Automatic Tank Gauging in Custody Transfer Applications

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Abstract

Today Automatic Tank Gauges (ATG’s) are commonly used worldwide for custody transfer of petroleum products. International standards from both ISO, API and OIML describe the requirements on the equipment for use in custody transfer applications. This document gives a summary of the performance requirements in these standards, how they are adopted for legal metrological control in various countries.

Further, the document describes the components in an ATG system used for custody transfer, and expected performance on level, temperature, density and volume.

Also, an ATG system is compared with flow meters and it is briefly discussed when ATG’s or flow meters may be the best choice.

World wide view on using ATG systems for custody transfer

Automatic Tank Gauge (ATG) systems have been used for custody transfer at least during the last 50 years. The technology has been refined a lot over these years, and even though the first float operated level gauges still can be seen in some use today, they are hardly used for custody transfer purposes. The major technology in custody transfer based tank gauging purchased today is based on highly accurate radar level gauges. One example is the Rosemount Tank Gauging system, which has an intrinsic accuracy of 0.5 mm over 30 meters measuring range and high accuracy inputs for temperature and density measurement.

Even though transfers are often based on static level measurement, there is often a conservative approach in the petroleum industry when it comes to using an ATG for determination of a transfer instead of manual hand dip. This is despite the fact that a hand dip rarely is capable to compete in accuracy with a custody transfer class ATG system. Much of this is probably related to tradition and conservatism in the industry, but also to the fact that it is often required to have an independent party to perform the hand dip at a transfer. For manual hand dip this is simple to arrange, and an independent surveyor is just called in for the job.

If a tank gauging system shall act as an independent measuring system, it implies that someone has to guarantee its independence. This requires an organization which supervises the equipment, and in most countries this is performed by the national metrological authority. Often the requirements on the equipment are formulated in a national law, i.e. the transaction is defined to be legal. There are today certain differences between countries how common it is to have legal custody transfer based on ATG’s. Countries which have defined requirements on legal custody transfer for ATG’s are:

- Most European countries including Russia
- Many countries in Asia (China, India, Indonesia, Malaysia, Thailand etc)
- A few countries in Latin America

Countries which have no defined requirements for legal custody transfer are:

- North America
- Middle East countries

In USA, API has defined requirements on ATG’s used for custody transfer (API chapter 3.1B), but there is today no authority which certifies equipment or supervise the use of it. In USA custody transfer is more defined as an activity which is a “mutual agreement between a buyer and a seller”, without involvement of a supervising party. There is however a lot of discussions going on within API, to go in the direction to accredit laboratories for certifying equipment which fulfills requirements according to API ch. 3.1B. So far however, no ATG systems have been certified.

In Europe, there is a long history and tradition to use ATG’s for custody transfer. Metrological institutes are most often involved, and the testing and supervision of the equipment is extensive. Countries and institutes which could be mentioned to have a high reputation and competence in ATG’s used for custody transfer are:

- PTB, Germany
- LNE, France
- BMS, Belgium
- SP, Sweden
- NMI, the Netherlands
- GOST, Russia
The typical procedure an ATG must pass to be able to be used for legal custody transfer is:

**A pattern approval test.** This test is often quite extensive where the system is tested for intrinsic accuracy, influence on measurement from ambient temperature, humidity, electrical emission, electrical immunity etc. The pattern approval will also specify limitations of the use of the equipment (e.g. measuring range etc), and limitations on installation.

**Delivery test record.** This test is often quite extensive where the system is tested for intrinsic accuracy, influence on measurement from ambient temperature, humidity, electrical emission, electrical immunity etc. The pattern approval will also specify limitations of the use of the equipment (e.g. measuring range etc), and limitations on installation.

**Installation test.** When the equipment has been delivered to customer, a local representative from the metrological authority or an independent surveyor checks the installation and calibration on tank. After successful inspection, the equipment is metrologically sealed and the equipment is ready to be put in operation. The metrological sealing prohibits any change of the calibration without breaking the metrological seal.

**Subsequent verification.** Performance of the equipment is checked at certain intervals on the tank. Common intervals are 1-2 years.

The procedure may vary a bit between different countries. In France e.g., the equipment must also prove its suitability to perform in field, and it is required to test three systems during a time period of 3 months before approval is granted.

In general there are very few suppliers that fulfill testing and requirements as above. In France, as an example, there is only one type of radar based level gauge that is approved.

**Standards for ATG’s used for custody transfer**

There are primarily three standard organizations that specify requirements on ATG’s used for custody transfer. These, and the standards are:
- OIML R 85, 2008 (Organisation International Metrologie Legal)
- API ch 3.1B, ch 3.3, ch 3.6, ch 7 (American Petroleum Institute)
- ISO 4266, part 1-6 (International Organisation of Standards)

Of the above mentioned, the OIML R 85 edition from 2008 can be considered as the most developed and important, since it has been accepted as national requirements in a large number of countries. More or less all European countries have adopted OIML R 85, 2008 as the base for legal custody transfer, and it is widely spread also in Asia, Australia and some countries in Latin America. OIML R 85 has the advantage that it precisely specifies the tests that a system must perform to be accepted. Since OIML R 85 also is a harmonized standard, it is also sufficient to test at one accredited laboratory, and the test report will then be accepted in other countries.

API standards are mostly recognized in US, but also frequently used in the Middle East. The primary task of the API standards is to give important guidelines for installation, calibration etc, which is not the focus in OIML R 85. Until now, there is no dedicated test laboratory which tests that ATG’s fulfills the custody transfer requirements as specified in API standards, and it is more up to the user to verify this by himself.

ISO 4266 is very similar to API ch 3.1B, ch 3.3 and ch 7. As the API standard, it gives general guidelines for the use of ATG for custody transfer.

Performance requirements have during the last years, to a certain degree, been harmonized between the standards above. The table below shows requirements on temperature and level for the different standards when used for custody transfer.

<table>
<thead>
<tr>
<th></th>
<th>Level lab</th>
<th>Level installed</th>
<th>Temp lab</th>
<th>Temp installed</th>
</tr>
</thead>
<tbody>
<tr>
<td>OIML</td>
<td>1 mm</td>
<td>4 mm</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>API</td>
<td>1/16 inch</td>
<td>3/16 inch</td>
<td>0.5 °F</td>
<td>1 °F</td>
</tr>
<tr>
<td>ISO</td>
<td>1 mm</td>
<td>4 mm</td>
<td>0.25 °C</td>
<td>0.5 °C</td>
</tr>
</tbody>
</table>
Which are the components in an ATG System used for custody transfer?

Figure 1 shows a typical ATG system that is used frequently for custody transfer applications in many countries. The necessary components in an ATG system used for custody transfer are:

1. Automatic Level Gauge (ALG), for measurement of the level at start and end of transfer.
2. Automatic Temperature Transmitter (ATT), for measurement of average product temperature at start and end of transfer.
3. Tank strapping tables for calculation of Observed Volume
4. Density measurement of the product, for calculation of Standard Volume.

Figure 1. The Rosemount tank gauging system

The density may either be measured manually from samples which are analyzed in laboratory, or automatically measured by connection of a high precision pressure transmitter to the system.

In the latter case the ATG system is a “Hybrid Tank Gauging System”, and there is no need for manual sampling of density, see figure 2. Calculation of observed and reference density is then performed in the control room PC.

A Hybrid Tank Gauging system can give:

Custody transfer accuracy on Level, Temperature
- Custody transfer accuracy on Density
- Custody transfer accuracy on Standard Volume
- Custody transfer accuracy on Mass

In case the tank is non-atmospheric, an additional pressure transmitter is necessary for measurement of the tank atmosphere pressure.
Calculations
The calculations in an ATG system follows international standards and are summarized in the following flowchart:

(TCT=Tank Capacity Table)

<table>
<thead>
<tr>
<th>Calculated value</th>
<th>Input data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Observed Volume</td>
<td>Level, temperature, TCT table, of weight, observed density, tank wall temperature</td>
</tr>
<tr>
<td>Gross Observed Volume</td>
<td>Free water level, TCT table</td>
</tr>
<tr>
<td>Gross Standard Volume</td>
<td>Reference density, average product temperature, API tables</td>
</tr>
<tr>
<td>Net Standard Volume</td>
<td>Base Sediment and Water</td>
</tr>
<tr>
<td>Weight in Air</td>
<td>Air density</td>
</tr>
</tbody>
</table>

For a normal custody transfer situation some of the above mentioned calculations may not be necessary, e.g. it is unlikely that free water is involved since a transfer usually is stopped before the level is close to the free water in a tank.

Uncertainty in an ATG system
The installed uncertainty of an ATG system depends on a number of factors like: the intrinsic accuracy of the transmitters, uncertainty due to the selected installation method, uncertainty in the Tank Capacity Table (TCT) etc. Realistic uncertainty figures in level, average product temperature, and density can be estimated to:

Uncertainty in Level: ± 2 mm
This assumes a high performance custody transfer level gauge with proven performance. The method of installation is important, where the installed level gauge must be rigidly mounted to the most mechanically stable point of the tank. This is normally achieved by installing the level gauge on a still-pipe, which either is mechanically fixed to the tank bottom or the lower corner between tank wall and tank bottom. For further installation guidelines see API ch. 3.1B. Certain corrections may be necessary to perform to achieve 2 mm installed accuracy like correction of thermal expansion of still-pipe etc. Corrections like this are normally available in these types of level gauges.

Uncertainty in Average product temperature: ± 0.3 °C
To achieve 0.3 °C installed accuracy, a multi-spot RTD with sensor elements at various heights in the product is in most cases required. A stable electronic temperature conversion unit converts the resistance value to digital format, and the electronics should be designed for having full accuracy at all ambient temperature conditions.

Uncertainty in Density measurement: ± 0.5 – 1.5 kg/m³
Figures on accuracy for manual density sampling is often in the range of 0.5 kg/m³. The actual accuracy of just the laboratory measurements is better, but handling of the sample on the tank roof, representativity of sample etc may introduce additional errors.

For automatic measurement with the hybrid type system, the accuracy is mostly determined by the precision of the pressure transducer. The accuracy will also vary depending on the liquid level in the tank, i.e. at low liquid levels the accuracy will deteriorate, since offset drift in the pressure transmitter will affect the reading more than at high liquid levels. Typical accuracy figures which are achievable with standard pressure transmitters are around 1.5 kg/m³ at 3 meter liquid level (with better results at higher levels).

The main impact density has on the transfer calculations is when using API tables for calculation of Volume Correction Factor (VCF) and standardized volume. However, the API tables are not very sensitive to density variations. In most areas of the API table one can vary the density approx. 7 kg/m³ without any visible change in the last decimal of the VCF figure. An example of this is shown in figure 3, where density can vary from 739.4 – 746.9 kg/m³ without affecting the value of the VCF figure.

Uncertainty in Tank Capacity Table: 0.01% - 0.10 %
The precision in the Tank Capacity Table varies with respect to which calibration method that has been used, and the time since the calibration was performed. Old calibration methods often states an uncertainty of 0.10 % in the TCT, but recent calibration methods based on the EODR method has shown figures as low as 0.01 % – 0.02 %.

The fact that custody transfer is a difference measurement also affects the uncertainty in the TCT and errors are to a certain degree cancelled out. Particularly on small transfers one can expect that this cancellation effect has a large impact and uncertainty is far better than the figures above.
Volume uncertainty, an example

The uncertainty in volume depends on the shape of a tank, and has to be calculated for each tank type individually. To give some idea of what can be expected the following can serve as an example:

A “normal” shaped tank 20 m high, 36 m in diameter has a volume of 20 000 m$^3$ (i.e. each mm in level corresponds to 1 m$^3$).

When completely emptying the tank the uncertainty can be estimated as:
1. Uncertainty from level gauge (2 mm) corresponds to: 2 m$^3$
2. Uncertainty from temperature/density measurement corresponds to approx 4 m$^3$ at full tank, and to 0.4 m$^3$ at 2 m level. Worst case is full tank (temp 0.3 °C, 0.5 kg/m$^3$): 4 m$^3$
3. Uncertainty from TCT (0.02 %) corresponds to: 4 m$^3$

**Total estimated uncertainty of transfer: 6 m$^3$** (root sum square value)

If one compares an ATG system with a flow meter one could estimate what accuracy is required by the flowmeter to have the same uncertainty. In this case the 6 m$^3$ corresponds to 0.03 % of the 20 000 m$^3$, i.e. the flow meter must have an accuracy of 0.03 % including conversion to standard volume, to be able to match the ATG system.

Flow meter or ATG system for custody transfer

There is often a discussion if metering or ATG should be used for determination of a transferred batch size. In practice it is common that both are used, and the figures from metering is compared with the result from the ATG measurement. However both methods have their characteristic pro’s and con’s, and in general one could say that at large batches there may be better performance with an ATG system compared to metering and the opposite at small batches. The performance may be illustrated schematically as in figure 4.

The Pro’s and Con’s in different applications may be illustrated as below:

(+) indicates preferred

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**Figure 3. Effect on VCF by uncertainty in density.**

<table>
<thead>
<tr>
<th>Density @ 15 °C (kg/m$^3$)</th>
<th>739.0</th>
<th>739.4</th>
<th>741.3</th>
<th>742.0</th>
<th>742.8</th>
<th>745.0</th>
<th>745.8</th>
<th>746.5</th>
<th>746.9</th>
<th>747.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty (%Reading)</td>
<td>-0.80</td>
<td>-0.75</td>
<td>-0.50</td>
<td>-0.40</td>
<td>-0.30</td>
<td>0.00</td>
<td>0.10</td>
<td>0.20</td>
<td>0.25</td>
<td>0.30</td>
</tr>
<tr>
<td>VCF Computed</td>
<td>0.9938</td>
<td>0.9939</td>
<td>0.9939</td>
<td>0.9939</td>
<td>0.9939</td>
<td>0.9939</td>
<td>0.9939</td>
<td>0.9939</td>
<td>0.9939</td>
<td>0.9940</td>
</tr>
</tbody>
</table>

**Figure 4**

<table>
<thead>
<tr>
<th>ATG</th>
<th>Meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude receipts/sales, large batch</td>
<td>+</td>
</tr>
<tr>
<td>Crude transfer via pipe line</td>
<td>-</td>
</tr>
<tr>
<td>Crude, trucks, tankcars</td>
<td>-</td>
</tr>
<tr>
<td>Refined products receipts/sales</td>
<td>+</td>
</tr>
<tr>
<td>Refined products, trucks, tankcars</td>
<td>-</td>
</tr>
<tr>
<td>No service capability for meters</td>
<td>+</td>
</tr>
<tr>
<td>Internal transfer (non-custody)</td>
<td>+</td>
</tr>
<tr>
<td>Mass based transfer</td>
<td>+</td>
</tr>
<tr>
<td>LPG</td>
<td>+/-</td>
</tr>
<tr>
<td>Asphalt, lube oil, viscous products</td>
<td>+</td>
</tr>
<tr>
<td>Cost *</td>
<td>+</td>
</tr>
</tbody>
</table>

*Purchase and maintaining ATG’s are generally cheaper compared to meters.*
Where the intersection of the two curves is located varies between different tanks, where the shape of the tank has certain influence. There is however also a lot of other factors that may influence the performance, and in general one can say:

ATG’s may not perform well if
- Batches are small
- Tank Capacity Table is old or badly strapped
- Tanks are deformed or mechanically unstable

Meters may not perform well if:
- Batches are large
- Product contains abrasive material which tears mechanics
- Product is viscous (bitumen, lube oil, waxy crude etc)
- There is a lack of proper calibration facilities

Particularly the last point above may be considered. Calibration of an ATG system is normally very simple and low cost compared to meters which requires complex and expensive equipment.

An ATG system is normally required also for other purposes. These may be:
- Operational Control
- Inventory Control
- Mass balance and Loss control
- Leak alarm

If we assume there is an ATG system installed for purposes as above, one could estimate the additional cost for also using the ATG system for custody transfer.

There is of course a bit higher price on a custody transfer class ATG system compared to a less well performing system. However, the life time of an ATG system is often very long with an average of maybe 15-20 years. In this long time perspective the additional investment in better performing equipment will be more or less negligible. Also, the procedure of supervision of the performance (subsequent verification) when installed on a tank is limited to some hour per year by an independent resource. The total overall additional cost to have an ATG system in custody transfer shape can therefore be considered low.

The status of the Tank Capacity Table should also be considered. In particular it could be well worth to consider a re-strapping of an old tank according to new modern methods especially if the strapping was made in the far past. The cost for re-strapping may not be very high, and it may be well motivate against the measurement error in product volume that can occur on just one single emptying or filling operation of a tank.