ALTOSONIC III: Dedicated three beam liquid ultrasonic flowmeter for custody transfer and pipeline leak detection

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1. Introduction

The market for ultrasonic flow meters has developed rapidly over the past years. Reputed market research companies claim that ultrasonic flow meters have the highest growth rate and forecast an explosive market growth. One of the main drivers for this robust growth is the emerging adoption of ultrasonic flowmeters for custody transfer measurements of, (refined) liquid petroleum products and natural gas.

The introduction of a highly accurate, multiple beam ultrasonic flowmeter for liquids in the nineties formed a true revolution in the market for custody transfer metering. Up to then the market was dominated by turbine and PD meters. Over the past years ultrasonic flowmeters gained full acceptance and customers are using the multiple beam ultrasonic flowmeter in a growing number of custody transfer metering applications worldwide.

Based on the market experience gained over the years with the five-beam ultrasonic flow meter and continuing basic research and development, a new and cost effective ultrasonic flowmeter concept for custody transfer has been developed. This ultrasonic flowmeter has three beams and is designed for dedicated custody transfer. A number of inherent qualities make the three-beam ultrasonic custody transfer flow meter very suitable for pipeline operations:

- high stability, no shifting k-factor;
- highly repeatable and accurate measurements;
- no moving parts;
- no strainers;
- low pressure drop i.e. savings on pumping costs;
- large dynamic range;
- minimal maintenance;
- bi-directional.

This paper describes:
- Recent technical improvements and developments of multiple beam ultrasonic flowmeters; and its
- Application for pipeline leak detection systems.

2. Technical developments ALTOSONIC III

2.1 Improvements in accuracy and stability

Significant improvements in accuracy, repeatability and stability are major reasons behind the success of ultrasonic flowmeters with wetted transducers for custody transfer applications. What makes inline ultrasonic flowmeters very stable and repeatable over time is that they have no accuracy drift and thus do not require regular calibrations for establishing a new k-factor. Contrary to mechanical meters, the condition of the measurement section remains the same over time as they have no internal (moving) parts, a stable geometric construction, and a fully welded, all stainless steel, construction. The path length between the transducers is fixed and the position of sensor windows remains the same under all circumstances.

Further contributing to the predictable and stable behavior of the multiple beam ultrasonic flowmeters is the continuing internal research and development on the sensor construction and extensive tests performed at the certified calibration facilities, of KROHNE, which is one of the most accurate in the

world.

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

A symmetrical construction of three beams creates a three-dimensional cross section of the velocity distribution (or flow profile) of a medium flowing through the pipe and subsequently the measurements are less subject to changes in the Reynolds number. The position of the paths and transducer pockets are based on a stable and well-known (calibrated) geometry, which has been empirically defined and based on various tests like LDA (Laser Doppler Anemometry) and PIV (Particle Image Velocimetry). The result of the three (or five) beams into the new generation ultrasonic flow meters:

- is less sensitive to flow disturbances such as non-axisymmetrical flow profiles and swirls; and
- has a higher accuracy over the complete Reynolds range, a good repeatability and reproducibility.

2.2 Transducer design and signal processing

Ultrasonic transducers generate and receive acoustic (ultrasound) signals and form an important part of an ultrasonic sensor. For ALTOSONIC III small sized transducers with smaller transducer pockets have been developed for all diameter sizes, which have reduced the influence on the flow profile.

A new acoustically decoupled transducer design improved the quality of the signals by achieving a larger band width, an optimum signal to noise ratio and a better stability.

Digital signal processing software has enabled signal processing based on advanced algorithms. Advanced signal processing includes sophisticated filtering techniques, improved signal detection, and other techniques. The results are that measurements have a higher accuracy, more robust measurements allowing for more harsh conditions such as gas bubbles, viscosity, and particles, a better zero stability and a higher reliability and stability of the

flowmeter..

2.3 Diagnostics for internal checks

In accordance with the requirements of OIML R-117, several internal checks and tests are implemented in the ALTOSONIC III. In addition, the ultrasonic flowmeter provides an "insight view" on the properties of the medium flowing through the pipeline. Implemented tests for self-diagnostics include for example: memory checks, parameter validity check, plausibility checks, validity check of the measured values, sound velocity check. Next to information on the sound velocity, data is provided on signal strength (or level of attenuation), the signal-to-noise ratio and the reliability of the individual channels. A combination of these parameters can be used for process analysis. For example changes in the level of attenuation are an indication for the presence of higher viscosities, or entrained air, gas or wax. The sound velocity check per measurement path can be an indication of scaling as the relative influence of scaling will differ per path.

2.4 Field test results with ALTOSONIC III

Several field tests with the new ultrasonic flowmeter are running on custody transfer applications for already more than half a year. For example ultrasonic flowmeters with a diameter range of 6" to 10" are tested in pipeline operations of Colonial Pipeline, Buckeye Pipeline, Sunoco and Exxon Mobil. Mediums measured include jet fuel, kerosene, gasoline, diesel, and fuel oil. The customers are very satisfied with the measurement results, which are well within the specifications, and plan to purchase the meters.

2.5 Compliant with OIML R-117 and API

An important step in the acceptance of UFM was the release of a draft standard by the American Petroleum Institute (API) "Measurement of Liquid Hydrocarbon by Ultrasonic Flow Meters" in 2002. ALTOSONIC III performs within the requirements of the API standard, which specifies an uncertainty

of ±0,027%.

ALTOSONIC III also received a certificate of compliance with OIML R-117 "measuring systems for liquids other than water for class 0.3 (measuring system in pipeline). Many National Weights and Measures Authorities worldwide approve the use of multiple beam ultrasonic flowmeters for (fiscal) custody transfer metering based on the certificate of compliance with OIML R-117. The required volumetric accuracy specified in OIML R-117 is ±0,2%, repeatability has to be within a 0,12% band.

2. Pipeline Leak Detection Systems

2.1 ALTOSONIC III for pipeline operations

For pipeline operations a long term stability and good repeatability of flow measurements are major criteria for selecting a flowmeter technology. ALTOSONIC III provide a stable and highly accurate (custody transfer) performance. Other benefits of ultrasonic flowmeters is that they can be used for product identification based on sound velocity, have negligible pressure drop, and continue to measure accurately after a situation of overspeed, Other benefits of ALTOSONIC III for pipeline applications and for pipeline leak detection, include a fast response time, inherent diagnostics capabilities giving an indication on the reliability of the flowmeter and the ultrasonic flowmeter can indicate process conditions such as changing viscosities or sound velocities or entrained particles, gas or water in oil.

2.2. Continuous monitoring of pipelines

Many countries require continuous monitoring of pipelines as many liquids and gasses transported by pipelines are critical for hazardous, safety or environmental reasons. In order to identify the condition of pipelines, safety precautions are standard required in the area of leaks. Various conditions can cause leaks like: fatigue leaks, stress corrosion due to external tension, hydrogen induction, material failure, external influences.

A new generation of pipeline leak localization systems, so called Real Time Transient Model (RTTM), is gaining attention. The static and dynamic behavior of pipelines can be calculated real-time by an online computer. Leak detection systems (LDS) have to comply with national and international regulations like TRFL (Technische Regeln für Fernleitungen) and API 1130 2nd edition (Computational Pipeline Monitoring for Liquid Pipelines CPM).

2.3 TRFL regulation

The German TRFL standard is a general accepted standard for new and modified pipelines. The scope of TRFL concerns pipelines transporting:

- flammable liquids;
- liquid dangerous for water;
- gas.

The TRFL is divided into two parts "Operation" and "Constitution" of pipeline systems. Five different Leak Detection Systems (LDS) are required:

- One LDS for leak detection during stand still operation
- One LDS for creeping leaks
- One LDS for fast leak detection
- Two independent LDS for continuous operating leak detection and localization during stationary operation. One of the two LDS should be able to detect leaks during transient operations e.g. during start up of the pipeline

2.4 API 1130 2nd edition regulation

The scope of the API standard is limited to single phase medium pipelines and focuses on the design, implementation, testing and operation of CPM systems. A CPM system is defined as an "algorithmic approach to detect hydraulic anomalies in pipeline operating parameters". The API standard describes external- and internal based LDS.

- External based LDS use local sensors for generating a leak alarm. Usually the costs and design complexity of the system are high. Consequently applications are limited to special high risk areas for example near rivers or nature

protection areas. Examples of external based LDS are: acoustic emission detectors, fiber optic sensing cables, vapor sensing cables and liquid sensing cables.

- Internal based LDS use field sensors for flow pressure and temperature to monitor internal pipeline parameters. The field signals are used for inferring a leak.

Another section in the API 1130 regulation covers:

- Field instrumentation, SCADA / communication and data presentation;
- Operation maintenance and testing;
- Description of internally based CPM systems

3. New generation of pipeline leak localization systems based on RTTM

3.1 Introduction

Using the increasing computing power of modern digital computers, it is possible to calculate - in real time - the profiles for flow v, pressure p and density ρ (or temperature T), based on solving the partial differential equations (PDE) for continuity, momentum and energy. Using and applying a mathematical model in real time, it is possible to eliminate transient effects by taking into consideration liquid compressibility, pipe wall elasticity and density deviations.

The corresponding LDS are real time transient model (RTTM) systems. RTTM-LDS can also be used during transient pipeline operations, e.g. during start-up of a pipeline. There are two options for using mathematical model information:

1. *Deviation analysis:*

   Only three boundary conditions are required to drive the numerical solution algorithm, e.g.

   $p_I(t)$ and $p_0(t)$ for inlet and outlet and

   $p_I(t)$ (or $T_I(t)$) for inlet.

   If more measurements are available

   (e.g. flows $v_I(t)$ and $v_0(t)$ or additional pressure measurements along the pipeline),

   these measurements can be compared with the simulated values. If there is a significant

deviation, a leak alarm will be given.

2. *Model Compensated Volume Balance:* This is an extension of the traditional Volume Balance Approach. Like the deviation analysis, the method uses a simulation model to compensate for the transients in pipelines, thus enabling it to produce leak detection even in the presence of transients in the pipeline.

The LDS of KROHNE Oil & Gas B.V. is based on a combination of the deviation analysis and model based compensated volume balance, resulting in an Extended Real Time Transient Model LDS. In figure 1 an overview of the system is shown in which the "observer" and "classifier" are the main parts.
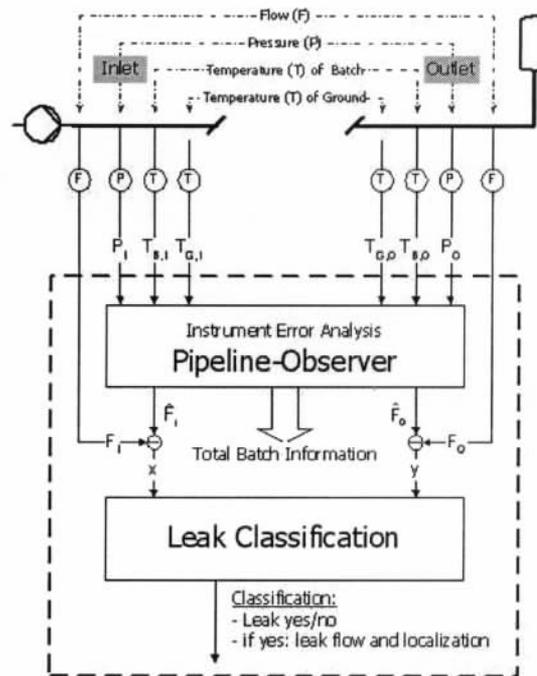

figure 1: Overview of the KROHNE LDS

3.2 Observer

The pipeline observer represents flow-mechanics and thermodynamics along the length of the leak-free pipeline as described earlier. For this purpose, pressure p_I and p_0 are measured at the inlet and outlet, respectively. In addition, the temperatures of the fluid (batch) and the ground are required.

The flow rates $\hat{F}_I$ and $\hat{F}_O$ of the inlet and outlet

are calculated from these values. These estimated values are compared with the measured values; the residuals $x \equiv F_I - \hat{F}_I$ and $y \equiv F_O - \hat{F}_O$ resulting in the leak-free case, $x, y \approx 0$.

If a leak occurs, deviations occur from which both the leak position x_{Leak} and the leakage rate (speed, volume flow or mass flow) F_{Leak} can be derived:

$$F_{Leak} = x - y$$

$$x_{Leak} = \frac{-y}{x - y} L$$

L = the length of the pipeline.

3.3 Classifier
The main purpose of the leak classifier is to decide whether there is a leak or not. Statistical methods are used for this purpose to avoid false alarms.

3.4 Leak Detection
The inlet and outlet flow are displayed and a leak is indicated on the LDS monitoring computer. It also calculates leakage rate and determines the location of the leak (see figure 2).
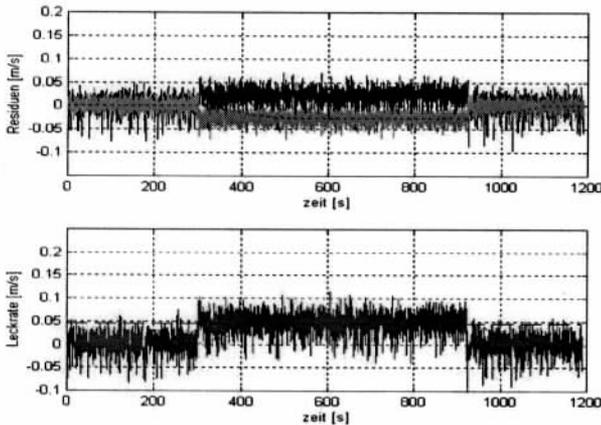

Figure 2: Sample residuals and estimated leakage rate with t_{Leak} of approximately 0,.05 m3/s after 300 seconds.

3.5 Leak localization
To locate the leak, a model is employed based on the gradient intersection method.

If there is no leak, the transient pressure drop per unit length along the pipeline is constant, i.e.

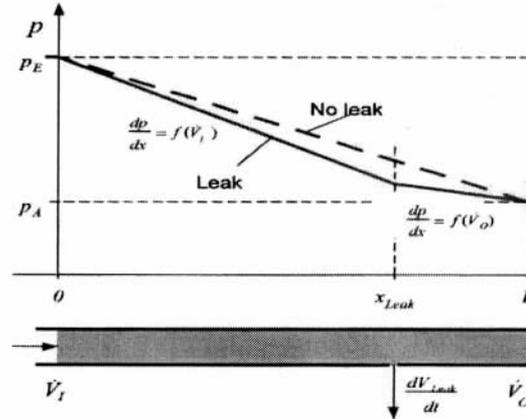$$No\ Leak: \quad \frac{dp}{dx} = f(\dot{V}_I) = const.$$

Figure 3: Leak localization using gradient intersection method

If a leak occurs, the flow rate upstream of the leak will be greater than the flow rate downstream of the leak; therefore the pressure drop per unit length upstream of the leak will also be greater than the pressure drop downstream of the leak, i.e.

$$Leak: \quad \frac{dp}{dx} = f(\dot{V}_I)\ for\ 0 \leq x \leq x_{Leak}$$

$$> \frac{dp}{dx} = f(\dot{V}_O)\ for\ x_{Leak} < x \leq L$$

If an intersection is drawn as shown in Fig. 3, the location of the leak will be established. In the model of KROHNE, the pressure drop per unit length is calculated from the remainders, therefore

$$\frac{dp}{dx} = f(\dot{V}_I) = f(x) \quad for\ 0 \leq x \leq x_{Leak}$$

$$\frac{dp}{dx} = f(\dot{V}_O) = f(y) \quad for\ x_{Leak} < x \leq L$$

3.6 Preventing false alarms

An important consideration when selecting a leakage monitoring system is the prevention of false alarms. A number of measures have therefore been implemented to prevent these occurring.

Compressibility of the fluid and elasticity of the pipe wall contribute to line packing. This means that over time, more product flows into the pipeline than flows out of it (assuming there is no leakage), particularly during transient operations. This leads to major problems when using the "classical" quantitative comparison method, as this scenario tends to produce false alarms. This rather restricts the use of quantitative comparison systems in practice, as they are often turned off when starting up or shutting down the pipeline. This is a serious drawback of this type of system, as it is particularly during these times that hammer in the pipeline causes a comparatively high risk of leakage.

Density changes as the result of changes in temperature often results in false alarms in conventional systems. Due to the pipeline monitoring feature of the KROHNE LDS system, line packing, and density deviations effects are compensated for.

4. Conclusions

The features and benefits of the ALTOSONIC III, like long term stability, accuracy, fast response time, diagnostic capabilities and product identification, creates in combination with the KROHNE LDS system a reliable pipe line monitoring system, compliant with API and TRFL regulations.

References

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