Paper 4.2

ALTOSONIC III – A Dedicated Three-Beam Ultrasonic Flowmeter for Custody Transfer of Liquid Hydrocarbons

Jankees Hogendoorn and Dick Laan
KROHNE Altometer

Herman Hofstede and Helen Danen
KROHNE Oil & Gas

North Sea Flow Measurement Workshop
26-29 October 2004

ALTOSONIC III – A DEDICATED THREE-BEAM ULTRASONIC FLOWMETER FOR CUSTODY TRANSFER OF LIQUID HYDROCARBONS

Jankees Hogendoorn, KROHNE Altometer
Dick Laan, KROHNE Altometer
Herman Hofstede, KROHNE Oil & Gas
Helen Danen, KROHNE Oil & gas

1. INTRODUCTION

The introduction of a highly accurate, five-beam, liquid ultrasonic flowmeter in the nineties formed a true revolution in the flow market for custody transfer metering. Up to then the market was dominated by turbine and PD meters. Over the past years ultrasonic flowmeters gained full acceptance and customers are using the five beam ultrasonic flowmeter in a growing number of custody transfer metering applications worldwide. The success of ultrasonic flowmeters can certainly also be dedicated to their inherent benefits: no moving parts, no wear, low pressure drop, wide rangeability and minimal maintenance.

Meanwhile many National Weights and Measures Authorities worldwide have approved the use of ultrasonic flowmeters for fiscal metering. Another important step forward in the acceptance of ultrasonic flowmeters was the approval of a standard by the American Petroleum Institute (API) "Measurement of Liquid Hydrocarbons by Ultrasonic Flow Meters".

Based on experience gained over the past years with ultrasonic flowmeters for fiscal metering in the field and further basic research and development, a new – cost effective – ultrasonic flowmeter concept for custody transfer has been developed for the market. The ultrasonic flowmeter has three beams and is designed for dedicated custody transfer applications with light crudes and refined liquid hydrocarbons.

This paper describes:
- technical developments regarding ultrasonic flow metering;
- a new concept for proving ultrasonic flow meters; and
- results of tests performed in the field with ultrasonic flowmeters.

2. TECHNICAL IMPROVEMENTS OF THE ULTRASONIC FLOWMETER FOR CUSTODY TRANSFER

2.1 Improvements in accuracy and stability

Significant improvements in accuracy, repeatability and reliability are a major reason behind the success of ultrasonic flowmeters with wetted transducers for custody transfer applications. What makes inline ultrasonic flowmeters extremely stable and repeatable over time is the fact that they have no accuracy drift and thus do not require regular calibrations for establishing a new k-factor. Contrary to mechanical meters, the condition of the measurement section of ultrasonic flowmeters remains the same over time as they have no internal (moving) parts, a stable geometric construction, and a fully welded, all stainless steel, construction. The path length between the transducers is fixed and the position of sensor windows remains the same under all process conditions.

Further contributing to the predictable and stable behaviour of multiple beam ultrasonic flowmeters is the continuing internal research and development on the construction of the meter body and the transducers, developments in electronic processing and extensive tests performed at certified calibration facilities, such as of KROHNE, one of the most accurate calibration rigs in the world.

Multiple beams have caused a major breakthrough in accurate and stable ultrasonic flow metering. This is not only the result of multiple beams, but due to the combination of:

- the number of paths,
- a unique configuration of the paths,
- geometrical optimisation, and
- sophisticated software algorithms.

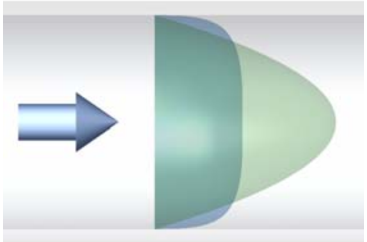


Figure 1: Flow profile in the pipe

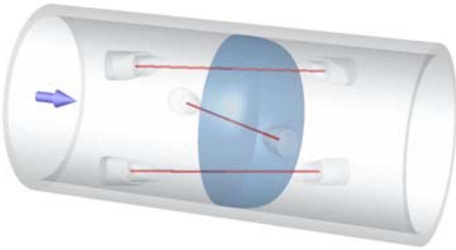


Figure 2: Configuration of the 3 beams

A symmetrical construction of three beams creates a three-dimensional cross section of the velocity distribution (or flow profile) of a medium flowing through the pipe and subsequently the measurements are less subject to changes resulting Reynolds number deviations.
The exact position of the paths and transducer pockets is based on a stable and well-known (calibrated) geometry, which has been empirically optimised and based on various tests like LDA (Laser Doppler Anemometry) and PIV (Particle Image Velocimetry).
With three (or five) beams the new generation ultrasonic flow meters:

- is less sensitive to flow disturbances such as non-axisymmetrical flow profiles and swirls; and
- has a higher accuracy over the complete Reynolds range, and
- has a good repeatability and reproducibility.

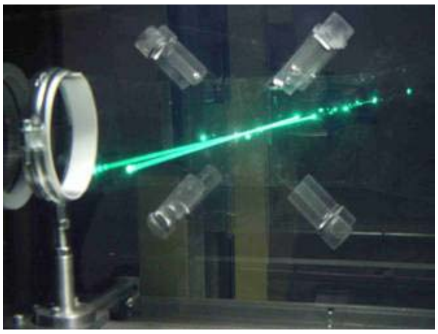


Figure 3: Laser Doppler Anemometry (LDA) for automatic and accurate velocity profile measurements and accurate turbulence intensity measurements

2.2 Transducer design and signal processing

Ultrasonic transducers form an important part of an ultrasonic sensor as they generate and receive acoustic (ultrasound) signals. For ALTOSONIC III small sized transducers with smaller transducer pockets have been developed for the complete diameter range. The smaller dimensions of the transducers have further reduced the influence on the flow profile. A new, acoustically decoupled, transducer design improved the quality of the signals by achieving a larger band width, an optimum signal to noise ratio and an improved stability.

Digital signal processing software has enabled signal processing based on advanced algorithms. Advanced signal processing includes sophisticated filtering techniques, improved signal detection, and other techniques. Tests demonstrated that the flowmeter has

- a higher accuracy,
- more robust measurements allowing for more harsh conditions such as gas bubbles, viscosity, and particles,
- a better zero stability, and
- a higher reliability and stability of the flowmeter.

2.3 Diagnostics for internal checks

Following the requirements of OIML R-117, several internal checks and tests have been implemented to provide the user with information on the condition of the ALTOSONIC III flowmeter. In addition, the ultrasonic flowmeter provides an “insight view” on the properties of the medium flowing through the pipeline.
Implemented tests for self-diagnostics include: memory checks, a parameter validity check, plausibility checks, validity checks of the measured values, and a sound velocity check.
Next to data on the velocity of sound per path, data is provided on the signal strength (or level of attenuation), the reliability of the measurements of the individual channels, and on the possible malfunctioning of a transducer.

Combinations of these parameters can be used for diagnosing the instrument and the process. For example a warning will be given that the measurements may not be within the specified accuracy class. Changes in the level of attenuation are an indication for the presence of higher viscosities, or entrained air, gas or wax. The velocity of sound check per measurement path can be used for an indication of scaling. Should scaling occur, differences in velocity of sound (VOS) per path are demonstrated. The relative influence of scaling will differ per path and consequently also the velocity of sound per path presented will be different. Chances for scaling to happen, however, are small. In various long term field tests with ALTOSONIC V operating on waxy crudes, the meter body and more importantly the transducer pockets, showed no sign of wax or deposition.

3. NEW CALIBRATION AND PROVING CONCEPT FOR ULTRASONIC FLOWMETERS

3.1 Uncertainty

Major research and tests have been carried out in the area of proving as it appeared that proving concepts presently in use on turbine and PD meters were not always suitable for ultrasonic flowmeters. In the applicable API standard on proving (chapter 4.8.2.1) repeatability under stable flow conditions is used as a criterion (5 consecutive runs within a repeatability band of 0,05%).
Under certain conditions this repeatability criterion can be difficult to meet for ultrasonic flowmeters, given their non-inertia measuring principle in combination with the high measurement frequency (refresh time). This is for example the case with small prover volumes in combination with non stable flows. At the same time the API advocates on-site proving for custody transfer flow measurement devices. The current draft ultrasonic standard forms no exception to that, although for allocation measurements, laboratory proving is acceptable.

The API COLM (American Petroleum Institute – Committee on Liquid Measurement) has therefore decided to convert the repeatability criterion of 0,05% repeatability into a ±0,027% uncertainty criterion with a 95% confidence level for ultrasonic flowmeters. The draft API standard on ultrasonic flowmeters includes a table of chapter 4.8 of the Manual of Petroleum Measurement Standards.
This table indicates that proving results with a higher repeatability (than 0,05% in 5 runs) can still be within the ±0,027% uncertainty level when more measurements are done. For example 5 runs within a band of 0,05% and 10 runs within a band of 0,12% are both within the ± 0,027% uncertainty limit on the calculated meter factor. This also means that more than 5 proving runs can be done to generate a meter factor within the ± 0,027% uncertainty level. This means that for example in case small prover volumes are used, comparable uncertainty levels can be obtained even if more runs need to be taken. In essence a small prover volume is now turned into a larger prover volume by increasing of the number of meter runs that is used to derive the meter factor. Accepting the uncertainty criterion on the established meter factor also means different proving methods can be introduced.

The uncertainty approach is already for some years implemented in the NPD (Norwegian Petroleum Directorate) guideline. Preliminary work in this area has been done by Mr Folkestad of Norsk Hydro as described in his paper for the NSFMW of 1999 titled: “Proving a fiscal 5-path ultrasonic liquid meter with a small volume ball prover. Can it be done?”

3.2 Developments in calibration and proving with respect to linearity

In Europe only limited calibration capacity is available for the calibration of flowmeters on liquids other than water. Calibration at external facilities is relatively time-consuming and expensive especially for large diameters and, adding to the cost price of the flowmeter.

In addition, the three-beam ultrasonic flowmeter is aimed at the retrofit market, i.e. replacing turbine and PD meters in custody transfer applications. A goal set for the new development was that the three-beam ultrasonic flowmeter could be calibrated by making use of the certified calibration facilities already available on site.

Performance requirements expressed as uncertainty, limited calibration facilities and other developments contributed to the demand for a new calibration and proving concept for the three beam ultrasonic flowmeter for custody transfer. The idea rose to cover the viscosity range up to 10 cSt by calibrating at water at low flow velocities. A few restrictions had to be considered including the availability of a calibration rig that is highly accurate even at low flow velocities, the flowmeter needs to function accurate and stable and the custody transfer regulations should allow for it. KROHNE has been able to fulfil all these requirements.

KROHNE has certified and accredited in-house calibration facilities available for the calibration of flowmeters on water. The calibration facility operates by direct comparison and is traceable to National Standards. The best measurement capability (BMC), as certified by RvA, the Dutch Council for Accreditation, is 0,04% over a flow range of 18 to 18.000 m^3/hr. Even at low flow rates the calibration rig allows for stable, accurate and reliable measurements.
Recent developments in stable electronics now enable very high repeatabilities up to very low flow rates (for example 0,1 % accuracy down to 0,1 m/s) including for flowmeters with very small diameters.

The combination of the above mentioned developments now allow us to calibrate with water at low flow velocities for reaching low Reynolds numbers. In this way applications with higher viscous liquids can be simulated at typical flow rate velocities in the field.
The Reynolds number is a function of the mean flow velocity (v), the internal pipe diameter (D), and the kinematic viscosity (ν):

$$Re = (v \times D) / \nu$$

The above statement can be illustrated with a simple example.

- The Reynolds number with a viscosity of 1 cSt, a diameter of 0,1 meter and a flow velocity of 0,1 m/s, is $(0,1 \times 0,1) / (1\times10^{-6}) = 10^4$.
- The Reynolds number with a viscosity of 10 cSt, a diameter of 0,1 meter and a flow velocity of 1 m/s, is $(1 \times 0,1) / (10\times10^{-6}) = 10^4$.

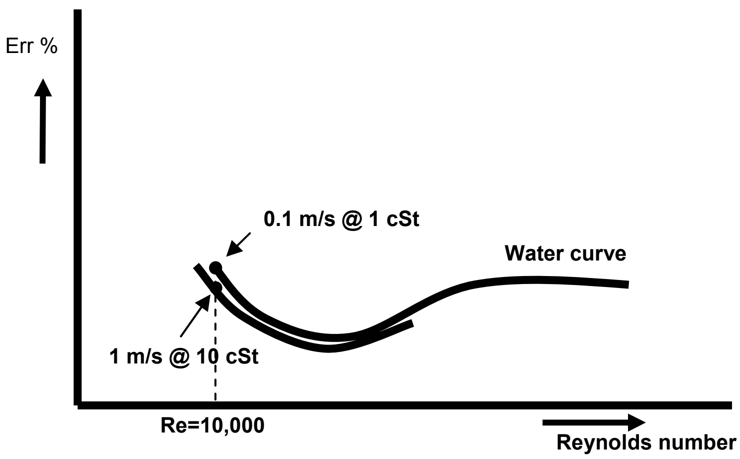


Figure 4: Relation between Reynolds number (Re) and linearity (in %)

Now it has become possible to simulate low Reynolds numbers with the calibration of ultrasonic flowmeters on water (with a viscosity of 1 cSt), with a high accuracy and repeatability, while calibrations with hydrocarbons with higher viscosities are no longer strictly necessary.
During calibration with the three beam ultrasonic flowmeter on water at the certified calibration facilities of KROHNE a linearization curve is determined, expressed in Reynolds numbers.

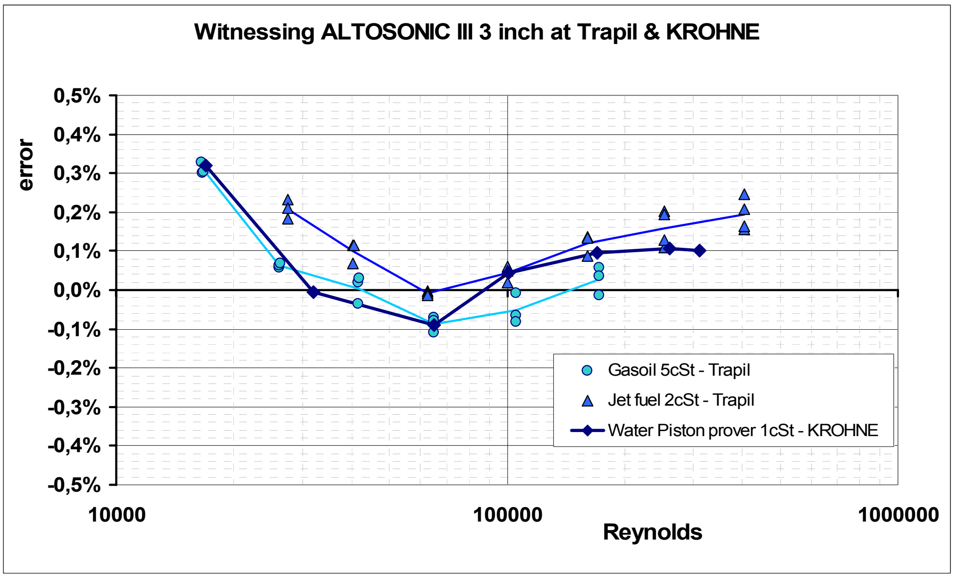


Figure 5: Calibration of ALTOSONIC III with water at KROHNE Altometer and with Gasoline and jet fuel at Trapil in France

The linearization (Reynolds) curve can be converted to a flow rate curve for the specific hydrocarbon liquid to be measured on site. The viscosity range of the hydrocarbon products is, however, limited from 0,2 to 10 cSt for a flow range of 1 to 10 m/s. This measurement range is specified for the complete diameter range. For higher viscosities KROHNE should be consulted. As explained above since the water calibration can be done on flow velocities as low as 0,1 m/s, lower Reynolds numbers can achieved.

After entering the linearization curve ALTOSONIC III can be proved on site. In situ proving of the ALTOSONIC III can be applied for a number of reasons:

- To reduce the total chain of uncertainty.
- To compensate for installation effects.
- To compensate in case of significant changes in process conditions, such as large changes in viscosity.
- To comply with custody transfer requirements, as agreed by the parties involved.
- To comply with national regulations for custody transfer or fiscal metering as defined by the national authorities (local Board of Weight & Measures);

An advantage of the new proving method for ALTOSONIC III is that the fine-tuning of the meter factor can be established at only one or two flow rates in the field. Consequently, it is not necessary to calibrate the flowmeter over the complete flow range of for example 1 to 10 m/s. This in its turn means that for on site proving the requirements for the prover installation are quite straightforward in the sense that it is not necessary for the prover to have a large dynamic range.
Of course it is also possible to prepare a linearization curve based on tests on an external certified calibration facility with a dedicated hydrocarbon liquid or if large prover facilities are available on site the establishment of the linearization curve can also be done on site. As part of the quality assurance procedure the flowmeter will be standard calibrated on water at the KROHNE Altometer calibration facilities before leaving the factory.

If there are no proving facilities on site, for example in case of new custody transfer installations, ALTOSONIC V can serve as reference meter with the ALTOSONIC III as a duty meter.

Summarising the new proving concept comprises of a combination of:
1. Calibration for establishing the linearization curve
    - Prior to installation at KROHNE Altometer calibration facilities at water
    - Calibration on a large prover on site on hydrocarbons.
2. On site proving based on uncertainty.

3.3 Long term reliability

Long term results on the reliability of the measurements are of course not ready available for the newly developed flowmeter. However, it is possible to say something on the long term reliability, based on the inherent characteristics of the meter, and from a practical approach based on experiences with ALTOSONIC V.

Paragraph 2.1 of this paper describes the inherent characteristics of the multiple beam ultrasonic flowmeter, which contribute to the long term stability of the flowmeter. The condition of the measurement section inside the meter body remains fixed over time as it has no internal moving parts, thus no wear, a stable geometric construction, a fully welded all stainless steel construction. All these features will cause no accuracy drift and thus no shift in k-factor over time. Based on these qualities for the custody transfer ultrasonic flowmeter a stable and predictable behaviour can be expected. The lack of moving parts and filters, no pressure loss, no problems after overspeed and no scaling also means the ultrasonic flowmeters requires no maintenance. In this respect an ultrasonic flowmeter differs from a mechanical flowmeter of which the internal parts are influenced by e.g. process conditions, causing wear and tear and therefore resulting in k-factor shifts.

The theoretical background for the long term stability of multiple beam flowmeters are subscribed by many calibration results available for ALTOSONIC V. Long term reliability has been proven with 5-beam ultrasonic flowmeter, of which the first meters are in use since 1997. Test results obtained demonstrate stable verification data and no systematic shift or drift has been observed. Based on its construction the same results can be expected for ALTOSONIC III.

The following graph demonstrates a very stable performance of a 6” ALTOSONIC V. It concerns data over a period of three years verified at the calibration facilities of Trapil in France. Based on the results the conclusion can be made that the flow meter shows no systematic shift over periods of at least three years. The average variation lies between 0,05% to 0,07%. This variation is caused by the reproducibility of the flow meter, calibration and installation effects. The verifications are done in different seasons of the year, showing that ambient temperatures have no effect on the performance of the ALTOSONIC V.

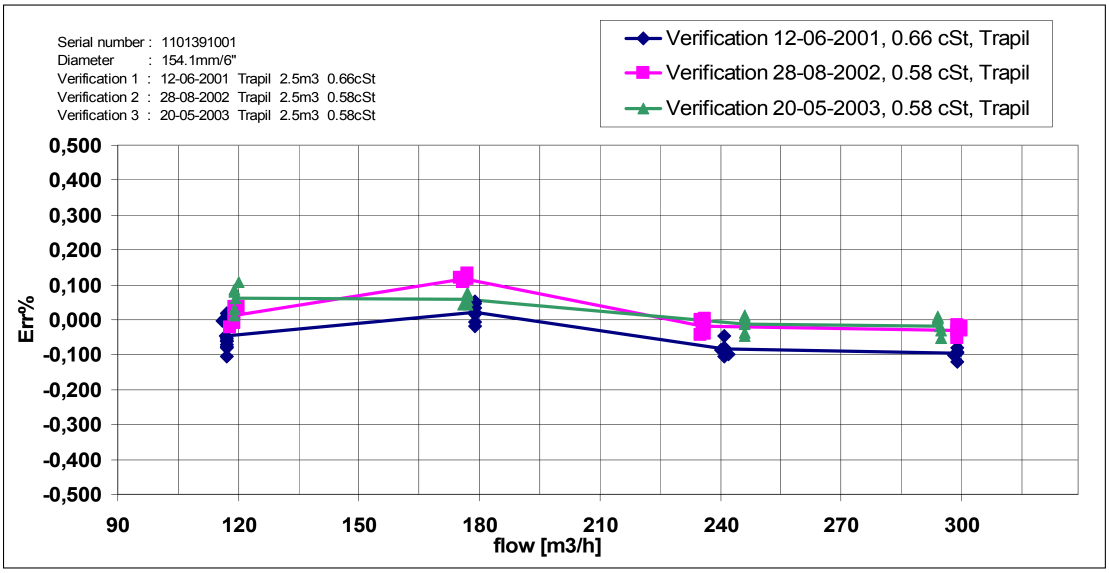


Figure 6a: Calibration and a verification of ALTOSONIC V 6" (DN 150) (in 2001, 202 and in 2003) on a 10 m^3prover installation of Trapil with an oil products

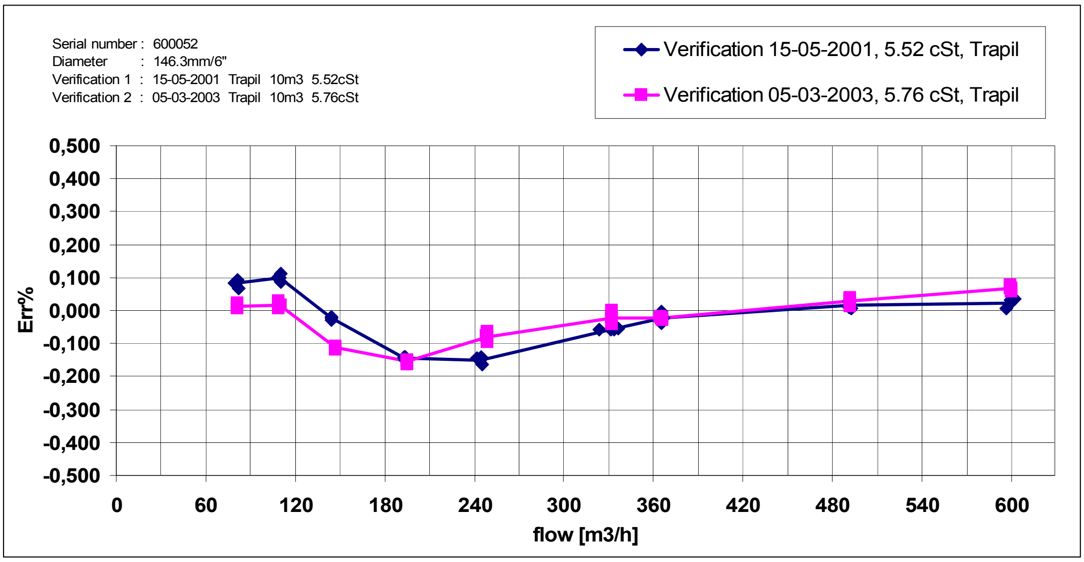


Figure 6b: Calibration and a verification of ALTOSONIC V 6" (DN 150) (in 2001, 2002 and in 2003) on a 10 m^3prover installation of Trapil with an oil products (5,5 and 5,8 cSt)

The laboratory results are further subscribed by field experiences with ALTOSONIC V. The first series of ultrasonic flowmeters for custody transfer applications have been installed in 1997. Two ALTOSONIC V ultrasonic liquid meters installed offshore in 1997, are used for oil transfer between the Snorre and Vigdis process trains at the Snorre tension leg platform. No maintenance has been performed on the meters over a period of six years of operation. Maron J. Dahlström of Statoil presented field results with the ALTOSONIC V in a paper titled "Two years of fiscal performance by the liquid 5path KROHNE Altosonic-V Saga Petroleum ASA ultrasonic meter at the Vigdis/Snorre Crossover measurement station at the NSFMW 1999. One of the conclusions from the paper is: "the duty ultrasonic meter K-factor determined from synchronized comparison with the master ultrasonic meter, after the initial set-up challenges, were all well inside +/- 0,10 %. In similar applications, such good results could never be achieved with turbine meters, even with frequent washing and cleaning procedures."
Recent provings by the customer showed that the k-factor was within 0,02% of the first k-factor in 1997.

Trond Folkestad of Norsk Hydro ASA presented a paper at the NSFMW of 2001 describing the results of two test series performed on a 12” ALTOSONIC V ultrasonic flowmeter. First the meter was tested over three months at Norsk Hydro’s Sture crude oil terminal in Norway. Then the meter was tested for six days at SPSE in France. The paper concludes with: “The conclusion of the experience and proving results from the Sture fiscal metering export station, clearly demonstrated the feasibility of operating a 12” ALTOSONIC V on normal crude oil, within fiscal uncertainty requirements, using a large volume bi-directional prover and statistical evaluation of meter factors.”

The Forties Pipeline System (FPS) in the United Kingdom installed a 12” 5 path ultrasonic flowmeter at the Dalmeny Export Terminal in 1999 for an extended trial period of nearly 15 months. The flowmeter was used as an integral part of a fiscal tanker loading system. The primary purpose of the trial was to establish whether the meter, in particular the transducer holes, would suffer from wax or particulate deposition. The second aim of the project was to verify the accuracy, the repeatability and long term stability of the multibeam flowmeter.
The same proving criteria were used for the ultrasonic flowmeters as for the turbine meters. Five consecutive runs were used required within ± 0.05% repeatability. If this was not achieved within 10 runs by the bi-directional prover than the fiscal status of the flowmeter was not valid and the ultrasonic flowmeter would not be lined up for use.
The trial was a success with the flowmeter showing no significant long-term drift and it was reliable and repeatable with virtually all proves results within +/- 0.10% of the original k-factor. The flowmeter showed no sign of wax or particulate deposition and did not require any intervention for maintenance or calibration during the 15-month trial period.

4. FIELD TEST RESULTS WITH ALTOSONIC III

Several field tests with the new three beam ultrasonic flowmeter for custody transfer are running on custody transfer applications for already more than half a year. 3-Beam ultrasonic flowmeters for custody transfer with a diameter range of 6” to 10” are tested in pipeline operations of for example Colonial Pipeline, Buckeye Pipeline, Sunoco in the USA. The mediums measured include jet fuel and kerosene. The field test results, which are well within the specifications of the 3-beam ultrasonic custody transfer meter, form the basis of the decision of the customers to purchase the tested meters.

One 10” ALTOSONIC III is installed in Greensboro, North Carolina, on a pipeline, owned by Colonial Pipeline, from Houston in Texas to Greensboro. The ultrasonic flowmeter is used for fiscal metering. The products flowing trough the pipeline are finished products like gasoline, fuel oil, kerosene, and jet fuel. Graphic 7 show the results on the meter factor variation. Graphic 8 shows the repeatability during these proving runs.

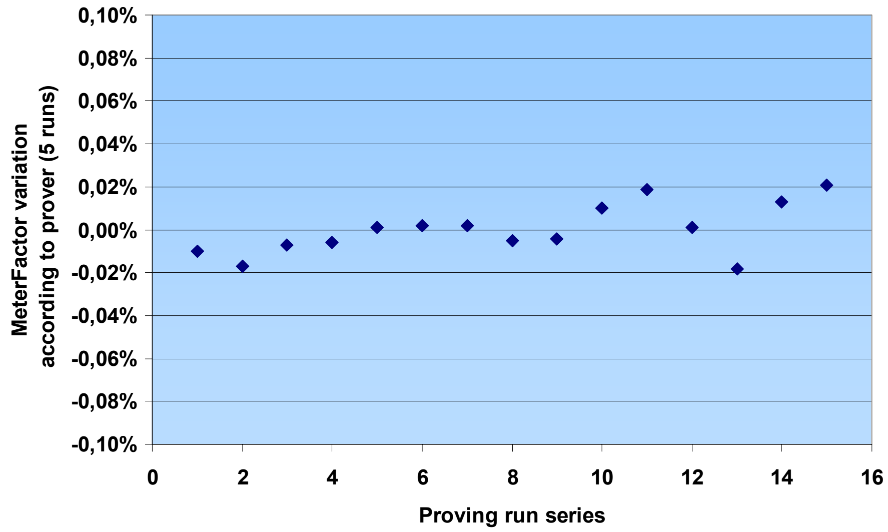


Figure 7 ALTOSONIC III at Colonial Pipeline. Meter factor variation according to the prover.

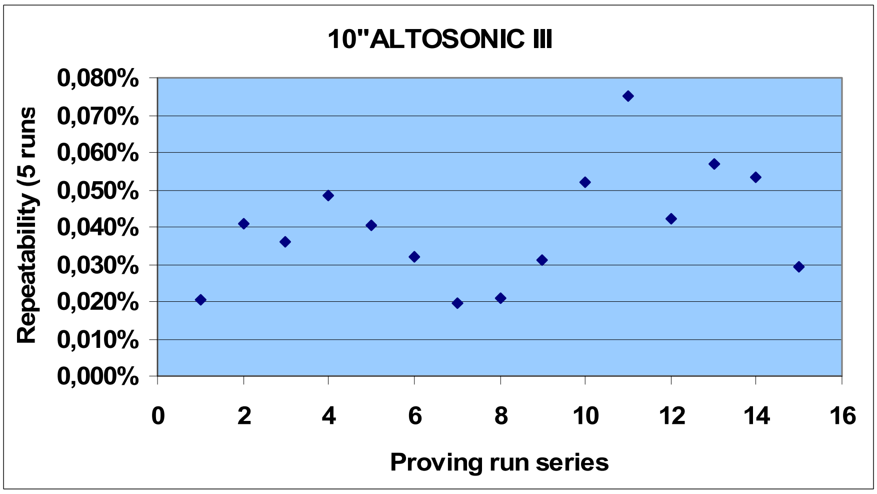
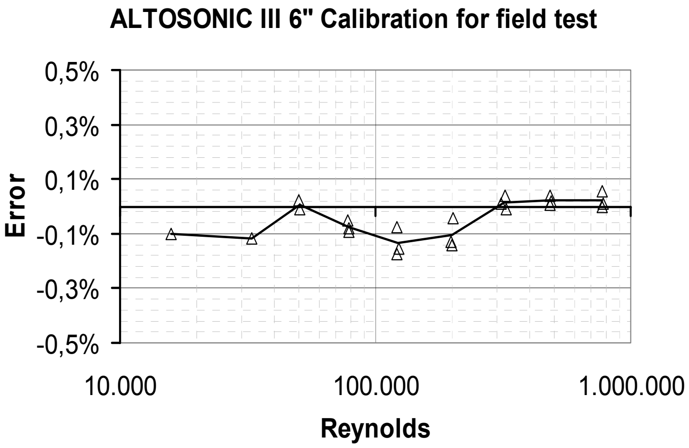


Figure 8 ALTOSONIC III at Colonial Pipeline. Meter factor variation according to the prover

A second ALTOSONCI III with diameter 6" is being tested at a pipeline system of Sunoco in Philadelphia in USA. Various refined oil products flow through the pipeline like diesel and kerosene. The graphic below show the results of the calibration with water at KROHNE Altometer.



F*igure 9: Non- linearised flow curves of the calibration with water at KROHNE Altometer calibration facilities.*

To verify the ALTOSONIC III performance in the field, per batch the measurement results have been compared with a tank level measurement. The table below gives the *cumulated* monthly results per tank. Again it concerns non-linearized measurement results.

ALTOSONIC III versus Tank number	**Difference with tank**
Tank 19	-0,050%
Tank 1	0,161%
Tank 8, 18, 7, 17, 16	-0,094%

5. COMPLIANT WITH OIML R-117 AND API

An important step in the acceptance of UFM was the release of a standard by the American Petroleum Institute (API) "Measurement of Liquid Hydrocarbon by Ultrasonic Flow Meters". As mentioned already in the introduction at the recent API Fall meeting in September 2004 the ballot on the API standard on ultrasonic flowmeters received no negative votes, and it is expected that the standard will be moved to the Manual of Petroleum Measurement standards (MPMS) in December 2004. With this the standard on ultrasonic flowmeters will be final. One important remark to this is that status of a draft standard is the same as of a final standard.

The new API Official Standard forms a major step in making custody transfer with ultrasonic flowmeters an easy and standardized process. Both ALTOSONIC V and ALTOSONIC III meet the requirements of the API standard, which specifies an uncertainty of ±0,027%.

ALTOSONIC III also received a certificate of compliance with OIML R-117 "measuring systems for liquids other than water for class 0.3 (measuring system in pipeline). Many National Weights and Measures Authorities worldwide approve the use of multiple beam ultrasonic flowmeters for (fiscal) custody transfer metering based on the certificate of compliance with OIML R-117. The required volumetric accuracy specified in OIML R-117 is ± 0,2%, repeatability has to be within a 0,12% band.

6. CONCLUSION

This paper looks at the technical improvements of a newly designed three-beam ultrasonic flowmeter for custody transfer applications. ALTOSONIC III is aimed at retrofitting of turbine and PD flowmeters.
A new proving concept has been developed based on:

- the uncertainty approach in accordance with the draft API standard on ultrasonic flowmeters and the NPD guideline; and
- a linearization during calibration at water at the KROHNE calibration facilities.

A number of requirements have been fulfilled for the new proving method in order to be successful. At first, the flowmeter has to be very stable even at low flow rates, and secondly, it is necessary to have a highly accurate calibration rig - even at low flow velocities, available. Based on the inherent qualities of the multiple beam ultrasonic flowmeter and on the long term experiences in the field with ALTOSONIC V long term stability is expected for the ALTOSONIC III.

7. REFERENCES

[1] A. Boer, Draft API standard “Measurement of Liquid Hydrocarbons by Ultrasonic Flowmeters Using Transit Time Technology”, NSFMW 2003.

[2] Maron J. Dahlström, KROHNE ALTOSONIC V, with master meter approach – Rough road to success with oil ultrasonic fiscal meter at the Snorre B export station, paper 18, NSFMW 2003

[3] Maron J. Dahlström, Two years of fiscal performance by the liquid 5path Krohne ALTOSONIC-V Saga Petroleum ASA ultrasonic meter at the Vigdis/Snorre Crossover measurement station, NSFMW 1999

[4] Trond Folkestad, Testing a 12” KROHNE 5-path ALTOSONIC V ultrasonic liquid flowmeter on Oseberg crude oil and on heavy crude oil, NSFMW 2001

[5] Trond Folkestad, Proving a fiscal 5 path Ultrasonic Liquid Meter with a Small Volume Prover Norsk Hydro ASA Can it be done?, NSFMW 1999