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PROVING AND STABILITY OF MULTI-PATH ULTRASONIC FLOW METERS

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Abstract: *The present study identifies the principal factors influencing the provability of multi-path chordal ultrasonic meters. It also presents a comprehensive dataset of proving results for meters of various sizes, collected from multiple independently certified hydraulic laboratories and from diverse field installations. The findings indicate that repeatability is both predictable and predominantly governed by hydraulic or turbulence statistics. Furthermore, the data demonstrates that, when appropriately designed, multi-path chordal ultrasonic meters can be successfully proved using small-volume provers and ball provers in accordance with API proving standards.*

Key words: *Proving Systems, Measurement Error, Natural Gas, Custody Transfer, Meter Calibration, Operational Reliability.*

1. INTRODUCTION

Proving mitigates installation effects and ensures meter performance, crucial for custody transfer operations where in-situ proving of liquid flowmeters, especially turbine types, is mandated by regulations and best practices. Ultrasonic meters, though exhibiting higher short-term variability, provide better average calibration stability, prompting a need to examine factors affecting this variability and consider reducing proving frequency.

Amid the energy crisis, the increased use of natural gas as a transitional energy source toward green energy, significant price fluctuations, and new international regulations, stakeholders in commercial natural gas transactions are increasingly focused on optimizing measurement methods and minimizing losses from unaccounted-for gas.

The autumn-winter season typically increases natural gas demand. In Europe, November 2024 saw a 16% rise in Dutch Title Transfer Facility (TTF) gas prices, reaching levels not seen since October 2023. On 22 November, front-month December TTF contracts traded at 47 €/MWh, up from a three-year low of 25 €/MWh in February [1]. By 30 December 2024, February 2025 TTF futures rose to 47.87 €/MWh, continuing the upward trend [2]. The natural gas market remains highly volatile due to weather and geopolitical factors.

A 0.1% measurement error in systems handling 100,000–150,000 Sm³/h can cause annual discrepancies of 600,000–650,000 Sm³, leading to under- or overbilling of approximately 200,000–250,000 euros. This underscores the importance of accurate measurement and investing in proving systems to prevent significant financial losses and ensure reliable transactions between buyers and sellers [3].

2. PURPOSES FOR CONDUCTING FIELD METER PROVING

Although the meter installed in the field underwent comprehensive verification and precise calibration in the factory, including the application of an error curve for linearization, a variety of factors can still influence its performance under actual operating conditions [4].

Measurement systems can develop errors over time due to factors like damaged orifice plates, worn turbine meter bearings, and contamination on flow conditioners and piping. Straightening vanes may become obstructed,

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and advanced meters such as ultrasonic types can degrade from contaminants, leading to inaccurate readings. Additionally, input data for flow computers and electronic devices might be inadvertently altered, compromising accuracy. Newly installed meters are particularly vulnerable to construction debris.

Meter proving is essential to ensure both meter accuracy and the integrity of the entire measurement system, especially in custody transfer applications, providing assurance to buyers and sellers and minimizing disputes.

3. METER PROVING SYSTEMS

Numerous methods and devices are available for verifying the accuracy of a natural gas meter. Examples include calibrated Master Meters, Sonic Nozzles, Bell Provers, and Volume Provers. Each of these devices has distinct advantages and disadvantages. They can be grouped into two main categories: primary and secondary proving devices [5], [6].

A primary measurement device - such as a Bell Prover or Volume Prover - is one whose volumetric flow rate measurement accuracy has been confirmed against standardized references traceable to national or international standards (e.g., mass, time, and length). This type of device can then be employed to validate Master Meters. Once a Master Meter has been calibrated, it becomes a secondary standard and may be placed in series with a field meter to verify the field meter's accuracy [7].

By contrast, a secondary device is one that has been validated against a primary device and is subsequently used to prove another meter. An example is an In-Situ Meter Prover equipped with a Master Meter. The In-Situ Meter Prover consists of the Master Meter and its associated piping, which can be transported to the field to verify the accuracy of a meter on-site.

4. INSTALLATION OF THE PROVING SYSTEM

The high-pressure, in-situ Master Meter Prover is typically a Master Meter positioned directly downstream of, and in series with, the operating Field Meter. It is installed on-site to conduct accuracy verification under actual flow, temperature, pressure, and density conditions. The Master Meter may be permanently mounted on the metering skid or configured as a portable unit, which can then be connected to an existing three-valve manifold as needed [8].

A flow conditioner should be installed in the Master Meter pre-run piping, upstream of the Master Meter, to mitigate any flow profile disturbances caused by elbows and valves leading into the Master Meter Run.

Equipment required for onsite proving of gas ultrasonic meters includes:

- Master Meter
- Flow Computer
- Temperature and Pressure transducers

Fig. 1. Flow conditioner

A Master Meter is used to verify the field meter and must possess an accuracy significantly exceeding that of the meter under assessment. The ability of a meter to consistently produce identical measurements, known as repeatability, is essential. By applying linearization, flow computers can capitalize on the inherent repeatability of turbine meters to enhance overall measurement precision [9], [11].

A calibration is needed in order to demonstrate the accuracy of data. In Table 1, the errors observed across different flow rate intervals and the adjustments applied to mitigate measurement inaccuracies are detailed. The calibration of the master meter was conducted on a specialized calibration stand, where flow conditions were meticulously controlled, and the meter's parameters were systematically adjusted to align with reference standards. This rigorous process ensured the accuracy and reliability of the measurement system by verifying the meter's performance against the required specifications under controlled conditions.

The graphical representation in Figure 2 further illustrates the impact of these adjustments. It compares the error percentages before and after the calibration process at various flow rates, alongside a verification curve. As depicted, the errors before adjustment exhibited a wider deviation, particularly at lower and higher flow rates. Following calibration, the error margins were significantly reduced, showcasing the enhanced precision of the master meter. For instance, at a flow rate of 10,001 m³/h, the error improved from -0.38% to 0.01%. Similarly, other flow rates also displayed substantial reductions in error, as seen in Table 1.

This figure also highlights the repeatability of the master meter's performance post-calibration, with the verification curve aligning closely with the post-adjustment data points. This alignment underscores the effectiveness of the linearization techniques applied during calibration. By leveraging the repeatability characteristic of turbine meters, the flow computer was able to optimize the measurement accuracy, as reflected in both the numerical data and graphical trends.

Table 1

Error Comparison Before and After Adjustment at 24 Bar

Error-->	**Before adjustment**		**After adjustment 0.39%**	
Reference	Flow m³/h	24 bar (er. %)	Flow m³/h	24 bar (er. %)
124	10001	-0.38	10001	0.01
14	7020	-0.32	7020	0.07
14	4019	-0.53	4019	-0.14
1	2513	-0.52	2513	-0.13
1	997	-0.32	997	0.08
1	502	-0.18	502	0.21

In contrast, Figure 3 highlights the differences in relative error between the master meter and the ultrasonic meter during the proving process. The master meter exhibits superior repeatability and accuracy, with errors consistently within tighter bounds after adjustment. The ultrasonic meter, while providing reliable measurements, shows slightly greater variability in error, particularly at higher flow rates. This underscores the necessity of employing a calibrated master meter as a reference standard to ensure the accuracy of field meter assessments.

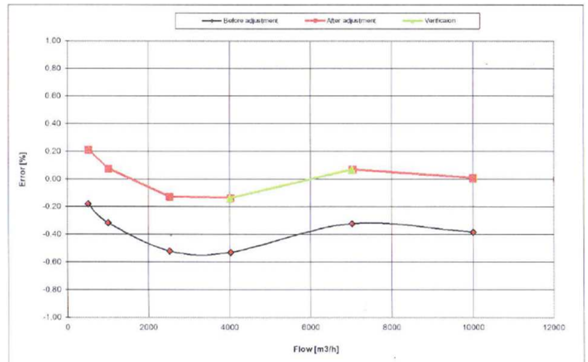

Fig. 2. Before (black line) and after (red line) calibration

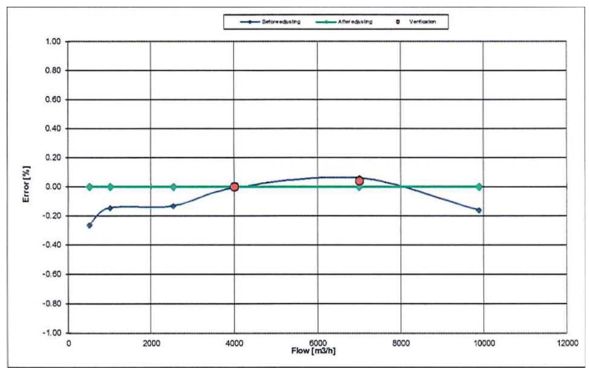

Fig. 3. Post-Proving Error Curve of the Ultrasonic Flow Meter

The engineering calculations conducted by Flow Computer should adhere to the methodologies outlined in the current AGA and API standards. Moreover, the Flow Computer's output must be presented such that every step, from raw data to final compensated volumes, can be validated through manual calculations when necessary

Modern Flow Computers enable the linearization of the typical calibration curve for a precision master meter. During meter proving, the stated volume of both the calibrated Master Meter and the field meter under evaluation can be measured with high accuracy throughout the proving cycle by using pulse interpolation.

Temperature and Pressure transducers: The gas pressure, temperature, and differential pressure of differential pressure (DP) meters must be measured with high precision at both the

Master Meter and the meter under test. Given the minimal pressure drop between these two meters, a differential pressure transducer is generally the most effective instrument for capturing pressure measurements. Utilizing a multi-variable transducer between the meters eliminates any potential pressure or calibration discrepancies that might occur when employing two separate transducers.

As line pressure decreases, accurately detecting small differences in pressure between the two meters becomes increasingly challenging. In atmospheric Transfer Meter Prover systems, a differential pressure transmitter can be used to determine the gauge pressure at the first meter by leaving the high-pressure port open to the atmosphere and connecting the low-pressure port to the meter's pressure port. Atmospheric pressure may be entered manually based on meteorological data or measured using a highly accurate atmospheric pressure transmitter.

To ensure accurate temperature measurement, the gas temperature should be measured at a location situated at least five pipe diameters downstream of each meter. A slight discrepancy in gas temperature between the two meters typically arises, attributable in part to the pressure drop between them. Given that this pressure drop is minimal, only a relatively small change in temperature is observed. Consequently, highly precise and well-calibrated temperature sensors and transducers are required to measure this subtle temperature differential.

The rationales for employing proving can be succinctly summarized as follows:

Proving can mitigate the influence of pipe fittings and installation hydraulics - such as reducers, planar and nonplanar elbows, and flow conditioner characteristics - that may generate profile asymmetry, swirl, pulsations, and elevated turbulence levels. These factors often affect the majority of meters in unpredictable ways.

In its most fundamental sense, proving ensures that any given meter - be it Positive Displacement, Turbine, Coriolis, or Ultrasonic - achieves a level of calibration uncertainty that satisfies the requirements of both parties involved in the custody transfer.

On-site proving can mitigate the effects of variations in fluid properties, such as viscosity.

When monitored over extended intervals, proving results can indicate when meters require maintenance.

Proving not only confirms the accuracy of the meter itself, but also verifies the integrity of the ancillary equipment employed in the proving process (e.g., detector switches, transducers, valves).

Finally, as the economic value of liquid hydrocarbons continues to rise, minimizing measurement uncertainty has become increasingly crucial. Proving is now mandatory under certain national standards, and it is also likely to be sought by users of ultrasonic flow meters.

In summary, proving remains the sole direct method for ensuring independent verification, providing the necessary assurance that measured data satisfies the stringent requirements for custody transfer operations.

5. VERIFICATION STAGES

Verification of gas quantity measurement systems via proving is conducted in the following stages:

The validity of the calibration certificates for the reference system's components is verified.

The validity of the chromatographic analysis report is verified in situations where the system under verification employs a fixed gas composition. If the composition is measured online by a gas chromatograph and transmitted to the volume converter, it must be confirmed that both converters are updated simultaneously.

The installation of the gas meters is verified by ensuring the following:

a) The meters are connected in series without any intermediate components that could disrupt fluid flow.

b) The distance between the two meters meets the specifications in the manufacturer's documentation or type approval, thereby preventing mutual interference.

The configuration of the verified system and the corresponding volume converter parameters are documented, including the converter type, gas composition, gas compressibility standard, pressure transducer type, temperature transducer type, measurement ranges for pressure and temperature, the “Kv” factor (imp/m³), as well as any potential meter correction factors (MFv) based on flow.

The date and time in the reference system’s converter are synchronized with those in the verified system’s converter (either automatically via laptop or manually), ensuring a maximum discrepancy of no more than one second.

The gas volume converter in the reference system is configured to use the same gas composition and the same gas compressibility standard as the converter in the verified system. For the reference meter’s parameters, the Ke factor is set, and, whenever feasible, the reference meter’s error corrections as a function of flow (MFe), calculated from its calibration certificate, are also applied.

A fluid flow is established in the circuit of both measurement systems. If feasible, the flow rate is adjusted to the desired level, and the critical parameters are monitored to ensure they remain within the specified tolerance limits.

The readings from both systems are recorded over a sufficiently long interval to allow for the appropriate selection of data in which critical parameters remain within the specified variation limits. The selected data must represent consecutively recorded values throughout these chosen intervals.

6. DETERMINATION OF THE MEASUREMENT ERROR

In order to determine the measurement error of the verified gas quantity measurement system, the following input parameters provided by both converters/flow computers are recorded.

- The volumes under measurement conditions, VV and VE (from the verified meter and the reference meter, respectively);
- The volumes under base conditions, VVb and VEb, respectively;
- The gas temperatures at both meters;
- The absolute gas pressures at both meters.

Data are selected in accordance with the established criteria for critical parameters.

The data presented in Table 2 were generated during the most recent proving conducted in April 2024 on an ultrasonic meter located in Romania. Proving activities are scheduled biannually, coinciding with the transition between the injection and extraction cycles at the gas storage facility. These results were obtained through meticulous measurements performed under controlled conditions and incorporate data provided by the field measurement devices.

The proving process relies on the synchronized operation of the measurement system components, including the ultrasonic meter and the turbine flow meter, to assess the relative error and validate compliance with prescribed accuracy standards. During the proving, parameters such as gas temperature, absolute pressure, flow rate, and corrected and uncorrected volumes were recorded by both flow computers of the verified and reference meters. These values were subsequently processed to calculate the relative error of the measured volumes under base conditions, as per the relationship defined in Equation (1) [3]:

$$e = \frac{V_{Vb} - V_{Eb}}{V_{Eb}} x100\ (\%) \qquad (1)$$

The data encapsulated in Table 2 reflect the accuracy and reliability of the ultrasonic flow meter during the proving. For example, the relative error percentages, ranging between -0.19% and -0.27%, demonstrate that the ultrasonic meter's performance remains within the permissible error margins. This confirms the meter’s operational integrity under nominal conditions. Such results are critical for ensuring the quality and reliability of gas quantity measurements in compliance with industry standards and regulations.

The system is considered to be operating correctly at a specified flow rate if the relative measurement error of the volume under base conditions remains within the prescribed maximum tolerated error limits (Et). The maximum tolerated error of the verified measurement system (Et) is determined by the quadratic summation of the tolerated errors of the meter and the gas flow computer, utilizing the following values:

- The maximum tolerated error of the gas meters under nominal operating conditions (during subsequent verification) is:
  - ±2% for Qt ≤ Q ≤ Qmax,

- ±4% for Qmin ≤ Q < Qt.

- The maximum tolerated error of the gas flow computer under nominal operating conditions (during subsequent verification) is ±2%.
- Maximum permissible errors of the gas quantity measurement system components under nominal conditions (during subsequent verification):
  - ± 0,6% for flow computer;
  - ± 0,4% for temperature transducer;
  - ± 1,0% for pressure transducer.

Based on the aforementioned considerations and by meticulously adhering to each step of the verification process, a proving report is generated from which it can be concluded whether the ultrasonic meter undergoing verification falls within the permissible error margins.

Table 2

Proving results

The verification result **Success**		Start of proving		00:08:20 PM
		Finisf of proving		1 :38:31 PM
Insertion Cycle		1	2	3
Turbine Flow Meter				
Average Temperature	°C	10.36	9.24	8.20
Average Pressure	bara	26.05	26.18	26.27
Average flow rate	m^3/h	3877.08	3796.63	3797.58
Flow meter capacity	%	38.77	37.97	37.98
Corrected Volume	Sm^3	53782.390	53291.989	53737.082
Uncorrected Volume	m^3	1938.507	1901.556	1901.865
Ultrasonic Flow Meter				
Average Temperature	°C	10.36	9.24	8.21
Average Pressure	bara	26.11	26.24	26.33
Flow meter capacity	%	38.77	37.97	37.98
Corrected Volume	Sm^3	53678.351	53157.595	53593.488
Uncorrected Volume	m^3	1930.245	1892.539	1892.542
Relativ error	%	-0,19	-0,25	-0,27

Following the completion of the proving process, subsequent service operations are conducted on the meter to systematically observe and evaluate its operational parameters. The program compliant with AGA Report 10 is used to generate the inspection report for the ultrasonic meter [10]. These parameters include axial velocity, cross-flow velocity and its deviations, flow profile characteristics, swirl intensity, turbulence levels, overall performance metrics, and the speed of sound within the medium. By meticulously analyzing these factors, technicians can diagnose potential anomalies, perform necessary calibrations, and ensure that the meter maintains optimal functionality and accuracy in its gas measurement applications.

Figure 4 illustrates the speed of sound (SoS) measured along each path of the ultrasonic meter. Notably, path 1 shows a slight deviation from the expected range, suggesting a potential issue with the sensor associated with path 1, which may be on the verge of failure. This early detection highlights the importance of routine monitoring and the proactive maintenance that can be undertaken to address such anomalies before they affect overall meter performance.

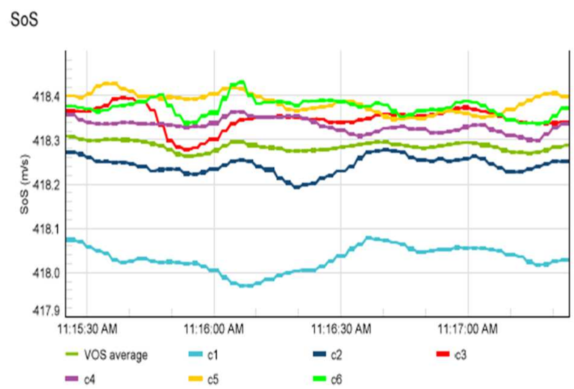

Fig. 4. Speed of sound in the gas measured along each path of the ultrasonic meter

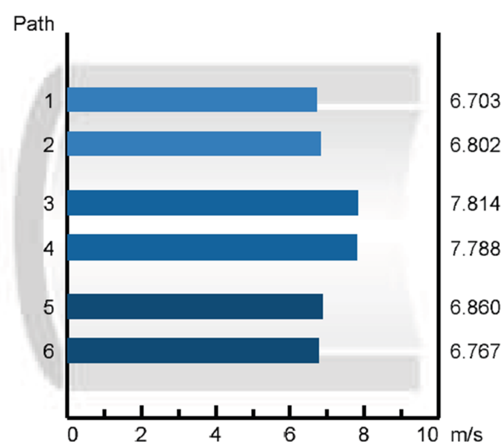

Fig. 5. Path Velocity

Figure 5 represents the velocity of the gas along each measurement path at the time of generating the report. The distribution indicates a bullet-shaped velocity profile, which is desirable as it suggests a stable and consistent flow condition. This result confirms that the meter is operating effectively under the current flow conditions, without significant disruptions or irregularities.

Figure 6 illustrates the swirl intensity across three planes of measurement within the meter. The data shows that the flow remains well within acceptable limits, indicating that the flow conditioner upstream of the meter is functioning effectively. The consistent and symmetric distribution across the planes suggests minimal swirl interference, thereby ensuring reliable and accurate flow measurements. This result confirms that the meter is operating optimally under current flow conditions, with no significant rotational disturbances affecting its performance.

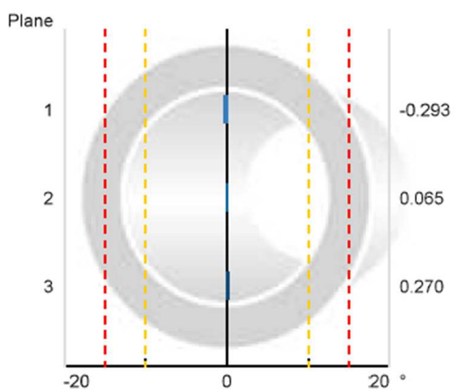

Fig. 6. Swirl

7. CONCLUSIONS

The implementation of proving procedures within gas quantity measurement systems offers a multitude of significant benefits that enhance both operational integrity and economic efficiency. This paper demonstrates how proving serves as a critical mechanism for ensuring the accuracy and reliability of various types of flow meters, including ultrasonic, turbine, Coriolis, and positive displacement meters. Our study explores the factors influencing measurement uncertainty and highlights the effectiveness of calibration processes in minimizing these discrepancies. By systematically verifying and calibrating these instruments, proving minimizes measurement uncertainties, thereby safeguarding against substantial financial discrepancies arising from underbilling or overbilling.

Furthermore, proving mitigates the adverse effects of installation-related variables such as pipe fittings, flow asymmetries, and turbulence, which can otherwise lead to unpredictable measurement errors. This validation process ensures that meters operate within their specified performance standards under actual field conditions, thereby enhancing the overall robustness of the measurement system.

From an economic perspective, the cost-effectiveness of proving becomes evident when considering the potential financial losses associated with inaccurate measurements. The investment in appropriate proving equipment and regular verification processes is substantially outweighed by the prevention of significant economic losses and the optimization of gas measurement accuracy. Additionally, proving facilitates compliance with stringent national and international standards, thereby ensuring that measurement practices meet regulatory requirements and industry best practices.

Moreover, the ability to detect and address meter performance issues through proving extends the lifespan of measurement equipment and reduces the need for frequent maintenance or replacement. By identifying deviations and enabling timely interventions, proving contributes to the sustained operational efficiency and reliability of gas measurement systems. Our findings underscore the importance of implementing robust proving practices, particularly in high-stakes applications such as custody transfer operations, where even minor errors can lead to significant economic consequences.

In the context of increasing reliance on natural gas as a transitional energy source towards greener alternatives, the precision afforded by proving becomes even more paramount. Accurate gas measurements are essential for effective resource management, pricing strategies, and the overall sustainability of energy systems. Further studies should investigate the role of emerging technologies, such as advanced sensors and AI-based diagnostics, in enhancing the accuracy and efficiency of proving procedures.

In summary, this paper highlights the indispensable role of proving as the primary method for independent verification of gas quantity measurement systems. Its comprehensive benefits encompass enhanced measurement accuracy, economic savings, regulatory compliance, and improved operational reliability. As the energy landscape continues to evolve, the adoption of rigorous proving practices will remain a cornerstone in ensuring the precision and dependability of gas measurement and management.

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Testarea și stabilitatea contorarelor de debit ultrasonice

Studiul de față identifică principalii factori care influențează verificabilitatea contorarelor de debit ultrasonice cu corzi. De asemenea, prezintă un set cuprinzător de date privind rezultatele verificării pentru contoarele de dimensiuni variate, colectate din mai multe laboratoare hidraulice certificate independent și din diverse instalații de teren. Rezultatele indică faptul că repetabilitatea este atât previzibilă, cât și guvernată predominant de statisticile hidraulice sau de turbulență. În plus, datele demonstrează că, atunci când sunt proiectate corespunzător, debitmetrele ultrasonice multi-cale cu corzi pot fi verificate cu succes utilizând provere cu volum mic și provere cu bile, în conformitate cu standardele de verificare API.

Cuvinte cheie: *Sisteme de verificare, eroare de măsurare, gaze naturale, transfer de custodie, calibrare contor, fiabilitate operațională.*

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