Paper 7.2

AGA Report No. 11 Expands Market for Proven Metering Concept

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1 INTRODUCTION

Micro Motion Coriolis flow meters have demonstrated high reliability, high accuracy and reduced maintenance in gas metering applications in chemical processing industry (CPI) and refinery plants for many years. Typical applications include monitoring natural gas feed-lines, combustion control systems, critical phase ethylene, and refinery fuel gas measurement. Next to the CPI and refinery plants, more than 15000 Coriolis meters are installed for Compressed Natural Gas (CNG) measurement (natural gas at 200+ bar for vehicle fueling). The Australian gas distribution company 'GPU GasNet' [1] installed more than 80 Micro Motion Coriolis flow meters in small to medium size metering installations (e.g. city gates) and even uses portable Micro Motion meters as a reference to proof turbine and Coriolis flow meters in the field. Recognition of the meter suitability is the result of a successful series of flow tests on actual low and high-pressure natural gas flows at different test facilities (Pigsar/Ruhrgas in Germany and Gasunie in the Netherlands amongst others).

These experiences encouraged both the American Gas Association (AGA) as well as the European Gas Research Group (GERG) to consider Coriolis technology for use as a natural gas custody transfer meter. The recent publication of the AGA Report No. 11 [2] was developed to assist designers and users in operating, calibrating, installing, maintaining and verifying Coriolis flow meters used for natural gas flow measurement. This report applies to Coriolis meters used in medium to high-pressure natural gas applications.

This paper presents an overview of the advantages Coriolis flow meter technology brings on natural gas measurement against the more traditional flow measurements such as orifice (dP) or turbine flow meters. Furthermore, it makes a proposal for a new generation of metering stations (e.g. city gates and pressure & reducing stations) incorporating the advantages and philosophy of Coriolis technology. Data will be presented to illustrate the experiences Micro Motion has with custody transfer natural gas applications, as well as third party (Pigsar/Ruhrgas and Gasunie laboratories) test data.

2 CORIOLIS TECHNOLOGY

Coriolis is a proven technology, with more than 500000 units installed around the world, from more than 5 manufacturers, in various applications and industries. Coriolis has been used since the late 1970's for liquid process applications, and has been in use since 1992 for process gas measurement (e.g. hydrogen, critical phase ethylene, fuel gas, etc.) with more than 20000 installed units. Another 15000 units have been used for Compressed Natural Gas (CNG) measurement. The AGA Report No. 11 joins other worldwide approvals, such as PTB (German Weights & Measures), NMi (Dutch Weights & Measures), and Measurement Canada and allows and guides Coriolis technology for use in natural gas applications.

Market growth for Coriolis technology has been very rapid; Coriolis' growth in gas phase applications is growing even faster than for liquid applications. Older design Coriolis meters were known to have some fairly well justified limitations for use on gas. In general a relatively high pressure drop (around 2,5 bar) was required to obtain a high accuracy flow reading, and large meters (3"-4" meter) did not work well due to sensitivity to noise and effects of process pressure. Since the market was rapidly growing, Coriolis vendors mostly focused on liquid applications.

Newer designs and technology developments since the early 1990's have changed this, allowing accurate gas flow measurement for even low-pressure gases down to 1 bar. Sensitivity has been significantly improved, and the pressure drop has lowered (a typical 35 bar distribution application is now sized for 0.2 bar pressure drop). Typically Coriolis technology offers even more value for gas than liquid measurement; this is because gases are compressible. With traditional gas flow meters (dP/orifice, turbine, rotary), process pressure, temperature, and gas composition must be accurately measured or controlled. Next to it, these devices require regularly maintenance (orifice plates checked, turbine bearings rebuilt), and adequate flow conditioning provided. Since Coriolis measures the flowing mass of the gas, the mass flow rate accuracy is independent of pressure, temperature, compressibility, composition changes and changing flow profile/swirl.

Coriolis is a smaller in-line-size technology; the largest offering from any vendor for gas applications is a 6" meter (handling natural gas flows up to 8-10" lines). Coriolis meters are multi variable meters that offer mass and/or volume flow, fluid temperature and liquid density.

Fig. 1.1 - Micro Motion Elite-Series (1/8" to 4")

Fig. 1.2 – Micro Motion Elite-Series (4") In Action

Coriolis technology is best known for its:
High accuracy, especially over changing fluid conditions of density, viscosity, composition, as well as high useable turndown (50:1 flow range from max to min is common). Coriolis flow meters are known in the market for their high mass flow accuracy for liquid measurement 0.1% of rate. Less well known is that the Micro Motion Elite product range are the most accurate gas flow meters currently available in the market. The Elite series have a mass flow accuracy of 0.35% of rate, typically this is in general twice more accurate on mass and energy flow than the PTZ corrected turbine flow meters available in the market.
High reliability. With no wearing parts, there is virtually any routine maintenance. With fewer devices installed (compare to fully compensated orifice or turbine), there are fewer sources of error, leakage, maintenance and calibration.
Low cost of ownership. Coriolis flow meters are very cost competitive with other metering technologies on an installed cost basis, where installed cost includes:

- Instrument purchase price
- Temperature and pressure compensation (volumetric technologies)
- Flow conditioning and straight runs (profile sensitive technologies)
- Flow computer (volumetric technologies) for mass flow & standard volume calculations
- Calibration costs (turbine meters need to be calibrated on gas at operating conditions)
- Labor to installation of these instruments

Application "sweet spots" include:

- Line sizes 8-10" and smaller (it is although possible to install parallel meters for larger lines)
- High turndown requirements (20:1 up to 80:1 is common), eliminating parallel metering runs of other technologies
- Dirty or wet gas where maintenance can be an issue
- No room for adequate straight-runs (re: AGA-3 revision)
- Changing gas composition and density.

The selection of the right size Coriolis meter is a tradeoff between accuracy (smaller meters being better) and permanent pressure loss (a larger sensor being better). Typically a Coriolis flow meter is selected one size smaller than it is line size.

3 HOW THE TECHNOLOGY WORKS

A Coriolis meter is comprised of two main parts, a sensor (primary element) and a transmitter (secondary element), see Fig. 3.1.

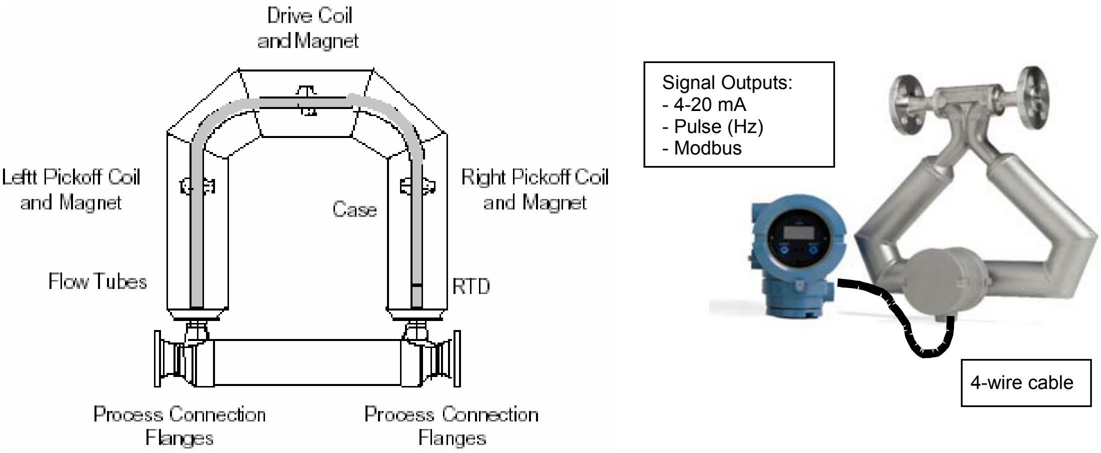


Fig. 3.1 – Coriolis Meter

With this design, the gas flows through a U-shaped tube. The tube is made to vibrate in a perpendicular direction to the flow. Gas flow through the tube generates a Coriolis force, which interacts with the vibration, causing the tube to twist. The greater the angle of the twist, the greater will be the flow. The sensing coils located on the inlet and outlet oscillate in proportion to the sinusoidal vibration. During the flow, the vibrating tubes and gas mass flow, couple together due to the Coriolis force, causing a phase shift between the vibrating sensing coils. The phase shift, which is measured by the Coriolis meter electronics, is directly proportional to the mass flow rate. The vibration frequency is proportional to the flowing density of the flow. However, the density measurement from the Coriolis meter is not normally used as part of the gas measurement station.

3.1 Theory Of Operation

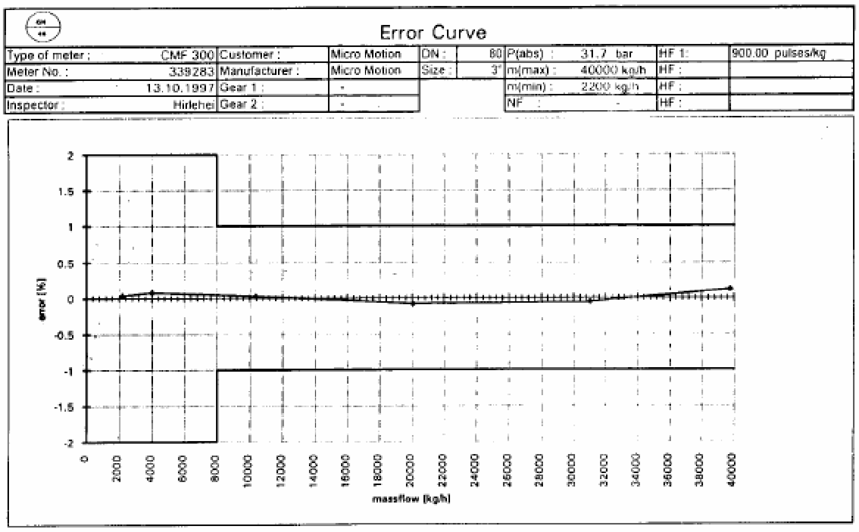
A compact analytical description about the theory of Coriolis flow meters can be found in the AGA Report No. 11 or on the Micro Motion web page www.micromotion.com [6]

4 STANDARDS, APPROVALS & THIRD PARTY TESTING

4.1 Third Party Laboratory Testing

Micro Motion Coriolis meters have been tested extensively over the past 10 years in the same flow laboratories that are used to calibrate orifice, turbine and ultrasonic meter runs. They have been tested on compressed air, critical phase ethylene, pipeline natural gas and compressed natural gas. They have been compared against sonic nozzles, turbine master meters, bell provers and weighing scales. A key objective of this testing has been to define both Coriolis installation and application practices as well as develop accuracy specifications. Extensive testing has been conducted at Southwest Research Institute (SwRI -San Antonio), Colorado Engineering Experimental Station (CEESI -Colorado), Pigsar/Ruhrgas (Germany), Gasunie (The Netherlands).

A sample test from Pigsar, using natural gas as a test fluid, is presented below for a Micro Motion Elite CMF300 (3”) meter. Accuracy is better than +/-0.2% for an 18:1 flow range.



Pigsar Test Lab.

CMF300 3” Sensor

+/- 0.2 accuracy
over 18:1 range
versus master turbine meters

P = 31.7 bar
Q_m = 2200 – 40.000 kg/h
Q_v = 2750 – 50.000 Nm^3/h

Fig. 4.1 – Micro Motion CMF300 (3”) Natural Gas Verification

4.2 Custody Transfer Approvals

Based in part on the testing at Pigsar, PTB (German Weights and Measures) approval for custody transfer was made to the first Coriolis meter since 1997 [3}. The German PTB and the Dutch NMi have approved the Micro Motion CMF050 (1/2”), CMF100 (1”), CMF200 (2”), CMF300 (3”), CMF400 (4”) and DS600 (6” PTB approved only) [4].

4.2.1 Micro Motion water calibration factor transfers directly to gas

The Dutch NMi has approved the CMF050, CMF100, CMF200, CMF300 and CMF400 to be used on custody transfer gas applications, while they are calibrated and verified in the factory on water against weighing scales only! [5] This means that a gas calibration or field calibration is no longer required. Tests have proven that the accuracy on water is representative for the accuracy on other liquids or gases, within a certain tolerance.

The advantages a water calibration offers against a natural gas calibration are manifold:

- The mass uncertainty of the Micro Motion water calibration lab. is only 0.03%. The mass uncertainty of a typical gas calibration lab. is in between 0.2% - 0.3%.
- A water calibration is aproximately a factor 10 lower in cost than a gas calibration
- A water calibration facility is easier to design, build and maintain than a (high pressure) natural gas calibration facility.

4.3 AGA Report No. 11

Most exciting to the natural gas industry is the recent publication of the American Gas Association (AGA) Transmission and Measurement Committee (TMC) Task Group No.11, who published AGA Report No.11, covering Coriolis for use in fiscal transfer of natural gas, in November 2003. This document, reflecting “best practices” in Coriolis natural gas flow metering describes the technology, common application, and usage in fiscal transfer. Next to the AGA, Coriolis technology has recently been evaluated by the European Gas Research Group (GERG), which consists of several European natural gas companies amongst others Ruhrgas, Gasunie, Gaz de France, SnamReteGas, etc.

The interest in Coriolis technology both from AGA & GERG arises from three “sweet spots” for Coriolis:

1) Transferability of a water calibration to gas, giving the gas industry a method to economically calibrate/verify Coriolis meters
2) Coriolis proven high mass flow accuracy and long-term calibration stability which offers reduced maintenance and field proven/verification
3) Economical metering for medium to high-pressure distribution metering points. These city-gates or industry-gates often have high turndown requirements, and require stringent straight run requirement for precision metering. In the use of ultrasonic metering these locations often have their pressure regulation downstream of the metering and testing has shown that noise from the regulators is causing problems with the ultrasonic meter.

5.0. NATURAL GAS CUSTODY TRANSFER APPLICATION EXAMPLE

Coriolis meters have been used in a wide variety of natural gas applications. This section discusses the selection criteria and the philosophy why the Australian GPU Gasnet has decided to use Coriolis flow meter technology for their low and medium sized metering stations (e.g. city gate) in spite of traditional flow metering solutions such as orifice and turbine flow meters. The author suggests that there is a great resemblance between the choices and decisions the Australian Gas companies had to make 7 years ago and the choices and decisions the gas companies are facing today.

5.1 Introduction

GPU GasNet Australia, owns and maintain approximately 2,000 km of natural gas transmission pipelines predominantly in the state of Victoria South Eastern Australia. This natural gas transmission system supplies a gas market of approximately 1.4 million customers that use approximately 200PJ/annum.
During the mid 1990s, the Victorian Gas Industry was privatized and split into seven major companies. The gas transmission system (now owned by GPU GasNet) was physically separated from the distribution systems during 1997 by the new custody transfer metering points. Measurement of natural gas both into and out of the transmission system is now carried out at approximately 120-custody transfer metering sites.

5.2 Metering Project Requirements

- Over 100 Custody Transfer metering points
- About 40% of skids required bi-directional flow metering
- Some metering sites underground in the middle of the road
- Major upgrade of flow computers and communication system

5.3 GPU Gasnet Metering Philosophy

5.3.1 General

The metering philosophy of GPU Gasnet is: accurate and reliable gas metering for Custody Transfer (CT) is required at all delivery points such as inlet and outlet facilities in order to manage pipeline operations and more specifically for billing purposes.

The main aim of GPU GasNet in selecting CT flow meters is:
- To use the latest, but proven technology to be utilized well into the 21st century
- Necessary to have the most accurate meters at the best possible total ownership cost (life cycle cost)
- To select meters with the lowest calibration frequency and as low maintenance requirement as possible.

5.3.2 Meter preference

Table 5.1 indicates the minimum accuracy required and the metering technology preferred by GPU. The preference is established on the grounds of accuracy and total life cycle costing (LCC), that is the ownership cost including calibration and maintenance over the life of a meter.

Category	Peak Flow Rate (SCMH)	Accuracy Limits (Volume)	Accuracy Limits (Energy)	Preferred Meter Type
I	> 300000	±0.5%	< ±1%	Ultrasonic*
II	> 40000 < 30000	±0.8%	±1.2%	Turbine/Coriolis*
III	> 4000 < 40000	±1.2%	±1.8%	Coriolis*
IV	< 4000	±1.5%	±2.0%	Coriolis*

Table 5.1 – * Denotes GPU GasNet Preferred Technology

5.3.3 Flow computers

Unless called for by specific State Legislation or the customer (end user) it is not desirable to use dedicated flow computers to perform flow calculation where Coriolis meters are used. Flow computers do not add to accuracy of reading nor do dedicated flow computers enhance the reading process in any way.

For orifice, turbine and ultrasonic meters dedicated flow computers must be used, capable to make the most recent AGA 3, AGA 7 and AGA 8 calculations.

5.3.4 Meter runs

For standard installation, GPU Gasnet recommends a single meter with bypass and provision for a master meter to be placed in series. All installations shall be in accordance with manufacture's specifications and recommendations and or relevant AGA standards. For high flow and availability, dual meters, single meters with bypass and proving arrangement may be sufficient.

5.3.5 Flow conditioning

The use of flow profiler i.e. a Gallagher plates, Zankler plate of Daniel flow profiler plates that both restore flow profile and swirl are strongly recommended for installation employing ultrasonic meters. Turbine meters shall employ manufacturers recommended flow profilers. Coriolis meters do not require any form of flow conditioning.

5.3.6 Flow limiters

Where turbine or rotary (positive displacement) meters are used, to protect these meters from damage, it is strongly recommended to use some form of flow restriction devices to limit the maximum flow to about 120% of maximum meter range (or as indicated by meter manufacturer). Coriolis meters have no moving parts and therefore cannot be over speeded.

5.3.7 Filtration

Turbine, rotary, and orifice plate meters require filtration to better than one-micron. Turbine and rotary meters can be permanently damaged if slugs of liquid are present in the measured medium in such applications in addition to good filtration a coalescer (separator) must be used. For Coriolis & ultrasonic flow meters it is sufficient to use strainers only.

5.4 GPU Gasnet Calibration Guidelines

5.4.1 General

The highest Life Cycle Cost (LCC) is due to calibration frequency, therefore equipment selected shall be of such a construction that affords the longest time interval between the calibration periods. All meters should have an initial high pressure gas calibration performed at an approved test facility and verified at Agility's test facility at Horsley Park. This calibration verification performed at Horsley Park will provide a "finger printing", for each meter, which will aid in future calibration checks.

5.4.2 Pressure and temperature transmitters

It is pointless to buy meters then calibrate them, to obtain highest accuracy, than use "garden variety" pressure and temperature transmitters. Therefore Agility favors to use smart pressure and temperature transmitters in metering applications, specifically Rosemount as these exhibit long-term stability. Where smart transmitters are used yearly calibration check is sufficient. As adequate data is gathered from specific site, the calibration interval can be extended (with an agreement of all parties concerned) to a biannual calibration check or even longer.

5.4.3 Turbine meters

Turbine meters have moving parts and therefore need to be calibrated on gas to require a calibration characteristic (K factor). This factor is expressed in pulses per volume. This flow calibration should be carried out over the entire operating range of the meter as the K factor may vary with flow. This variation with flow is the turbine meter's linearity. In an ideal case, this K factor should be constant across the meters entire flow range. However at low flows, the mechanical friction of the bearings and counter, fluid friction and pick-up all limit this linearity.

As turbine meters use moving parts they must be lubricated during each calibration check or at an interval nominated by the equipment manufacture whichever period is the shorter. Failure to lubricate these meters will in time adversely effect the metering accuracy due to bearing wear. The accuracy verification can involve calibration check of temperature and pressure transmitters

GPU noted that due to high LCC i.e. calibration verification rate coupled with high maintenance requirements, turbine meters should only be used in application where other technology is not suitable for given application.

5.4.4 Ultrasonic multi-path meters

The frequency of calibration of ultrasonic meters shall be in accordance with contract requirement and as detailed in the Safety and Operating Plan as a guide, however due to high stability of these meters yearly calibration check is considered sufficient.

The calibration is accomplished without removing the meter by checking the meter's parameters and verification of speed of sound in the measured medium (unless the meter was calibrated with nitrogen then nitrogen should be used for calibration also). Where the composition of gas is difficult to determine it is recommended to fill the meter run with nitrogen to perform the verification of speed of sound.

Using ultrasonic multi-path meters, it is feasible to have calibration intervals every two years. As ultrasonic meters have no moving parts, there is no need for preventive maintenance.

5.4.5 Coriolis meters

The frequency of calibration or calibration verification of Coriolis meters shall be in accordance with contract conditions and as detailed in the Safety and Operating Plan. As Coriolis meters do not use moving parts (no wear) as a guide the calibration verification in a single meter installation can be performed every two years dependent on contractual and installation's requirement.

In accordance with manufacturer's recommendation is to check the zero of the meter on regular basis (seasonal change). A Coriolis meter can be exchanged with a calibrated meter or calibration verified against a master meter temporarily installed in the stand by run.

If calibration of Coriolis meter is required it can be performed using water and as indicated above, two years is a suitable period to be considered.

5.4.6 Orifice plate meters

Contrary to popular belief orifice plate meters although the technology is thought to be well understood (as they been around since Roman times) are neither low cost nor accurate. Extensive recent USA study into orifice plate meters have established that in the greatest majority of cases specifically with normal complications in piping arrangements such as out of plane bends with in the metering facility the orifice meters showed –16% +8% inaccuracy of measurement.

This has led to revision of AGA3 standard in which the original straight lengths of 10 diameter up stream have now been revised to be over 80 and up to 200 diameters under some situations. The flow straighteners in form of tube bundles have been replaced with flow profiler plates.

The orifice plate total installed cost is reasonably high. Additionally if a total LCC is considered it is soon understood that, these installations are twice to three times more expensive then comparative other technology. Due to this, the use of orifice plates for custody transfer application is strongly discouraged.

5.4.7 Design summary

In the selection of instruments for Custody Transfer station applications the design engineer shall in addition to equipment's accuracy consider long-term stability (5 years or longer). As well as temperature performance with the aim of selecting equipment with the lowest drift over a longest period of time.

Additionally future calibration and maintenance requirements shall also be considered with the aim of achieving the lowest LCC. Therefore, instruments that exhibit best long-term stability with little or no maintenance shall be selected in preference to other equipment. The selection criteria shall also consider skid requirements, i.e. the need for filters / coalescers.

Based on the above discussion the selection of the following flow measurement equipment is recommended

For large flow conditions	Ultrasonic multi-path meters (Daniel)
For lower flow conditions at high pressure	Coriolis meters (Micro Motion)
Where Coriolis meters are unsuitable	Turbine meters (Instromet or Daniel)

5.4.8 Installed base

More then 80 Micro Motion meters have been installed in small to medium sized metering stations the last 7 years. See below some pictures of these stations.

Fig. 5.1 – City Gate Metering Station

Fig. 5.2 – Coriolis Master Meter

Fig. 5.3 – Medium Size Metering Station

6 CONCLUSIONS & RECOMMENDATIONS

The unique features and characteristics of the Coriolis flow meters offer the following advantages for the design, installation, maintenance and cost of ownership for natural gas metering stations compared to the traditional metering stations with e.g. turbine flow meters:

Metering Station Design

- The footprint of a metering station can be reduced because there is no need for straight pipe runs up- and down stream of a Coriolis meter **(economical & technical advantage)**.
- There is no need to use a coalescer/separator. Slugs of liquid present in the gas do not damage a Coriolis meter **(economical & technical advantage)**.
- It is recommended to design the pressure & reducing metering station with a Coriolis meter installed on the high pressure side (Coriolis meters measure directly the mass flow of a gas, therefore they are not affected by pressure, temperature and compressibility changes). Typically a smaller line size flow meter can be used on the high-pressure side instead of on the low-pressure side **(economical advantage).** Secondly, it will improve the metering turndown **(technical advantage)**.

Metering Station Installation

- Micro Motion Coriolis meters are insensitive to the noise which typically developed in pressure & reducing metering stations, unlike ultrasonic meters.
- No need to install flow computers to perform flow calculations, since these do not add to accuracy of reading **(economical & technical advantage)**.
- No need to install additional pressure & temperature transmitters **(economical & technical advantage)**.

Metering Station Maintenance

- Coriolis meters do not have wearing parts, therefore there is no need for lubrication **(economical & technical advantage)**.
- Coriolis meters are capable of handling wet gas and pulsating flows. **(economical & technical advantage)**.
- The Coriolis density measurement can be used for diagnostic purposes and to check the health of the meter.

Metering Station Life Cycle Cost

- Re-calibration can be low or even zero **(economical advantage)**.
- (Re)-calibration cost can be low, because water calibration is sufficient **(economical advantage & technical advantage)**.

REFERENCES

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[3] PTB Type-approval for Micro Motion Mass Meter, No. 1.32-1-5.411-ROS 91.05, Braunschweig, October 08, 1991.

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[6] Micro Motion is a division of Emerson Process Management, www.micromotion.com