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Paper 8.1

First Experiences with Coriolis Metering in Natural Gas

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Gasunie Research

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1. INTRODUCTION

Coriolis flow measurement is one of the new measurement techniques in natural gas that is growing fast in popularity. Whereas for liquids the successful application already started more than 25 years ago, there is still lack of knowledge about its potential for natural gas custody transfer. One of the main reasons could be the fact that the gas industry deals with transported gas volumes rather than gas masses.
Practical experiences of Coriolis metering in custody transfer applications to natural gas have been reported in Australia starting in 1995 at Alinta company. Its installaton was novel to the gas industry since by that time no approved standards were available [1]
More recently several natural gastests on Coriolismeters have been performed in the USA by GRI [2] resulting in a new AGA-11 working standard [3].
Also in Europe the gas industry -organised within the framework of the European Research Organisation of Gas transporting companies (GERG)- have performed studies to investigate the use of Coriolis meters for natural gas custody transfer applications. At first a literature search has been performed by POGC which revealed a growing potential for the natural gas custody transfer applications [4].
Therefore it was decided to initiate a following stage to increase the knowledge on Coriolis metering in natural gas flow. A test program has been set up to investigate the long term stability and the meter accuracy in several practical circumstances. Special attention is given to configurations with noise, vibrations and swirl conditions.
Gasunie Research, being one of the partners in the GERG group, has more than two years of practical experience with calibrating and testing Coriolis meters. The majority of Coriolismeters tested and calibrated were meters of the manufacturer Micro Motion [5] at this stage the only company able to provide all necessary official approval documents [6] for custody transfer in natural gas applications.
All the test have been performed at the High Pressure test facility in Groningen (HDP), which is a NMi accredited test facility with a CMC < 0,17%. HDP is the first natural gas step in the Dutch Traceability chain of natural gas volume measurement at high pressure which ends in Bergum and Westerbork.
In section 2 a report will be given on the calibration of several CMF300 Coriolismeters, showing a very good overall performance without justification of the meter parameters based on the water calibration provided by the manufacturer.
However, as we analysed the data on the long term duration tests we found that the meter performance was much worse than could be expected on the basis of our earlier experiences. Closer examinations revealed that the recorded meter deviations were strongly correlated with unexpected variations in the gas quality. Since, being sort of based right upon the Groningen field we usually experience hardly any change in gas quality or normal density. Moreover, since the facility has been set up for the calibration of volume flow meters, the gas composition was known to play only a minor role in the overall uncertainty. Therefore the facility has been equipped with a proces gas chromatograph with a 15 minutes analysis time. So, before showing the meter performance we had to find out how the quality recordings affected the accuracy of the calibration results of the Coriolis mass meter and to make the necessary corrections. Also an analysis of the uncertainty of the calibration of mass flow meters with volumetric reference meters has been made in section 3.
In section 4 the results of the long-term duration tests performed with a Micromotion CMF300 mounted inside a city gate station set up are presented. The Coriolis meter was mounted on the low pressure side downstream of a pressure regulator valve.

As the last tests were part of the tests performed on behalf of the GERG group we greatly acknowledge the willingness of the GERG partners to allow us to show the results.
In the final section (section 5) we will conclude and address some specific recommendations.

2. CALIBRATIONS OF CORIOLIS METERS ON NATURAL GAS

In figure 1 and figure 2 some typical examples of natural gas calibrations of several Coriolis mass meters of the type CMF300 are shown at 27 bar(a) and 9 bar(a) respectively. Apart from a zero-check/ adaptation after installation the Coriolis meters have not been adapted what so ever for gas flow measurement after the water calibration. The presented flow curves are out-of-the-box calibration curves of the meters using parameters as specified by the manufacturer.

Calibration results Micro Motion CMF300 at 27 bar (a)

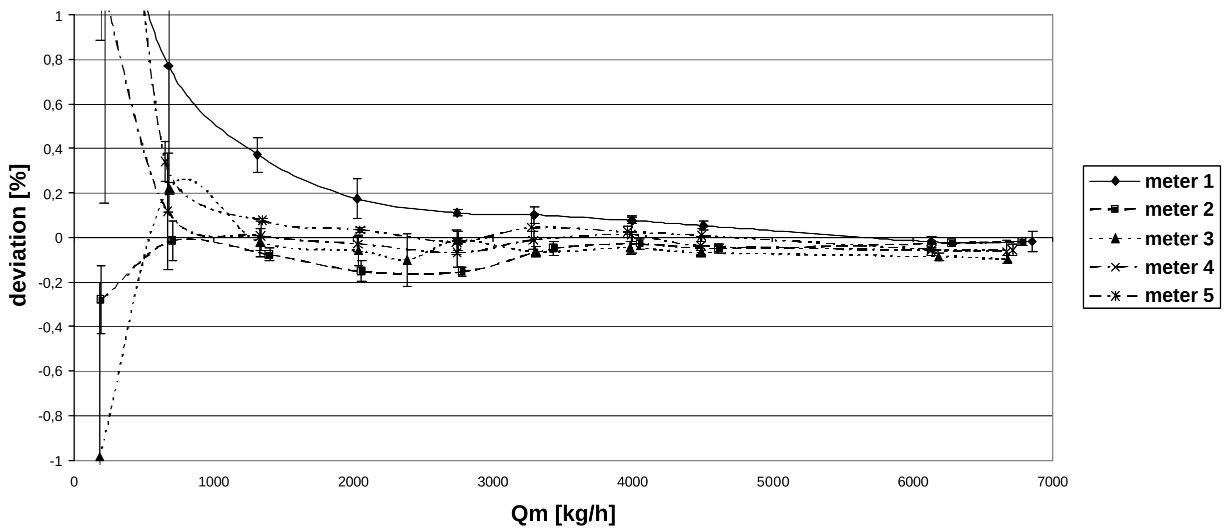

Fig 1 set of calibration results with typical series of CMF300 meters at 27 bar

Calibration results Micro Motion CMF300 at 9 bar (a)

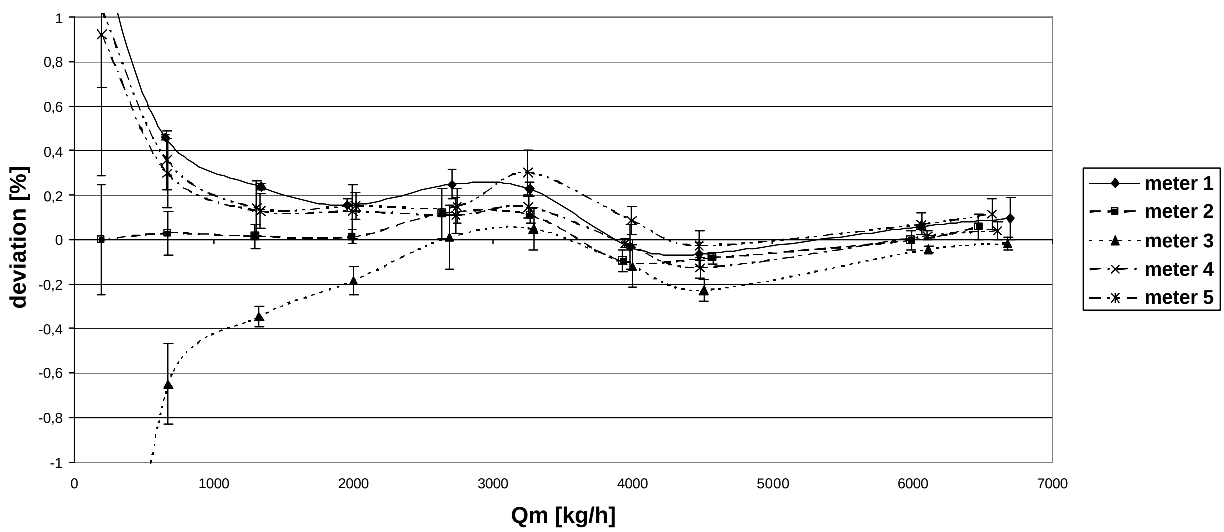

Fig 2. set of calibration results with typical set of CMF300 meters at 9 bar

The 27 bar curves are slightly more straight than the 9 bar curves, which show some systematic but small flow dependant behaviour. However, the overall flow weighted mean average deviations are small for the meters reported above: they are +0,05% (varying between –0,11% and +0,12%) for 9 bar and even as small as +0,03% (varying between –0,03% and +0,08%) for 27 bar in the flow range from 600 kg/hr to 6000 kg/hr. These results are very promising and show that the potential accuracy and reproducibility of the Coriolis meters for natural gas with pressure as low as 9 bar is very good.

3. ACCURACY ANALYSIS OF MASS VS. VOLUMETRIC REFERENCES

3.1 Sensitivity and uncertainty analysis of mass flow calibrations in HDP Groningen

This section describes an accuracy analysis on the mass flow meters like Coriolis vs. volumetric flow references like turbine meters.
Whereas the delayed availability of the gas quality analysis has an insignificant influence on the calibration of volume flow meters when using volume flow meters as reference standards, for the calibration of mass flow meters its exhibits more influence. The GERG project on Coriolis meters, executed in the High pressure test facility (HDP) of Gasunie Research (GUR), was the first occasion on which the influence of the gas quality could be evaluated, especially on the occasion of a changing gas composition.
During a long-term test of a Coriolis meter, the deviation of the Coriolis appeared unstable during a period of changing gas composition. A study was performed in order to find out in what sense the changing gas composition could account for the observed flow deviations.

The reason for the insignificant influence of the gas quality in the volume flow meter against volume flow meter-reference calibration is shown by the formula for the calculation of the deviation (meter under test =MUT; reference standard =REF):

$$\Delta = \left(\frac{V_{MUT} \cdot P_{MUT} \cdot T_{REF} \cdot Z_{REF}}{V_{REF} \cdot P_{REF} \cdot T_{MUT} \cdot Z_{MUT}} - 1 \right) * 100\% \qquad (1)$$

The influence of the gas quality appears in the ratio of the compressibility parameters Z_{REF}/Z_{MUT}. When MUT and REF are operated at comparable pressure and temperature values, the gas quality influence on the numerator is almost completely compensated by the gas quality influence on the denominator, thereby reducing the gas quality influence to a second order effect.

The reason for the more significant influence of the gas quality in the mass flow meter against volume flow meter-reference calibration is shown by the formula for the calculation of the deviation:

$$\Delta = \left(\frac{M_{MUT}}{V_{REF} \cdot r_n} \cdot \frac{P_n \cdot T_{REF} \cdot Z_{REF}}{P_{REF} \cdot T_n \cdot Z_n} - 1 \right) * 100\% \qquad (2)$$

The influence of the gas quality appears in $Z_{REF}/(r_n\ Z_n)$. There is hardly any compensating mechanism between numerator and denominator, like there is in case of the calibration of volumetric flow equipment.
In the Appendix A sensitivity and uncertainty analysis has been done for 8 bar Groningen type of natural gas.
From the sensitivity analysis we see, that

- For volumetric flow meters a compensating effect exists between pressure and temperature measurements at MUT and REF position, essentially giving rise to sensitivity related to temperature and pressure differences instead of absolute values.

- For the calibration mass flow meters there are no compensating effects giving rise to sensitivity to absolute values of pressure, temperature and density, which are even slightly enhanced by secondary order effects through the compressibility sensitivity.

For the uncertainty analysis we see, that whereas for volumetric flow meters a value of 0,17 % needs to be used, for mass flow meters the uncertainty is increased to 0,25%.

3.2 Effect of delay time in quality parameters at HDP Groningen

The gas quality has been determined by a gas chromatograph with an analysis time of 900s (15 minutes). At the time of the flow measurement, the available gas quality information available has been analysed from a gas sample taken between 15 and 30 minutes earlier. For volume flow meter against volume flow meter calibrations, this delay time has been shown to be insignificant.

The rate of change of the gas composition and in particular the normal-density determines the error made by the uncompensated delay-time.

For the determination of the influence of the delay time a reconstruction has to be made of the actual gas quality based on the reported gas quality.

A long-term test executed on July 2nd 2004 proved to offer the necessary conditions:

- Long measurement times, offering many hours of uninterrupted gas quality data enabling time-shifting of data over 15 to 30 minutes: 30 hours.
- Frequent logging of gas quality parameters offering satisfactory resolution: logging every minute.
- Significant change of the normal density during 11 hours (max 0,851; min 0,833 kg/m3n) and unchanged normal density during the remaining 19 hours.

A gas quality parameter on moment X is reconstructed by calculation of the average value from the period of time between X+15 minutes and X+30 minutes.

Two important limitations to this reconstruction method are distinguished:

1. A linear development of the concerned parameter is assumed. Luckily, the rate of change of the normal density in this example is low, enabling a proper recalculation.
2. The logging frequency of the gas quality (constant for 15 minutes) determines how precise the quality change can be timed.

July 2nd 2004 a long-term test of a Coriolis meter has been performed at almost constant flow rate. The test is performed with reference standard “F2”, being a turbine meter. The reported normal density during the test is depicted in figure 3 as the black line. The reconstructed normal density is given as the dotted line.

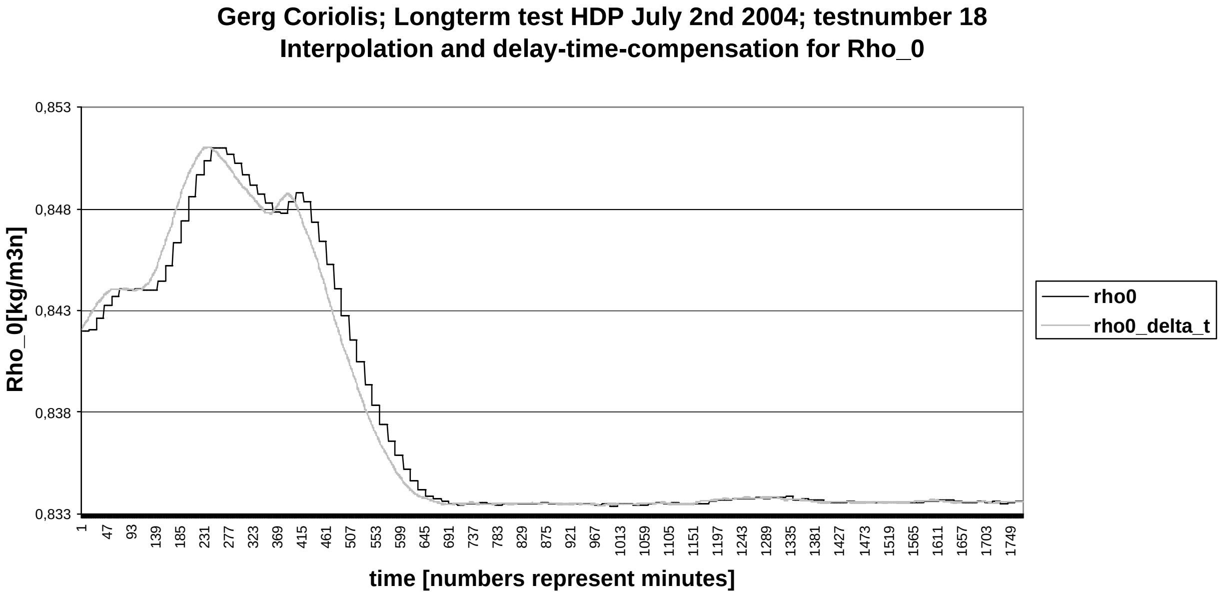

Fig 3. The rate of change of the normal density; reported and reconstructed values. Rho0 = reported normal density; rho0_delta_t = time shifted and interpolated normal density.

The rate of change of r_n varies between +0,0045 kg/($m^3{}_n$*h) and –0,0050 kg/($m^3{}_n$*h).

By reconstructing the calorific value and the carbon dioxide percentage values, also compressibility, flow, volume and finally, deviation to F2 could be reconstructed. The flow values of the volume flow reference meter F2 (turbine meter) are insignificantly influenced by the time shift. however, the flow rate at normal conditions derived from the Coriolis meter is significantly affected. Consequently, also the reconstructed deviation values are different from the reported values for the Coriolis meter against F2.

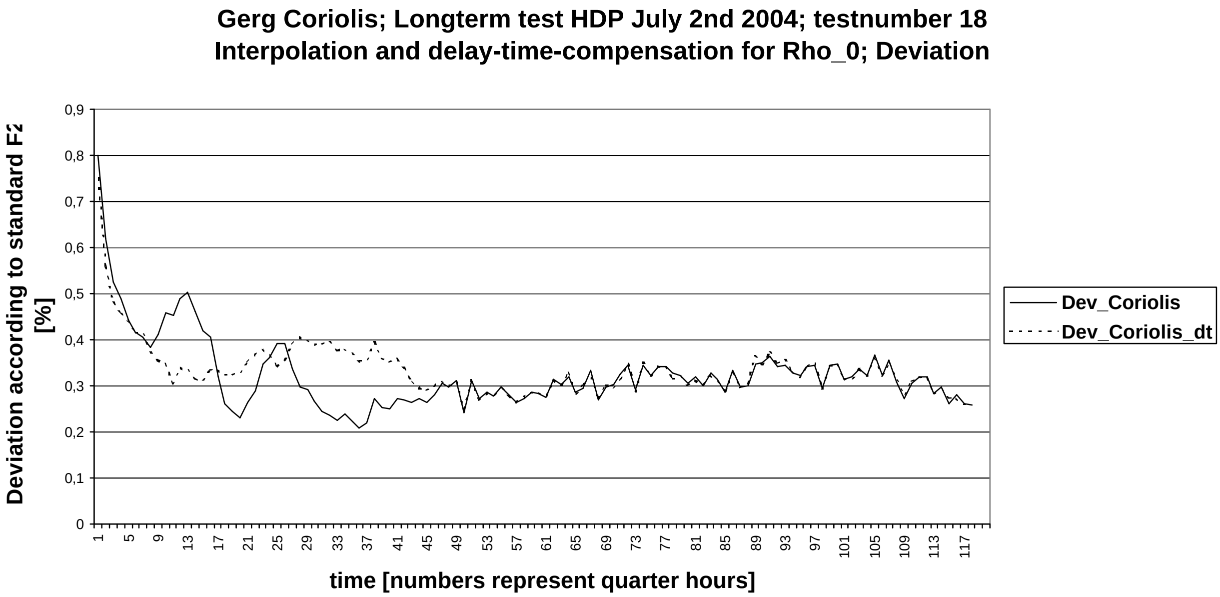

Fig 4. reported and time-compensated deviations of Coriolis meter

The reported deviation (dark line) is fluctuating during the gas quality change. The reconstructed deviation (dotted line) is almost free of these fluctuations, which proves that the time delay for the gas quality accounts for the meandering effect in the reported deviation.

In figure 5, the error induced by the time delay of the gas quality is depicted. The maximum error corrections on the reported deviations of the Coriolis meter are aranging from –0,15% to +0,15%.

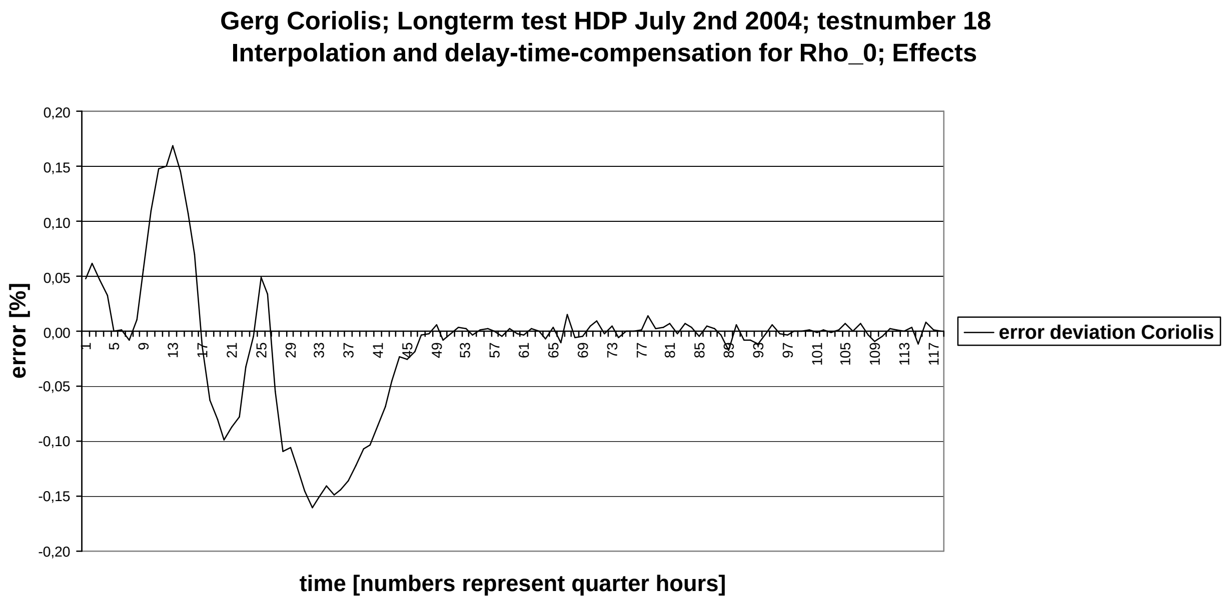

Fig 5. Difference between reported deviation and corrected deviation

Combining cause and error: 0,15% error in the deviation is reached where the rate of change of r_n amounts 0,0050 kg/(m^3_n*h).

To conclude here we can state that the delayed availability of the gas quality analysis has

- A significant influence on the calibration of mass flow meters: from +0,15% to –0,15% in the investigated case
- An insignificant influence on the calibration of volume flow meters

when using volume flow meters as reference standards.

4. RESULTS OF DURATION TEST

A Micro Motion CMF300 Coriolis meter serial number 484051 was provided by the manufacturer to test its application in a new design of a pressure regulating and metering station. The meter was placed along with a US meter on the upstream side of the test configuration at a pressure of 40 bar. Several extensive tests were performed in 2003 including tests with glycol and compressor oil injected into the gas. The results are published at the forthcoming IGRC [7].
The overall performance of the meter was very promising.
The same meter has been submitted to a long term test in a skid containing a pressure regulator (see figure 6). During the period of time between May 2004 and September 2004 several intervals of 24 hours have been used to test the meter. The pressure regulator with an upstream gas pressure of approx 40 bar, reduced the pressure to 8 bar and after a U-turn the Coriolismeter was positioned. The flow rate has been varied between 200 kg/h and 7300 kg/h (Qmax). Gas temperature was intended to remain constant at approx 15°C to 20°C. The research set up was completed with a monitor gas meter in series with the reference standards; note: the lowest flow set points of the tests are well below Qmin of the monitor meter (Qmin = 1400 kg/h @ 8 bar).

Fig 6. Coriolis meter mounted in a skid together with a pressure regulator

Four calibrations have been performed of which three were done in the skid and one in the calibration facility. The results of these calibrations along with the average flow and deviation of the 24hr duration test points are included in the figure 7.

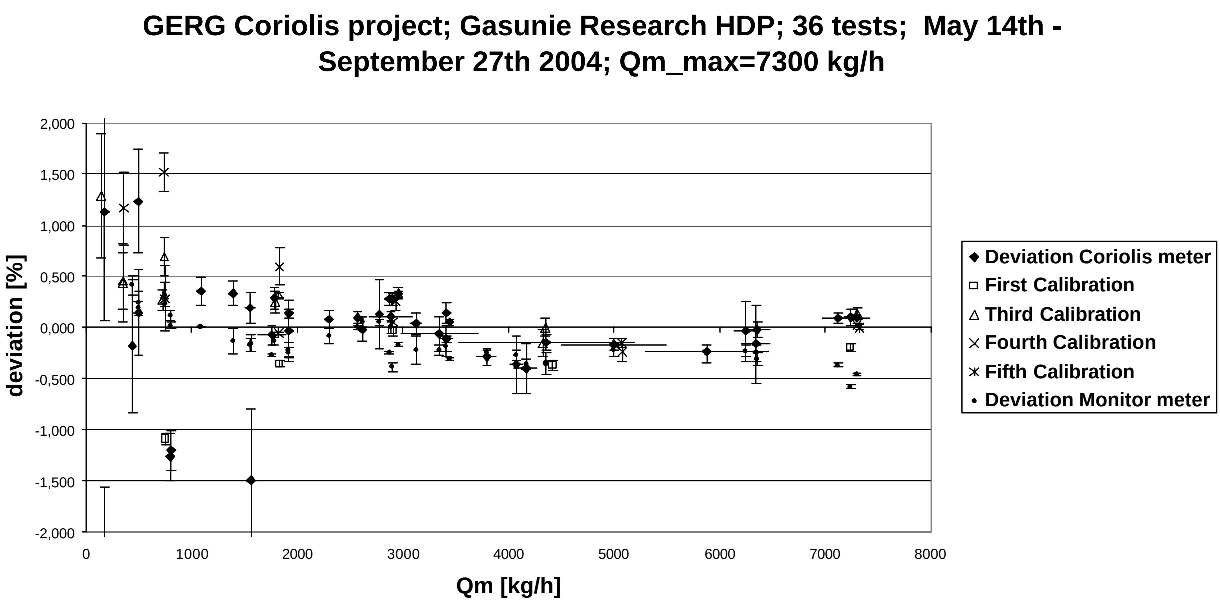

Fig 7. results of the duration test and some intermediate calibration tests

The results shown in figure 7 express the general note, that the meter performs well at high flow rates, whereas its performance drops at lower flow rates. The quantitative results of the duration test expressed in reproducibility (month-to-month) and repeatability (day-to-day) are given in the table below.

Table 1. Repeatability and reproducibility figures from the long term test. Numbers are given with 95% confidence level.

Flow regime	Variations within day Repeatability	Variations over months Reproducibility
Q < 1000 kg/hr	0.6%	2%
1000<Q < 2000 kg/hr	0.3%	1%
Q>2000kg/h	0.1%	0.3%

The large errors at lower flow rate are in line with the usually reported accuracy curves expressed by the “trumpet-like” curve. As an example at low flow set points (<1000kg/h) a large drift of the meter was observed: between July 8th to July 22nd the deviation of the meter drifted from +1.5% to –1.5%. A summary of these tests is shown in figure 8.

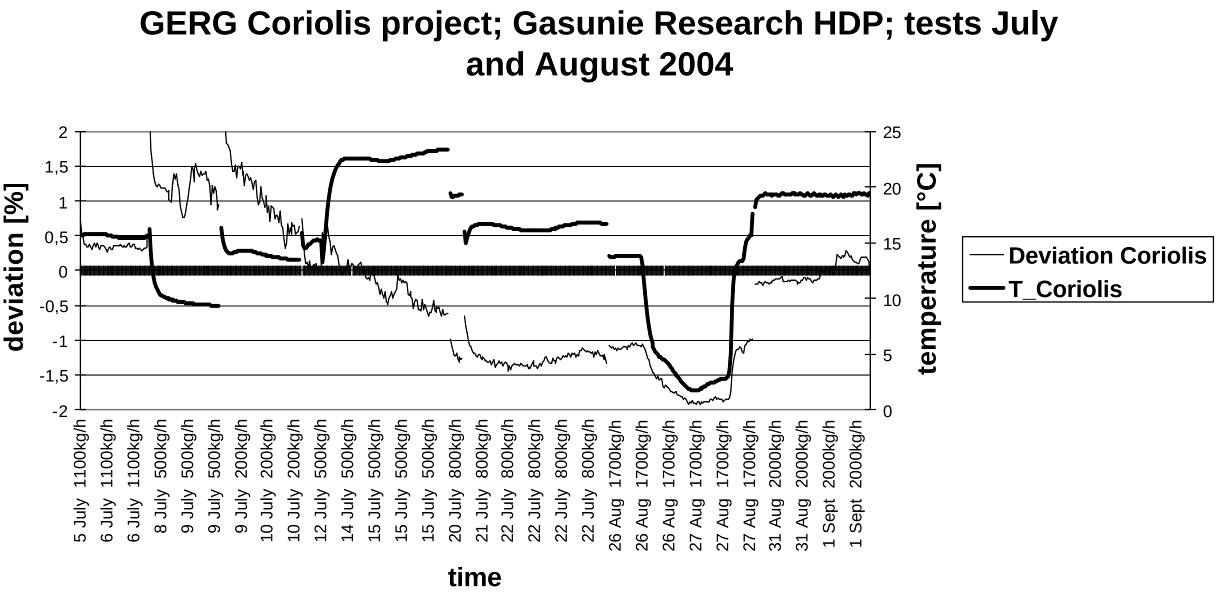

Fig 8. Deviation of the Coriolis meter between July 5th and September 1st showing a large portion of drift, which on August 26th and 27th is correlated with its temperature

Except for 26,27 August period no relation to either normal density or temperature variations was found. Moreover, the absolute values of the measurements of density and temperature could be checked against independent other measurement equipment:

- The density was checked to another GC delivering to the city of Groningen which showed a slightly time-shifted behaviour without significant systematic differences in determined values of $\rho_{n.}$
- The temperature sensor mounted close to the Coriolismeter was checked against the logged values of the transmitter mounted inside the meter to perform temperature corrections. These signals agreed well within the accuracy limits.

The most likely explanation for this drift lies in the assumption that the zero set point has changed. After consulting the manufacturer it was confirmed, that such zero deviations are possible and that they are within their specifications. They are a result of temperature changes away from the zeroing temperature. The deviations appear quite large, because the Coriolis meter is used at the low end of its range.
During one of the tests, the boiler failed, lowering the temperature at the Coriolis meter to temperatures as low as 2°C. Simultaneously, the deviation of the Coriolismeter drops from –1 to –2%, see figure 8 during August 26th and 27th .
It is therefore recommended in designing metering skids with Coriolis meters to

- Apply the meter on the high-pressure side in the metering and regulating skid as the rangeability increases with increasing pressure;
- According to the manufacturer thermal insulation on the meter will help in reducing temperature gradients across the metering body, thereby reducing the zero point temperature drift.

5. SUMMARY AND CONCLUSIONS

In this paper we have shown some of our first experiences using Coriolis meters for natural gas custody transfer applications.
The first reported experiences were the calibration of several CMF300 Coriolismeters of Micro Motion, showing a very good overall performance. The flow weighted mean average deviations are small for the meters: they are between –0,11% and +0,12% for 9 bar and even as small as between –0,03% and +0,08% for 27 bar in the flow range from 600 kg/hr to 6000 kg/hr with average standard deviation of 0,05% .These results are very promising and show that the potential accuracy and reproducibility of the Coriolis meters for natural gas even with pressures as low as 9 bar is very good.
The long term test showed variations in the deviations strongly correlated with normal density variations. Although the rate of change in normal density were as small as +0,5%/hr or -0,5%/hr, the resulting changes in deviations on the mass flowmeter vs. the volume flow reference of +0.15% to –0.15% respectively due to the time delay in the recorded GC signals.
Coriolis meter readings are shown to be sensitive to this effect.
It is strongly recommended when comparing Coriolis mass flow meters with volume based flow meters (turbine or ultrasonic flow) in a long term duration test to apply fast and accurate normal density measurement instruments: a fast process GC, a normal density cell u or potentially even better an Ensonic© device, enabling a very fast gas quality measurement or density measurement based upon a newly developed VOS based technology [8]. In this way time delay between recorded pressure, temperature and flow variables and the density recording can be minimised. In the near future we will install such a device at our flow test and calibration facility HDP to ensure our most accurate calibration capacities for Coriolis meters.
The results of the duration tests after being corrected for this effect -i.e. after the time delay has been compensated for- shows that the Coriolis meter under test shows a repeatability of 0.1% and a reproducibility of 0.3% at flow rates above 2000 kg/h. At lower flow rates these numbers are larger.
A serious drawback in the current application of the Coriolis meter at 9 bar natural gas is its limited rangibility. During our tests the meter performance was optimal in the range between 2000 kg/hr and 7000 kg/hr, but seriously deteriorates as the flow rate drops below 1000 kg/hr. The most probable cause of this deterioration at lower flows is a zero set point drift caused by temperature, which has a large effect at the low flow rates. It is therefore recommended in designing metering skids with Coriolis meters to

- Apply the meter on the high-pressure side in the metering and regulating skid as the rangeability increases with increasing pressure;
- Apply thermal insulation on the meter which will help in reducing temperature gradients across the metering body, thereby reducing the zero point temperature drift.

The GERG research project will put a selection of Coriolis meters to a severe test programme (see Appendix B) of which the results will be shown in a later stage.
As a final conclusion based on our first experiences we have obtained the confidentiality, that Coriolis meters in natural gas custody transfer in its current state-of-the-art needs to be seen as a serious option in the natural gas market for challenging the current flow meter types like turbine meters or ultrasonic meters. Its main application area will be for custody transfer of natural gas either to industrial end-users or to systems which transfer gas between transportation and distribution grids.
Special attention is needed at the low end of its range where zero point drift can occur when the process temperature significantly deviates from the “zeroing” temperature.

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8] Ensonic is a trademark of Instromet (www.instromet.com); For detailed information about its working principle: H.J. Panneman, et. al , Development of an Accurate, Low Cost Energy Meter for Custody Transfer; The Last Step from Prototype to Commercial Product. Proceedings of the 22th World Gas Conference, Tokyo, 2003

APPENDIX A uncertainty of massa flow calibration using volumetric references

The error propagation or sensitivity “B” of the compressibility ratio Zn/Z calculated with sGERG, for the average gas quality of the Netherlands at a gas pressure of 9 bar(absolute) and a gas temperature of 20°C, is approximated by:

$$B\left(Z_n / Z \right) = 0{,}017\,B(P) - 0{,}061\,B(T) + 0{,}024\,B(Hs) + 0{,}016\,B(\rho_n) + 0{,}00027\,B(CO2)$$

<u>For the calibration of a turbine meter</u>

$$\Delta_{tur} = \left(\frac{V_{MUT} \cdot P_{MUT} \cdot T_{REF} \cdot Z_{REF}}{V_{REF} \cdot P_{REF} \cdot T_{MUT} \cdot Z_{MUT}} - 1 \right) * 100\%$$

$$B(\Delta_{tur}) = B(V_{mut}) - B(V_{ref}) + 1{,}017\big(B(P_{mut}) - B(P_{ref})\big) - 1{,}061\big(B(T_{mut}) - B(T_{ref})\big)$$

The uncertainty “U” is given by:

$$U^2(\Delta_{tur}) = U^2(V_{mut}) + U^2(V_{ref}) + 1{,}034\big(U^2(P_{mut}) + U^2(P_{ref})\big) + 1{,}13\big(U^2(T_{mut}) + U^2(T_{ref})\big) + U^2(sGERG)$$

<u>For the calibration of a Coriolis meter:</u>

$$\Delta_{Cor} = \left(\frac{M_{MUT}}{V_{REF} \cdot \rho_n} \cdot \frac{P_n \cdot T_{REF} \cdot Z_{REF}}{P_{REF} \cdot T_n \cdot Z_n} - 1 \right) * 100\%$$

$$B(\Delta_{Cor}) = B(M_{mut}) - B(V_{ref}) - 1{,}017\,B(P_{ref}) + 1{,}061\,B(T_{ref}) - 0{,}024\,B(Hs) - 1{,}016\,B(\rho_n) - 0{,}00027\,B(CO2)$$

The uncertainty “U” is given by:

$$U^2(\Delta_{cor}) = U^2(M_{mut}) + U^2(V_{ref}) + 1{,}034\big(U^2(P_{ref})\big) + 1{,}13\big(U^2(T_{ref})\big) +$$
$$+ 0{,}00058\,U^2(Hs) + 1{,}032\,U^2(\rho_n) + 7e^{-8}\,U^2(CO2) + U^2(sGERG)$$

Assuming $U(M_{MUT})=U(V_{MUT})$ and neglecting the contributions of P_{MUT}, T_{MUT}, Hs and CO2 compared with $U(?_n)$ the following approximation is found:

$$U^2(\Delta_{cor}) = U^2(\Delta_{tur}) + 1{,}032\,U^2(\rho_n)$$

For HDP facility this calculation implies, that using the uncertainty for the calibration of turbinemeters, 0,2%, and the uncertainty of the normal density measurement based on a GC is 0,15%, the uncertainty for the calibration of mass flow meters is found to be 0,25% at 9 bar and 20°C.

APPENDIX B Test programme of GERG Coriolis test programme

Gasunie is currently participating in a GERG research project on Coriolis measurement techniques. In this project the possibilities of using Coriolis measurement technique for natural gas custody transfer applications are being investigated. Additional lab tests were defined to investigate the performance of Coriolis meters for natural gas custody transfer applications.

To perform the tests at the HDP research facility in Groningen the following types of Coriolis meters were selected (based on the experience records shown by the manufacturers in gas applications):

- CMF 200 (Micro Motion)
- RHM 33 (Rheonik)
- Promass 83 F (Endress & Hauser)

These three Coriolis meters were subjected to a test regime to investigate the performance of the Coriolis meter in the natural gas application under different circumstances. The Aim of this project is to provide independent and reliable data on the performance of Coriolis meters in natural gas. The test programme will be described below. Results will not be shown here as they are subject to agreements made with the manufacturers and the GERG working group.

Effect of different pressures

In this test the Coriolis meters were tested at three different pressures: 10, 20 and 30 bar and with a temperature of 20^{0}C. At each pressure eight different flow points of the maximum meter capacity were tested. The reason for these tests is to investigate the performance of the meters under ideal calibration conditions. Also these tests are used as baseline for further tests in the GERG project.

Effect of temperature

The effect of temperature of the gas on the Coriolis meter is investigated at a fixed pressure of 20 bar and three different temperatures: 5^{0}C, 20^{0}C and 40^{0}C. The test at 20^{0}C were used as a reference as they were already measured at the previous test. For this test six calibration points were used at 5, 10, 25, 40, 70 and 100 percent of the maximum meter capacity, respectively.
The reason for this test is to see whether temperature is affecting the Coriolis meter performance, the main reason is that in city gate stations the temperature can fluctuate over time. Also each gas company has its specific operating temperatures.

Effect of asymmetric and Swirl profiles

The effect of Asymmetry and swirl profile on the Coriolis meter is tested with a swirl generator at 20 bar and 20^{0}C. The Swirl generator is placed upstream of the meter. At each setting three flow calibration points are measured: 10%, 40% and 100% of the maximum meter capacity. Before testing with asymmetry and swirl profile a reference test is performed whereby the swirl generator valve angles for both valves are 0^0. In this setting the flow disturbance of the swirl generator is as small as possible.
In the first test ("asymmetry test") with asymmetry the angles of the valves of the swirl generator are 0^0 and 90^0, sort of simulating an extreme single bend flow profile, because one of the valves is blocking the flow whereas the other valve is completely open.
In the second test ("swirl test") with a swirl profile a severe swirl profile is chosen by setting the valves of the swirl generator in the position of –30^0 and 30^0. This means that a clock-wise type of swirl is created.

Effect of vibration with pressure regulator

In this test the effect of noise and vibration produced by a pressure regulator on the performance of the meter has been tested. The background for this test is that many applications for custody transfer for the GERG participants occur in a pressure reduction station. For the tests a pressure regulator of the type RMG, type R06-110b-35L-10bHv-MA has been used, because this type is known for its severe noise conditions. The regulator produces broad band noise which has most of the acoustic energy in the frequency region between 500 and 1500 Hz. The pressure regulator is placed upstream of the meter, the reason for this is to create some extreme noise conditions for the meter.

Effect of pulsating flow

The effect of pulsation on a Coriolis meter is investigated by using a pulsator which essentially is a rotating disk with holes mounted on a drive with flexible frequency control between 50 and 900 Hz. This rotating disk serves in combination with a resonating pipework as a generator of pulsation in the pipeline. In this test three different frequencies have tested for the different Coriolis at frequencies f_0, 0.5*f_0 and 2*f_0 with f_0 being the frequency of the tubes of the Coriolis meter under test. Also at the start a new reference test has been performed without any rotation of the disk. In the end a sort of sweep test has been performed from 50-900Hz at flow rate of 40% of the maximum meter capacity.