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Oil and Gas Custody Transfer

When money changes hands, flow measurement accuracy matters.

When flow measurement is performed in process control, the accuracy of measurement is typically not as important as the repeatability of the measurement. When controlling a process, engineers can tolerate some inaccuracy in flow measurement as long as the inaccuracy is consistent and repeatable. In some measurement applications, however, accuracy is an extremely important quality, and this is particularly true for custody transfer.

How Custody Transfer Works

Custody transfer, sometimes called fiscal metering, occurs when fluids or gases are exchanged between parties. Payment is usually made as a function of the amount of fluid or gas transferred, so accuracy is paramount as even a small error in measurement can add up fast, leading to financial exposure in custody transfer transactions.

For example, Pump Station 2 on the Alaska Pipeline is designed to pump 60,000 gallons per minute (227 cubic meters per minute) of oil. A small error of 0.1% equates to an error of 2,057 barrels of oil a day. At a spot price of \$105 a barrel, that 0.1% error would cost \$216,000 a day. Over a year, the 0.1% error would amount to a difference of \$78.8 million. Note that the error could either be on the high side, benefiting the seller; or on the low side, to the buyer's benefit.

Because errors in measurement for custody transfer can be so expensive, custody transfer and fiscal metering are regulated in most countries and involve government taxation and contractual agreements between custody transfer parties. Custody transfers are also influenced by a number of industry associations and standards organizations such as American Gas Association (AGA), American Petroleum Institute (API), US National Institute for Standards and Technology (NIST), Physikalisch-Technische Bundesanstalt (PTB) in Germany, China Metrology Certificate (CMC), and gosudarstvennyy standart (GOST) in Russia.

Custody transfer applications require more than an accurate flowmeter. There are a number of critical components that comprise a complete metering system including:

- Multiple meter runs with multiple meters in parallel
- Pressure and temperature transmitters
- Flow computers
- Quality measurement
 - For gas energy content, online gas chromatography
 - For liquids, sampling systems and water monitoring (BS&W)

- In-situ calibration using provers or master meters
- Automation

Custody Transfer Measurement Technologies

While there are many types of flow meters in general industrial use, many of these are not suitable for custody transfer. Generally, five technologies are used when flow measurement means money.

Differential pressure (DP) flowmeters are the oldest of the technologies and the first to be studied and approved for custody transfer for natural gas. In 1930, the AGA issued Report AGA-1 to cover the use of DP flowmeters with orifice plates for custody transfer applications. DP meters can operate in very harsh environments and also feature a high degree of robustness and reliability.

It wasn't until 1981 that AGA-7, involving turbine meters, was published. During the 1990s, turbine flowmeters began to displace DP flowmeters, especially for gas applications. The main reasons were the higher accuracy of many turbine flowmeters, along with their greater rangeability. Turbine meters are also used for custody transfer of petroleum liquids.

Positive displacement (PD) meters are common for small line size applications. It is unusual to find PD meters in line sizes above 10". They are very good at measuring fluid at low flowrates. Downsides of PD meters include pressure drop and mechanical moving parts.

Recent advances in measurement technology have introduced two highly accurate and repeatable flow measurement technologies to custody transfer: Coriolis mass flow meters and multiple-path ultrasonic flow meters.

In the oil and gas industry, as in many others, the transition from traditional-technology to new-technology flowmeters is evident not only in custody transfer applications, but also elsewhere in the flowmeter world. However, traditional meters still have the advantage of a large installed base.

Ultrasonic Flowmeters

Ultrasonic flowmeters are volumetric devices that measure the velocity of flowing liquid or gas, and use that velocity to calculate flow rate.

Transit-time ultrasonic flowmeters use a pair of transducers, one pointed upstream and one pointed downstream in the meter body. The difference in transit times of the downstream-directed pulses and the upstream-directed pulses is used to determine the average velocity of the fluid. Multiplying velocity by the cross-sectional area of the pipe gives volumetric flow rate ($Q=VA$). Mass flow can be computed using input from a densitometer.

Ultrasonic flowmeters often use multiple sets of transducers mounted in the pipe wall. Multi-path meters allow highly accurate readings of average axial velocity, with diagnostic information about flow disturbances which could impact measurement accuracy.

One difference between custody transfer and non-custody transfer applications for ultrasonic flowmeters is that custody transfer applications require three or more measurement paths within the meter. Multi-path ultrasonic meters measure flow velocity at more than one location in the pipe. A path is the route traveled by an ultrasonic signal from one side of a pipe to the other and back.

Since approval by AGA in 1998, ultrasonic flowmeters have become widely used for custody transfer of natural gas. They are typically available from 2"-line sizes and can handle large natural gas pipelines, which often range from 20 to 42 inches-line sizes. Ultrasonic flowmeters are also used for custody transfer of petroleum liquids – from the oil well through the refinery to the ultimate distribution point.

Advantages of ultrasonic flowmeters include no moving parts, high accuracy and turndown ratio, and virtually no pressure drop. Because there is little or no pressure drop, ultrasonic meters minimize the loss of energy due to friction losses through the meter, and improve the efficiency of pump stations in oil and gas pipelines. They can be used for measurement of crudes, including the heavy crudes found in oil shale and oil sands. Advanced models have sophisticated transmitters and flow computers with full diagnostic suites that make calibration easier and reduce measurement uncertainty. This capability simplifies operations (*please See "Meters with Intelligence" on page 29*).

Coriolis Mass Flowmeters

Unlike ultrasonic meters, Coriolis flowmeters are not volumetric flowmeters, but instead measure mass flow directly. As fluid flows through a Coriolis flowmeter, the measuring tubes twist slightly due to the Coriolis force. The natural vibration frequency of the tubes changes with the mass flow of the fluid.

Micro Motion was the first manufacturer of Coriolis mass flow meters, beginning in the 1970s. In 2002, the API approved the use of Coriolis flowmeters in custody transfer and fiscal metering (API Chapter 5.6). Coriolis meters are currently supplied for line sizes 1/14" to 16" (1-400 mm).

While Coriolis flowmeters can have pressure drop and are not available for line sizes above 16" (400 mm), these disadvantages are outweighed by a lack of moving parts and significant accuracy improvement over many other flow meters, even those that are temperature and density compensated. In iscal metering and custody transfer applications, this accuracy is critical.

About Accuracy and Uncertainty

Accuracy is the ability of the meter to measure close to the true value of the flow. Manufacturers usually state the accuracy of their flowmeters. This is often the accuracy of the flowmeter in the calibration lab, but it can be affected by many installation parameters including temperature and density changes, piping configuration, and obstructions in the flow upstream of the flowmeter. Also, vibration (noise) or flow pulsations from nearby rotating equipment can interfere with an ultrasonic sensor's measurement or affect a Coriolis meter.

Total calculated measurement uncertainty of the installed flow meter takes into account: the accuracy of the flowmeter itself, the contribution to inaccuracy of piping and obstructions, and the accuracy of the flow computer and other electronics, including the flow computer's A/D converter. Because of the significant financial risks in custody transfer and fiscal metering applications, close attention must be paid to small details that would be ignored in a process application.

Alignment of the metering tube and the upstream piping is critical. If the misalignment is less than 1/8" (3.2 mm) and the misalignment is concentric, an ultrasonic flowmeter can handle the discrepancy. If the misalignment is eccentric, errors up to 0.2% can be caused. Such an error can result in under- or over-billing of very large amounts over a year's time.

As with process flow applications, upstream obstructions and disturbances in the flow stream must be reduced. However, due to the accuracy requirements of a fiscal metering or custody transfer application, it is even more critical to reduce noise and flow disturbance from control valves, thermowells, elbows, wyes, and tees upstream of the meter.

Where practical, there should be a sufficient straight run of piping upstream and downstream of the flowmeter. Also, control valves and temperature instruments that protrude into the pipe should be located downstream of the flowmeter. Noise and vibration damping devices may be required, especially when using Coriolis and ultrasonic flowmeters.

In many custody transfer installations, multiple meters are installed off a single header. This permits each flowmeter to be operated independently of any other meter, allows one meter to be used as a master meter, and gives the operator and maintenance technician the ability to isolate one flowmeter for repair, calibration and maintenance without shutting off the flow.

It is also important to size headers correctly as header sizing can be critical to the performance of the system. Header sizing is especially important when retrofitting an existing metering skid or metering installation. Care must be taken to ensure that headers are actually built as depicted in the drawings.

Thermowells are challenging, though necessary. AGA 9, for gas metering, recommends installing thermowells at least 2 to 5 pipe diameters downstream of the flowmeter. For bi-directional systems, the standard recommends 3 diameters from the meter. Many flow experts consider these distances to be too close, and add a margin of safety to increase measurement certainty. Vortices shed from thermowells disrupt the flow profile and can reduce installed metering accuracy.

Flow Provers

Each gas or liquid flowmeter can be calibrated against a master meter onsite, or in liquid metering applications, by a stationary or portable prover (Figure 1). For pipe sizes below 42" diameter (1.07 m), on-site provers can be used. Flowmeters in larger pipe sizes must be shipped to a calibration facility capable of handling larger meters, unless another means of volumetric calibration can be found.



Figure 1: A flow prover is installed in a custody transfer system to provide the most accurate measurement possible. Periodic provings are necessary to confirm or re-establish the performance accuracy of the accounting meter before, during, and after a transfer.

In master meter proving applications, one flowmeter is designated as the flow prover. It must have an accuracy that is better (some claim one order of magnitude better while others claim that four times better is necessary) than the meter to be tested. The master meter must also have been calibrated against a primary standard within the past 12 months.

To prove a flowmeter, that is, to check the calibration, the meter to be tested is valved in series with the master meter prover. The error between the meter under test and the prover or master meter is used to produce a correction factor. This correction factor is programmed into the flow computing system connected to the meter under test. In a multi-run metering system, each flowmeter must be proved in turn. Proving of the meters is done as often as necessary for the particular application.

Good Planning Improves Performance

Selecting the right flowmeter is not enough – for custody transfer, the entire installation must be carefully designed and constructed to reduce measurement uncertainty (Figure 2).

The engine of a custody transfer or fiscal metering installation is the flow computer. It is the device that takes the inputs from the measuring devices (flowmeters, pressure sensors, temperature sensors, density sensors, gas chromatographs, and others) and calculates the amount of liquid or gas that has been transferred. These calculations are based on a variety of industry standard flow calculation algorithms.

Many flow computers can handle multiple flow measurement trains. For example, the Daniel S600 flow computer can handle up to 10 meter runs, or six meter runs and a prover. In many applications, flow computation is seen as such a critical function that redundant flow computers are employed to ensure continuous measurement in the event of a single flow computer failure.

Although compact piping is aesthetically pleasing and can consume less real estate at the installation site, it often introduces flow profile distortion and noise. Good planning includes making sure that the appropriate straight runs of pipe with no valves or taps before and after the meter are provided, and that there is sufficient space around the meters to clean them, perform other maintenance, and remove the meter for repair and calibration.

Something that is often forgotten is to provide enough physical access room for service trucks, portable flow provers, and other calibration equipment. The area and the mounting pad must be designed to properly bear the weight of the installation and of any temporary equipment.

The electrical integrity of the system must be maintained, ensuring proper grounding and adequate electrical service to all metering system devices. If the power service is especially noisy, electrical noise filtration must be provided upstream of the connections to the meters and the flow computer to avoid the possibility of noise being introduced into meter and device signals. Other factors become important when a prover is included in the installation. For example, valves should be designed as “double block and bleed.” This prevents bleed-through of fluid past a leaky valve, bypassing the prover and resulting in proving errors. Entrained gas in liquid flow streams must be eliminated as well. Likewise, pockets of gas in a liquid stream can cause metering error and/or damage to some types of liquid meters.

Metering Skids

Because building a custody transfer or fiscal metering system requires special expertise that is often hard to find in-house in a typical end user company, the best solution can often be the purchase of a purpose-built metering skid (Figure 3). If this option is selected, it is important to pick the right supplier. The selected skid builder must have extensive experience and knowledge of flowmeter technologies, flow characteristics, accepted meter proving practices and technologies, government and agency regulations, and much more.



Figure 2: An example of a full-scale pipeline system. The fact that it may handle between \$5 and \$10 million worth of oil each day explains why accuracy and repeatability are so important. Error levels that would be tolerable in a process plant context can cost one side or the other tens of thousands of dollars in a matter of hours.

All figures are courtesy of Emerson Process Management

Many liquid applications must include provisions for proving meters in place under actual operating conditions. That can mean connecting a prover skid directly to the metering station, or making it possible to easily connect a portable prover.

In order to get the correct metering skid, it is important to make sure that your skid builder has the relevant expertise. When a company such as Emerson Process Management builds a metering skid, their engineers will need answers to these and other questions:

- What is the area safety classification, and what safety standards are in force?
- What flow measurement standards should be used?
- What are the temperature and pressure parameters?
- What is the flow range? Does it vary? By how much?
- What type and size of meters are needed?
- What mechanical standards apply to the installation?
- Is flow unidirectional or bidirectional?
- Is there ambient and/or electrical noise, and how much?
- Are flow conditioners required?
- Should the meters be horizontal?

Headers, piping, flanges, elbows, and other piping fittings must be properly designed based on meter system design and physical site parameters. If the flow computer and any flow, pressure, and temperature transmitters must communicate with a control system, the interconnections must be specified. If improved performance and modern diagnostics are required, digital connectivity such as HART

or Foundation Fieldbus should be considered. Calibration requirements, and the means to meet them both before and after installation, must be taken into account.

Once all the above questions are satisfactorily answered, the skid builder will build the system. During construction, the system and the skid must be subjected to meticulous calibration, quality control and testing. Before the skid is delivered, the site needs to be properly prepared. It must be graded and filled, and the support pad must be poured and cured. Electrical and instrumentation service must be provided, and the skid must have the proper components to hook up to the existing piping at the inlet and outlet.

After installation, the skid builder can commission and startup the system, connect it to the plant control system, perform initial calibration testing if required, and provide whatever training is required to operate and maintain the metering station. Because maintaining a metering skid is a specialized operation, many skid builders provide ongoing technical and complete lifecycle support.

Custody transfer is an exacting science that requires expertise in a number of different areas. For most companies, the best way to procure, install, and operate a custody transfer system is through partnering with an experienced provider. Whether the custody transfer system is built on-site or delivered on a process skid, close cooperation between the owner and the provider will result in the optimal system for the particular application.



Figure 3: Completed meter on a skid, ready for installation. The tubes are factory aligned meter-to-tube, conditioner plates, and approach/discharge spools are concentrically aligned, and bolts are drawn up in sequence. All flowmeters, thermowells, analyzers, and other equipment have been installed, wired and calibrated.

Meters with Intelligence

As with most automation components, there have been large changes in the instrumentation and related systems used for custody transfer. Flowmeters are smarter – and with modern electronics, software, firmware, and connectivity – they can perform diagnostics and communicate information, alarms, and process variables digitally.

Expert systems embedded in the diagnostics firmware of the flowmeter or flow computer can identify troublesome and error-producing conditions like liquid fractions in a gas stream, or entrained gas in a liquid flow, as well as pipeline deposit layer buildup.

Liquid fractions in a gas stream, for example, can help spot liquid condensate giveaway. Accumulated deposit layer buildup inside the pipe, especially inside the metering run itself, changes the inside diameter of the pipe and can lead to large errors in measurement.

Daniel ultrasonic flowmeters are an example of a family of meters that take advantage of many modern technologies to improve performance. When viewing meter operation with Daniel's MeterLink™ advanced ultrasonic flow meter diagnostics or AMS Device Manager software, operators and maintenance people can see immediately when and where problems are developing, and make suggestions for corrective action.

MeterLink Baseline Viewer™ provides a consolidated view for monitoring the performance of the meter within ranges predefined by the operator. This often allows problems to be detected before they can adversely affect accuracy of the meter or overall measurement uncertainty. Predictive alerts can be generated by investigating deviations from the baseline value of the meter at startup. These baselines are generated either at the calibration laboratory or in the field during commissioning (Figure 4).



Figure 4: MeterLink™, Daniel ultrasonic flow meter diagnostic software, enables easy access to expert flow analysis, alerts operators of abnormal flow profiles, and suggests corrective actions. Baseline Viewer™ provides immediate visual indication that the meter is operating within desired ranges.

Daniel ultrasonic flowmeters can also trigger alarms that allow operators and maintenance personnel to identify installation problems that can add to measurement uncertainty. Actionable alerts can be programmed to identify abnormal flow profiles, upstream blockage, deposit buildup on the walls of the meter and liquid hydrocarbon carryover.

Daniel ultrasonic meters provide real-time AGA 10 speed of sound (SOS) calculations, a useful parameter in many applications. AGA 10 SOS calculations can be compared with the SOS calculations performed within the flow meter. This reduces measurement uncertainty, and can be used to validate the integrity of the meter's calculation of flow, the gas analysis being fed to the flow computer, and other measurements. 