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QUALITY MAINTENANCE OF FLOW MEASUREMENTS IN INDUSTRY.

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Abstract: There is keen interest in the total accuracy of flow measurements in industry. Total accuracy is defined as the accuracy of the whole measurement chain which can be determined only in a field calibration. Indmeas has for several years carried out quality maintenance work for industry using the radiotracer methods for field calibrations of liquid and gas measurements.

Comprehensive data from these calibrations show that the dominating uncertanties of flow measurements in industry lie outside the flow meters themselves. The large error components, however, are often fairly stable and can be eliminated by constant corrections.

Experiences show that by using a quality maintenance system based on repeated field calibrations an accuracy level of 1-2 % is effectively reached and maintained.

1 INTRODUCTION

Quality maintenance of pressure and temperature measurements based on in situ calibrations is part of everyday life in industry today. For flow measurements, specially those for large flows, corresponding measures are rare, the reason being the lack of a calibration method generally suited to largely varying calibration conditions in industry.

The need for good controlled flow measurement accuracy has always existed in industry as long as material and energy balances for processes have been calculated and flow measurements have been used for charging fluid deliveries. The necessity for controlled accuracy has increased even more during recent years because of the general adoption of the ISO9000 and ISO14000 quality systems and energy audits.

2 THE TOTAL ACCURACY OF FLOW MEASUREMENTS

The total accuracy of a flow measurement means the accuracy of the final flow value, ie. the accuracy of the whole flow measurement chain. In the process industry the flow value is often the digital value in the automation system which is used for process control, process reports, calculation of energy and material balances etc. For industry flow measurement accuracy is a meaningful concept only if it means the total accuracy.

The flow measurement chain is presented in Fig. 1 in a general form.

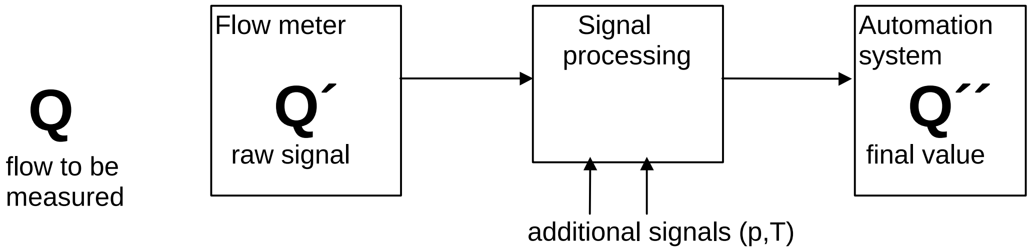

Figure 1. The flow measurement chain

The total measurement uncertainty e_{tot} of the whole measurement chain can be expressed as:

$$e_{tot} = \sqrt{e_1^2 + e_2^2 + e_3^2 + \ldots + e_n^2}$$

The uncertainty components e_i refer to the following sources of uncertainty:

e_1 = the meter in ideal measurement conditions
e_2 = installation tolerances (mechanical)
e_3 = installation inaccuracies (electronic)
e_4 = the fluid properties
e_5 = a non-ideal flow profile
e_6 = instability of the meter electronics
e_7 = changes in the contact between the fluid and the sensor
e_8 = compensation (measurements and algoritm)
e_9 = measurement signal transport and processing
e_{10} = tolerances of the automation system components
etc.

The list above shows that plenty of uncertainty components exist. The components are added in squares which means that the largest terms dominate and the small terms can be ignored. Due to the large number of uncertainty components the target level for quality maintenance in industry has to be much lower that that in the ideal measurement conditions of a flow laboratory.

e_1, the measurement uncertainty in ideal laboratory conditions is in most cases the only reasonably well known uncertainty component. It is most often of the order of 0.5 - 1 % and is given for flow meters, for instance, in delivery specifications. The reports on the total measurement accuracy in industry [1], [2] indicate that e_1 is almost always a negligible component in the total uncertainty budget.

In order to achieve and maintain quality in industrial flow measurements the whole measurement chain has to be calibrated. This is possible only by the field calibration.

3 FIELD CALIBRATION METHODS

3.1 Industry`s own possibilities

Industry can often calibrate its small liquid flow measurements by using the simple method of a stopwatch and known volume. The principle has been to some extent used for somewhat larger flows, too, by using a tank lorry and scale.

Large process vessels equipped with level measurements offer at least in principle a means to calibrate large flow measurements. In practice, however, due to the operational limitations of the process and to other technical difficulties this option is very seldom used.

3.2 Field calibration methods based on radiotracer techniques

Indmeas has developed the radiotracer transit time method [3] to serve as a generally applicable field calibration method for pipe flow measurements. A small amount of radiotracer is injected as a pulse into the pipe. After a mixing distance the velocity of the tracer pulse is measured on a suitable straight pipe section by using two sets of radiation detectors mounted on the pipe. The volume flow is obtained by multiplying the measured average fluid flow velocity by the inner pipe cross section. This reference flow value is compared with the simultaneous flow value given by the flow measurement to be calibrated. The tracer injection is repeated several times on the same flow level and the calibration result is obtained as the mean value from the repetitions. If the process allows the flow level is changed and new calibration points are measured in order to cover the main part of the normal measurement range. Since 1994 Indmeas has carried out the transit time field calibrations on an accredited level. The best accredited accuracy for liquids is 0.8 % and for gases 1.0 %.
The radiotracer dilution method [4] is used to calibrate open channel flow measurements. A solution with a known tracer concentration is injected at a constant known velocity into the channel flow. Downstream where the tracer solution is thoroughly mixed over the flow cross section a continuous

sample is taken and its tracer concentration in relation to that of the injected solution is determined. The flow reference value is determined by using the tracer balance condition between the injected tracer flow and the diluting flow. Except for open channel flows the method is also used for pipe flows when the transit time method is not applicable. The total calibration uncertainty when using the dilution method has typically been on the level of 1.5 %.

4 THE TOTAL ACCURACY OF DIFFERENT INDUSTRIAL FLOW MEASUREMENT APPLICATIONS

4.1 District heating flow measurement

One would expect a good general measurement accuracy in large district heating flow measurements because the measurement circumstances are close to those for which meters have been specified. The fluid is water, measurement chains are simple and meter installations carefully planned due to clear commercial interests. The results from first time calibrations of large district heating flow measurements are shown in Fig.2. The error distribution shows that although the average error is practically zero the 2σ -value of the distribution is about 12 %. This means that today´s installation practices lead to correct measurement on average but that approximately every third single installation has a total measurement error larger than ± 6 % and every twentieth installation an error larger than ± 12 %.

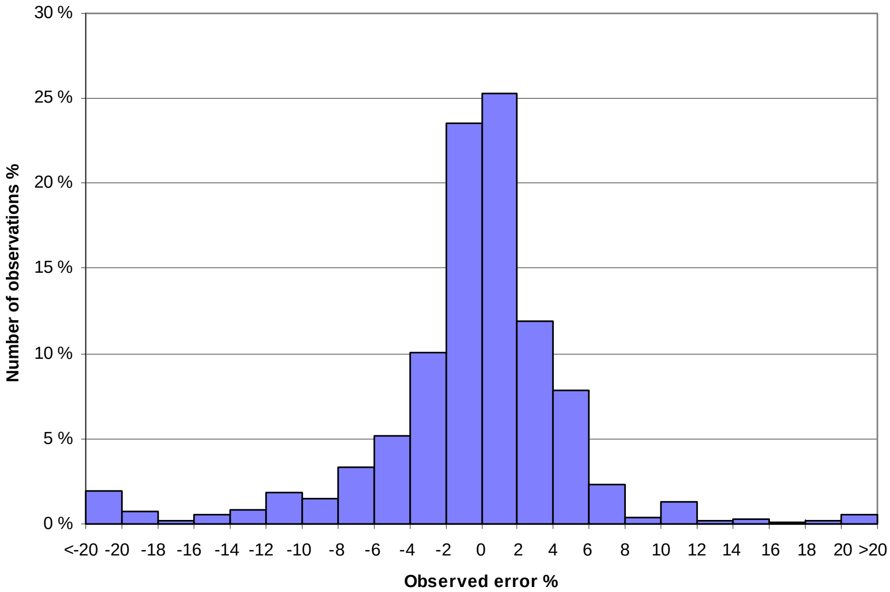

Figure 2. Total measurement errors in district heating flow measurements observed in first time field calibrations. All meter types. Number of observations 871.

The error distribution of Fig. 2 includes all the usual meter types used for district heating flow measurements. The differentiation of the data between magnetic, ultrasonic and differential pressure flow meters does not reveal significant differences between the measurement principles.

4.2 Steam measurements

Compared with district heating flow measurements steam measurements are clearly more complicated because the measurement chain also includes measurements for pressure and temperature and the flow value compensation. The effect on measurement uncertainty is shown in Fig. 3. The average error is again practically zero but the 2σ -value has grown to the level of 20 %. The large errors in steam measurements normally originate from clear logical faults in the measurement chain.

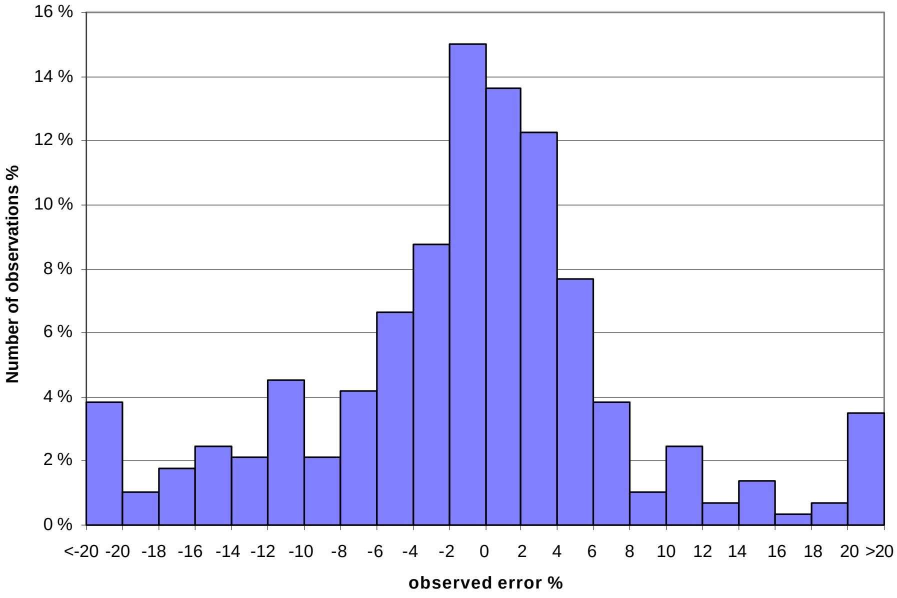

Figure 3. Total measurement errors in steam measurements observed in first time field calibrations. Number of observations 218.

4.3 Flow measurements for pulp and waste water

Pulp flow rates are measured by magnetic flow meters manufactured for water flow measurement. The measurement situation for pulp is somewhat unclear because pulp flow profiles may differ entirely from those for water and depend on pulp consistency. Another unknown uncertainty component is caused by air normally present in pulp both in a dissolved form and as bubbles. According to the data from first time field calibrations the total measurement accuracy for pulp is on average roughly the same as in steam measurements.

The calibration data for waste water flow measurements concern mainly open channel measurements used by the pulp and paper mills for recording their effluent discharges. The quality level of instrumentation used in these measurements varies largely. At many mills part of the measurement set-ups dates back to times when effluent discharge measurements became obligatory. So this is probably the reason behind the largest 2σ -value, over 30 %, observed in first time calibrations.

5 MEASUREMENT STABILITY

5.1 The observed stability of flow measurements

Fig. 4 shows the observed measurement instability in district heating flow measurements. The instability is obtained as the average change/year in the measurement error between two field calibrations. The distribution in Fig. 4 is significantly narrower than the distribution from the first calibrations. In the distribution there are seven observations, 3 % of all observations, with measurement instability more than 6 % per year. Removal of these clearly unstable flow measurements reduces the 2σ -value of the distribution to $\pm$ 2.2 %. The repeatability of the field calibrations was typically better than $\pm$ 1 %. Hence the great majority of large district heating flow meters measure flow with a stability better than 2 % per year.

For steam, pulp and waste water flow measurements the field observations equally confirm that the measurement instability is small compared with the dominant constant errors encountered in the first field calibrations. However, clearly unstable pulp and waste water flow measurements are found 2 - 3 times more often than unstable district heating flow measurements. This is not surprising because there are more instability sources present.

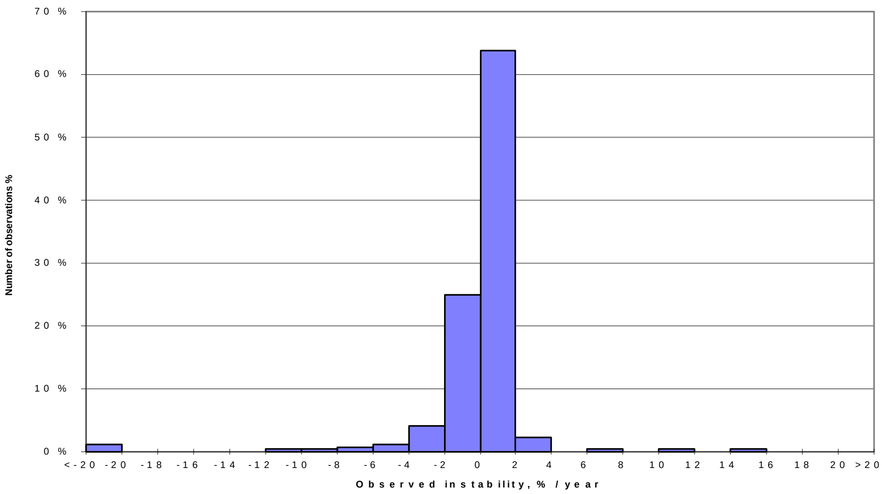

Figure 4. Instability in district heating flow measurements observed as the change of the total error / year. All meter types. The number of observations 256.

5.2 Reasons for measurement instability

In district heating flow measurements the reason for the observed instability is evidently the meter electronics.

Steam measurements in industry are practically all differential pressure measurements. The most common reason for instability is old differential pressure transmitters. The new smart type transmitters have proved to be very stable leading to accurate steam measurements even with fairly long field calibration intervals.

The reason for instability in pulp measurements is not yet fully understood. Magnetic flow meters seem to be able to measure pulp flow in many positions as accurately as they measure water flow. In some positions, however, large unstable measurement errors occur. At present most people suspect that the reason for the instability is the varying amount of air in pulp.

In open channel waste water flow measurements most instabilities have been traced to unstable water level measurements. Hence simple in situ calibrations of the level measurements can be effectively used to lengthen the intervals between the more laborious flow calibrations.

6 IMPROVEMENT OF TOTAL ACCURACY

6.1 Principle

Measurement chain analyses carried out have proved that in most cases a significant part of the total measurement uncertainty originates from the chain outside the flow meter itself. These errors are mostly clear logical faults producing significant errors in the final flow value. In order to identify and locate these faults and also other uncertainties in the chain the meter raw signal is registered during the field calibration and the possible auxiliary measurements in the chain like differential pressure, pressure, temperature and fluid level measurements are calibrated, too. The clearly identified errors are corrected in their positions in the chain. The remaining part of the total error, which cannot be further analysed, is due to a combination of uncertainties from fluid characteristics, flow profile, installation tolerances, individual meter characteristics etc. This remaining error is mostly constant or fairly slow changing and can thus be eliminated using a correction constant or a correction curve. If the calibrated flow measurement belongs to a modern automation system the correction can be carried out easily and in a logically clear way in the system. The trials to eliminate this remaining error by changing the meter or meter installation position have generally proved to be ineffective. This kind of change tends to yield a different error.

6.2 Quality maintenance system

The quality maintenance system based on field calibrations consists of the following tasks:

a) Routine instrumentation maintenance work by mill personnel
This includes basic maintenance of the instrumentation and, for instance, regular calibrations of differential pressure, pressure and temperature measurements.

b) Field calibrations
The whole measurement chain is controlled in the field calibration. The calibration interval may be in the beginning, for instance, one year. Thereafter the interval may be stepwise lengthened when justified by the observed measurement stability.

c) Corrections
First the observed clear faults in the measurement chains are eliminated. The remaining measurement error is corrected by a constant correction factor or curve preferably in the plant automation system. Unstable flow measurements are screened up for closer studies and stabilising measures.

d) Documentation
The routine maintenance measures, field calibration results and correction measures are documented in a data base which allows an easy follow up of the uncertainty history in each measurement position.

e) System evaluation and development
The flow measurement quality system is revised at certain intervals in order to check the target levels and the balance between the routine maintenance by the plant personnel and the field calibration work. The list of measurement positions included in the quality management system is updated as well.

6.3 General conclusions

The experience from the quality maintenance work carried out has lead to the following conclusions:

- The hidden errors in measurement chains and the unstable flow measurements are effectively
  revealed for corrective measures.
- The 1 - 2 % measurement uncertainty is a realistic target level in most flow measurement positions in industry.
- The flow calibration interval can be lengthened in most positions to be well over 1 year without risking continuous good accuracy.

REFERENCES

[1] R. Kuoppamäki, A Quality System for Flow Measurements in Industry,
Z. Baoyu, H. Lide, Z. Xiaona (ed.), *Proceedings of the 8th International Conference on Flow Measurement* (Beijing, October 20-24, 1996), Beijing, China, 1996, p.579-584.
[2] P. Ravila, The Improvement of the Total Measurement Accuracy of Large District Heating Flow Meters, *7th International Symposium on District Heating and Cooling*, 20 May 1999, Lund, Sweden
[3] ISO 2975/VII - 1977 (E), ISO 4053/IV - 1978 (E)
[4] ISO 555/3 - 1982 (E)

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