

OVERVIEW OF CURRENT TRENDS IN THE DEVELOPMENT OF ULTRASONIC GAS FLOW METERS. CHALLENGES AND PROSPECTS FOR REPLACING ROTARY AND TURBINE GAS METERS

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Abstract – This paper presents an analysis of the current trends in the development of industrial ultrasonic gas meters, emphasizing the shift from traditional rotary and turbine meters to more advanced ultrasonic technologies. The study delineates the evolution into three generations of ultrasonic meters, highlighting technological advances, regulatory updates, and the comparative advantages of ultrasonic meters. The prospects of integrating third-generation ultrasonic meters for varied applications are discussed, alongside the challenges of high costs and the need for pipeline reconstruction.

Keywords: Ultrasonic gas meters; Flow measurement; Regulatory standards; Mathematical modeling; Additive technologies

1. INTRODUCTION

The evolution of ultrasonic gas meters began in the late 20th century, marking a significant advancement over traditional mechanical gas meters like turbine and rotary meters. The first notable prototype of an all-electronic gas meter, employing time-of-flight technology for measuring gas flow, was reported in 1992 [1]. However, it was the development and introduction of ultrasonic flow meters for industrial natural gas measurement in the late 1970s that set the stage for modern ultrasonic gas metering.

Ultrasonic flow meters operate based on the principle of measuring the time difference between ultrasonic pulses traveling upstream and downstream through the gas. This method, known as the transit time or time-of-flight principle, provides an inferential measurement of gas flow rate, similar to traditional turbine meters. However, ultrasonic meters offer several advantages, including low measuring dependence from gas composition and the absence of moving parts, which reduces maintenance time and increases reliability.

The introduction of multipath ultrasonic sensing technology, which employs multiple pairs of ultrasonic transducers to improve measurement accuracy, was a key development in the field. This innovation led to the increased adoption of ultrasonic meters in utility gas industries and the establishment of standards and regulations for their use in natural gas custody transfer applications.

Despite the advantages of ultrasonic gas meters, they face significant challenges in competing with mechanical

meters, primarily due to their higher cost and technical complexities. Mechanical meters, which include turbine and diaphragm types, are traditionally used in over 80% of metering stations globally. Their drawbacks include mechanical wear and tear—even with advanced bearing technology—friction, high pressure drop, unstable measurements, and susceptibility to vibration and temperature fluctuations. These meters measure flow indirectly through the speed of rotation, which is proportional to flow rate. Despite these issues, mechanical meters remain popular because they are cheaper, widely manufactured, and familiar to end users. Currently, the primary obstacles to replacing mechanical meters with ultrasonic ones are the high costs of modifying gas pipelines, which must accommodate the long straight runs required by ultrasonic meters, and the higher costs of the meters themselves. Nonetheless, ultrasonic meters have demonstrated their effectiveness in providing accurate, reliable, and cost-efficient gas metering in a range of applications, from industrial to residential. This reflects the continuous innovation in gas measurement technology, driven by the need for enhanced accuracy, reliability, and efficiency.

2. EVOLUTION OF ULTRASONIC GAS METERS

Considering the evolution of ultrasonic gas meters over the past 30-40 years, three generations can be distinguished, each of which is approximately 10-15 years

Generation 1: Focused on industrial flow meters designed for large flow rates and high pressure. Key characteristics included basic accuracy between 1-3%, operation at pressures over 10 bar, and a minimum of two channels. The disadvantages of such devices include sensitivity to changes in the (uneven) flow profile, low sensitivity of ultrasonic sensors, high power consumption, and bulky, non-ergonomic designs without built-in diagnostics, which required calibration under natural gas operating conditions.



Generation 2: Targeted industrial flow meters for medium to large flow rates across a range of pressures. These meters featured improved accuracy (0.5-1%), could operate at atmospheric pressure and above, and included at least two ultrasonic beams. They offered advanced diagnostics, more ergonomic designs, and lower power consumption but required longer straight runs than turbine meters and special conditioners for top accuracy, alongside a need for external power and calibration.



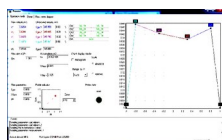
Generation 3: The latest generation aimed at replacing turbine and rotary meters across all flow rates and pressures. These meters have:

- Accuracy from 0.5 to 1%;
- Flow rate not less than 1:160
- Working pressure from 1 bar to 160 bar;
- At least 2 ultrasonic beams;
- Deviations of the flow profile at the entrance to the meter do not affect the measurement error. There is no need for straight pipe sections before and after the meter
- Does not require calibration on natural gas;
- Autonomous power supply from built-in batteries (at least 4 years);
- The dimensions of the housing from flange to flange must correspond to the existing dimensions of similar rotary and turbine meters;
- Built-in flow corrector (EVC), pressure and temperature sensors;
- Ergonomic design;
- Advanced diagnostic functions: diagnostics based on the speed of sound, diagnostics by current profile, diagnostics based on the signal/noise ratio, prediction of possible breakdowns, for example due to contamination of the sensor, possibility of diagnostic sessions to record all device parameters, availability of archives of non-standard situations and breakdowns.

Each generation marks a significant step forward in addressing the operational inefficiencies and technical limitations of the preceding models, reflecting ongoing innovation and adaptation in ultrasonic gas meter technology.

The diagnostic features of ultrasonic gas flow meters Generation 2 and Generation 3 are sophisticated and ensure robust performance under varying conditions. Key diagnostic capabilities include:

- **Speed of Sound Diagnostics:** This checks that the speed of sound measured across different channels does not deviate by more than 0.3%, ensuring accuracy in flow measurement.
- **Flow Profile Diagnostics:** This evaluates the flow profile across the meter to detect any anomalies or shifts that could impact measurement accuracy.



- **Signal-to-Noise Ratio Diagnostics:** This monitors the quality of the signal relative to background noise, which is crucial for maintaining measurement precision.

- **Predictive Diagnostics:** These systems predict potential breakdowns, for example, due to sensor contamination, enabling preventative maintenance.

- **Diagnostic Sessions:** They allow for the recording of all device parameters during specific sessions to analyze the meter's performance comprehensively.



- **Archives of Anomalies:** Ultrasonic meters maintain logs of non-standard events and breakdowns, providing valuable data for troubleshooting and improvement of meter performance.

3. EVOLUTION OF REGULATORY STANDARDS

We see the same periodicity of approximately 10 years in regulatory documents regarding ultrasonic gas meters. These include:

AGA Report No. 9 is "Measurement of Gas by Multipath Ultrasonic Meters." [2] This document, developed by the American Gas Association (AGA), outlines the specifications and guidelines for using multipath ultrasonic meters to measure natural gas flow, focusing on accuracy, reliability, and the application requirements for custody transfer. AGA 9 has 4 editions:

- **First Edition (1998):** *Purpose:* Introduced the framework for the use of ultrasonic meters in gas measurement, particularly focusing on multipath ultrasonic meters. It set out the initial standards for their application, focusing on installation, maintenance, and accuracy requirements. *Key Updates:* This edition provided foundational guidelines on how these meters should be implemented within the natural gas industry, addressing technical specifications, data processing, and meter verification methods.

- **Second Edition (2007):** *Purpose:* To refine and expand upon the initial guidelines based on industry feedback and advancements in ultrasonic meter technology. *Key Updates:* This revision included more detailed procedures for calibration, enhanced diagnostics, and performance evaluation. It improved clarity on the conditions under which these meters operate optimally, and expanded the scope to cover a wider range of installation environments and gas compositions.

- **Third Edition (2017):** *Purpose:* Further to update and refine the practices as ultrasonic technology and digital processing capabilities advanced. It aimed to increase the reliability and accuracy of these meters under varying operational conditions. *Key Updates:* The 2017 edition emphasized improvements in the diagnostic capabilities of meters, helping operators better monitor and maintain meter performance. It also introduced guidelines for more complex installations and updated standards to reflect improvements in sensor technology and data handling.

- **Fourth Edition (2022):** *Purpose:* To continue to adapt to the latest technological innovations and regulatory changes within the industry, ensuring that the standards remain relevant and useful. *Key Updates:* This latest edition likely includes further enhancements to meter diagnostics,

integration capabilities with modern digital systems, and possibly new standards related to environmental impact and energy efficiency, although specific details would need to be confirmed by reviewing the 2022 document.

ISO 17089-1 [3] is "Measurement of fluid flow in closed conduits — Ultrasonic meters for gas — Part 1: Meters for custody transfer and allocation measurement." This standard applies to ultrasonic gas flow meters used for critical applications such as custody transfer and allocation metering, which require high accuracy and reliability. ISO 17089-1 has 2 editions:

- ISO 17089-1:2010 - This edition applied to transit time ultrasonic gas flow meters used for custody transfer and allocation metering.
- ISO 17089-1:2019 - This is a more recent update that continues to cover ultrasonic meters for gas, focusing on meters used for custody transfer and allocation measurement. This represents the second edition of the standard.

OIML R 137-1&2 [4]: Gas meters — Part 1: Metrological and technical requirements, Part 2: Metrological controls and performance tests. This standard covers comprehensive requirements and testing methods for gas meters, focusing on ensuring accurate and reliable gas metering under regulated conditions. OIML R 137 has few editions:

- OIML R 137-1 (2006): First edition, focusing on the metrological and technical requirements for gas meters.
- OIML R 137-1 (2012): An updated edition which replaced the 2006 edition.
- OIML R 137-1&2 (2020): Latest available edition that continues to refine standards based on technological advancements and industry feedback.

As follows from the above, changes in regulatory documents quickly reflect changes occurring in subsequent generations of ultrasonic gas meters from the 1st generation to the 2nd generation and further to the 3rd generation

4. MATHEMATICAL MODELING AND PRODUCTION TECHNOLOGIES

Powerful software tools for mathematical modelling, such as ANSYS, SolidWorks etc are instrumental in developing and testing third-generation ultrasonic gas meters. These advanced simulation tools enable developers to test meter operations without being physically present in a laboratory setting. This facilitates addressing key design issues such as optimal placement of sensors and selecting a device construction that minimizes the impact of local resistances on flow measurement errors. For instance, consider a simulation conducted on SolidWorks, where the flow profile for a four-channel ultrasonic gas meter, model GFA414 DN100, is calculated. This type of modeling provides insights into how the meter's design can influence its performance and accuracy, allowing for refinements before physical prototypes are constructed and tested. These simulations are crucial for enhancing meter reliability and efficiency, ensuring that the meters perform accurately under various conditions.

Sophisticated software tools for mathematical modeling, such as ANSYS and SolidWorks, serve as powerful instruments in the development and testing of third-

generation ultrasonic gas meters. These tools enable developers to simulate the operation of meters without the need for a physical laboratory setting. This capability is critical for optimizing sensor placement and designing the meter in a way that minimizes the impact of local resistances on flow measurement accuracy.

It is important to note that various standards require a specific number of tests to assess the influence of local resistances on the accuracy of gas flow measurements by meters:

- AGA-9 specifies at least 5 tests.
- ISO 17089 specifies at least 9 tests.
- OIML 137 also specifies at least 9 tests.

Through mathematical modeling techniques, developers can swiftly evaluate potential changes in the accuracy of the designed ultrasonic gas meters to ensure compliance with these regulatory standards.

To illustrate, consider a simulation conducted in SolidWorks on the flow profile for a four-channel ultrasonic meter model GFA414 DN100 at a flow rate of 650 m³/h and atmospheric pressure. The simulation examines the impact of local resistance caused by two elbows positioned in different planes. The flow profile was analyzed both with a Zanker-type flow straightener (Figure 1) and without it (Figure 2).

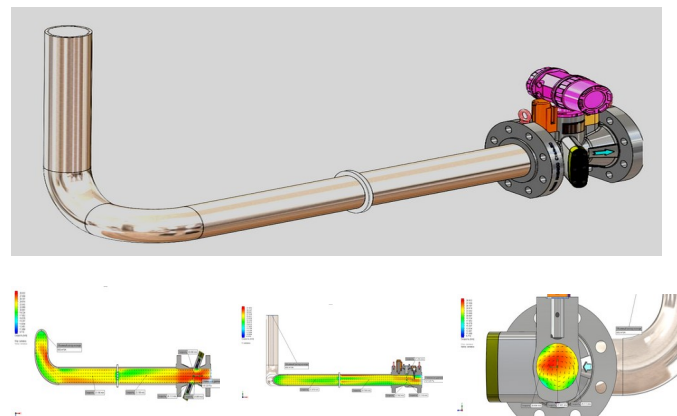


Figure 1. Calculated profile with Zanker flow straightener

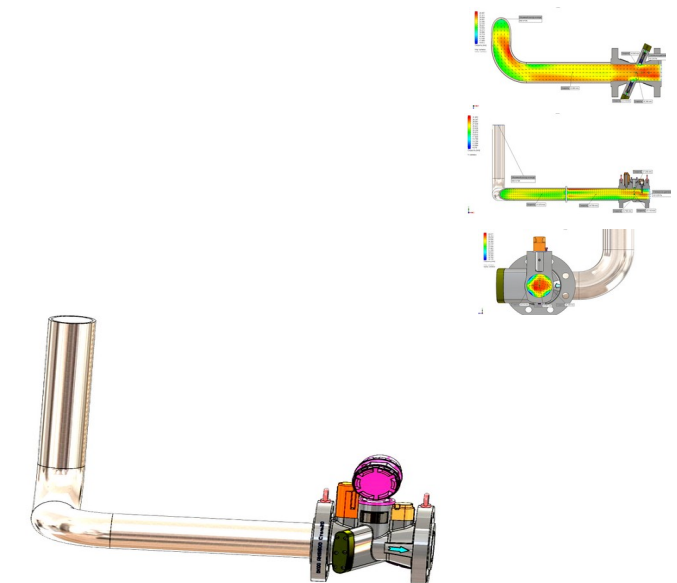


Figure 2. Calculated profile without Zanker flow straightener

This example underscores how modeling can help predict and optimize meter performance under varied installation conditions and configurations, providing crucial insights for design improvements and compliance with industry standards.

By leveraging these advanced modeling tools, meter developers can achieve higher precision and reliability in their products, paving the way for more accurate and efficient gas flow measurement solutions in various applications.

The application of mathematical modeling in the development of third-generation ultrasonic gas meters can also be seen in the approach described in article [5].

Although mathematical modeling is a powerful tool, it cannot provide definitive answers about the final metrological characteristics of the device under design. The ultimate verification of these characteristics can only be achieved through testing on calibration stands. Rapid prototyping, facilitated by 3D printing, plays a crucial role in this process. Currently, the capabilities of 3D printing technology are extensive, offering a wide range of materials suitable for prototyping. These materials need to possess sufficient strength and hermeticity post-printing, which can make them quite costly. However, the ability to produce initial prototypes of modeled meters within 20-40 hours offers significant advantages over traditional prototyping methods.

Thus, combining mathematical modeling with 3D printing of prototypes enables manufacturers of third-generation ultrasonic gas meters to swiftly address the challenges of designing meter configurations whose measurement results are minimally influenced by the presence of local resistances. This integration of advanced technologies ensures that new designs can be rapidly iterated and tested, accelerating the development process and enhancing the reliability of the meters.

5. CHALLENGES AND PROSPECTS

A major challenge in the mass deployment of third-generation ultrasonic gas meters is their cost. It's clear that if these meters are significantly more expensive, consumers are likely to be hesitant about adopting them on a large scale, despite their substantial technical advantages. This could limit their market to a small segment. However, even under these circumstances, the use of third-generation

ultrasonic meters, capable of measuring a wide flow range and replacing mechanical meters without needing to reconstruct metering stations, will be highly demanded. This demand is driven by the significant volumes of unaccounted gas at gas distribution stations during summer or night time due to low consumption, as for example, situation described in [6] for the Italian gas transmission network, which has over 7,000 rotary and turbine meters installed.

At the same time, if the production of third-generation ultrasonic gas meters can be scaled up and their cost brought in line with that of traditional mechanical meters with an Electronic Volume Corrector (EVC), the market prospects are virtually unlimited. Manufacturers who can enter this market first will gain a significant competitive advantage.

6. CONCLUSIONS

We are on the brink of revolutionary changes in gas flow measurement, namely the mass replacement of turbine and rotary meters with third-generation ultrasonic gas meters. These meters offer superior metrological and operational characteristics and come equipped with a broad set of diagnostic functions. Mechanical meters, which have dominated the market for over a century, are likely to be significantly displaced by ultrasonic meters within the next 5-10 years. The regulatory and manufacturing base is already ripe to support this transformation.

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