

The prospect of self-diagnosing flow meters

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Abstract: Flow meters delivering inaccurate data is an economical and customer relation concern in most areas of application where flow meters are key components for billing. Solution to this have so far been improved standards and schemes to implement and maintain such standards for the life time of the flow meter.

In contradiction to quality standard comes the flow meter self-diagnostic solution. Here the flow meter itself is capable of diagnosing the magnitude of its own metering error. It can then issue an alarm or even better impose corrections thus reducing the metering accuracy to an acceptable level.

This paper will discuss strategies for obtaining self-diagnosis and show some recent on-going work going towards self-diagnosing or even self-correcting flow meters. Indicating that real intelligent flow meters is a possible future.

Keywords: *flow meters, self-diagnostics*

1 Introduction

Once a flow meter is installed we have no control over if it is measuring correctly or not. To develop trust in flow metering extensive systems for calibration and test of meters in lab have been developed [1] [2] [3]. Most of these are non in-situ test methodologies. A few in-situ test methodologies have been developed over the years [4] [5]. Despite these efforts most often well established and properly cali-

brated flow meter technology show miserable performance in real environment. This is concluded from more than 1500 in-situ tests made by Indmeas Oy, Finland [6] in a variety of industry applications. As a reference method is used a radioactive tracer cross-correlation method. The reference method is certified at PTB to an accuracy of 1%. A histogram over installed meter deviation from the reference method for more than 1500 tested meter in figure 1.

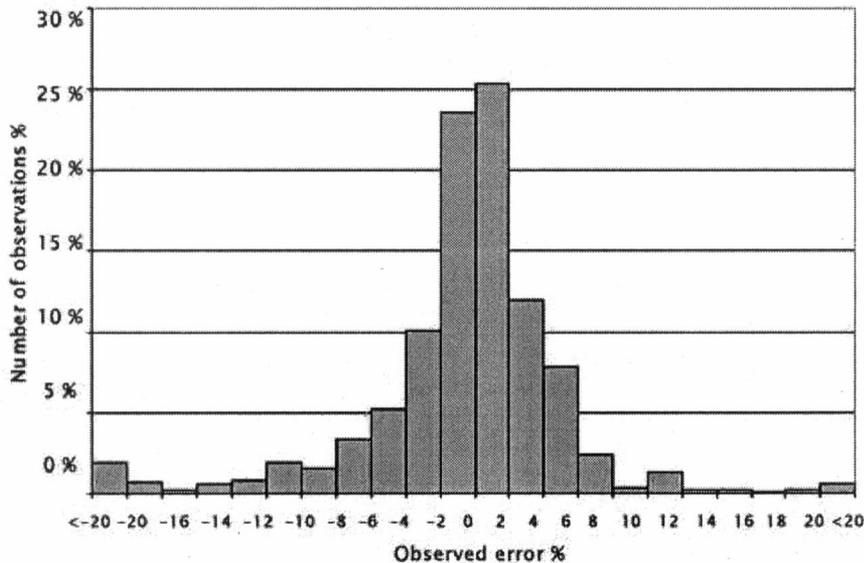


Figure 1: Histogram of percentage of more than 1500 in-situ tested flow meters and their deviation from the used traces calibration methodology.

Based on this it is clear that self diagnosis of flow meters would be of high commercial, legal and fiscal interest. This paper will discuss the prospect of techniques for self diagnoses of flow meters.

2 Self diagnosis concepts

The general problem of self-diagnosis is very complex. It have to be possible for all type of measuring method and implementations etc. Further in most real conditions we meet a large number of situations that can and most often will impair the flow meter functionality. A few examples are:

- Different type of installation effects, static, dynamic etc.
- Different implementations of flow metering principles
- Malfunction of electronics and mechanics
- Aging effects of flow paths and materials
- Temperature effects
- Changes in fluid properties

From this it is clear that self diagnosis of a flow meter will have to handle a large variety of situations. This indicates that we have to find a large number of methods and indicators to be able to provide a general self diagnoses.

In general we can find a few general approaches to self diagnosis of a sensor and inparticullary flow meters. The following general principles have been identified:

- Secondary information in primary signal
- Use of additional real time sensor data
- On-line modification of measurement method

Each of these are discussed in more detail below.

2.1 Secondary information burred in sensor signal

A sensor signal always is dependent on other things than the information of interest. For a sensor to work we need that the primary influence on the sensor signal is dominant to a degree that is acceptable to form a measurement. Thus we in a measurement sensor design work try to minimize influence by all secondary measures. For a measurand m this can be written as:

$$m = f(p, s_1(t_1, t_2, \dots), s_2(t_1, t_2, \dots), \dots) \quad (1)$$

When secondary variables s_1, s_2 etc. are sufficient small compared to the primary measurand p this is successful. Each of the secondary variable can in turn be influenced by a third third generation of influences t_y changing the relative magnitude of secondary variables compared to the primary measurand.

If we can find methods to separate secondary variable, s_x , from the primary one, p , it will be possible to do self-diagnostics. Thus for self-diagnostics flow meters it is of interest to investigate secondary information buried in the flow meter signal itself.

For the case of secondary information burred in the flow signal itself it is of interest to investigate the origination of such information. Here we for example are seeking secondary information that:

- have a correlation to flow
- indicate conditions known to introduce errors into the measurement principle used
- indicate unreliable operation of implementation of the measurement principle
- indicate unrealistic data behavior based on overall system information

For a flow meter such burred information can be generated for a number of reasons [7] [8]. Such conditions are for example:

- Turbulent noise due to pipe bends
- Sensor data sampling noise due to under-sampling
- Sensor method noise generated due to insufficient sensor model
- Sensor implementation noise originating from electronic or mechanical properties

The major problem is to find conditions and techniques to analyze the flow signal enabling the identification of changes in secondary influences that will be significant compare to the primary measurand.

When we find such information we can use it as indicators of in-proper operation of the flow meter. The major problem is to deduce the origin of the secondary information and be able to isolate it from primary flow information. Combining such data with the knowledge of conditions causing such data will form a basis for self-diagnosis. Work by Carlander [7] and Berrebi [8] on turbulent noise due to static and dynamic installation effects shows that erroneous flow measurement can be detected. The approach used is analysis of statistical properties of the flow signal such as standard deviations and harmograms reveals pattern that nicely correlates with metering errors. An example of this is detection of static installation effects on an ultrasonic flow meter as shown in figure 2.

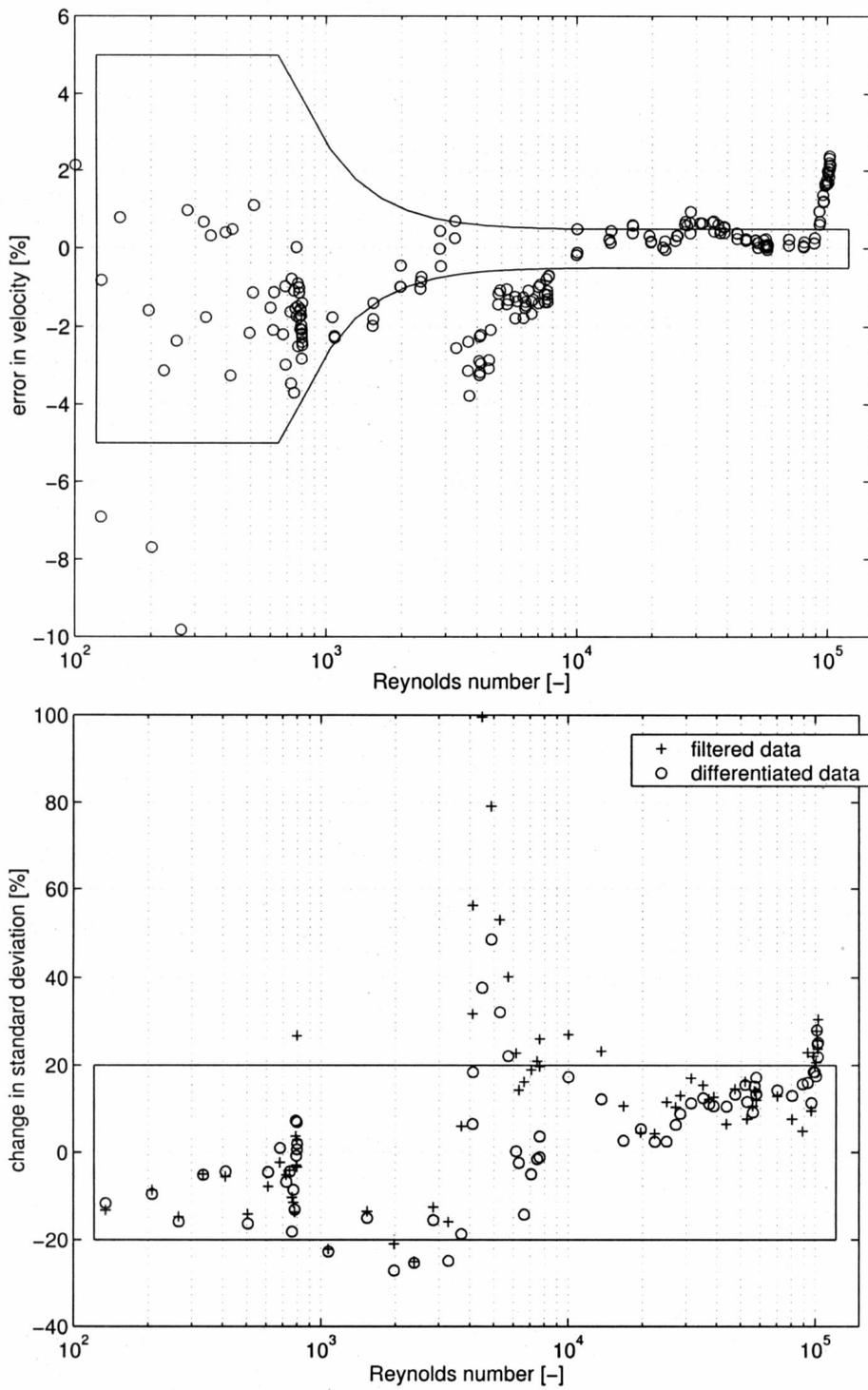


Figure 2: The error (top) and noise standard deviation using two different filtering techniques (bottom) of an experimental ultrasonic flow meter down stream of a double elbow. The deviation in the noise pattern correlates well with erroneous flow measurement see Re 4000 and Re 10^5 [7].

It is obvious that unrealistic data can be detected. The simple version is just setting limits to a possible data range. More interesting is to deploy other limiters saying that for example first and/or second derivatives of the meter reading should be bounded. All such limiters have to be based on pre-knowledge of the used meter and which system it is deployed in.

2.2 Sensor method modification

The concept of deliberately modifying the sensor method to identify a problem in the measurement can be described based on equation 1. We complicate slightly it by adding time using an sampling approach. Thus a general description of sensor method modification can be given as follows:

$$m = \sum_{t=\Delta t}^{infy} f(p, s_1(t_1, t_2, \dots), s_2(t_1, t_2, \dots), \dots) \quad (2)$$

In this model we can change the measuring function f and the sampling time δt thus altering the sensing method.

By changing the measuring model function f it is possible to from the modify the sensor method such that we can obtain additional information helping us deducing the correctness primary measurand. An example of this is for an ultrasonic flow meter. The simplified standard ultrasonic flow measuring model function f becomes:

$$v = \frac{k(Re)L}{2} \left(\frac{1}{t_d} - \frac{1}{t_u} \right) \quad (3)$$

where v is the flow velocity, k a calibration constant/function, L the transducer distance and t_d, t_u are the

down and up-stream transit times respectively. By modifying it to:

$$c = \frac{L}{2} \left(\frac{1}{t_d} + \frac{1}{t_u} \right) \quad (4)$$

we obtain speed of sound c instead of flow velocity. Speed of sound is highly correlated to temperature but also correlated to fluid composition and thus possible changes in fluid properties like viscosity and density. All these properties will influence Reynolds number, Re , and thus the velocity reading since the calibration factor k is a function Reynolds number.

The effects of changing the sampling time can be exemplified as follows. Consider a slightly fluctuating or pulsating flow. If the sampling rate of the flow meter is less than 2 times the fundamental pulsation/fluctuation frequency aliasing will occur that will introduce large errors [9]. By for example sweeping the sampling frequency it will be possible to detect large changes in meter readings due to the changing sampling frequency. Another solution is to estimate the pulsation/fluctuation frequency and check how it comply with the meter sampling frequency. From here conclusions can be made regarding level of errors introduced in the measurement, thus forming the basis for a self-diagnosis. Berrebi [10] has extended this idea to also correct the flow meter operation to better handle the pulsating flow thus reducing the error introduced by the pulsation. This is done by adjusting the sampling meter frequency to an for the flow condition optimal sampling rate thus causing not only an error diagnosis but also an error correction method. An example of this is show in figure 3.

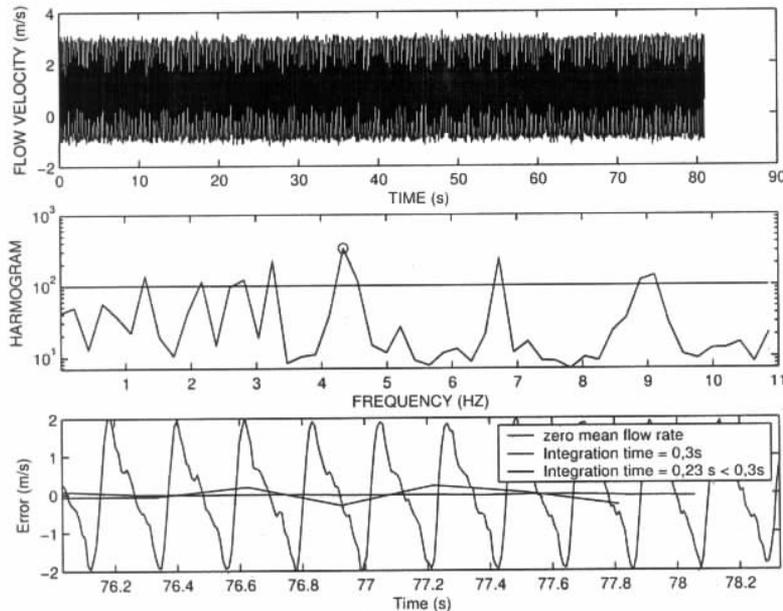


Figure 3: Error detection on a ultrasound flow meter measuring a pulsating flow, top. Harmogram identifying fundamental frequency, middle, is used to adjust the based on harmograms with subsequent introduction of an optimized meter sampling frequency causing reduced error.

2.3 Diagnosis based on available system sensor information

From what is said above it is clear that the environment will play games with measurements. Thus it is of interest to obtain local or system wide real time data that based on our knowledge of the sensor model will introduce an error into the measurement. This approach is most often used in large and economically important installations. In such cases it is a diagnosis technology not a self-diagnoses technology, i.e. it is not made by the meter itself.

To turn this scheme into a real self-diagnosis we need the concept of sensor networks. The general idea is that sensors locally and globally can connect to the Internet. Thus they will be able to utilize data from each other. Thus each of them can do self-diagnostics based on relevant additional information from other sensors, actuators or devices in the system. Much work is currently going regarding sensor networking for an technology overview see for example [11] [12]. The to the author most appealing approach

of sensor networks is Embedded Internet System, EIS, and minimal implementation of EIS. The major feature of EIS devices is their use of widely accepted standard, such as the TCP/IP suite of protocols. Such EIS flow meters will enable both flow meter self-diagnose, communication as well as utilization of other sensor data in the system feasible for self-diagnosis.

A few example of sensor networking used for self-diagnostic from the district heating community will be given below. In a district heating system there are other sensors available that give information about the condition that a flow meter will have to handle. A typical such scenario is a heat meter in a district heating substation. Here flow and two temperatures are measured. With appropriate electronics and signal processing it is possible to make a cross correlation of the temperature noise signal. Since it is well know that such cross correlation can be used for flow metering we here have a possibility for self-diagnosis [13]. In this case the accuracy of the secondary correlation to flow will give by the cross-correlation accuracy.

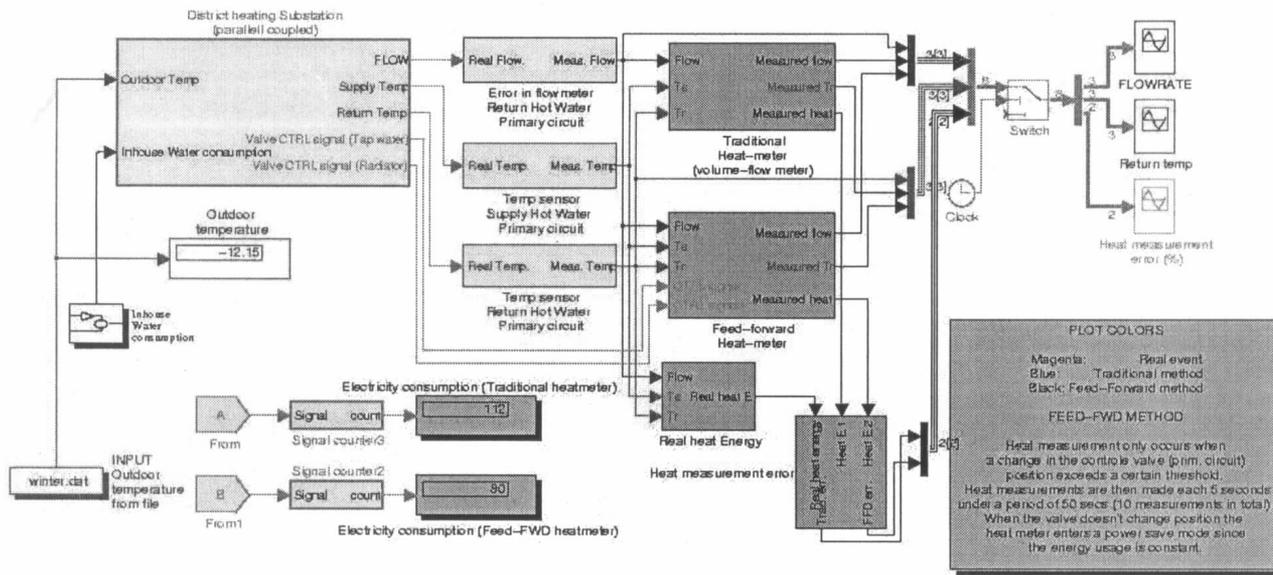


Figure 4: Schematics of a Simulink model for a district heating substation. The flow meter and the two temp-sensors are the key components of the energy meter.

In another example from a district heating substation we can make use of the fact that a substation holds an energy meter with a flow meter and a control unit controlling the main valve settings relevant for the space and hot water heating, see figure 4. If the valve set point data is made available to the flow meter the following is possible. Based on the valve setting the flow reading should be in a certain ballpark which probably is fairly small. Thus if we are outside this ballpark we can issue a self-diagnostic alarm. This information can further be used for adapting the flow to an operating mode that is more favorable for the changed flow condition. An example is a feed forward situation where a change in valve set point can cause a change

in the flow meter sampling frequency thus enabling a more accurate measurement of the upcoming rapid flow change and a more accurate energy measurement which is of economical interest. This approach has been implemented and successfully tested by Jomni [14]. He has shown that energy measurement improvements in the order of 5-10% is possible see figure 5. In addition the meter energy consumption in this feed-forward arrangement is about 30% less the standard way of measuring, implicating a longer battery life time.

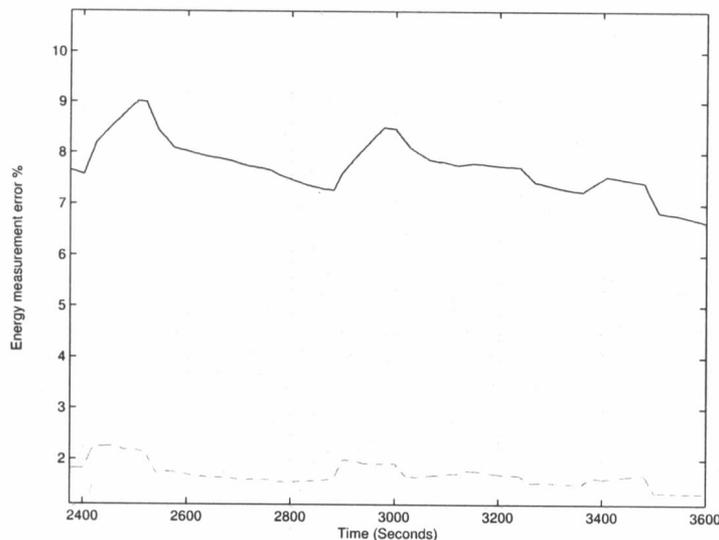


Figure 5: Comparison of total Energy measurement error using standard energy meter (solid) and feed-forward energy meter (dashed).

3 Conclusion

In conclusion the prospect of having self-diagnosing flow meters in the future is now more likely than ever. We find emerging technology capable of handling a fair number of reasons for upcoming error measurements. It is obvious that the possibilities to obtain self-diagnoses most often require an electronic flow meter. Further the development of the concept of sensor networks will certainly improve self-diagnoses of flow meters in the future.

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References

- [1] M. R. Shafer and F. Ruegg, "Liquid-flowmeter calibration techniques," *Transactions American Society of Mechanical Engineer*, vol. 80, pp. 1369–1379, 1958.
- [2] G. Mattingly, "Fluid measurement: Standards, calibrations, and traceabilities," in *National Heat Transfer Conference, Heat Transfer Measurements, Analysis, and Flow Visualization*, vol. HTD-Vol. 112, 1989.
- [3] K. van Dellen and L. Rustemeier, "Design and operation of a unique new flow facility based on automated hydrostatic head reading with a high accuracy system," in *In Proc. FLOMEKO'98*, 1998.
- [4] R. Kuoppamäki, "Quality maintenance of flow measurements in industry," in *Proc. Flomeko 2000*, Brasil, 2000.
- [5] K. Mattiasson, "Experience from field calibration of flow-meters with a mobile piston prover," Swedish Research and Testing Institute, SP, Tech. Rep. SP-RAPP 1987:24, ISBN 91-7848-066-2, 1987.
- [6] N. Ginnman, "Quality assurance of dispensing systems using isotope technology," Presentation at Automationsdagarna 2004, ITF, Stockholm, Feb. 2004.
- [7] C. Carlander, "Installation effects and self diagnostics for ultrasonic flow measurement," ISSN 1402-1544, Luleå University of Technology, 2001.
- [8] J. Berrebi, "Self-diagnosis techniques and their application to error reduction for ultrasonic flow measurement," Ph.D. dissertation, Luleå University of Technology, 2004.
- [9] E. Håkansson and J. Delsing, "Effects of pulsating flow on an ultrasonic gas flow meter," *Flow Measurement Instrumentation*, vol. 5, no. 2, pp. 93–101, 1994.
- [10] J. Berrebi, J. van Deventer, and J. Delsing, "Reducing the error caused by pulsating flows," *Flow Measurement and Instrumentation*, 2004, accepted for publication.
- [11] D. Estrin, "Wireless sensor networks: From rhetoric to(ward) rigor," Sigmetrics Keynote, June 2002.
- [12] J. Delsing and P. Lindgren, "Sensor communication technology towards ambient intelligence, a review," *Meas. Sci. Technol.*, 2004, submitted for publication.
- [13] A. Plaskovski and M. S. Beck, *Cross Correlation Flowmeters*. Adam Hilger, Bristol, UK, 1987.
- [14] Y. Jomni, J. van Deventer, and J. Delsing, "Improving heat energy measurement in district heating substations using an adaptive algorithm," in *to appear in Proc. DHC 2004*, 2004.