Use Guided-Wave Radar to Measure Water Level in Steam Loops

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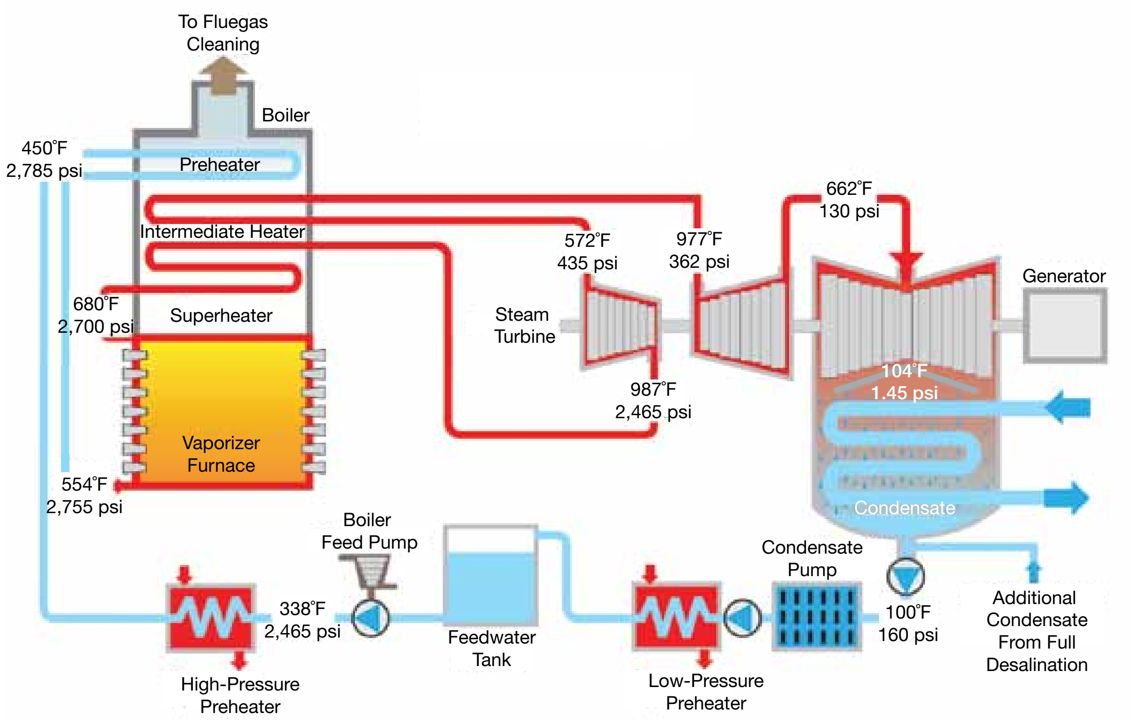
Guided-wave radar (GWR) is a useful tool for measuring water level in steam loops. This article describes GWR design and operation, and how this technology differs from more traditional forms of level indication.

Steam is critical throughout the chemical process industries (CPI). Chemical plants demand a high level of operational stability, safety, and reliability from all of their systems, especially the boiler system. The heart of any boiler system is the steam loop or circuit (Figure 1).

Operating a boiler without paying careful attention to its water level is akin to driving a car without monitoring the air pressure in the tires. Although it is possible to drive on tires with a high or low air pressure, doing so affects the car's performance and eventually causes damage to the tires.

Just as it is necessary to check tire pressure, it is important that the water level in the boiler be monitored closely. Significant damage to boiler equipment can result from long-term level problems that have gone unnoticed. Proper adjust-



▲ **Figure 1.** Proper operation of a steam loop in a chemical plant depends on the level of water in the boiler, feedwater tanks, hotwells, and preheaters.

ment of water level is a form of preventive maintenance that can support years of reliable operation. Optimizing the boiler water level prevents damage to the boiler's internals and helps in maintaining good heat-transfer efficiency.

Without the proper water level in a boiler, efficiency suffers. In some cases, damage to other components from either too much water (carryover) or too little water (low-water condition) can occur and shorten a boiler's lifespan. In extreme situations, a very low water level (below the low-low cutoff alarm level) can cause a dry fire accident, which could result in severe equipment damage and personnel injury. Operating at a low water level over a long period of time can damage the steam loop internals, which necessitates operation at nonideal conditions, forced reductions in service, or removal of the boiler from service for major repair work or replacement.

Guided-wave radar (GWR), also known as time domain reflectometry (TDR), has recently become an option for steam-loop level measurement. Used in conjunction with other technologies, it is a reliable, cost-effective choice for redundant level measurement in steam loop applications.

Traditional level indication in steam systems

Level indication in the steam loop is critical, but measurement methods have been slow to evolve. Previous code requirements (*e.g.*, PG-60 of the ASME Boiler and Pressure Vessel Code) and a lack of confidence in new technology have slowed the development of novel measurement techniques. Only within the past 15 to 20 years have technologies such as magnetic level gages and differential-pressure transmitters been used in place of direct-reading glass gages on applications such as feedwater tanks, high-pressure preheaters, and hotwells. These technologies are now utilized for drum-level indication as well.

The ASME code once classified level indicator types as either direct reading for visual level gages or indirect indication for all other types of indicators. ASME now distinguishes the two groups as gage glass and remote water-level indicators. The sections of the ASME Boiler and Pressure Vessel Code PG-60 (2009) that directly impact drum level measurement are:

• *PG-60.1:* All boilers with a fixed water level (the steam/water interface) shall have at least one gage glass (a transparent device that permits visual determination of the water level).

• *PG-60.1.1:* Boilers with a maximum allowable working pressure exceeding 400 psi shall have two gage glasses. Instead of one of the two required gage glasses, two independent remote water-level indicators (two discrete systems that continuously measure, transmit, and display water level) may be provided.

• *PG-60.1.1:* When the water level in at least one gage glass is not readily visible to the operator in the area where control actions are initiated, either a fiber optic cable (with no electrical modification of the optical signal) or mirrors shall be provided to transfer the optical image of the water level to the control area. Alternatively, a combination of two of the following shall be provided: (a) an independent remote water level indicator; (b) an independent continuous transmission and display of an image of the water level in a gage glass.

• *PG-60.1.1.2:* When two independent remote water-level indicators are in reliable operation (continuously indicating water level), the one required gage glass may be shut off, but shall be maintained in the serviceable condition.

GWR operation

Radar, or radio detection and ranging, was patented in 1935. Radar was originally intended for military actions, and was used to locate and identify ships and airplanes.

In contrast, radar devices used for level measurement operate with electromagnetic radiation at much shorter wavelengths — 1.5 to 26 GHz — commonly known as microwaves. They are available in two configurations, free-space/noncontact and guided-wave/contact. The level of the liquid is determined by measuring the time it takes for the microwave pulse to travel from the sensor to the liquid and back (Figure 2) with the following equation:

$$D = C \times \frac{T}{2} \qquad (1)$$

where D is the distance from the transmitter to the liquid, C is the speed of light, and T is the amount of time for microwaves to travel from the device to the liquid and back.

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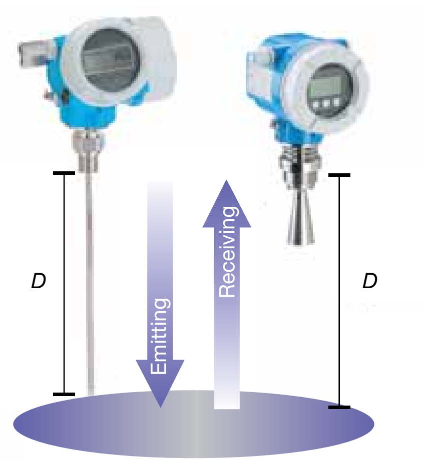

▲ **Figure 2.** A noncontact radar level sensor (right) transmits a microwave signal that reflects off the liquid. A guided-wave radar sensor (left) has a wave guide to help focus energy on the process media, resulting in improved overall performance.

◀ **Figure 3.** In a guided-wave sensor, 80% of the emitted radar energy stays within an 8-in. radius of the wave guide, which provides increased accuracy.

A guided-wave radar sensor uses the same principles as a noncontact radar device — it transmits and receives reflected microwave energy. The primary difference between the two is the typical operating frequency (1.5 GHz for GWR, vs. kHz frequencies for noncontact radar) and the presence of a wave guide. The wave guide is a metal rod or cable that directs (guides) the energy to the process media (Figure 3); a transmitter directs the pulse down the guide, with approximately 80% of the available energy staying within an 8-in. radius *(1)*. This means that more energy is reflected back to the transmitter than with non-guided radar. Therefore, GWRs perform well in liquids with low dielectric constants and other characteristics that can attenuate signal strength such as agitation or foam.

Guided-wave radar devices have high accuracies of ±0.4 in. independent of the liquid's conductivity and density. In most cases, instrument reconfiguration is not necessary if changes in the process liquid occur.

GWR in steam loop applications

The propagation speed of a microwave pulse generated by a radar device is well defined and stable. Typical process fluctuations in pressure or temperature have minimal effect on this speed. However, in certain cases, this speed will be affected by the presence of some vapors. The process medium's ability to reflect microwaves, based on its dielectric constant, must be taken into account. The dielectric constant is a measure of the polarization power of an insulating material, or the relative amount of charge that can be stored in a material versus air.

If the vapor in question is a polar gas, its dielectric constant can change due to pressure and temperature, which in turn affects the propagation speed of the microwave pulse. The dielectric constant of a hydrocarbon changes very little even at high pressures and temperatures. Steam's dielectric constant, on the other hand, is significantly influenced by the pressure and temperature of the application (Table 1).

If the dielectric constant of the vapor in the headspace of a vessel rises above 1.0, the propagation speed will be reduced, and it will take more time for the pulse to reach the liquid surface and return to the transmitter. As a result, according to Equation 1, the GWR detector will indicate a level that is lower than the actual level.

At low saturated steam pressures, the error caused by increasing dielectric constant is relatively small and typically disregarded. At high temperatures, the error is significantly larger (Table 2), exceeding 3% at 400°F, and 19% at 600°F.

Traditionally, the only way to offset this measurement error was to implement a correction factor in the transmitter. However, a correction factor is only valid for a given pressure/temperature setting. If operating conditions change or fluctuate, such as those experienced during startup, the correction factor would not be valid. In fact, it could make the measured error worse than if no correction factor were used.

Dynamic gas-phase compensation is the best method to correct for the changing dielectric constant of steam. A compensation table may be programmed into the distributed control system (DCS) or programmable logic controller (PLC) to correct the raw signal from the GWR. A dynamic form of compensation is a better solution than a constant correction factor, because it ensures accurate level measurement regardless of changes in the process.

Dynamic gas-phase compensation can be achieved

Table 1. The dielectric constant of steam varies with temperature and pressure.

Temperature		Pressure							
°C	°F	1 bar 14.5 psi	2 bar 29 psi	5 bar 72.5 psi	10 bar 145 psi	20 bar 290 psi	50 bar 725 psi	100 bar 1,450 psi	200 bar 2,900 psi
100	212	1.005806							
120	248	1.005227	1.010601						
152	306	1.004476	1.009048	1.023424					
180	356	1.003950	1.007964	1.020432	1.042934				
212	414	1.003458	1.006960	1.017743	1.036765	1.079856			
264	507	1.002840	1.005705	1.014456	1.029597	1.062307	1.192220		
311	592	1.002418	1.004851	1.012252	1.024933	1.051729	1.147384	1.424747	
366	691	1.002036	1.004082	1.010283	1.020834	1.042799	1.116952	1.282623	3.086361

by incorporating a reference section on the wave guide (Figure 4). A section of known length, the reference section resides in the vapor or steam phase and sends a small return signal to the transmitter. The transmitter compares the received return signal to the reference length of the section. If the computed length and the reference length match, then the transmitter does not need to correct the level measurement. If they do not match, then the controller will use a proportional offset algorithm to compute the actual level.

A GWR system supplied with dynamic gas-phase compensation provides highly accurate level measurement. A properly designed unit can operate in saturated steam conditions up to 2,900 psig at 690°F.

GWR devices used in high-pressure and high-temperature applications need a robust mechanical design to withstand harsh conditions. Every GWR system employs an isolation material between the wave guide and the electronics that emit and receive microwave pulses. In standard units, this isolation material is a polymer such as polytetrafluoroethylene (PTFE, *e.g.,* Teflon) or polyetheretherketone (PEEK). These materials are suitable for low-temperature applications (below 300°F for PTFE and 450°F for PEEK), but do not possess the durability needed to withstand higher temperatures. Higher-temperature steam gradually degrades the polymer, which eventually results in damage to the electronics and failure of the device. Higher-pressure/temperature applications require temperature-resistant isolation materials such as ceramic and graphite to ensure a long service life.

Comparing level technologies

Direct-reading glass gages. For measuring the water level in the boiler drum, direct-reading glass gages are the only indication method that is absolutely necessary to conform to PG-60 of the ASME Boiler and Pressure Vessel Code. A direct-reading glass gage can be used in conjunction with other non-direct-reading devices, but cannot be eliminated. Consequently, at least one operational glass gage must be present in all steam loop systems.

Direct-reading glass gages were traditionally used on other non-code vessels in the steam loop. Over time, the numerous gaskets on a glass gage wear, corrode, and fail. A glass gage in high-pressure/temperature service should have a mica shield to prevent etching, which causes weakening and can lead to failure. Belleville washers are required to help maintain seal integrity against pressure and temperature cycling. Eventually, many of these units on non-code vessels have been slowly replaced with less-maintenance-intensive instruments that can be monitored from the control room.

Displacer transmitters. A displacer transmitter is a semi-submerged float or weight connected to a spring balance. The complete assembly is typically enclosed in a chamber attached to the boiler drum. As the drum water level changes, the float moves up and down, and the varying tension on the spring balance is converted to a level signal.

Over time, metal fatigue will result in measurement drift and error in level indication. Corrosion can also impact the performance of the unit, especially if water quality is not tightly controlled. The setup for a displacer is based on the water's specific density; should the pressure/temperature of the water vary, the level indication will be incorrect.

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Table 2. For steam at 5 bar (72.5 psi), as temperature increases, the error in level measurement also increases due to variations in dielectric constant.

Temperature		Error
100°C	212°F	0.26%
120°C	248°F	0.50%
152°C	306°F	1.14%
180°C	356°F	2.10%
212°C	414°F	3.9%
264°C	507°F	9.2%
311°C	592°F	19.3%
366°C	691°F	76%

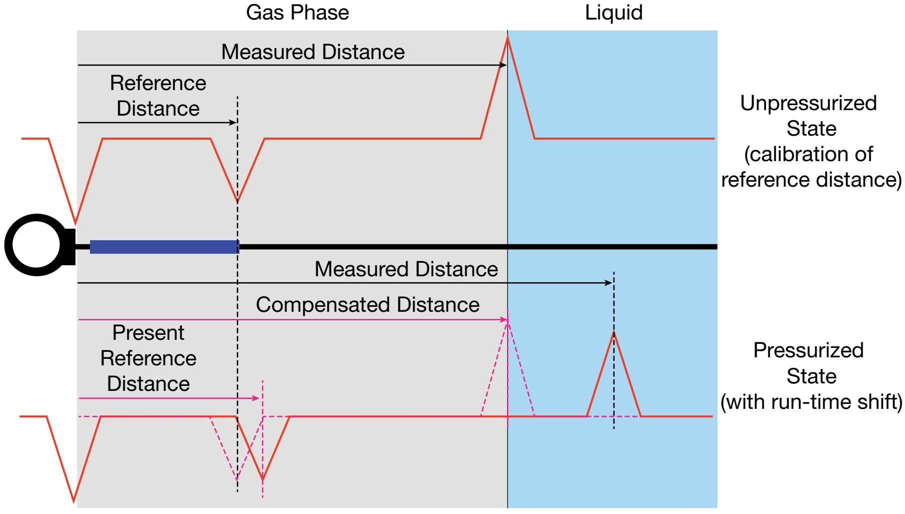

Figure 4. A GWR sensor can include a reference section on the wave guide that defines a known distance. The transmitter uses this signal to compensate for changes in dielectric constants and gas-phase errors.

Water columns with conductivity probes. These are used in conjunction with direct-reading glass gages to provide remote indication to the control room. The conductivity probe sends a signal to the control panel, which interprets this signal and displays the level measurement. It can also support high/low relays as well as a 4–20-mA output. Although conductivity probes do not offer a continuous signal, when fully functional they do provide good indication without the need to have an operator physically at the boiler drum.

Maintenance of these instruments is often a challenge. Because the conductivity probes are in contact with the process water, they are subject to corrosion, and they require regular replacement. As most systems have 10 to 20 probes per column, this can be expensive.

Magnetic level gages. A magnetic level gage is typically the most common replacement for traditional direct-reading glass level gages in steam loop vessels, including boiler drums. Even though a magnetic gage has local visual level indication, it is not considered a direct-reading level gage because the level indication depends on the magnetic attraction between the internal float and exterior indicator.

Magnetic gages can be very reliable when properly maintained. However, without proper maintenance, they can develop problems that hinder operation. The strength of the magnetic coupling between the float and the indicator is directly proportional to the distance separating them. Consequently, the clearance between the outside face of the float and the inside face of the chamber needs to be very small. If any dirt or debris flows into the chamber, it can become lodged between the float and inner wall, preventing the float from following the change in liquid level.

Like other displacer-type devices, a magnetic gage is designed for a specific liquid density. If the float is not properly manufactured or the density of the process liquid changes, an error in measurement will result.

Differential-pressure transmitter. This level-indication device uses hydrostatic pressure to infer the liquid level. In a vessel, the hydrostatic pressure is equal to the height of the liquid multiplied by the liquid's specific gravity. Because the specific gravity of the liquid is known, by monitoring pressure, the liquid level can be inferred.

This is an accurate and dependable method of level indication. However, over time, the diaphragm or sensing component is subject to metal fatigue as it responds to changes in pressure. This results in measurement drift and the need for recalibration.

As with the displacer-type instruments, a differential-pressure transmitter is calibrated based on the liquid's density. If the density changes, measurement errors will occur.

Guided-wave radar. GWR devices have digital electronics, a linear output, and no moving parts. They are not subject to drift or calibration problems unless they are physically damaged. As noted earlier, GWR is susceptible to the changes in a liquid's dielectric constant that occur with increasing pressure or temperature; employing dynamic gas-phase compensation can mitigate the effects of high-pressure/temperature conditions on signal propagation in polar media.

GWR with dynamic gas-phase compensation, and certified per IEC61508 as SIL2- or SIL3-capable, can be employed in an emergency shutdown (ESD) safety system for a low drum water condition to prevent boiler damage or a safety hazard. It is possible to find a GWR that supports *in situ* proof-testing as well; *in situ* proof-testing checks the functionality of a device in service without taking it offline. This drastically cuts maintenance time and validates safety processes.

Closing thoughts

There is no shortage of choices for continuous level-measurement devices in a steam loop. All gages have unique features and benefits that need to be carefully evaluated before selecting one for a specific application.

In the case of GWR, one of the first considerations is the operating temperature and pressure. For saturated steam below 400°F, a standard GWR will provide excellent service. For saturated steam above 400°F, measurement errors due to a changing dielectric constant will be more pronounced, and dynamic gas-phase compensation should be employed for maximum accuracy. In addition, at these higher temperatures, a more-temperature-resilient design is needed to prolong device lifespan.

Application flexibility, resistance to the effects of process conditions, low maintenance requirements, and dynamic compensation make GWR an accurate and reliable level-indication method for steam loop applications. These features also result in a low cost of ownership and tighter control over system operation. CEP

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