

A new generation of inline liquid ultrasonic flow meters

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Introduction

The ultrasonic flow meter market has developed rapidly and has seen a significant growth. Due to its high performance and unique properties, ultrasonic flow meters have built up a prominent position in the flow meter market and in many industrial processes. Reputed market research companies claim that the ultrasonic flow meter market is the fastest growing market and expect further explosive market growth.

One of the reasons for this success is that new and innovative product developments have broadened the application capabilities. For example intelligent processing of the transmitted signals allows for higher contents of entrained gas and solids in the medium. By increasing the number of measurement beams, an intelligent configuration of the beams, and innovations in transducer design and electronics, major improvements have been made in the accuracy and the stability of the measurements. From the early days ultrasonic flow meters have been used in the upstream and downstream side of the oil industry. In the early nineties, the first multiple beam ultrasonic flow meter for custody transfer of gas was introduced followed in the late nineties by an UFM custody transfer meter for liquid hydrocarbons.

A broader acceptance of the technology and decreasing prices have further spread the use of ultrasonic flow meters in the chemical and in the water and waste-water industry. The success of ultrasonic flow metering can be explained not in the least because of their inherent benefits over conventional measurement techniques in use today as they operate independently of viscosity, have no moving parts, a very low pressure loss, are maintenance-free and do not require regular or product calibrations.

This paper goes into the technological developments implemented in the new generation ultrasonic flow meters with three beams, such as digital signal processing, transducer design, and internal diagnostics.

Particles in the medium

A constraint for the application of ultrasonic flow meters (and for many other flow meter technologies) has been that the flow meters require fairly homogeneous liquids. Reflections of particles in the fluid can interfere with the transmission and receipt of the sound pulses. The presence of entrained gas bubbles, gas mist or solids in the liquid leads to attenuation or damping of the transmitted signals and subsequently may influence performance. Another effect, e.g. the result of the presence of large bubbles in the medium, is a strong fluctuating attenuation of the acoustic signals.



In general guidelines can be given for the acceptable percentage of particles, however, the effect of particles on the performance also depends on for example the distribution and the size of the

bubbles or solids in the flow. Because ultrasonic flow meters are non-intrusive, the presence of particles in the medium will not lead to a breakdown of the sensor, nor will they influence the performance of the meter on the long run when the amount of particles is again within the acceptable margins.

The implementation of an intelligent digital signal processor (DSP), new signal filtering techniques and detection methods has much improved the handling of noisy and heavy fluctuating signals created by gas and solids. New developments like optimum signal detection, a continuous reliability check of the quality of the signal have been implemented. Thirdly, should one or two measurement beams temporary fail due to application conditions, the measurements are always continued. As a result of the new technologies in use a much more stable output is generated and the application range of the flow meters is extended. For the three beam ultrasonic flow meter the maximum percentage of gas bubbles in the medium is 2% and for solids 5% is advised. Should the percentage be higher it is advised to check the process conditions.

Improved Accuracy & Stability

Transducer Design

The most important part of an ultrasonic flow sensor is the transducer. The transducer generates and receives the acoustic (ultrasound) signals. The piezo crystal in the sensor converts a voltage pulse into a sound pulse and vice versa. Not surprisingly continuous research and development is done on improving the transducers.

For smaller diameter sizes smaller sized transducers with smaller sensor pockets are introduced which will less influence the flow profile. With an acoustically decoupled transducer design the quality of the signal has improved, i.e. a better signal to noise ratio (cross talk ratio) was achieved thereby improving the stability. A larger transducer bandwidth leads to a better receipt of signals, and better signal processing and thus better accuracy. This in turn means a better zero point stability and a good reproducibility and repeatability.

Multiple beams

The average flow velocity across a pipe is not uniform but has a certain distribution. Flow profile is a way of describing the velocity distribution within a pipe and can be expressed as a function of the Reynolds number. The shape of the flow profile varies with flow rate, viscosity, density and the pipe diameter. The Reynolds number is a ration of the inertial forces to the viscous forces. Oil products, for example, can have a range of viscosities from as low as 0,5 cSt for super gasoline up to 120 cSt for fuel oil and higher. In addition, in large size pipelines laminar flow profiles can occur.

In principle two main areas of flow velocity distribution, i.e. flow profiles, can be distinguished; laminar and turbulent flow. In theory for Reynolds numbers higher than 4000 there will be a turbulent flow profile (flattened shape), whereas for Reynolds numbers below 2300 a laminar profile (parabolic shape) will be established. Practice and theory, however, are not always the same, which has resulted in the definition of, a more undefined, flow profile called the transition area, existing in a Reynolds range from 2300 to 4000.

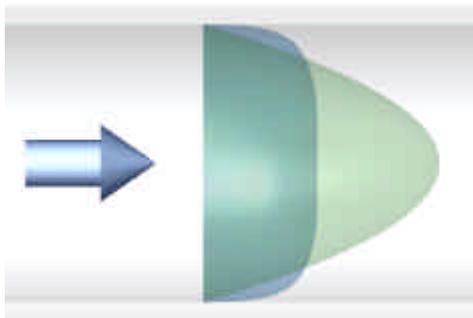


Figure 2: Flow profile in the pipe

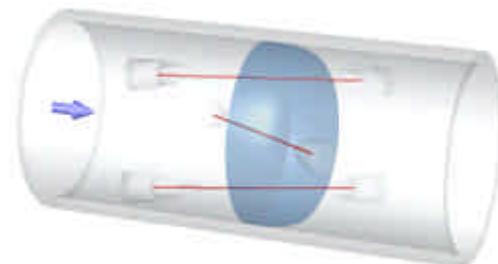
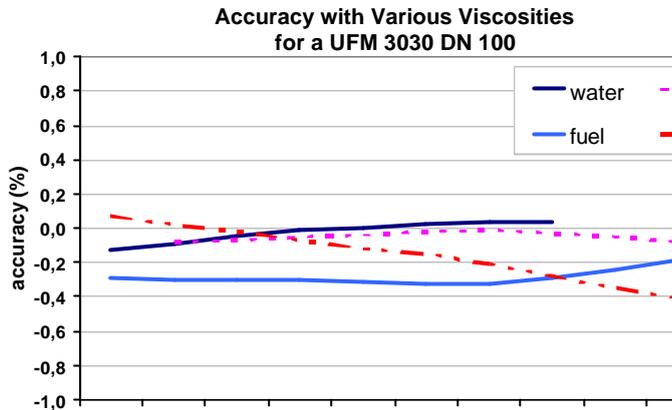


Figure 3: Configuration of the 3 beams

In case of a single beam ultrasonic flow meter the average flow velocity is measured over the measurement path between two transducers, thereby crossing the centre of the pipe. To decrease

the effect of the flow profile and changes in viscosity multiple beams have been introduced. Since we do not have an a-priori way of knowing the flow profile, flow measurement instruments should be insensitive to deviations from ideal flow profiles.



Path Configuration

Multiple beams have caused a major breakthrough in accurate flow metering. This is not only the result of multiple beams, but a combination of the number of paths, the configuration of the paths and sophisticated algorithms.

The paths are placed in parallel thereby covering a larger part of the flow profile and subsequently the measurements are less subject to changes in the Reynolds number. If all multiple paths cross all in the centre, no information on the flow profile is gained. Research performed in the late 70's revealed that the measurement paths could better be located towards the pipe walls in order to become less dependent on the flow profile. The next step is to integrate the measured velocities of each of the paths over the pipe cross section.

Theoretical models, based on Gaussian quadrature principles, have been defined for finding the optimal path configuration for a 3-beam ultrasonic flow meter. Experimental research has subscribed the theoretical predictions. Further fine-tuning of the flow meter even resulted in better results.

As a result with three beams the generation ultrasonic flow meters has

- a higher accuracy over the complete Reynolds number range,
- a good repeatability and a good reproducibility, and is
- less sensitive to flow disturbances.

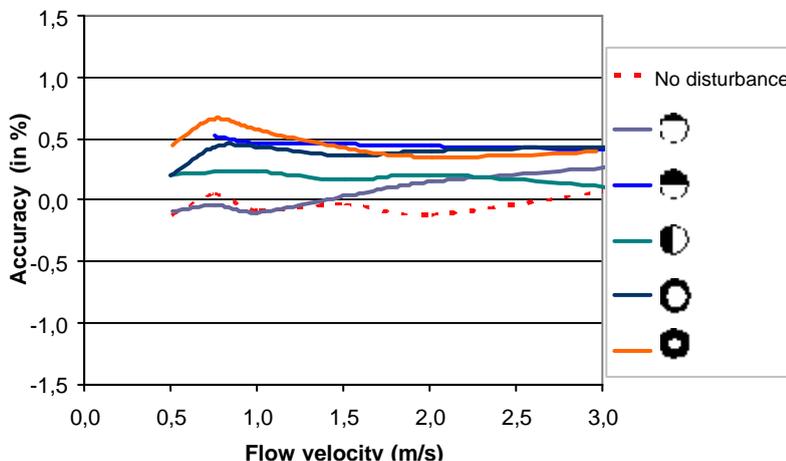


Figure 5:
 Tests with 3-beam ultrasonic flow meter with flow disturbances 8D upstream of the flow meter

Electronics & DSP

A third development contributing to the improved accuracy, repeatability and stability of UFM is the application of the digital signal processor (DSP). Digital signal processing with sophisticated filtering techniques and optimum signal detection, calculated triggering techniques and better signal handling result in a higher temporal resolution, which in its turn results in an improved stability and reliability. In other words DSP has enabled much more robust measurements. In case of noisy signals, because of solids or gas bubbles, with DSP the converter always receives signals and will continue to measure, no matter how high the noise and continuously and reliability check will be performed.

Multiple outputs with ultrasonic flow meters

Fuelled by the trend of digital communication with the sensors in the field, also the functionality requirements for flow meters are changing. A growing number of process-related data and sensor-related data are communicated between the sensor and control system, which can be used for controlling the process and for predictive maintenance of the instrument itself. Here ultrasonic flow meters have an outstanding benefit, since the available data can be used to yield more than just information on volumetric flow. The sound velocity of medium can be generated and, in combination with a pressure and a temperature input (4 to 20 mA), the standard corrected volume and the mass flow can be calculated.

Flow meter measurement

The flow meter is measured with a high precision (better than 0,1%), because the flow measurement is based on delta t(ime), which requires a very high resolution, with respect to the absolute time measurement. The flow meter can be calculated from the transit time of the signal upstream, the transit time of the signal downstream and the path length. The path length is determined very accurately during calibration and forms an integrated part of the meter factor. Although the measurement of the flow meter seems obvious, the use of the parameter in practice is not.

The ability of ultrasonic flow meters to monitor sound velocities can be used for interface detection of different liquids in a pipeline. When the mediums are known beforehand their sound velocities can be programmed in the converter for product identification.

One application where the sound velocity is used concerns an oil terminal that receives many different types of crude oils. In order to have a constant viscosity of the crude during transport, ultrasonic flow meters are used to assure the proportionality between the flow of high and the low viscosity crude oil. For leakage detection two or more ultrasonic flow meters can be installed, in line, over long distances. Data of the instant flow measurements can be transmitted to a central system. Based on a pre -defined acceptable difference between two flows, the oil transport can be stopped immediately to prevent possible pollution, caused by the breaking of the pipeline construction.

When the process medium has a constant composition, the relation between the sound velocity and density can be established. Another example of the use of the sound velocity in practice is for the measurement of acoustic soda solution concentration. A mere density measurement is not accurate enough to determine the saturation point of the acoustic soda solution. The sound velocity, however, shows large changes near the saturation point. In combination with a temperature input, it has proved to be a accurate parameter to control the process.

Actual volumetric flow or calculated mass flow rate

Optionally ultrasonic flow meters are able to process inputs from a pressure and a temperature transmitter, installed in the flow line, for flow computations. The nett (or corrected) oil volume flow rate totalisation is calculated according to API 2540 (/ IP 200 / ASTM D 1250). The volumetric flow rate is converted to standard conditions at 15°C and 1,01325 bar (absolute).

- (1) Corrected Volume = Actual Volume x VCF
VCF = CTL x CPL
VCF (Volume Correction Factor)

CTL (Correction Temperature Liquid)
CPL (Correction Pressure Liquid)

The volume correction factors are based on API chapter 11.1; the hydrocarbon compressibility is based on API chapter 11.2.1. The API standard 2540 @ 15°C equals the ISO standard ISO 91.1 and API standard 2540 @ 20°C equals the ISO standard ISO 91.2.

Batching function

A unique optional feature introduced with the new generation of ultrasonic flow meters, is the integration of a basic simple stage batching function. Up to now in applications for the batching of volumes an external device was required. One of the properties of the batching function is the pre-programming of a pre-established volume in the converter. When the programmed amount of volume is reached a digital output signal is provided. A digital input can be assigned to reset the batch counter for starting the next batch. Examples of batching applications are e.g. blending of crude oil or refined products in the petrochemical industry, and the transfer of various mediums by truck, ship or rail.

Self diagnostics

Signal strength indication

DSP can also be used for internal diagnostics. Maybe one of the biggest benefits of ultrasonic flow meters is the "insight view" provided on the properties of the medium flowing through the flow sensor. Next to the flow meter, explained in the chapter above, information is provided on the signal strength (or the level of attenuation), the signal-to-noise ratio and the reliability of the individual channels. In combination the parameters give a lot of information useful for process analysis. For example changes in the signal attenuation are an indication for the presence of larger viscosities, or entrained air, gas or wax.

Other

With a failure of one measurement line as the result of process conditions the flow measurement continues and is compensated for. This makes the flow meter more redundant.

Thirdly the ultrasonic flow meter does constantly check the reliability of the individual measurement. A warning is given should a measurement may not be within specified accuracy class e.g. in case of gas, air, bubbles. The measurement, however, will continue.

Future of ultrasonic flow meters

In the introduction we have mentioned that ultrasonic flow meters are the fastest growing flow measurement technology. With more than 25 years of experience inline ultrasonic flow meters have proven to function reliable and require no maintenance. Extended capabilities based on new technologies have turned the ultrasonic flow meter into the universal applicable flow meter for a very wide spectrum of applications including critical applications. In the oil and gas industry the meters are in use in applications on offshore platforms up to truck filling for a wide range of viscosities from heavy crudes up to LPG. In the chemical industry an-organic mediums from sulphur to chlorine and organic mediums from liquid gases up to bitumen form no problem for the inline ultrasonic flow meters. In the water industry they are used not only for drinking water and wastewater but also cooling water and demi-water with a low conductivity. With a more robust sensor construction ultrasonic flow meters are able to handle almost all temperature and pressure ranges encountered in industrial processes.

Users are not only interested in the capabilities but are also looking for attractive acquisition prices for their field devices and for ways to further decrease their maintenance costs. By becoming a standard flow meter product and higher sales volumes has made mass production and more efficient production methods possible. An innovative streamlined manufacturing concept has reduced the cost price and even positively influenced the robustness and performance of the instruments. As a true universal flow meter with no limitations on e.g. conductivity, viscosity, density, pressure, low flow conditions and a high chemical resistance and high temperature ranges engineering is easy.

Installation of ultrasonic flow meters is simple as no filters need to be installed and no extra measures for grounding or vibration are required. An advantage of the non intrusive meter body is that there is hardly any pressure drop or wear and therefore maintenance-free. Concluding the future for the truly universal applicable flow meter, based on the ultrasonic transit flow measurement technology, is very positive.