FLUID MEASUREMENT

Some practical aspects regarding the traceability of systems measuring large quantities of fluids

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Abstract

Ensuring the traceability of systems measuring large quantities of fluids gives rise to a series of problems. Solving these requires data analysis using methods which are generally infrequently used in metrological activity.

This paper analyzes some theoretical aspects of the way in which current normative documents deal with the uncertainty problems specific to large systems, and emphasizes the need for a more careful definition of the "reference" notion when dealing with traceability, resulting from a practical approach.

Finally, examples of solutions to some of the problems encountered in estimating uncertainty and ways of diagnosing improper functioning modes are also presented.

Introduction

Current systems that measure quantities of fluids using computing micro-systems, either built into the components or autonomous, have two functions: the main measurement function is complemented by the capacity to transfer and analyze large amounts of data using techniques which are easily accessible to those having only limited knowledge of the field. It therefore becomes possible to control systems comprising many components, situated hundreds or even thousands of kilometers away, thus providing important technological and financial benefits.

These benefits to the user can be outweighed if they do not pertain to the main purpose, which is the traceable measurement of a certain amount of fluid, with a certain degree of uncertainty.

A number of normative documents deal with these problems [1–6] but sometimes only in a general way, and sometimes geared towards the components.

In this paper the author analyzes some problems specific to large systems (i.e. ones which measure large quantities of fluids), from the point of view of traceability and uncertainty.

Traceability

Traceability is a property of the result of a measurement that allows this result to be viewed in relation to "stated references" through a series of comparisons, each of them being characterized by a determined uncertainty (VIM 6.10, 1993).

When applying this definition to systems that measure large quantities of fluids, some practical aspects need to be addressed:

a) It is difficult (and sometimes impossible) to devise experiments to calibrate the primary transducers (such as the orifice flow transducers in systems that measure large volumes of gases) to flow or volume (mass) standards.

b) When the final result desired by the user is the volume of fluid in standard conditions, this result is an output of the whole system, obtained by correcting the measurement output of the primary transducer. Sometimes, the system cannot be checked as a whole.

c) When the final result is the fluid mass, the correction is no longer necessary but the uncertainty in the density of the fluid can have an important impact on the general uncertainty of the system. In such a way, the metrological control of the devices that measure the density or composition of the gases becomes an important issue.

d) When the final result is the fluid energy, the same problem must be solved related to the calorific value of the fluids.

When the above-mentioned problems concern the system structure the sets of rules provided by the reference documents (forms, limits, relations) may be applicable, even though they do not belong to the same (physical) class as the main measurand.

For example, an orifice device for measuring the amounts of natural gas can be traced to:

- ISO 5167 [2] for converting flow to pressure difference;
- AGA 8 [6] for converting the flow (volume) of gas from working conditions to standard conditions.

These facts lead to the necessity for the user to perform a precise, even though indirect, estimate of the uncertainty.

A system such as the one described above can produce an uncertainty parameter of 0.7–1.0 % in the case of correctly solving the environmental problems for secondary and tertiary devices (Fig. 1), when choosing the optimal excursion interval for the working point (dynamic ratio).

Sometimes, much smaller values of this parameter are needed. The obvious solution to the problem would be the use of a system having a more efficient and more traceable primary transducer, based on a different principle. However, such a system might be expensive, and the transducer more difficult to control, leading to reduced accessibility for most users.

A second solution might be the subsequent use of the data recorded during its use, in order to establish a maintenance policy, thus achieving a better coherence of the systems from a certain technological area [8], [9]. Even though this solution is not simple and implies systematic actions at the level of the working procedures, it is preferred by users since it uses data collected anyway for management needs. In the final part of this paper the author presents an example that uses such a solution.

A system for measuring the volume of oil products with a positive displacement (PD) meter is traceable to:

- The volume standard, through calibrations usually done on site, using a prover or a master meter;
- API - MPMS Chapter 11.1 [4] for correcting the volume from the working conditions to the standard conditions.

It is to be noted that the two traceability references are different: the volume standards are physical entities, while the reference for corrections comprises calculus methods or tables.

The calibration or verification methods were elaborated according to this separation of references. For a volume meter, the calibration method has as a goal the determination of the meter factor (MF) through the direct comparison of the volume meter's measurements with those of the standard, while the same fluid flows through both devices.

The volume correction is actually done using a subsystem that contains secondary and tertiary elements. For oil volume measurement there are normative references [7] that deal with all the problems related to the correction.

For the system as a whole, there are prescriptions stressing different issues [1]. An important aspect to be mentioned is the fact that for pipeline measurements, systems with a 0.3 % overall uncertainty are recommended, but it is necessary to use volume transducers with an error limit of 0.2 %, covering most of the system uncertainty.

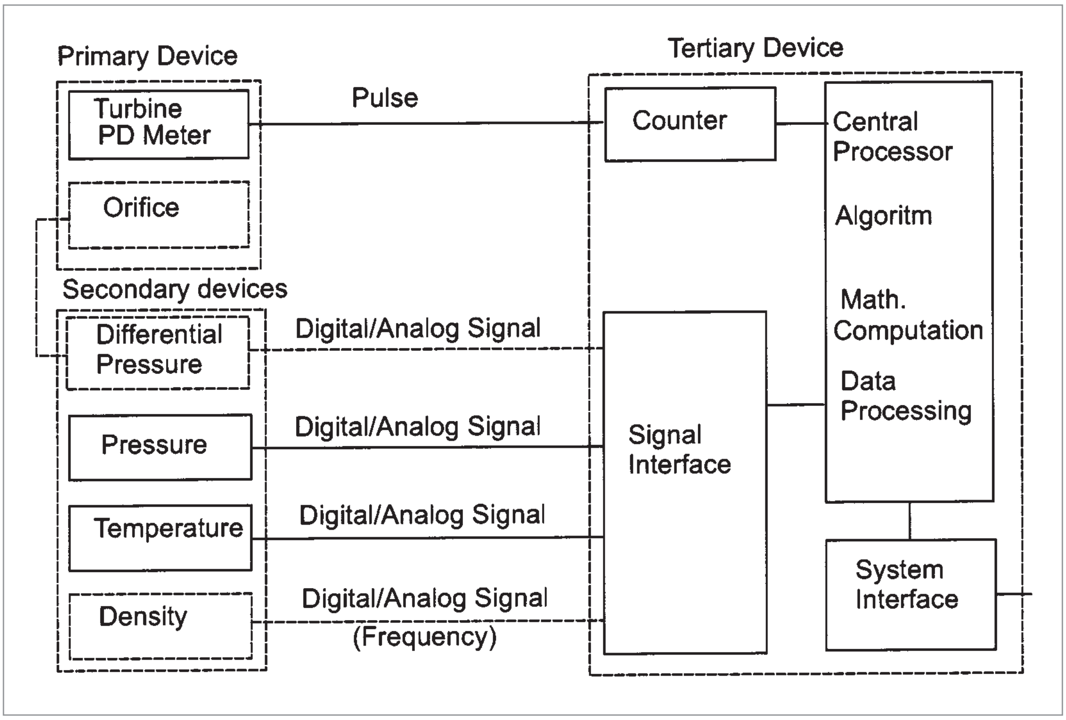

Fig. 1 Schematic of a system for measuring the amount of fluid

Once these goals are fixed, one needs to analyze from a practical point of view which conditions need to be imposed on both the components and on the system as a whole, in order for the desired performance to be achieved. Additionally, the reliability of this performance to varying technological parameters, system parameters and influence quantities needs to be ascertained.

Under such circumstances, it is useful to note that about 2/3 of the system uncertainty is due to the meter, and that for the majority of commercial meters there are non-negligible dependencies of the measured flowrate, temperature and viscosity.

Among such dependencies, the flowrate issue is usually resolved by the flow computer [10] through the linearization procedure. Correcting for temperature and viscosity dependence when measuring large quantities of fluid is more difficult, implying a lack of precise knowledge about the fluid properties under discussion. Practically, such problems can be solved in additional steps, through repeated calibrations under different circumstances and a systematic analysis of the outputs of the system associated with laboratory data (function of densities or viscosities vs. temperature).

Uncertainty

As presented above, when it is impossible from a practical point of view to devise experiments to characterize a system as a whole, the system uncertainty is the only indicator for its traceability and the quality of the measurements made using the system.

As both the cost of the system and the quality of its main function are determined by its uncertainty, estimating this parameter becomes extremely important, leading to the need to establish a standard form for the estimation method and associate the result with a confidence level.

All the regulations issued by national or international institutions deal with the problem of estimating the uncertainty, but in order to correctly apply the recommendations a thorough classification and interpretation is needed. These regulations can deal with the uncertainty of:

- the whole system;
- a part of a system (for example, the volume correction sub-system);
- a device belonging to the system (for example, the volume meter).

The recommendation for estimating the uncertainty can have different forms:

- an equation to be used for calculations;
- an interval suitable for different conditions;
- a precise value.

Or it may have different destinations:

- limits that have to be respected under certain circumstances;
- reference values or intervals.

The procedure for calculating the composed uncertainty can be:

- through quadratic addition;
- through linear addition of the component parts;
- a combination of the first two.

Table 1 presents a synthesis of the prescriptions regarding the five most important international normative documents in the field.

Table 1 Synthesis of the prescriptions regarding the five most important international normative documents in the field of composed uncertainty

Characteristic	Criterion	OIML R 117	ISO 5167	CEN TC 237	API Ch. 21 / 1	API Ch. 21 / 2
Goal	System	×	×			
	Sub-system	×		×	×	×
	Component	×				
Form	Equation		×	×	×	×
	Interval	×				
	Punctual	×	×	×	×	×
Destination	Limit	×	×	×	×	×
	Reference	×	×			
Addition method	Quadratic		×		×	×
	Absolute value, linear			×		
	Composed	×				

The five documents define an extremely valuable system of criteria for solving practical problems such as pattern approvals, comparisons of measurement systems, or determining the influence of a component of a system on the uncertainty of the whole system.

One of the important issues to be discussed here is the addition method for the partial uncertainties in order to determine the uncertainty of the whole system, meaning the uncertainty with which the quantity of fluid is measured. This value needs to be associated with a confidence level.

The published literature recommends quadratic addition in the case of the non-correlated components with normal distribution, or the addition of the absolute values for those situations where the components are non-randomly distributed. These addition methods, resulting from the practical experience of well-established laboratories, rely on the careful analysis of the physical phenomena and are geared towards obtaining the uncertainty level of the system with only a small computational effort. At the present time and considering the developments of computational techniques, such considerations are no longer of importance.

It is important to stress, however, that the level of confidence (usually 95 %) is assumed and specific to a normal distribution of the components. Such a condition is not always fulfilled.

A more realistic hypothesis is the assumption that, in the case where the component of the system is a transducer, the measured value can be found with equal probability in the interval delimited by its maximum permissible error (± MPE), around the conventionally true value. In such a way, a device can be modeled using a random number generator for uniform distributed values.

The algorithm of the system can be written in a code that can be executed within a short time period. Each run of the program uses as input data randomly generated numbers (distributed uniformly, or, if needed, according to any other kind of distribution). The code is run a large number of times in order to ensure the stability of the distribution of the result (the corrected volume). By analyzing the results, one can obtain a high "hit rate" (for example 95 %) when defining the uncertainty of the system at the working point.

This estimation technique, relying on the Monte Carlo method, allows the user to obtain results in a very short time - in the order of seconds for today's computers.

An important advantage of this method is the fact that, when graphically representing the histogram of the results, one can obtain an intuitive estimate of the balance of the system at a certain working point.

The results (the uncertainty of the systems) obtained with this method were compared to those obtained through quadratic addition. The maximum differences between the two uncertainty estimates are less than 12 % (1.12 % with 95 % confidence level using the Monte Carlo method vs. 1 % using the quadratic addition method).

Examples

1 The instrumental uncertainty of an orifice system for measuring the flowrate (volume) of gas

Figure 2 presents the schematic of a station measuring the flowrate (volume) of gas using a sensor with a flange tap orifice connected to two instrument assemblies (primary and test). The estimation of the volume of gas is done according to ISO 5167 and AGA 8 GROSS 2 [2], [6]. Table 2 presents the main characteristics of the secondary (transducers) and tertiary (flow computer) elements of the primary system.

For performing the calculations, the uncertainty of the primary sensor (and associated uncertainties) and that of the secondary and tertiary systems were separated. The calculations were made for a known gas (Amarillo, [6]).

By applying the statistical model of analyzing the uncertainty of the secondary and tertiary elements described above, the data set whose histogram is presented in Fig. 3 is obtained. The following important features are as follows:

a) The flat flow histogram is mainly due to the preponderance of one of the partial uncertainties (the pressure difference);

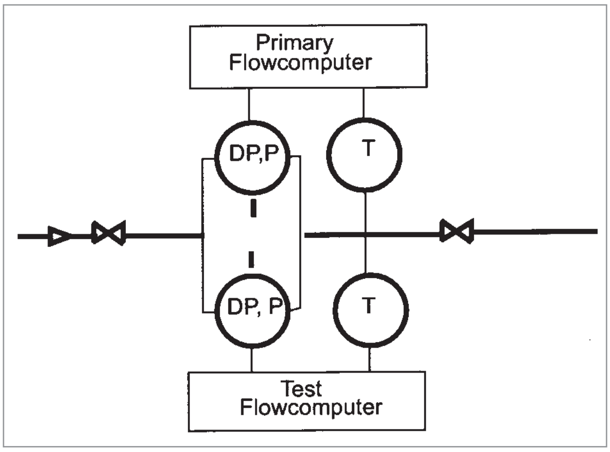

Fig. 2 Schematic of a station for measuring the amounts of natural gas

Table 2 Main characteristics of the secondary (transducers) and tertiary (flow computer) elements of the primary system

Element	Interval	Accuracy		Working point
		class	type	
Differential pressure transducer	0 to 37 kPa	0.1	% FSD	6 kPa
Static pressure transducer	0 to 35 bar	0.1	% FSD	25 bar
Temperature transducer	–20 to 80 °C	0.25	°C	20 °C
Flow computer	Configurable	0.1	%	

b) The uncertainty estimated through statistical modeling (0.39 % at a 95 % confidence level) is 10 % larger than that estimated through quadratic addition (0.34 %). The difference can be explained by the relatively flat shape of the histogram.

c) The height of the green rectangles indicates the level of uniform distribution. Their position on the x-axis represents the values of uncertainty at a 95 % confidence level.

If the assumption of a uniform distribution of the input data on the interval of the error limits is correct, then the distribution of the output data (the gas flowrate) under standard conditions is a direct consequence of this assumption. Therefore, the estimated value of the uncertainty associated with a level of confidence is the best measure of the accuracy of the ensemble.

This kind of estimation can easily be achieved for any working point and can lead to an optimal choice for the characteristics of the secondary and tertiary elements of the system.

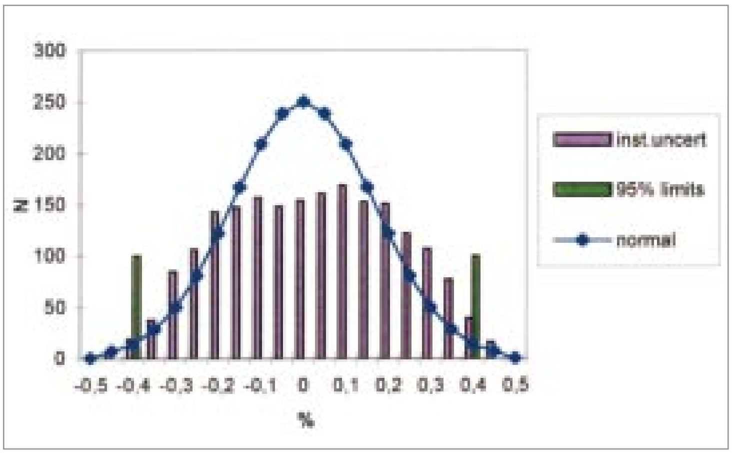

Fig. 3 Histogram of a test on the secondary and tertiary devices

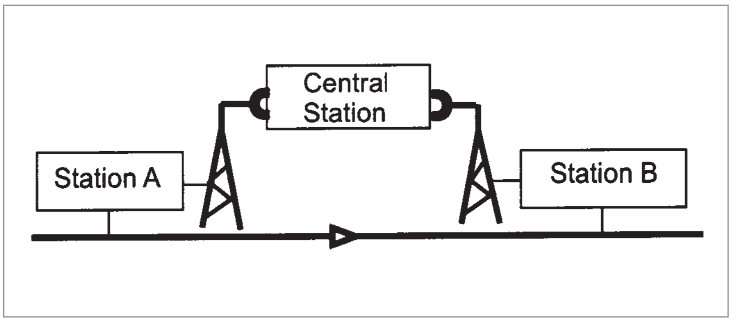

Fig. 4 Schematics of a centralized system

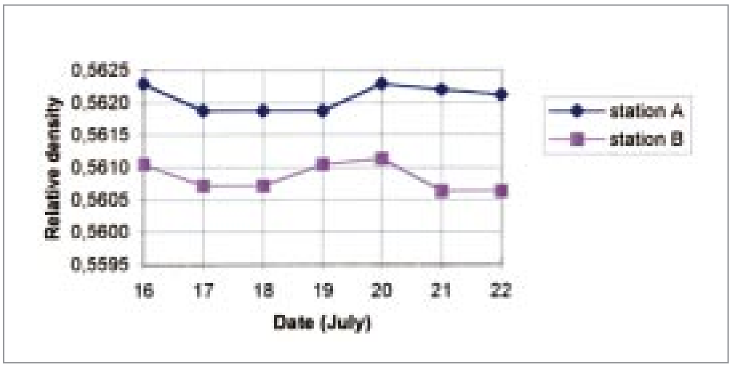

Fig. 5 Diagram of the evolution of the relative density of a natural gas

2 Tests for a central(ized) system

A centralized system is composed of two measuring stations on a natural gas transport pipe without ramifications (Fig. 4). When functioning normally, the two stations indicated the same volume of gas over long time scales. On short time scales, differences could appear due to perturbations of short duration.

Through data analysis, it was ascertained that while each system offered coherent information individually, there was a consistent difference of about 0.1 % between stations.

At a second analysis level, it became apparent that a density difference existed between the measurements made by two stations (Fig. 5).

Finally, at a third level of analysis performed by auditing the activity in the laboratories of both stations

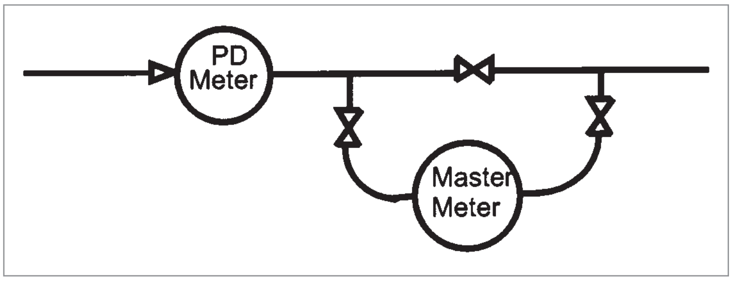

Fig. 6 A calibration scheme using a master meter

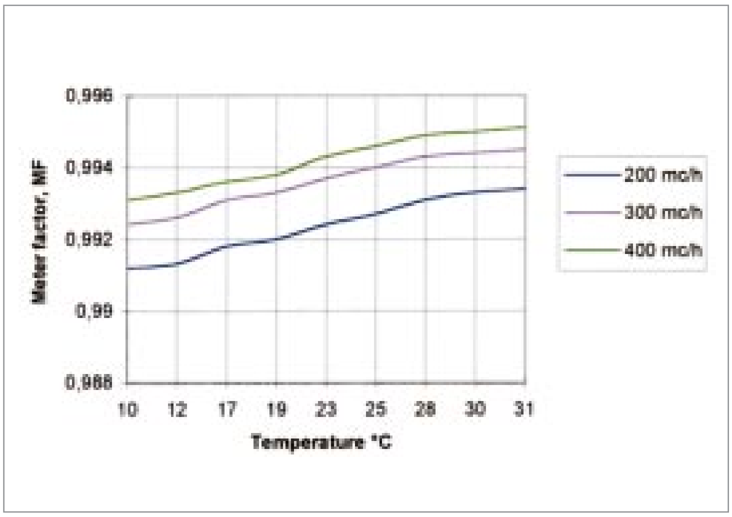

Fig. 7 Diagram presenting the evolution of the MF of a spiral gear meter as a function of temperature

it was found that an error existed in calibrating the chromatograph of one station.

Such tests are devised as a function of the configuration of the system and, in most cases, are performed automatically. The users are only informed of the results and, sometimes, of the possible correction methods [8], [9].

3 Dynamic ratio

The dynamic ratio is defined as the ratio between the maximum and the minimum flowrates, provided that the uncertainty of the system is lower than a pre-defined limit:

$$r = \frac{Q_{max}}{Q_{min}}$$

For systems measuring volumes of natural gas, the maximum value of this ratio is recommended to be 10, and sometimes 15. For an orifice device using a single differential pressure transducer (frequently, the second transducer exists but is used to increase the reliability of the system), functioning at a constant pressure, the maximum value of this ratio is usually 3, with an uncertainty of around 1 %. The most frequently used solution for performing measurements with large dynamic ratios is the splitting of the gas flowrate and the use of multiple, parallel measuring systems.

Of course, there are solutions using two or three differential pressure transducers with single primary transducers, but here the reliability is slightly less.

It useful to mention that the maximum value of the dynamic ratio very much depends on the conditions secured for the secondary elements. In most cases the secondary and tertiary devices are placed in a temperature-controlled environment.

In cases where the environmental influence on the primary transducer is significant, it is difficult to correct the result of the measurement for such influences. Figure 6 presents a schematic for calibrating a volume meter for oil products in working conditions. Generally, such a set-up allows the determination of an average meter factor (MF) for a small interval of flowrate variation, but only at the fluid's temperature.

Figure 7 presents the variation curves of the MF, as a function of temperature and flowrate. As can be seen from this figure, the temperature influence is 0.1 %/10 °C, while the flowrate influence is about 0.2 %/r = 2.

Usually, flow computers can correct for the influence of the flowrate, but not for that of temperature. As a consequence, the temperature will considerably influence the uncertainty of the system.

As a correction method, a MF for a temperature interval is sometimes associated, leading to the need to adapt the calibration frequency, and hence to an increase in the measurement cost. Consequently, there are strong connections between the dynamic ratio, variations in environmental conditions and the cost of the measurement, leading to the need for metrological assurance.

When dealing with large systems, from the practical point of view (tests, pattern approvals, parameter estimations, analysis and diagnosis) there are situations in which obtaining measurement results with controlled uncertainty requires techniques specific only to these particular systems. The development of the means of extracting information is extending the currently accepted notion of a system. The use of models in order to analyze metrological resources is already a common and essential practice.

This paper has attempted to anticipate several specific aspects of this evolution, as they have emerged from the practical experience of the author. ■

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