

**SELECTING
THE RIGHT
TECHNOLOGY
FOR TANK
LEVEL GAUGING
FOR CUSTODY
TRANSFER
APPLICATIONS**

TABLE OF CONTENTS

2	Introduction
3	Why Tank Gauging?
4	Tank Gauging Systems?
6	Custody Transfer Applications
7	The Working Principle of Tank Level Gauges
7	Working Principles of Servo
7	Working Principles of Radar
9	Selecting the Best Tank Measurement Solution for Custody Transfer Applications
9	Limitations of legal use
11	Functional requirements
11	Product & process conditions
12	Installation aspects
12	Costs and budget
13	Operational aspects
14	Conclusion

INTRODUCTION

Several technologies are available to determine the liquid level inside bulk storage tanks. Selecting the right measurement technology helps meet challenges related to maximizing storage space and satisfying a wide range of safety requirements.

The latter includes the need to use diverse technologies, proof testing for overfill prevention sensors, requirements for legal metrology and custody transfers, and considerations concerning measurements on vaporized applications and deeper or higher tanks. This article explains the impact of the choice between servo or radar level measurement technology on achieving the required performance and meeting these challenges.



WHY TANK GAUGING?

1

Tank gauging is the generic name for the static quantity assessment of liquid products in bulk storage tanks. Tank gauging is used on large storage tanks in refineries, chemical plants, fuel depots, pipelines, airports and storage terminals, but also on storage tanks containing beverages, including alcohol.

Bulk storage tanks are usually above ground and cylindrical or spherical in shape. A range of constructions exist:

- Vertical, cylindrical, fixed-roof tanks, with either a cone or dome roof construction. To reduce the vapor losses of fixed roof tanks, they can also be fitted with internal floating roofs or screens.
- Vertical, cylindrical, floating-roof tanks, with an external floating roof or a dome roof construction.
- Cooled or cryogenic storage tanks, which are usually double-walled insulated, fixed-roof tanks. Liquefied gasses are stored under pressure in spherical tanks, cylindrical vessels or under refrigerated or cryogenic conditions in specially designed, well-insulated tanks.
- Pressurized tanks of a spherical or horizontal cylinder design either above or below ground.
- Underground storage facilities such as caverns.

Tank gauging is essential to determine the inventory of bulk liquid storage tanks. Typical capacities of bulk storage tanks range from 1.000 m³ (6,300 bbl) to more than 120.000 m³ (755,000 bbl). The value of the products stored in those tanks amounts to many millions of dollars.

A simple calculation shows that a 3 mm level uncertainty results in large volume discrepancies:

Tank Diameter (m)	20	40	80
Product Height (m)	16	16	16
Volume (m ³)	5026.54	20106.19	80439.85
Volume + 3mm error (m ³)	5027.49	20109.96	80424.77
Volume Discrepancy(m ³)	0.95	3.77	15.08

Consequently, accuracy is a prerequisite for good inventory management. However, it is only one of the many considerations involved in tank gauging. Reliability to prevent product spills and ensure the safety of the environment and personnel are equally important.

TANK GAUGING SYSTEMS

2

Two methods for measuring the tank level are recognized:

- A volume-based tank gauging system, with quantity assessment based on level and temperature measurement
- A mass-based tank gauging system, with quantity assessment based on measurement of the hydrostatic pressure of the liquid column.

The petrochemical industry generally uses static volumetric assessments of the tank content. This involves level, temperature and pressure measurements.

There are different ways of measuring the liquid level and other properties of the liquid. Whatever method is used, a high degree of reliability and accuracy is vital when the data is used for inventory control or custody transfer purposes.

A tank gauging system is much more than just the instruments on the tank, however. Tank gauging requires large field bus networks to enable reliable data communication – wired or wireless. Tank gauging systems must also be able to calculate product volumes and mass according to industry standards.

The tank gauging system performs many different functions, from operator interface, batch handling and reporting, to alarm functions, connectivity to host systems and much more.

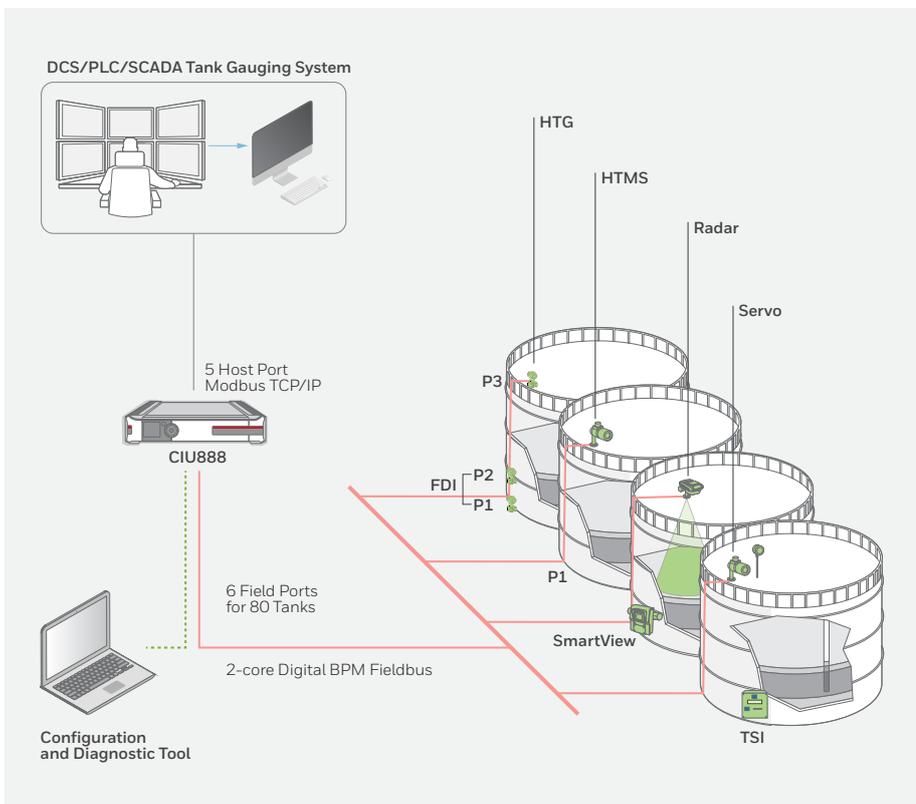


Figure 1: Architectural overview of a tank gauging system

Tank gauging is required for the assessment of tank contents, tank inventory control and tank farm management. System requirements depend on the type of installation and operation.

The following types of operation, each having its specific requirements, can be categorized:

- Inventory control
- Custody transfer
- Oil movement & operations
- Leak control & reconciliation
- Loss control & mass balance.

In this document, we will focus on level measuring principles for custody transfer applications.



Many installations use their tank gauging system for the measurements of product transfers between the ship and shore or pipeline transmission systems.

A tank gauging system is a cost-effective and accurate solution compared to flow metering systems, especially when high flow rates are present and large quantities are transferred. Moreover, when flow measuring systems are used, the tank gauging system offers a perfect verification tool.

When custody transfer or assessment of taxes, duties or royalties are involved, the gauging instruments and inventory control system are usually required to be officially approved and certified for this purpose. Even in countries where such legal certification does not yet apply, verification of the measurements is often carried out by surveying companies. These generally use dip tapes, portable thermometers and sampling cans to measure level, temperature and density before and after the product transfers. This is labor-intensive and requires considerable time.

Surveyors use the same procedures to calculate volumes or mass as modern tank gauging systems do. The presence of a reliable, certified accurate tank gauging system, therefore, facilitates their surveys and will reduce turnaround times. In cases where the quantity of product transferred is determined based on opening and closing tank measurements, a tank gauging system will also eliminate some systematic errors.

For legal or fiscal custody transfer, certification of the tank gauging system must be completed by international authorities, such as the International Organization of Legal Metrology (OIML). The tank gauging system may also be required to have approvals from local metrology entities such as NMI, PTB, LNE or other national notified bodies. Consequently, the uncertainty of such transfer measurements is lower than can be expected based on the uncertainties specified for tank inventory

THE WORKING PRINCIPLE OF TANK LEVEL GAUGES

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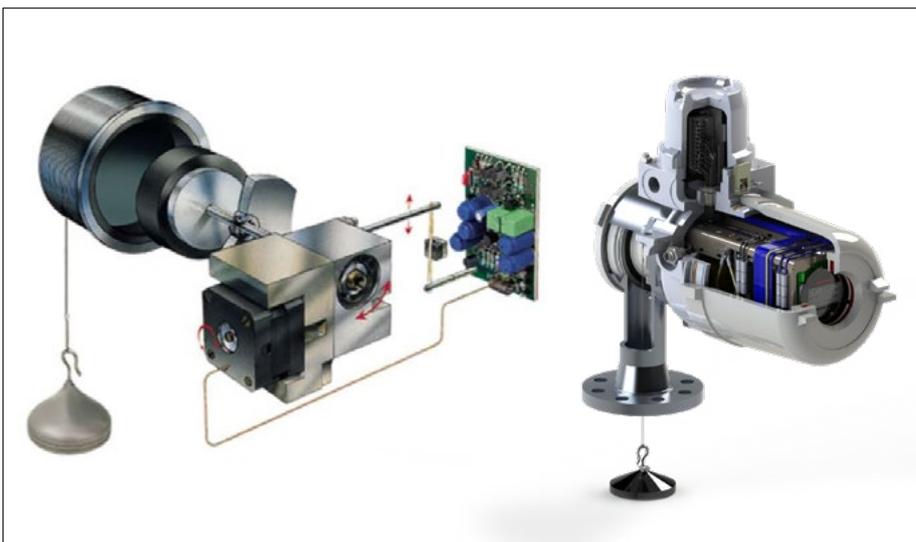
THE WORKING PRINCIPLE OF A SERVO TANK GAUGE

The principle of servo measurement is based on Archimedes' law: 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.

In this respect, Servo tank gauges are similar to mechanical float measurements. They are a considerable improvement over those instruments, however. The servo gauge, first developed during the 1950s, replaces the float with a small displacer, suspended by a strong measuring wire. Instead of a spring-motor, servo gauges also use an electrical servo motor to raise and lower the displacer. An ingenious weighing system continuously measures the weight and buoyancy of the displacer and controls the servo system. The motor also drives the integral transmitter accuracy of 0.4 mm (1/16 inch) over a 40 m (125 ft) range. This exceptional performance and their reliability have resulted in the acceptance of their measurements by legal metrology and customs and excise authorities in many countries.



Figure 2: A servo gauge.



THE WORKING PRINCIPLE OF A RADAR LEVEL GAUGE

Radar instruments in custody transfer use microwaves generally in the 10 GHz range to measure the liquid level. The distance the signal has travelled is calculated by comparing the transmitted and reflected signals.

With tank gauging, relatively short distances have to be measured, ranging from centimeters or inches to 20 m (66 ft). At the same time, electromagnetic waves travel at nearly the speed of light. Because of this and the required resolution, a measurement based on time is extremely challenging.

Despite this, Honeywell's FlexLine can offer best in class accuracies with no drift from ambient temperature effects. Xtreme Performance and High Performance models are certified as per OIML R85:2008 and API MPMS Ch. 3.1B recommendations. They can be used for country-specific legal metrology approvals within all OIML member states.

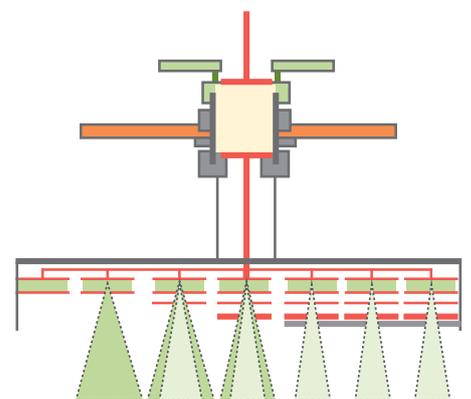
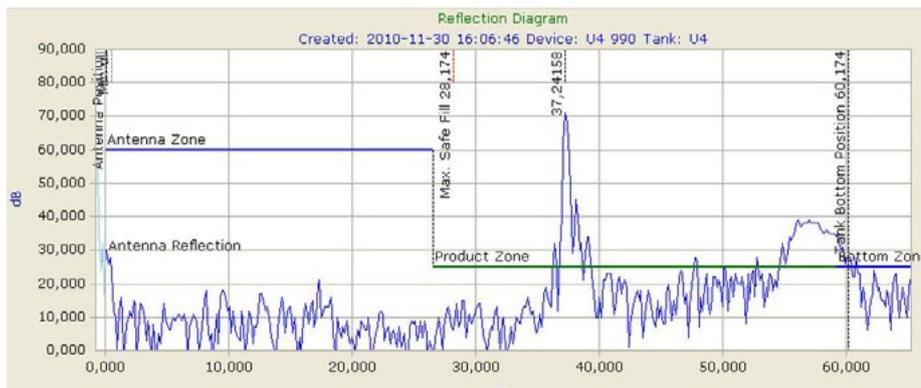


Figure 3: The Radar measuring principle.

The devices work using the Synthesized Frequency Modulated Continuous Wave (SFMCW) principle. This is based on sending a continuous radar signal with a continuously changing frequency in the form of a sweep towards the product surface. The frequency between the reflected signal and the transmitted signal is then compared. This frequency shift is directly proportional to the distance the radar signal has travelled.

Radar level gauges are suitable for product storage tanks found in refineries, terminals, the chemical industries and independent storage companies. The absence of moving parts, their compact design and non-intrusive nature, result in low maintenance costs. To achieve their instrument accuracy of $\pm 0.4\text{mm}$, specific antennas, as well as full digital signal processing, are required. In the past, this meant older radar instruments were equipped with large parabolic or long horn antennas. Modern radar level gauges use planar antennas, however. These are compact and much more efficient but deliver excellent accuracy.

Using innovative software algorithms and Honeywell's proven planar antenna technology, the SmartRadar FlexLine automatic tank gauge (ATG) consistently delivers the precision required in custody transfer and inventory applications. It provides accurate measurements even under the toughest operating conditions, whether on heated or pressured products, bad stilling wells or when installed close to the tank shell. Consequently, the device is also TUV certified for use in safety-rated loops up to SIL 2/3, as per IEC 61511, and meets major recommendations, such as API chapter 2350. It is widely used in overfill protection loops to prevent overfill accidents.



SELECTING THE BEST TANK GAUGING SOLUTION FOR CUSTODY TRANSFER APPLICATIONS

The most common question from tank gauging customers concerns selecting the best measuring principle for a particular application. It is common knowledge that various factors influence the determination of the most suitable technology for tank gauging. Those that should be considered include safety requirements, metrological aspects, product characteristics, application requirements, installation issues and costs. These aspects, their importance and their impact on measurements are considered below.

In general, both servo and radar measuring principle can be used on all liquid storage applications. The servo measuring principle was already on the market years before radar was introduced, and during that time all products were measured using this technology, even bitumen.

After radar was introduced from the marine market to tank farms in the late eighties, it seemed it would replace the entire servo market within a decade. However, experience and insights over the nineties revealed that radar was not ideal for all custody transfer applications. There remain applications where servo performs better. Consequently, the servo market continues to be active and to grow.

LIMITATION OF LEGAL USE.

All measurements are influenced by external factors that cause uncertainties. To make the assessment as accurate as possible, these must be considered when choosing a tank gauging solution.

The radar measuring principle (SFMCW type) is the better option for highly viscous and contaminating products such as bitumen or blown sulphur. Radar performance

In determining the best measurement principle for an application, we can usually divide the selection criteria into five categories:

1. Limitations of legal use
2. Product and process conditions
3. Functional requirements
4. Installation aspects
5. Costs and budget
6. Operational aspects

can be affected by the ever-changing vapor phase, however. The 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. There are four main effects: the dielectric constant, the magnetic permeability, the dipole moment (dipole movements of vapor molecules) and boil-off gas (BOG).

For high accuracy applications and especially in countries with legal metrology regulations, it is advisable to follow NMI and PTB recommendations. There is a list of radar gauge products for which the vapor influence has been calculated, and the maximum permissible error exceeds the limits for custody transfer applications. Figure 4 shows the relevant NMI section, where the maximum permissible errors are based on 10 m ullage, 20°C and 100% vapor saturation.

This vapor saturation calculation is not simply a P*V/T equation; it is much more complex. The tank and tank contents are not all at a single temperature, and there are also dynamic influences, caused by ambient effects such as sunshine or rain and loading and unloading.

Every radar system is calibrated in air, and the composition of the vapor is not stable, let alone known. As a result, we can wholly compensate for the vapor influence. 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, however, using vapor pressure and temperature measurement.

These considerations mean that for liquified gases and light chemicals, servo technology is generally better. For others, such as bitumen, sulphur and other high viscosity and contaminating products, radar is a better choice. For many refined products, either is appropriate. Figure 5 provides an overview.

Honeywell offers both radar and servo measuring technology, ensuring it can always provide a suitable solution.

Liquids of which the influence of its vapors on the measurement's accuracy of the maximum height, calculated with the following formula, meet the statutory requirements for the particular application.

This limitation is a direct result of propagation delay of the radar signal caused by physical properties of mentioned products. Compensation based on chemical properties and vapor saturation has not proven viable yet, and hence the use is restricted.

This formula for calculating the vapor influence has the following formula:

$$\frac{\Delta L}{L} = \frac{1}{2} \left(X\gamma_{sm} + \gamma_{air} - \gamma_{air,cal} \right)$$

$$\delta_L = \frac{1}{2} \left(X\gamma_{sm} + \gamma_{air} - \gamma_{air,cal} \right) \cdot 1000 \text{ mm/m}$$

$\gamma_{air,cal}$ = electric susceptibility of air during calibration
 ΔL = error in mm
 δ_L = error in mm/m

Figure 4. Section of the Radar legal metrology approval NMI approval.

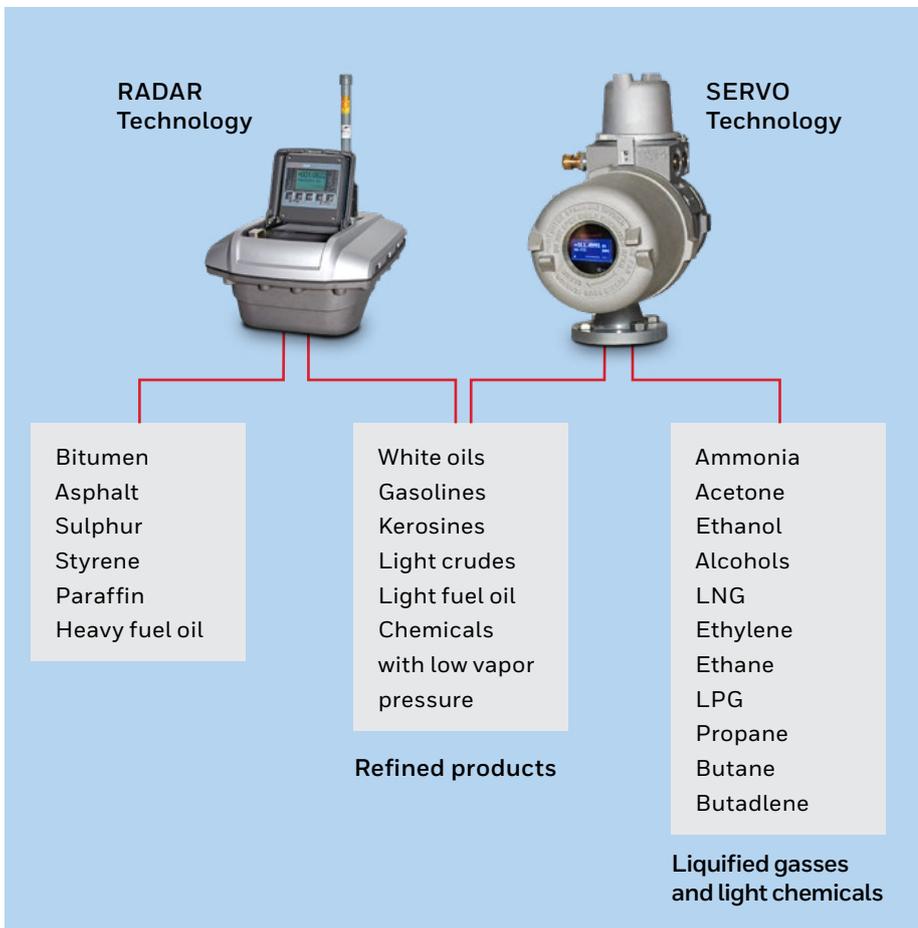


Figure 5: Selection of measuring principle based on products.

PRODUCT & PROCESS CONDITIONS

As well as vapor, product and process conditions such as foaming, boiling and crystallizing can also influence the performance of the ATG. In some cases, extreme foaming conditions might even mean that neither radar nor servo gauges are practical solutions. In such cases, a hydrostatic tank gauging (HTG) solution with pressure transmitters can be an option. However, HTG also has range limitations.

FUNCTIONAL REQUIREMENTS

Most custody radar or servo solutions can be equipped with a broad range of options such as inputs for average product and gas temperature, pressure transmitters, water bottom sensors, analogue outputs and alarms. Examples abound:

- Product and vapor pressure support	Radar&Servo
- Product temperature (spot or multi-sensor probe)	Radar&Servo
- Temperature profile measurement	Radar&Servo
- Vapor temperature (multi-sensor probe)	Radar&Servo
- Density calculation in combination with pressure transmitter(s) (HTMS)	Radar & Servo
- Safety function (SIL2/3) with relays or analog output	Radar&Servo
- Density profile measurement	Servo
- Interface measurement and interface profile	Servo
- Water bottom interface measurement	Servo

Some functions are supported as standard by servo, such as interface and water bottom measurement. In some cases, such as where density profile is required, servo is also the only option.

The latter is important when it comes to density stratification, which can occur when a different product batch is loaded on top of another into one tank. If the batch has a different temperature or even different composition than the rest of the tank content, it may sit on top as a layer. And it's not always the case that the lighter product rests on the heavier product or that they mix over time. How well the layers mix or extent they remain separate depends on how the tank is operated.

Layering can occur with heavy products, but also with refined products and very light products such as LPG and chemical gases. Batches may have different product compositions as a result of the production process, but also depending on whether they arrive from marine barges or pipelines. Operators should know whether density stratification is present in the tank so they can make sure samples used for quality purposes are representative of the entire contents. Mixing can be considered, provided the tank is equipped and sufficient time is available.

Some high-end servo level gauges, such as the Honeywell Enraf 954, can automatically measure up to a 50 spot density profile. Density profiling, which can also provide enhanced temperature information, allows the operator to visualize possible density stratification. This informs better and more energy-efficient mixing and is advantageous when it comes to pressurized tanks, for which representative sampling is cumbersome.

Radar gauges can also be enhanced with hybrid density measurements, called HIMS or HTMS. In this case, the average density over the total product height is assessed using pressure measurement. It does provide density profiles, however.

Besides the interface between air and product, a second interface may be relevant, such as the water bottom in a gasoline or diesel tank. With a servo gauge, water bottom measurement (or any second interface measurement

between different products) is a standard feature. When a measurement of the free water interface in a tank is required, it is important to install the servo gauge above the water sump, if possible, so that it can measure even the smallest quantities. The water interface measurement is an excellent and well-proven application on clean and not viscous products.

INSTALLATION ASPECTS

Greenfield installations:

In greenfield projects, tanks are usually designed with process connections for level, temperature and pressure devices. The correct installation can be designed from scratch.

Brownfield installations

The considerations for modifying or upgrading existing installations will depend on the current technology in place.

- Migrating old mechanical gauges or earlier generation radar gauges to servo can usually be done without major mechanical modifications. Installing a servo gauge is easy and straightforward, with nozzles available $\geq 2''$ or stilling wells $\geq 4''$, depending on the height of the tank.
- Migrating earlier generation servo gauges to modern servo is also straightforward. Usually, no mechanical modifications are required for servo.
- When migrating old mechanical gauges or earlier generation servo gauges to radar it is important to be sure that the installation meets the specifics applicable for radar. Status of the stilling well (smooth, straight, no burrs, welding) and type of slots, distance to the tank shell in case of free space (tank shell multipath effect), and obstructions, nozzles and deflection plates are among the factors to consider.
- Many stilling wells worldwide are equipped with a reducer, usually from 6" to 10" or 12". This is the so-called bottleneck. Migration to radar requires removal of the reducer. In some cases, this can be done with the tank in operation with a cold-cut method. However, there are cases where this is not possible so that taking the tank out of service is the only option. A servo gauge can be installed without issue on a stilling well with a reducer, of course.
- Migrations of earlier radar versions to servo or modern radar are usually straightforward. An advantage of migrating first-generation Honeywell radars to its latest generation radar gauges is that the antenna and tank separator can be re-used, so the tank doesn't need to be opened during replacement. Replacing radar by servo is plug and play; mechanical modifications are not required.

In general, a site survey is recommended when migrating to radar technology. Experienced technicians will evaluate all aspects of the installation and application during the survey, avoiding costly surprises at a later stage.

COSTS AND BUDGET

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

- Device costs, although the price difference between a servo gauge and a radar gauge is marginal. In general, this means they should not be a differentiator, but they may be when additional features such as density profiling or water interface measurement are needed. In that case, a servo gauge will be more cost-effective than a radar gauge.
- Costs of mechanical modifications should be considered. This will include consideration of any mechanical tank installation constraints, as discussed earlier. As stated, in brownfield migration projects, the costs for mechanical modifications are usually minimal for servo compared to radar.
- Maintenance costs may be higher when using servo gauges in applications involving contaminating products such as bitumen, asphalt, long and short residue and polymerizing products. Radar is an excellent solution for all

these products. For clean products, both servo and the radar gauges require minimum maintenance, so it should not form part of the selection criterion.

OPERATIONAL ASPECTS

Finally, some operational aspects should be considered in the selection process.

- Servo has the highest accuracy on pressurized, cryogenic and many chemical applications because there is no vapor influence.
- Servo gauges also measure from the top to bottom with a maximum measurement range.
- Radar performance can be affected by bottom reflections within 100-400 mm of the tank bottom, depending on the DC of the product. Radar level measurement can be improved by using a deflection plate close to the bottom.

In both cases, it is also quite common that product levels must be verified periodically. The methods of doing so will vary depending on the choice of meter:

- For servo gauges, this can be done under normal circumstances by manual dipping (a dip tape). However, there are applications where opening the tank for verification measures is either not possible (as in the case of pressurized tanks) or highly undesirable (as when toxic chemicals are involved). There are two approved methods for level verification in these cases.
 1. The top of the ball valve below the servo or the datum plate at the bottom is used as a reference point. The displacer is taken up, and verification is done on the ball valve.
 2. The calibration command is used to lift the displacer to the reference point below the servo. This verification can be done from the central control room and is common practice since it eliminates the need to climb and open the tank.
- For radar, under normal circumstances, the product level can be verified by manual dipping. In high-pressure applications, the radar level can be verified using verification pins in the 4" stilling well. The disadvantage of this is that the product can limit the visibility of the pins. For example, at a high level >75%, the pins are not visible to the radar. To verify chemical storage tanks, manual dipping is required, notwithstanding the significant safety measures needed.

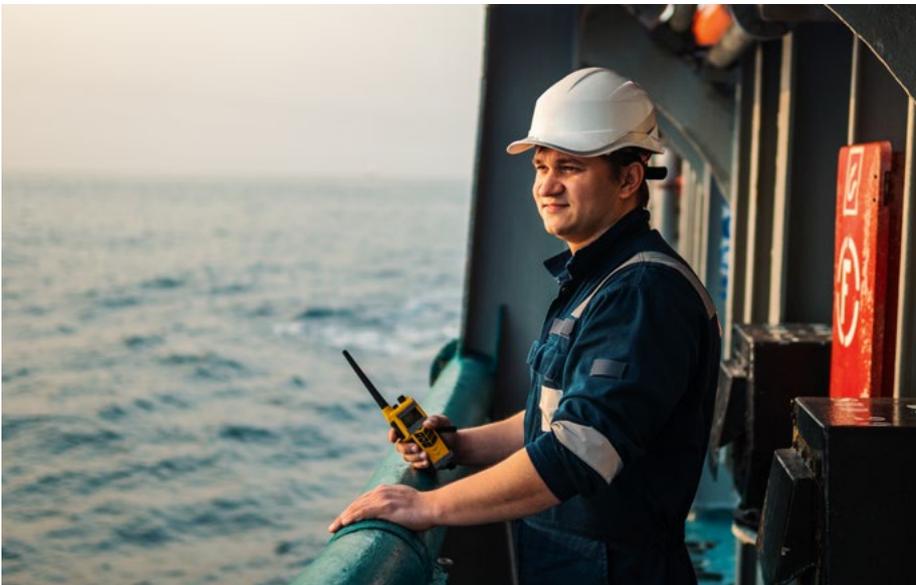
CONCLUSION

For custody transfer applications, the measuring principle must be carefully chosen. This selection should be based on actual requirements, and the most important criteria are described in this paper. They can be summarized as installation costs (including mechanical modifications); performance requirements for a specific product and application; functional requirements; and operational aspects. Other criteria might include the life-time expectancy of the tank gauge. There are many examples of Honeywell servo and radar gauges remaining in operation for over 25–30 years.

Tank storage facilities often consist of a mix of applications and various types of installations. It is therefore advisable to select a supplier that offers both servo and radar measurement solutions and products with the highest accuracy possible (0.4 mm) to obtain the best return on investment. Honeywell radar and servo solutions feature advanced algorithms for better overall performance, adaptive dynamic compensations for stable measurement under adverse conditions, compensation for guaranteed accuracy, and SIL-by-design capabilities with unique diagnostics for reliable operation.

To ensure the highest return on investment, operators should start with a thorough analysis of the tank farm. Honeywell's site survey includes an inventory of existing equipment, recommended instrumentation, and an evaluation of internal obstructions and external observations.

An accurate assessment of tank contents helps terminals run profitably and reliably. It not only keeps everyone safe but is crucial in satisfying stakeholders and supporting decisions to improve performance and drive down costs.



For more information

To learn more about Honeywell's Enraf product ranges, visit www.honeywellenraf.com or contact your Honeywell account manager.

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