Make Flow Metering Scientific! − II

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I mentioned that the current state of flow metering lacks science in principle. Many inconveniences cannot be solved there, and all of the measures being taken seem to be a stopgap measure. That alone should break that paradigm.

Flow metering is a fundamental technology for all engineering processes and, therefore, for all processes above or below it. On the other hand, it is also a fundamental technology necessary for quantitative evaluation of evidence even in scientific research based on experimental observations. With this in mind, I would like to discuss some of the issues that must be resolved for the future of all science and engineering activities.

☆ *Error or accuracy issues*

The scientific definition of flow metering is the areal integral (double integral) in the pipe of the velocity distribution of the actual flow inside the measuring device. The ultrasonic flowmeters in use today use the movement of sound waves in the flow to determine its average velocity, so it can be said that part of the definition is satisfied. However, it does not determine the areal fraction. The method using multiple measuring lines was patented by Westinghouse in 1973.[12] However, it is not discretized and expanded in the correct form. Moreover, the number of multilines that can be realized is only 4-6 at most, and it is difficult to say that the error can be discussed. A study using UVP of velocity distribution in a pipe[13] in the study using UVP of flow velocity distribution in a pipe, it was found that 18 measurement points are required to achieve an error of 1% or less for laminar flow, and much more for turbulent flow.

As a result, it is difficult to scientifically examine the measurement error and accuracy of the device without a proper understanding of the behavior of the fluid inside the measuring device, and it must be said that we are far from changing the conventional method of type approval.

☆ *Accuracy notation issues*

When I first started using flowmeters (late 1970s), I was surprised to find that full-scale FS accuracy was mostly used to express accuracy, and reading RD accuracy was rarely used. For example, a 2% FS accuracy for an instrument whose maximum range is 100 means that the accuracy is 2% of the maximum measurement range (FS) = 2 units, regardless of the values observed by the instrument. In other words, whether the displayed value is 80 or 20, the accuracy is 2. In that case, the reading value would be 80 ±2→ 2.5% or 20 ±2→ 10%. This is an expression of the accuracy of the measurement method or the flowmeter itself, and does not allow for a combined evaluation of observed values consistent with other devices (thermometers, pressure gauges, etc.). On the other hand, the RD accuracy of a reading corresponds directly to the percentage of the measured value that is read. This reading accuracy is a generalized expression that expresses the observed value that has been properly statistically processed in terms of the uncertainty of the true value in general measurements.

Let me explain a little. The true value is never obtained as an observed value. There are fluctuations of the phenomenon itself, fluctuations of the measuring instrument itself, measurement noise, etc., and there are always fluctuations relative to the unknown true value. Therefore, the measured values are statistically processed after multiple observations, and the center of the distribution (mean value S) is identified as the most reliable value, and it is expressed how far away from that value it can be regarded as the true value. Therefore, the degree of its correctness (the standard deviation value h obtained by the averaging operation) is the ″uncertainty,″ meaning that the probability of the true value falling within the range [s−h, s+h] is 68% or more. Such a method of processing data from quantitative observations of general physical quantities is well established, and the use of RD accuracy has become commonplace.

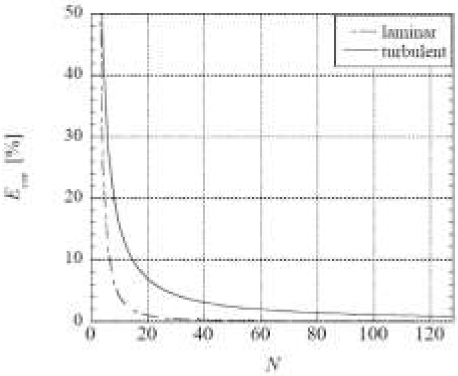

Figure 1 Results of how the error varies with the number of measurement points. Comparison of numerical and

Although many recent flow metering devices are now available with RD accuracy and are described in the specifications, it is still not common practice.

Flow metering itself has been around long before modern science arose, so there must be some historical background, but it is not clear to the author why FS accuracy has been commonly used. Perhaps the reason is the same root as the fact that ″accuracy″ is still used even though ″uncertainty″ is more clearly defined on scientific grounds than the expression ″precision″. However, due to the nonlinear and complex nature of the flow phenomenon itself, and the difficulty in separating temporal and spatial variables, we may surmise that the main reason is that the measurement field was ultimately ungraspable and the amount of variation could not be captured directly.

Or, in principle, it may be related to the fact that there is no such thing as an original instrument in flow metering. Generally, in connection with the observation and measurement of physical quantities, a standardization of instruments and measurement methods and international comparisons require a reference standard for the definition of the physical quantity. Recently, it has come to our attention that Japanese related organizations played an important role in the reestablishment of the international standard for length. Although it is a modest task, the existence of this prototype supports the root of technological development. Since flow rate is L^3 /T dimensional, the work is done by referring to the length and time prototype, but the principle basis is required for the flow metering itself. We once discussed that if we could measure fluctuating volumetric flows by direct methods, we might be able to create a method to use as the original instrument for flow rate.[14]

In the end, we can say that this is fundamentally due to the fact that we have not adopted a proper scientific evaluation method within the Q=AV paradigm.

The measurement of temperature and pressure, the basic quantities of industrial processes, is a fundamental technology of industry. There, they are rarely used in isolation, but must be known simultaneously in great conjunction with flow rates. In other words, they are combined to observe, monitor, and control plant conditions.

Let me give you an example. The thermal power of a nuclear reactor is measured by the product of the temperature rise at the outlet of the coolant (feed water) in the reactor and its flow rate. Therefore, the accuracy of the flow rate measurement is very important, and the safety margin of reactor operation is regulated by its accuracy. Currently, the accuracy of temperature measurement is so high that the measurement accuracy of the flowmeter is the basis for regulation as the accuracy of the reactor's thermal output. And there has even been a Meter Uprate proposal discussed that it might be possible to increase thermal output by 1% by improving the allowable accuracy of the flow meter from the current 2% to 1%.[15]

This situation is true not only for nuclear reactors, but also for plants that handle general chemical and pharmaceutical processes, and it is worth mentioning at the end that this issue is expected to become more important in the future.

☆ *The flow is fluctuating.*

The flow field is not a steady flow in the strict sense of the word; it is fluctuating, even if only slightly. The spatial distribution is also fluctuating accordingly, which is why spatial averaging is used, but it does not seem that attention is paid to temporal fluctuations. In the days when the time resolution of flow metering was not so high, simple time averaging of multiple measurements would have been acceptable, but as mentioned earlier, the flow field measurement methods have evolved revolutionarily, and it is now necessary to proceed more carefully. In this paper, we would like to discuss a few points in this regard.

① How should the time average be taken?

The conversion from the physical quantity obtained to the flow rate has become faster and can even be displayed continuously due to the increased speed of electronic circuits and computing devices. This has led to the misconception that the displayed quantity represents the instantaneous flow rate at that point in time. In reality, it is only a moving average of multiple measurements, but there is no indication that any consideration has been given to how to set the width of the average to obtain the correct flow rate. This should be determined by the frequency characteristics of the fluctuations in the actual flow at the site, and should not be determined solely by the convenience of the equipment. If the actual flow circuit has a certain extreme

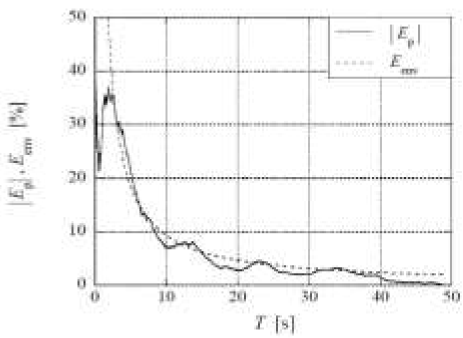

Figure 2 Results of how the error varies with measurement time. Comparison of numerical calculations and experiments. with a vibration characteristic of 3 Hz.

periodicity, the time width of the average operation may give extremely different values if the periodicity is within the time width of the average operation.

Considering that the flow field is constantly fluctuating, it has been investigated that there is an incompatible relationship between the variability characteristics and the measurement time (averaging time) . According to this, the measurement accuracy (E) is known to be inversely proportional to the time variability in the flow metering field (its angular frequency ω) and is known to be inversely proportional to the measurement time $E \propto 1/\omega T$。

In other words, for accurate measurement of flow rates and correct evaluation of their errors, it is necessary to know the characteristics of the fluctuations in the flow field and then to increase the product of its time constant and the measurement time. This ultimately means that we need to know the characteristics of the oscillations in the measurement field, which suggests the need to break away from the current simple Q=AV paradigm.

② Calibration Method?

It is inevitable that accuracy of measured value be nothing better than the characteristics of the calibration device. There are several methods used to calibrate flowmeters, but the most common method for liquid flow is the static weighing method. In this method, fluid is flowed through the flow path for a fixed period of time and its weight is weighed to determine the flow rate per unit time. Other calibration methods (volumetric methods) are similar and involve dividing the volume over a fixed time period by the time. Even if those measurements can be made continuously, they are basically time averages over a certain time range, and the continuous measurements are their moving averages (time range T). The calibrated value obtained by such characteristic device is only an average over T time, and even if it is continuously displayed with a fairly fast refreshing change, it cannot exceed the time resolution of T. If the true flow rate is time-varying because the flow field is generally time-varying, the time resolution of the flowmeter cannot be smaller than the time resolution of the calibration device. If the time constant of the fluctuating flow (the time characteristic of the fluctuation) is much larger than the time resolution of the flowmeter, this would not be a problem, but if the time constant is shorter than that, the flowmeter is not able to keep up with the fluctuations. How well do users understand these characteristics? Or how well do flowmeter manufacturers understand them?

To begin with, when a flowmeter is used in a custody transaction, accuracy with respect to the totalized amount is required, as can be seen when considering a water meter, for example. Therefore, even if the flowmeter does not follow fluctuations, as long as the final values are in agreement, it is all right. In addition, since various calibration facilities are focused on minimizing fluctuations, the effect of fluctuations during calibration is probably smaller than in the case of ordinary piping. These factors may be a detriment to examining the response of flowmeters to fluctuations.

It should be noted, however, that calibration methods for fluctuating flow rates are not easy. The authors have studied the response of various flowmeters to fluctuating flow and how to create a reference flow rate.[5] The authors have examined the response of various flowmeters to fluctuating flow. That is, how to obtain a reference value for the instantaneous flow rate. For example, suppose that a device that generates fluctuation is incorporated somewhere in a series of flow paths. The reference value of the fluctuation is calculated from the movement of this device. Naturally, there is a certain distance between this generator and the flowmeter under test, during this distance, the fluctuations will be dampened, or other fluctuations will be incorporated. Therefore, there is no guarantee that the instantaneous flow value guaranteed by the fluctuation generator will be the same at the flow unit under test. The only way to be certain seems to be by first-principles measurement in the flow section under test, i.e., calculating the flow rate from the instantaneous velocity distribution on the site of measurement. By improving the reproducibility of flow fluctuations by the fluctuator and correlating the instantaneous flow rate in the test section with the fluctuator by first principles, it is finally possible to consider a reference value for the fluctuation.

③ International trends

There have been many attempts to investigate the response of individual flowmeters to fluctuations, but as mentioned above, in the absence of a standard, it is impossible to know what instantaneous value is being measured. In recent years, research on how to define fluctuating flow has been progressing in Europe. For example, the PTB (Physikalisch-Technische Bundesanstalt) in Germany has taken the lead in developing projects under the Euromet on water and oil related on fluctuating flows. Each European country has built a device that produces the specified fluctuating flows, and is attempting to compare them and make them the standard in Europe. In Europe, there are many energy-related transactions between countries, and flow meters are required to play a much higher role. Consensus among countries is also very important in regulatory matters. It is not clear at this point whether the above project will be directly related to any transactions or regulations, but there is no doubt that interest in "metering of fluctuating fields" is growing in the field of metrology in Europe.