Several technologies are available for determining the liquid level inside bulk storage tanks. For accurate custody transfer and legal metrology-approved product level measurement, onshore storage tanks use mainly servo or radar technology. Over the years, there have been many industry discussions on whether measuring such applications should be accomplished with servo or with radar technology. This article explains these two measuring principles and provides criteria for selecting which to use in which custody transfer circumstances.

**Working principles of servo**

The principle of servo measurement is based on Archimedes law, which states “any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object.”

Typical servo gauges consist of three compartments: drum compartment, drive compartment, and power supply compartment. The drum compartment contains a precise machined drum on which the measuring wire...
is wound. The displacer is suspended by this wire into the tank. The drive compartment contains the drive train (servo motor and electronics) and the measurement electronics.

A magnet coupling is used to convey torque between the drive train and the drum and forms the isolation between the process and the electronics and environment. The displacer is moved by a stepper motor in the drive compartment.

As soon as the displacer reaches the surface of the liquid in a tank, buoyancy reduces the apparent weight of the displacer. This is measured by the servo electronics using the force transducer. By also keeping track of the exact position of drum and number of revolutions, the length of the expanded wire can be measured. In combination with the known position of the gauge (gauge reference height, GRH), the exact product level can be calculated. This level is then corrected for several typical tank uncertainties, such as product temperature, tank shell effects, changes in GRH due to hydrostatic tank bulging, etc.

**Working principles of radar**

The main radar technology used for custody transfer is the frequency-modulated continuous wave (FMCW) principle, a solution that does not use a repetition of pulse such as pulse radars, nor measures the direct time of flight, which is less accurate, but instead sends out a continuous radar signal of which the frequency continuously changes in the form of a sweep. The emitted FMCW radar signal, after being reflected by the liquid in the tank, is then received and compared. The returning signal, delayed over the distance, exhibits a frequency shift directly related to the measured distance. This distance, double the distance to the product surface, can then be used to establish the product level (or innage). This delay allows the precise establishment of the distance between radar antenna and liquid stored in the tank (also called ullage).

**Selecting the best measurement solution**

There are various aspects that can influence the selection of the most suitable measuring principle of a custody transfer application. Aspects that should be considered include:

- Metrological aspects and product characteristics
- Functional requirements
- Installation
- Costs

**Metrological aspects, product characteristics**

Since accurate measurement is essential in many fields, and since all measurements are influenced by external factors that cause measurement uncertainties, a great deal of effort must be taken to make the assessment as accurate as possible. This is also applicable for the measurement of the content of a tank, and therefore the following influences should be considered:
Vapor effect

Vapor effect is the influence of the product vapors on the propagation speed of a radar signal, compared with the reference (atmospheric) conditions. This effect is caused by specific physical properties of the vapor, which interact with the microwave energy emitted by the radar. The three main effects are the dielectric constant, the magnetic permeability, and the dipole moment.

When using radar technology for level measurement in closed bulk storage tanks containing light hydrocarbons, there are several issues to keep in mind from an accuracy point of view:

- The low dielectric constant difference between the vapor above the liquid and the liquid itself.
- The composition of the vapor is not only dependent on the liquid contained in the tank but also air and possibly by other products previously stored in the tank.
- The vapor affects the radar propagation speed and how much energy is reflected by the liquid product.
- The effect is not only dependent on the physical properties of the vapor but also the amount of vapor.
- The amount of vapor is related to the vapor pressure and also the saturation of the vapor.
- This vapor saturation is not simply a P*V/T equation. As the tank and tank contents are not all at one single temperature, there are also dynamic influences caused by ambient effects such as sunshine or rain and loading or unloading.

Source: Honeywell
Every radar system is calibrated in air, and the composition of the vapor is not very stable, let alone known. As a result, the vapor influence can never be completely compensated for. The main uncertainty is the variable saturation of the vapor constitution above the liquid. A certain level of compensation for this effect can be achieved using vapor pressure and temperature measurement.

Measuring so-called light products with low dielectrical constants such as liquefied petroleum gas (LPG) or liquefied natural gas (LNG) is also more complicated, as the signal strength reflected back from the product level is low. To ensure a reliable level reading, the radar signal has to be bundled, and the use of a stilling well is a practical solution. Here another aspect arises, as the diameter of the stilling well determines the radar propagation speed. Hence, the inner diameter of the stilling well should be constant over the entire measuring range.

Requirements for mechanical installation

Depending on the method of installation (roof-mounted or using a stilling well) specific requirements are applicable for custody transfer measurement with radar or servo. Some examples and pitfalls include:

- Measurement on stilling well using radar

Radar measurement requires a constant diameter of the stilling well. This can be an issue when the stilling well has a reducer. The variations in stilling well diameter, misalignment, and also tilting of the stilling well segments will influence the accuracy of radar measurement. The stilling wells may have a single or even a double row of holes, and sometimes they are elongated (so called slots). If the slots or holes are too wide, this will also influence the accuracy of the radar measurement.

For a stilling well with reducer, there are some possible solutions. One is to cut the reducer and provide a mounting flange for the radar. Another possible solution is the use of an insert pipe of a smaller diameter. This should be done on clean products. Even then, the user should be aware the application of an insert can prevent the product in the insert from mixing well with the tank content. As a result, the stilling well should not be used for sampling, and in extreme cases, the level can even be off when compared to the rest of the tank.

Smaller-diameter stilling wells are exponentially more sensitive to contamination than large diameter stilling wells. For low-viscous products, such as crude, the stilling-well diameter should always be larger than 10 inches.

- Measuring free space application using radar

When measuring with radar in free-space applications near the tank shell, one can observe the multipath effect. A minimum distance to tank shell and other obstructions in the tank should be observed so reflections of the obstructions and tank shell do not influence the accuracy of the measurement.

- Measuring using servo
With a free-space servo measurement, a servo can be installed on any stable position on the roof, if sufficient distance to vertical obstructions and inlet or outlet of the tank is maintained. For servo stilling-well applications, any stilling well with sufficient diameter can be used (in general 8 inches is enough, for smaller tanks even smaller can suffice).

**Measuring range**

A concern when measuring levels in tanks is the measuring range used for custody transfer. At the tank top, the minimum distance between the surface of a radar antenna and the liquid (ullage) is 50 centimeters (cm). At low levels, the radar measurement will be approved for custody transfer from approximately 30 cm above the tank bottom. This can be improved to 5-10 cm by installing a deflection plate at the lower side of a stilling well. However, this solution is not ideal as it also requires some space. For free-space applications a deflection plate will not help. Servo gauges can always measure the whole range.

**Thermal expansion**

Thermal compensation is essential for custody transfer applications. The content of the tank, as well as the physical parts (tank shell and/or stilling well), should be compensated, especially on larger tanks and when the tank shell differs more than 10˚C from the tank shell calibration temperature. Accurate measurement and compensation of the tank content can increase cost efficiency up to $15,000 per tank fill. This is for the servo as well as for radar gauging done with external temperature measurements.

Thermal compensation of the stilling well or tank shell can be done by measuring the temperature of the liquid and gas phase in the tank. With heated application with viscous product, where radar is the preferred choice, the radar should apply these corrections to the innage reading.

With servo gauge, the need of compensation of the tank shell is smaller, as the measuring wire itself already compensates for most of the uncertainty introduced by the dry part of the tank shell.

**Functional requirements**

Most custody radar or servo solutions can be equipped with a broad range of options, such as input for average product and gas temperature, pressure transmitters, water bottom sensor, analogue output and alarms.

**Density profile**

Density stratification can occur when a different product batch is loaded on top of another into one tank. If this batch has a different temperature or even different composition than the rest of the tank content, it can stay as a layer on top. The lightest product does not always rest on the heavier product, nor do the products always mix over time. How well these layers mix or remain separated over time depends on how the tank is operated.
The batches can have different product composition as a result of the production process, but it can also happen when they arrive from marine barges or pipeline. Operators should know whether density stratification is present in the tank in order to make sure samples used for quality purposes are representative for the whole tank contents. Mixing can be considered, provided the tank is equipped and sufficient time is available.

Some servo level gauges have the capability to automatically measure a 10-spot density profile. Density profiling, possibly also enhanced with temperature information, allows the operator to visualize possible density stratification. This allows better, energy-efficient mixing and the advantages on pressurized tanks, where representative sampling is cumbersome, are evident.

Radar gauges can be enhanced with hybrid density measurements (HIMS or HTMS) where the average density over the total product height is assessed using pressure measurement. However, it has no built-in density profiling capability.

**Interface measurement**

Next to the interface between air and product, a second interface may be relevant. With a modern servo gauge, water bottom measurement, or any second interface measurement between different products, is a standard available feature. When it is desired to measure the free-water interface in a tank, it is preferable to install the servo gauge above the water sump, so it can measure the smallest quantity.

**Installation**

For brownfield installations (modifying/upgrading existing installed base), the selection is a simple decision tree. If an earlier version of a servo is installed, an upgrade to a state-of-the-art servo type is easy and straightforward, as the installation was already suitable for servo. If an older servo is to be replaced by radar, one needs to make sure the installation meets the specifics applicable for radar. These specifics include stilling-well dimensions and slots, tank-shell effect, obstructions, nozzle, deflection plate, etc. In general, a site survey is advised.

**Costs**

The following costs should be considered when selecting a servo or radar gauge for custody transfer applications:

**Costs of a device**: The purchase price difference between a servo gauge and a radar gauge is marginal. In general, this should not be a differentiator except when additional features such as density profiling or water-interface measurement are needed. In that case, a servo gauge is more cost effective compared to a radar gauge.
**Costs of mechanical modifications:** Prior to the decision between a radar gauge and a servo gauge, check the mechanical tank installation constraints.

**Maintenance cost:** Contaminating applications such as bitumen, asphalt, long and short residue, polymerizing products can give relatively high maintenance costs using servo gauges. Radar is a good solution for all these products. On clean products, servo and the radar gauges require minimum maintenance. On clean products, therefore, maintenance should not be a selection criterion.

In order to select the best solution for custody transfer measurements, carefully select the measuring principle based on the actual requirements of the target application. It is recommended to always select a supplier that offers servo and radar measurement techniques with the highest accuracy possible to get the best return from an investment.

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