultrasonic liquid flowmeters, which utilize the transit time of ultrasonic signals to measure the flow of single-phase homogenous liquids in closed conduits. It also specifies performance, calibration and output characteristics of ultrasonic meters for liquid flow measurement and deals with installation conditions. It covers installation with and without a dedicated proving (calibration) system. It covers both in-line and clamp-on transducers (used in configurations in which the beam is non-refracted and in those in which it is refracted). Included are both meters incorporating meter bodies and meters with field-mounted transducers.

The standard does not put in any values for performance to give targets but goes into great detail with regard to performance testing. There are a number of sections that are applicable to higher uncertainty measurement, but the relevant sections include:

- Tests need to be carried out on at least two sizes of meter that differ in size by 2:1.
- Repeatability and reproducibility.
    - It describes the number of flows to be calibrated.
    - Repeatability, using three flows and 10 points. It does not specify the required repeatability, instead it requires the value to be reported..
    - Reproducibility.
- Fluid-mechanical installation conditions.
    - A baseline measurement (including a flow conditioner)
    - Tests with a number of specified installations (Single and double bends etc.)
    - Conducted at two Reynolds numbers
    - Conducted at a number of distances downstream of the disturbance)
- Path failure simulation and exchange of components.

To summarize, the standard does advocate performance type testing, but does not have any targets to be achieved. It also is putting forward the concept of installation testing, unlike most other standards. The choice of only two sizes and not commenting on the number of meters in each size does not cover type testing satisfactorily.

3.2 Gas

The standards for gas USMs are generally more performance based than for liquids. This is probably because of the lack of on-site calibration/ proving, available in the gas industry. It has been essential that gas meters have some form of reference calibration. The standard that is currently the most used for basic performance evaluation for a meter is the AGA 9 standard. OIML R137 is very similar in concept and layout to the liquid equivalent R117, in that it is defined as a legal metrology standard and advocates and describes type testing. ISO 17089 -2010 is a very detailed standard on gas USMs, with its avowed basis as AGA9. The standard is currently too modern to be widely used.

AGA 9 has two sets of performances quoted for large meter, 12" (nominal) meters and larger, and small meters, less than 12" (nominal).
The performance is summarized in figure 1.

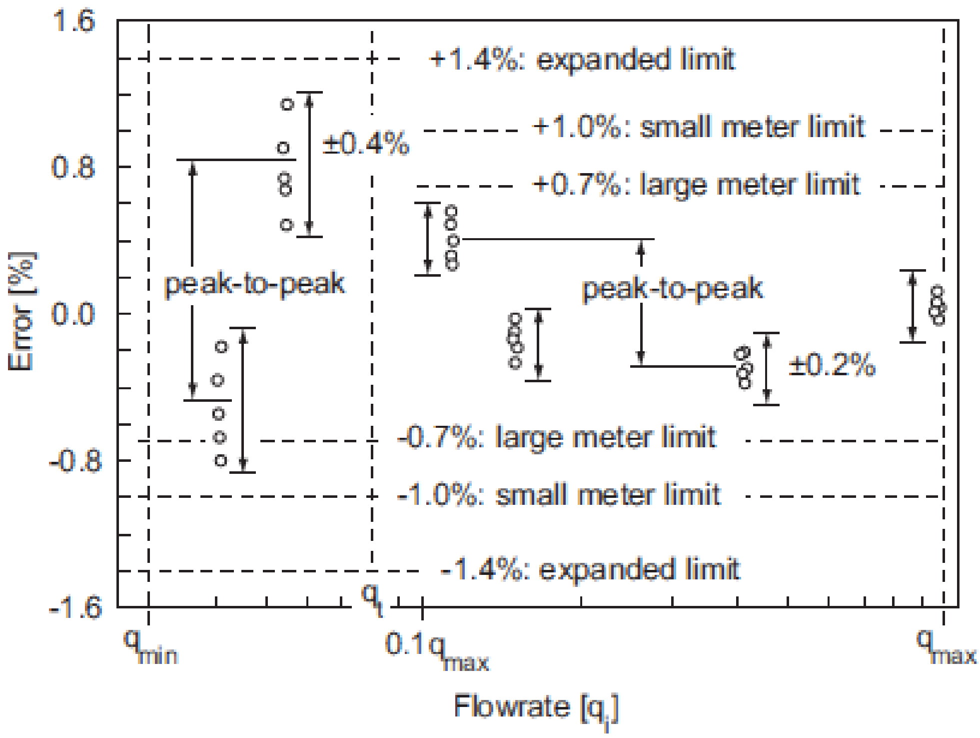

Figure 1 AGA 9 Meter Performance

Defining:
q_{max}: maximum flow limit
q_t: transition flow limit ($q_t < 0.1q_{max}$)
q_{min}: minimum flow limit
q_I: indicated UUT flow
The peak to peak limits are:
± 1.0% for qt ≤ qi ≤ qmax(small meter, = 10")
± 0.7% for qt ≤ qi ≤ qmax(large meter, = 12")
± 1.4% for q min ≤ qi ≤ q t

As can be seen there is a detailed performance defined and it is against this performance that a gas USM is calibrated. This includes repeatability's, (spreads) and linearity.The standard also includes such items as calibration facility preparation and the requirements for calibration.
In addition to the specific flow calibration criteria they have a few general requirements for repeatability, resolution, velocity sampling interval, zero-flow reading, speed of sound deviation and maximum SOS path spread. In Appendix B AGA 9 lists all the OIML R 6 and D 11 electronics design testing which is to be performed on one meter.

To summarise the standard is a very practical guide for the performance of gas USMs, but does not advocate or describe performance type testing. The data is however sufficient to use as the basis of type testing.

OIML R137 is a legal metrology based standard, aimed totally at achieving type testing. Like its liquid counterpart it is a general flow meter standard and does not concentrate on the performance of USM s.

Like R117, the liquid standard, R 137 specifies a number of different accuracy classes for different applications. The errors given in R137 given in a table, shown below in table 1.

Flow rate Q	On type approval and initial verification Accuracy Class			In-service * Accuracy Class		
	0.5	1	1.5	0.5	1	1.5
$Q_{min} \leq Q < Q_t$	± 1%	± 2%	± 3%	± 2%	± 4%	± 6%
$Q_t \leq Q \leq Q_{max}$	± 0.5%	± 1%	± 1.5%	± 1%	± 2%	± 3%

Table 1 Accuracy Classes from OIML R117

They annex the use of OIML R 6 and D 11 for electronics design testing which is to be performed on one meter.

Perhaps the biggest difference with regard to performance compared to AGA 9 is the addition of a proposed set of tests to determine the performance changes due to installation conditions. It will be noted also that these are very stringent in their requirements requiring changes of less than 0.165% for all the disturbance tests for the 0.5 Accuracy Class. Compared to the AGA 9 standard OIML R 137-1 can be used to present an “approval” in the form of a third party certified OIML test report, in the same way that has been normal practice with OIML R 117-1 for liquid meters.

To summarize OIML R137 is specifically a legal metrology document aimed at type testing meters generally for Gas. It suffers from the point of view for gas USMs of not being specific to those meters, and therefore has some eccentricities that are not appropriate, and also misses some features that are particular to USMs. There is no part of the standard that relates to the operation of USMs, or to the number of meters to be calibrated as representative of the range.

ISO 17089- 2010 is the newest of the standards for gas meters and is specific to USMs and in part I is directly concerned with the performance of custody transfer and allocation meters. It specifies requirements and recommendations for ultrasonic gas flow meters (USMs), which utilize the transit time of acoustic signals to measure the flow of single phase homogenous gases in closed conduits. The standard specifies construction, performance, calibration and output characteristics of ultrasonic meters for gas flow measurement and deals with installation conditions. It is very detailed in its description of the operation of USMs. The performance details are divided into two classes, Custody transfer, class 1, with an uncertainty of +/- 0.7% over a specified range and allocation meters, class 2, with an uncertainty of +/- 1.5% over a specified range. The performance of a class is described in a similar way to AGA 9, with similar linearity, and repeatability conditions. It does call up the use of type testing, described in section 6.4, “Type testing includes extensive tests in order to verify the compliance to all requirements of this part of ISO 17089. A USM having a type approval shall be tested as in 6.1, 6.2 and 6.3. Type testing shall be conducted by recognized bodies or independent certified laboratories”.

To summarize, the standard is new and it remains to be seen if it will become practically accepted along with the other standards or even supersede them, either on a world basis or locally.

3.3 API MPMS Chapter 22

Chapter 22 is now underway; it is an attempt by API to move towards a more performance based set of standards. One of the principles of 22 is that it helps define the performance of devices that don't have performance based standards. The main idea is that you will be able to develop a station uncertainty by combining the performance of each component of the station. If the component already has a standard (AGA9, or 3 for example), there is no need to include it in API 22.

- It represents a series of testing protocols:
  - 22.1 – General guidelines for developing protocols
  - 22.2 – Differential Producing Flow Meters
  - 22.3 – Flare Gas Meters
  - 22.4 – Pressure, Differential Pressure, and Temperature Measurement Devices
  - 22.5 – Flow Computers
  - 22.6 – Gas Chromatographs

While at present it does not include USMs the principle is to produce performance based testing protocols.
It will contain the following:

- Section 6 Parameter Variations Affecting Device Performance:
  - List of items that influence the device, i.e. – ambient temperature for a transducer
  - Each item listed in Section 6 must then be addressed in Section 7
- Section 7 Mandatory Tests:
  - Test Conditions
  - Test Installation
  - Test Results
  - Baseline (Ideal Condition) Testing
  - Non-Ideal Condition Testing
  - Special Testing
  - Testing Documentation
  - Testing Procedure
- Section 8 Test Facility Requirements:
  - Audit Process
  - Lab/Facility Qualification, i.e. – Test orifice to RHG equation
- Section 9 Uncertainty Analysis & Calculation:
  - Types of Uncertainty
  - Test Facility Uncertainty
  - Device Uncertainty
  - Significance Determination
  - How to Calculate Uncertainty
  - Presentation of Uncertainty
- Section 10 Test Reports:
  - Summary
  - Description of Device Tested
  - Identification of Device (Model/Serial Number)
  - Parameters Affecting Device Performance
  - Description of Test Facility
  - Tests Performed
  - Test Results
  - Uncertainty Analysis
  - Discussion of Test Results
  - Conclusions

As can be seen this is a very different standard to those previously produced, and is aimed at a performance type standard. It stops short at present of advocating type testing.

4 APPLICABLE TYPE TEST APPROVAL ORGANISATIONS

The current standards clearly are divided into two camps with regard to the qualifications of the test facility allowed to carry out type testing. The OIML standards for both gas and liquid are termed legal metrology standards. The conditions for the testing and qualifying terms are detailed in OIML B3, and clearly are aimed at the facilities being either national weights and measures organizations, or an approved surrogate. The ISO standards, on the other hand, are more relaxed, and typically state such words as, “Type testing shall be conducted by recognized bodies or independent certified laboratories”.

4.1 OIML B3 Requirements for a Type Approval Organization.

OIML B3, is a detailed report on the production and methodology of carrying out OIML type testing and producing the test reports and certificate of conformity for the product.
The OIML Certificate System for Measuring Instruments can be summarized as a system for issuing, registering and using OIML Certificates of Conformity for types of measuring instruments, based on the requirements of Recommendations of the International organization of Legal Metrology (OIML). The objective is to produce type or pattern approvals for instruments.

It defines Type or pattern evaluation as, “The Systematic examination and testing of the performance of one or more specimens of an identified type (pattern) of measuring instrument against documented requirements, the results of which are contained in an evaluation report, in order to determine whether the type may be approved”.

The authority permitted to issue a type test certificate, is defined as, Certifying body or person in an OIML Member State, and designated by its CIML (Member the International Committee of Legal Metrology) that issues OIML Certificates of Conformity according to the rules of the OIML Certificate System for Measuring Instruments. The issuing Authority that issues OIML Certificates may or may not be the same organization as the national body that issues national type approval certificates and whose responsibilities are governed by national regulations. In other words it can be a surrogate organization, appointed by the national body. It should be noted, however, in a given Member State, there may be one or several Issuing authorities; **however, for each category of measuring instrument, there shall be only one Issuing Authority.** The problem with this is that in states where there is more than one organization capable of performing the tests for a given category, only one can be authorized to carry out the work. This can be seen as both a restraint of trade, and restricts competition. Those companies that use the OIML certification for their products particularly for liquid USMs, will know that the process is very expensive, and currently non-competitive.

5 WHAT IS REQUIRED FOR GOOD TYPE TESTING

The issue with the current type testing methods is, are they the giving the end user, the main person requiring this data a good indication of how good is the meter performance? The liquid type testing is mainly around OIML R117. It certainly allows the comparison of the best meters that the suppliers can produce, but whether these are truly representative of the production meters is not truly clear. On the gas side OIML R137 has been used, particularly for its section on installation conditions. The problem as will be shown with these type test standards is their general nature. They do not make clear the type test requirements that are a function of the meter design. This leaves wide latitude for the type test authority to interpret the method of type testing. It is not clear that the ISO standards have yet been used as a basis for type testing on either liquid or gas. They at least have a concentration on the meter type.

What features are needed for a good basis of comparison of meter performance:

- **Batch Sampling or Sample size**: At present it is usual to review the calibration characteristics of a single meter of a given size. At worst this can lead to the use of “super” meters being presented for testing, at best it does not give a clear picture of how representative this meter is of the general population of meters of this design. There should be some safeguard, possibly by requiring the data for a number of meters of the same size and design to be calibrated and the performance checked, possibly picked at random, if this is physically possible. Determining sample size is a very important issue because samples that are too large may waste time, resources and money, while samples that are too small may lead to inaccurate results. In many cases, we can easily determine the minimum sample size needed to estimate a process parameter, such as the population mean. It may be sufficient to do this for one size only, as being representative of the rest of the meters in the range. It would also allow the producer to choose a size range that is likely to have the largest number of meters available. NIST state the problem as follows:
  - There must be a statement about what is expected of the sample. It must determine what is being estimated, how precise is that estimate required to be, and what is the value of that estimate. This should easily be derived from the goals of the standard.
  - An equation that connects the desired precision of the estimate with the sample size must be derived. This is a probability statement, and would be heavily influence the USM performance. There is a good chance that there will be a difference between Gas and Liquid meters. For example the effect of path angle on the meter calibration, and performance is almost an order of magnitude greater for gas compared to liquid meters.
  - This equation may contain unknown properties of the population such as the mean or variance. This is where prior information can help. In many respects this is related to data provided by manufacturers on reproducibility of there meters build and performance.
  - The final sample size should be scrutinized for practicality. If it is unacceptable, the only way to reduce it is to accept less precision in the sample estimate.

- **Meter Sizes**: Currently there is no clear indication as to the number of meters and sizes required for testing, when there is a range of sizes for meters. Typically both gas and liquid USMs cover a size range from 4” to 30”. If every size had to be tested, in the most common sizes this would lead to testing a minimum of 10 meters. While this would be good business for the calibration and type test facilities, the cost burden would be excessive, particularly for the large size meter calibration on liquid. There needs to be some agreed method of determining the number of sizes that are representative of meter design. Perhaps there should be the smallest, the largest and one in between? Often the larger meters are only built rarely, is it feasible to allow a meter, say 20” diameter to represent the 30”. There needs to be some consensus as to the methodology to determine the meters required to represent the range. At present it is by negotiation.
- **Design Variations**: With both gas and liquid USMs, there design variations, particularly with transducer frequency and design (Size). This leads to the question, at what point should type testing review these variations and should they be tested as part of the type test procedure. There are differences in performance with transducer changes on both gas and liquid. Higher frequency transducers used avoid the effects of valve noise may change the bottom range of the meter. Lower frequency transducers on liquid, used to improve performance on higher viscosity products, are often larger, with larger ports. They can affect the performance of the meter. There needs to be at the very least some reference to these changes within the type test regime to make it valid.
- **Software**: There is within the standards some attempt to control the software, but this is very difficult in practice. USMs are under continuous development, and software “bugs”, by the very nature of the complexity of the designs, are being found

and fixed. This means that very soon after type tests there are likely to be differences between the type test software, and that being used in current meters. To require retesting with these changes would impose an intolerable burden on the manufacturer, and slow down progress of meter development. Perhaps the solution is to take a leaf out of the book of aeronautical and nuclear standards and institute a requirement for internal control of software that would be part of an audit during type testing. There may be a need for some limitation on the level of software change at which a retest needs to be carried out.

- **Calibration**: The definition of the performance of gas meters is well defined particularly in AGA9 and ISO 17089, it would be useful for OIML 137 to recognize these standards and use them as they both relate directly to USMs, and recognize the eccentricities of the meter type. Liquid meters, however, do not have well defined performance standards. ISO 12242, talks about performance testing, but unlike the gas standards does not go into any detail on the performance requirements. For performance the only standard available is OIML R117. This has a blanket statement of uncertainty, for whichever level is required, a repeatability statement that ends up with the best repeatability being defined as a spread of 0.12% in 3 runs, which equates to an uncertainty of around 0.16% for the repeatability, which is well outside of the general requirements for custody transfer measurement of hydrocarbons. API require for proving the uncertainty to be 0.027%, which is difficult for direct proving of USMs, but is probably a more acceptable practical number. There needs to be some equivalent, in terms of performance definition, to the gas standards for liquids so that the playing field is kept the same for all. At present there is continual argument over the limits and performance between manufacturers, and a degree of acrimony relating to certificates of performance being issued to different users. A liquid performance guide should also include such issues as performance through transition and into laminar flow. It should possibly have a specification relating to temperature gradients in laminar flow as an installation issue.
- **Proving**: This has no issue in gas metering, but is a major issue in liquid metering. Any performance standards should have a reference to proving of liquid USMs. It is an area of great debate between suppliers and users, and would do well to have a set of performance requirements to enable a direct comparison of meter designs.
- **Installation**: Installation is a necessary issue relating to type testing of USMs, particularly in non-proved systems. Unlike an orifice plate where the fluid mechanical design is specified by the standard, USMs are of a variety of configurations and designs, and therefore do not react the same way with different installations. On the gas side OIML R137 and ISO 17089 have tests for performance with installation, AGA 9 does not. On the liquid side, the only standard that has a performance guide for installations is ISO 12242.
- **Environment, Electrical and Mechanical Performance**: This subject is not the remit of this paper, but it is adequately covered in the OIML documents.
- **Type Test Approval Organizations and Calibration Facilities**: Currently this is being carried out almost exclusively by MNIs or by surrogate organizations, to OIML legal metrology standards. The problem with this is that it stops organizations of good standing from being able to perform the type testing, and certainly the rule that only one organization can type test in one category in an individual country stops any competition. This is the opposite to, for example the ISO 17025 methodology for approving calibration facilities, which has provision for several accreditation bodies within countries by using ILAC (International Laboratory Accreditation Cooperation) to determine the suitability of the organization. The ISO standards are now showing performance data and advocating the use of type testing, but leave the statement of who can perform the task as very open to interpretation with such statements as: “Type testing shall be conducted by recognized bodies or independent certified laboratories”.

6 CONCLUSIONS

- Because of the complex nature of flow metering, there is a need to have some reference for meter users to compare the performance independently of different makes of USM.
- Type testing is one way in which this can be carried out effectively.
- The current specifications for performance are very variable in quality and detail.
- Currently OMIL has the most detailed methodology for type testing, but still misses some vital aspects, such as meter samples by size and manufactured numbers.
- OIML is also proscriptive on who can carry out the type test service, leaving little room for competition, in spite of there being large numbers of potentially qualified organizations not under the OIML umbrella.
- The ISO standards and AGA 3 offer some hope of a wider use of type testing, but the standards are still not good at covering all the bases required to define the performance and methodology.
- API 22 is at last, within the API organization, an attempt to produce a set of standards that will have a comprehensive test and performance base, and then be used to put together a system.

7 REFERENCES

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