MAINTAINING MEASUREMENT ACCURACY ON A FISCAL METERING SYSTEM

by

B Lind-Nielson
Dantest

Paper 1.2

NORTH SEA FLOW METERING WORKSHOP 1988
18-20 October 1988

National Engineering Laboratory
East Kilbride, Glasgow

Dantest

NATIONAL INSTITUTE FOR
TESTING AND VERIFICATION

MAINTAINING MEASUREMENT ACCURACY ON A FISCAL METERING SYSTEM

Birger Lind-Nielsen

Dantest, National Institute for Testing and Verification,
Copenhagen

SUMMARY

In order to satisfy customers, authorities, and other interested parties in a fiscal metering system, it is necessary not only to have an acceptable measurement accuracy on the metering system, but also to maintain this accuracy during the lifetime of the system.

The present paper will look into the evaluation and maintenance of the measurement accuracy of a metering system. After a brief survey of the basic concepts of uncertainty, the paper will discuss the ways of evaluating the uncertainty of a measuring system as supplied and the added uncertainty due to installation effects. The main part of the paper will concentrate on the quality system which is needed in order to maintain this uncertainty. The paper will describe the special demands the metering system will impose on the quality system, and the paper will refer in detail to the actual procedures which constitute the basis for the quality system.

1 INTRODUCTION

When a new project is underway a lot of work is expended in the early life of a fiscal metering system, from writing technical specifications to the commissioning of the system. The work involves many people within the oil/gas companies, the manufacturing companies, and the authorities [1], [2], [3]. When the work has been completed, the system is handed over to the operators who are expected to keep the system working in accordance with the policy of the company, especially to maintain the measurement accuracy within the agreed limits during the lifetime of the metering system.

By maintaining the measuring accuracy the operator ensures that:

- Production figures can be trusted.
- Production upsets can be recognized.
- All interested parties, i.e. customers, shippers, pipeline operators, authorities a.o. are satisfied that the measurements are correct.

The measurement accuracy of a metering system consists of the combined effects of the uncertainty of the metering system and the maintenance of this uncertainty, i.e. maintaining the metering system at a specific uncertainty level.

International standards contain information on evaluating the uncertainty but offer very little information about how to maintain the uncertainty.

The authorities in different countries have established different rules for maintaining the uncertainty. The Norwegian Petroleum Directorate (NPD), for example, requires the operators to have procedures for the operation and calibration of the metering system, and NPD sets up a detailed description of calibration requirements [4]. The Danish Energy Agency, on the other hand, relies on international standards and emphasizes the reliability of the system and the maintenance of the uncertainty.

The present paper will deal with the principles of measurement accuracy of a fiscal metering system. After a brief survey of the basic concepts of uncertainty, the paper will discuss the methods of evaluating the uncertainty of a metering system. The main part of the paper will concentrate on the quality system for maintaining the measurement uncertainty of such a system.

2 MEASUREMENT ACCURACY

The accuracy of a fiscal metering system consists of the combined effects of the installed uncertainty of the metering system and the maintenance level of the system.

The installed uncertainty consists of the combined effects of the supplied uncertainty and installation effects.

The maintenance level is the combined effects of the maintenance procedures and the control limits set up for each instrument.

2.1 Supplied uncertainty

The supplied uncertainty is the uncertainty of the metering system at the time of commissioning. It is the combined systematic and random uncertainty, and it depends on the uncertainty of each individual instrument and their calibration.

The basic concepts of uncertainty can be found in many standards and textbooks, e.g. ISO 5168 [5] describes the general theory of estimating uncertainty of a flow-rate measurement. The terminology used in this paper is based on ISO 5168.

ISO 5168 defines uncertainty as the interval within which the true value of a measured quantity can be expected to lie with a given probability. The key word here is probability. Every uncertainty should be associated with a stated confidence level. ISO 5168 recommends the use of 95% probability.

2.1.1 Systematic uncertainty

Systematic uncertainty is the component of the uncertainty, which in the course of a number of measurements of the same quantity remains constant [6]. The systematic uncertainty will never decrease or be eliminated by repetition of the measurements.

The systematic uncertainty can be estimated from the known characteristics of the instruments. In the evaluation of the systematic uncertainty, several contributions should be considered, for example:

- Linearity.
- Hysteresis.
- Repeatability.
- Ambient temperature effect.
- Long-term stability.

The systematic uncertainty is usually underestimated since it is easy to overlook parameters whose effect should have been included. For example, it is necessary to include the static pressure effect when considering differential pressure transducers.

The evaluation of the systematic uncertainty should be based on calibration of the instruments. The calibration should be traceable to International Standards.

2.1.2 Random uncertainty

Random uncertainty is the component of the uncertainty which, in the course of a number of measurements of the same quantity varies in an unpredictable way [6]. The random uncertainty of the average value of the measurements will decrease by repetition of the measurement.

The random uncertainty can be found by repeated experiments with the metering system. A measure for the random uncertainty is the standard deviation found for the experiment, multiplied by a weighting factor (Student's t distribution) which corrects for the number of degrees of freedom in the experiments. The ways in which the experiments can be performed can be divided into two groups: static and dynamic [7].

The static measurement can be exemplified by calibrating a pressure transducer using a dead-weight-tester. By keeping under control the influence parameters, such as laboratory temperature, vibrations etc., it is ensured that the random uncertainty of the dead-weight-tester is much smaller than the random uncertainty of the pressure transducer and repeated measurements will give an estimate of the random uncertainty of the pressure transducer.

When an instrument is used to perform a dynamic measurement, such as a flowrate measurement, the random uncertainty can be estimated by comparing two identical instruments in series on the same meter pipe. By taking pairs of simultaneous readings and evaluate the standard deviation of the difference in the readings, it is possible to estimate the random uncertainty of each individual instrument [7].

2.1.3 Combined uncertainty

It is generally recommended to list systematic and random uncertainties separately, as there is a great deal of controversy as to how to combine the two different uncertainties, when the distribution functions are unknown.

ISO 5168 [5] though, recognizes that there are many practical reasons for presenting a single combined value of the uncertainties and it provides guidelines for combining the uncertainties using the root-sum-square method. ISO 5168 does require though, that the random uncertainty is quoted separately.

Before the combination of the systematic and the random uncertainties, the standard requires that the random uncertainty is related to the recommended 95% confidence level.

2.2 Installation effects

The supplied uncertainty is the minimum uncertainty with the acquired instruments. When the instruments have been installed in the metering system, the uncertainty of the metering system increases due to installation effects. The added uncertainties not only depend on the mechanical and/or electrical effects but also on the flow itself and on environmental conditions.

As an example, flow disturbances in the upstream flow of a meter influence the uncertainty of the meter. This has been recognized in the international standards in the way the standards recommend minimum upstream lengths for the meter. If the actual lengths are larger than the minimum lengths, the standards states that there is no added uncertainty due to flow disturbances.

Another example is the effect of temperature on the measurement of density in the meter pipe using a densitymeter. If the densitymeter and the associated pipework is insufficiently lagged the sample flow to the densitymeter could acquire the temperature of the surroundings before entering the densitymeter causing a significant contribution to the uncertainty.

2.3 Influence of maintenance level on uncertainty

The maintenance level influences the uncertainty through the way the maintenance procedures are described, how often the procedures are performed, and which control limits are set up.

The maintenance procedure describes the actual steps for carrying out the maintenance work with reference to metering and the evaluation of the instruments. The procedures influence the level of maintenance by describing how detailed the maintenance checks should be carried out and how often.

The control limits are limits within which the values of an instrument's characteristic parameters should fall. If the values fall outside the limits, the operation of the instrument should be checked. Maintenance procedures used to maintain instruments at a specific uncertainty level can contain several control limits.

The maintenance procedures should be executed at regular intervals and the data from the tests should be evaluated and compared with the data from the previously performed tests. These test data together with the other information about each individual instrument (such as repairs, calibrations etc.) should be kept in the maintenance records. The development of the information in the maintenance records shows the history of the instrument, especially its long-term stability.

A special record in the maintenance records is the control chart. The control chart describes the variation with time of a specific parameter which is important for maintaining the accuracy of the metering system, e.g. the vacuum frequency of a densitymeter. Together with the actual data the control chart shows a mean value and the control limits for that particular parameter.

By analysis of the control chart an estimate of any added uncertainty due to the maintenance procedures can be made.

If the analysis shows, that the value of the instrument parameter never reaches the control limits, the control limits are too large and can confidently be reduced, thus reducing the uncertainty due to the maintenance procedures.

If, on the other hand, the value of the instrument parameter regularly reaches the control limits and nothing is done to correct this deficiency in the metering system, the uncertainty increases due to the maintenance procedures.

3 MAINTAINING MEASUREMENT ACCURACY

Maintaining measurement accuracy is a combination of maintaining installed uncertainty and carrying out external calibrations.

The primary requirement for maintaining the installed uncertainty is a quality system. The quality system should be so detailed that, for example, control limits, meter log, and personnel training are included. These items are often neglected and will therefore be mentioned in detail in the present paper. The quality system should also contain guidelines for external calibrations.

3.1 Quality system

The quality system should be organized according to the international standards ISO 9000 series [8] or similar standards and recommandations [9], [10]. According to these standards, the structure of the quality system should generally consists of three levels of quality documentation. The first level comprises the Quality Manual. This manual describes basic principles and policy statements.

The manual should include a section on the policy of metering, especially stating the uncertainty limits which are acceptable to the company. When it comes to fiscal metering though, the uncertainty limits will usually be defined by the authorities as the best obtainable. The quality manual should also define the line of responsibility for maintaining the measurement accuracy.

The next level in the quality system will be the general quality system procedures, which describe the interface controls between the departments. These procedures control the flow of information through the organization.

The lowest level in the quality system contains the maintenance procedures which can be divided into two parts, the general control procedures and the actual control procedures. The general control procedures control the flow of information through the department:

- Who receives the papers, in what order.
- What should be done to the papers.
- What should be done to the data.
- After processing, how and where should the papers be kept for the records.
- After processing, what action should be taken if the

evaluation of the data shows, that something has gone wrong.

The general control procedures should clearly state what should be done to the papers after they have been received in the department. Who should examine the papers, what sort of data evaluation should be performed.

The general control procedures should include enough information to ensure, that it is possible to build and maintain a history of the instruments. The general control procedures should also include instructions for evaluating the development in the history.

The actual control procedures should describe the checks which must be performed in order to evaluate whether the metering system fulfills the requirements that are set up so as to maintain the accuracy of the metering system. The procedures shall explain in sufficient detail how the checks should be executed so that the results obtained from the checks are independent of the operator.

The procedures must contain every step in the control process including preparations and possibly safety procedures. The procedures must be unambiguous, short and concise. The procedures must be adjusted to the actual metering system.

An actual control procedure can be divided into the following elements in the order stated:

- Description of purpose. Guidelines for the execution. Which department is responsible. Time schedule.
- Description of which equipment is to be checked and which equipment is to be used in the check.
- Description of the necessary preparations.
- A numbered, step-by-step and unambiguous explanation of every step in the check.
- A description of how the obtained results are forwarded in the quality system.
- A reference to the meter system log.
- Preprinted forms for recording data. The forms should have spaces for possible remarks and for all the data the operator is required to write down. The last two items are especially important for the revision of the procedures. These items also convey an insight into the operator's understanding of the procedures and help in locating errors in the metering system.

Although the procedure might be comprehensive, the procedure should not refer to subprocedures outside the procedure if the subprocedures are relevant to the control of the actual measurement process. If the procedure refers to a subprocedure, the procedure itself should contain adequate controls which show that the subprocedure has been performed at the right step in the procedure.

3.1.1 Control limits

In order to keep the metering system within agreed uncertainty limits, the deviation of each instrument from the reference value should be kept inside certain control limits. These limits should be established in such a way that it is possible to ascertain whether the metering equipment provides the desired uncertainty. The control limits should thus reveal if the metering equipment is working properly and stable.

The value of the control limit depends on:

- The agreed limit of the metering uncertainty.
- The uncertainty of the metering equipment.
- The installation effects on the metering uncertainty.
- The uncertainty of the check equipment.
- The applied control procedures.

The last item implies the interactive way control limits are set up. It is no good to use narrow control limits if the control procedures are poor. In that case, it is impossible to bring the instrument deviations within the control limits and the operators will discard the written procedures and execute the procedures in their own way. Thus loosing all possibilities for comparing the different check tests.

When the value of the control limits has been set it is necessary to determine through experiments that the limits are feasible in the actual measurement system before the control limits are used in the procedures.

For a large metering system it is difficult to establish control limits through experiments. So the limits will have to be set up á priori. This should be done with care. If the control limits are too small they will give rise to frequent unnecessary alarms which each have to be investigated. If the control limits are too large it might take too long time before an erring instrument is detected.

3.1.2 Meter system log with reference to measurement accuracy

There should exist a meter system log dedicated to the behaviour of the metering system with reference to measurement accuracy. It should not contain information about the general operation of the metering system such as when a meter pipe was closed or opened. This information should be kept in a separate log.

The meter system log should contain detailed information for each instrument about:

- Calibrations. When, where, and how.
- Name of operators executing control procedures.
- Possible repairs or adjustments of the instrument.
- Controls performed. Which, when, and by whom.
- Instrument operational disturbances.

The log should be kept next to the instruments in question thus ensuring that the log is used whenever it is necessary.

3.1.3 Personnel

Even the best quality system is of no avail if the personnel involved in maintaining the measurement accuracy are not trained for the job. The quality system should therefore include procedures for providing training for all personnel involved and particular attention should be given to training of newcomers to the system.

It is strongly recommended that the company use dedicated meter operators, i. e. technicians whose primary responsibility it is to maintain the metering system.

These operators should have a thorough knowledge of how the metering system works. They should know the requirements the quality system set up and they should have a basic knowledge of metering theory.

3.1.4 External calibrations

The check tests supply information about how well the metering equipment complies with the requirements. The check tests themselves do not usually provide enough data to evaluate instrument repeatability or the stability of the instrument.

As an estimate of the instrument repeatability is included in the measurement uncertainty it is necessary to subject each instrument to a periodic traceable calibration. That is, the instrument correction and the instrument repeatability is found by repeated comparisons of the instrument indication with one or several fixed reference values.

This external calibration should be performed by a recognized, preferably an accredited laboratory. The time interval between each external calibration depends on the development of the instrument history but should be performed after major reparations of the equipment.

3.2 Building confidence in the metering system

When the installed uncertainty has been evaluated and the quality system has been established, the metering accuracy has been provided. The next step is to establish confidence in the performance of the metering system. This is an interactive process.

The process starts with setting up á priori control limits and time intervals between each execution of the maintenance procedures. In the beginning the time intervals should be small so the instruments are followed closely until some confidence is obtained in the system. This confidence is based on evaluation of the measurement records with specific regard to the instrument history. From the evaluation of the instrument history it is possible to establish more reliable control limits and time intervals and thus increase the confidence in the metering system.

3.3 Independent audit

Even when the metering system operator has great confidence in the metering system it can be necessary to call in an independent audit if a disagreement should arise between the involved parties.

The independent audit can:

- Supervise the execution of the maintenance procedures and evaluate the usefulness of the maintenance procedures and their forms.
- Evaluate the control equipment, their use, and their calibration certificates. The evaluation will also include an inspection of the storage room for the check equipment and an assesment of how the check equipment is stored.
- Investigate the meter system log for events that might have affected the efficiency of the metering system.

The independent audit will evaluate whether the metering system performs within the agreed limits. If the evaluation turns out to be positive an independent audit will satisfy the authorities, possible partners and others that the metering system is acceptable. If the evalution is negative it will provide the management with the proper input to revise the quality system.

4 CONCLUSION

The measurement accuracy of a fiscal metering system is an important parameter in the approval of a metering system. When the desired value has been agreed upon, it is left to the combined efforts of the supplier and buyer to show that the meter system is supplied with an acceptable uncertainty, and that this uncertainty can be maintained during the lifetime of the metering system.

The evaluation of installed combined uncertainty is a cumbersome task which comprises estimation of systematic uncertainty from a detailed knowledge of the individual instruments, any installation effects, and experimental determination of random uncertainty. It is a one-time task. When it has been performed it does not have to be repeated, unless new instruments are introduced into the metering system.

Maintaining the uncertainty demands a quality system comprising:

- A quality manual with a statement of the metering policy and a definition of the line of responsibility for the metering system.
- General management procedures for the interdepartmental controls.
- General control procedures for handling the papers and data from the check tests of the metering system.
- Detailed actual control procedures for the execution of the periodic check tests.

When this quality system has been established it is a continuous process to maintain the uncertainty by executing the maintenance procedures on a regular basis. Otherwise, there is no guarantee that the uncertainty is kept within the agreed limits.

With well trained technicians and continually updated procedures, the quality system assures the operator of the metering system that it is possible to satisfy partners, pipeline operators and authorities that the measurements are correct and accurate.

5 ACKNOWLEDGEMENT

The author wishes to expres his thanks to his colleagues at Dantest for many fruitful discussions during the preparation of this paper.

6 REFERENCES

[1] Danielsen, H. B., Moestue, H. and Tunheim, H. - Fiscal Metering Systems for North Sea Oil & Gas. Experience from Purchasing to Start-Up. North Sea Flow Metering Workshop, Stavanger, 13-15 October 1987.

[2] Peters, R. J. W. - Purchasing a Fiscal Flow Metering Station. Suppliers Point of View. North Sea Flow Metering Workshop, Stavanger, 13-15 October 1987.

[3] Fosse, Steinar - Buying and Installing a Metering Station. North Sea Flow Metering Workshop, Stavanger, 13-15 October 1987.

[4] Øgland, T. - The Norwegian Petroleum Directorate (NPD) Regulations for Fiscal Measurement of Oil and Gas. The Metering af Petroleum and its Products. 7th and 8th March, 1985. London.

[5] International Standard ISO 5168. Measurement of fluid flow - Estimation of uncertainty of a flow-rate measurement. 1978 (E).

[6] International vocabulary of basic and general terms in metrology / Vocabulaire international des termes fondamentaux et généraux métrologie. Coedited by BIPM, IEC, ISO and OIML. Metrology, pp. 1-40, 1984.

[7] Hayward, Alan T. J. - Repeatability and Accuracy, Mechanical Engineering Publications Ltd., London and New York, 1977.

[8] International Standard ISO 9000. Quality management and quality assurance standards - Guidelines for selection and use. 1987.

International Standard ISO 9001. Quality systems - Model for quality assurance in design/development, production, installation, and servicing. 1987.

International Standard ISO 9002. Quality systems - Model for quality assurance in production and installation. 1987.

International Standard ISO 9003. Quality systems - Model for quality assurance in final inspection and test. 1987.

International Standard ISO 9004. Quality management and quality system elements - Guidelines. 1987.

[9] Nordtest Guidelines for Development of Quality Manuals for Testing Laboratories. NT TECHN. REPORT 082. Approved 1987-06.

[10] ISO/IEC GUIDE 49. Guidelines for development of a Quality Manual for a testing laboratory. 1986-11-01.

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.