Proper employment of guided wave radar in steam loops

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Executive Summary
This paper will address the application of Guided Wave Radar (GWR), also known as Time Domain Reflectometry (TDR), in your steam loop. Included will be discussions of how this technology functions and differs from more traditional forms of level indication.

About the Authors
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INTRODUCTION

The heart and soul of any boiler based power generation system is the steam loop or circuit. Without the proper availability of water in this system, efficiency suffers. In more extreme circumstances damage to other components from either too much water (carryover) or too little water (low water condition) will occur and shorten a boiler’s lifespan. In the most extreme situation a dry fire accident could occur resulting in severe damage and personal injury.

Level indication in the steam loop is critical, yet the methods employed to measure it have been slow to evolve or change. Some of that has been due to code requirements (PG-60 of the ASME Boiler and Pressure Vessel Code) or a simple lack of confidence in “new” technology. It has only been in the past 15 to 20 years (recent in terms of boiler/steam loop history) that technologies such as magnetic level gages or differential pressure devices have been used in place of direct reading glass gauges on applications such as feedwater tanks, high pressure preheaters or hotwells. These same devices are now utilized for drum level indication as well. The most recent addition to the technology basket for steam loop applications has been Guided Wave Radar. Used in conjunction with other technologies it is seen as a reliable cost effective choice for redundant level measurement in all steam loop applications, including drum level.
THEORY OF OPERATION

Radar, an acronym for Radio Detection and Ranging, was patented by the British in 1935. Radar was originally military based and used as a method for locating or identifying ships and airplanes. Consequently, those units were very powerful and use a Frequency Modulating Continuous Wave (FMCW) technology. By comparison, radar devices used for level measurement operate with electromagnetic radiation at much shorter wavelengths – 1.5 to 26 gigahertz – commonly known as microwaves. They are also available in two typical configurations, free space/non-contact or guided wave/contact.

Most radar devices utilized for level detection employ electromagnetic pulses (microwaves) to measure the liquid level in tanks. Like the speed of sound, the speed of light (electromagnetic radiation) is well known – 186,000 miles per second. The level of liquid is determined by identifying the time it takes for the microwave pulse to travel from the measuring device to the liquid and back.

\[ d = \frac{c \cdot T}{2} \]

Equation 1: \( d = \frac{c \cdot T}{2} \)
- \( d \) = distance from measuring device to liquid
- \( c \) = speed of light
- \( T \) = amount of time for microwaves to travel from device to liquid and back

Why do radar level devices use microwaves compared to other types of energy in the electromagnetic spectrum? Process conditions such as vapors, temperature, pressure, buildup and condensate have little effect on radar devices. However, the ability for the process medium to reflect or not reflect microwaves needs to be taken into account. One can determine the medium’s ability to reflect microwaves by looking at the dielectric number of the media. The dielectric number is a measure of the polarization power of an insulating material or how much charge can be stored in a type of material vs. air. Water has a dielectric number of 80 and is considered a great reflector of microwaves. Air has a dielectric number of 1 and is considered a poor reflector of microwaves.

A guided wave radar device uses the same principle as non-contact radar devices – it has the ability to transmit and receive reflected microwave energy. The primary difference between the two devices is the typical operating frequency (1.5 GHz for GWR) and the presence of a wave guide. The wave guide is a metal
rod or cable which guides the energy to the process media. The transmitter directs the pulse down the guide with approximately 80% of the available energy staying within an 8” radius.

Why would getting more energy directed on the process media be of help? It's all about the signal to noise ratio. Even with interference from nozzles or point level devices, more energy can be reflected back to the transmitter. More energy also means the ability to work better with lower dielectric liquids or other factors that can attenuate signal strength such as agitation or foam. Just like non-contact radar, guided wave radar devices are very accurate (±0.4 inches) and the accuracy is independent of the liquid’s conductivity, density and dielectric number. This means no re-configuration of the instrument is needed if changes in the process liquid occur.

STEAM LOOP APPLICATIONS

General advantages a GWR can provide in level indication applications have been discussed. Now, what sets steam loop applications apart and makes them unique?

The propagation speed of the microwave pulse generated by a radar device is well defined and stable. Typical process conditions such as pressure (vacuum or high pressure) or temperature have minimal if any effect on this speed. The same is true of vapor blankets. Normally they are not a significant concern. However, there are specific circumstances when this statement will not be true!

If the vapor in question is considered a polar gas, (a vapor whose dielectric constant can change due to pressure/temperature) the propagation speed of the microwave pulse can be affected. Hydrocarbons display very little change in their dielectric constant even at very high pressures/temperatures. Steam on the other hand is greatly influenced by the pressure/temperature of the application.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Pressure</th>
<th>Dielectric Constant of Steam</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>°F</td>
<td>1 bar 14.5 psi</td>
</tr>
<tr>
<td>100 °C</td>
<td>212 °F</td>
<td>1.005806</td>
</tr>
<tr>
<td>120 °C</td>
<td>248 °F</td>
<td>1.005227</td>
</tr>
<tr>
<td>152 °C</td>
<td>306 °F</td>
<td>1.004476</td>
</tr>
<tr>
<td>180 °C</td>
<td>356 °F</td>
<td>1.003950</td>
</tr>
<tr>
<td>212 °C</td>
<td>414 °F</td>
<td>1.003458</td>
</tr>
<tr>
<td>264 °C</td>
<td>507 °F</td>
<td>1.002840</td>
</tr>
<tr>
<td>311 °C</td>
<td>592 °F</td>
<td>1.002418</td>
</tr>
<tr>
<td>366 °C</td>
<td>691 °F</td>
<td>1.002036</td>
</tr>
</tbody>
</table>

Why does this phenomenon affect the performance of a GWR? A radar pulse travels at the speed of light, but that fact is predicated on the pulse moving through vapor with a dielectric constant < 1.0. If the dielectric constant of the vapor space in a vessel starts to become greater than 1.0, that propagation speed will be reduced. This means it is going to take more time for the pulse to reach the liquid surface and return to the transmitter. If you remember our formula on page 3, should the time increase due to a reduced propagation speed, the level indication provided by the GWR will be lower than what it actually is.
What effect can this actually have on my measurement?
At lower pressures for saturated steam, the measured error experienced is relatively small and probably not noticeable. However, once an operating temperature of 400°F is required that is not necessarily true. The measured error could be 3.5 to 4%. At 600°F that error can increase to 19 or 20%!

Example steam: Resulting errors in the gas phase

<table>
<thead>
<tr>
<th>Gas Phase</th>
<th>Temperature °C</th>
<th>Temperature °F</th>
<th>Pressure 72.5 psi</th>
<th>Pressure 72.5 psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam (water vapor)</td>
<td>100</td>
<td>212</td>
<td>0.26%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>248</td>
<td>0.23%</td>
<td>0.50%</td>
</tr>
<tr>
<td></td>
<td>152</td>
<td>306</td>
<td>0.20%</td>
<td>0.42%</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>356</td>
<td>0.17%</td>
<td>0.37%</td>
</tr>
<tr>
<td></td>
<td>212</td>
<td>414</td>
<td>0.15%</td>
<td>0.37%</td>
</tr>
<tr>
<td></td>
<td>264</td>
<td>507</td>
<td>0.12%</td>
<td>0.26%</td>
</tr>
<tr>
<td></td>
<td>311</td>
<td>592</td>
<td>0.09%</td>
<td>0.22%</td>
</tr>
<tr>
<td></td>
<td>366</td>
<td>691</td>
<td>0.07%</td>
<td>0.18%</td>
</tr>
</tbody>
</table>

How can this impact on my level indication be accounted for? Historically the only way to offset the physical effect of a steam phase was to implement a correction factor in the electronics of the transmitter. While this works, it has one large deficiency. The correction factor is only valid for a given pressure/temperature setting. During startup, or if the operating parameters for the application change, this adjustment will not be valid. In fact, it could actually make the measured error worse than if you had no correction factor at all. The other method is to program a compensation table into the DCS or PLC so it is responsible for correcting the raw signal from the GWR. A dynamic form of compensation is a much better solution and ensures your level measurement is accurate regardless of changes in the process. The best method for achieving this is by implementing a reference section on your wave guide.

The reference section provides the GWR with a known distance to compare a return signal to. It always resides in the vapor or steam phase of the application and provides a small return signal to the transmitter. The transmitter is looking for this signal and compares it to the reference distance it has been programmed for. If they match, the transmitter knows the level signal it receives from the process is correct. If the reference echo is farther away than the known reference distance the electronics in the transmitter know the level signal will have a proportional offset. At that point algorithms will automatically compensate for this and provide the DCS/PLC with an accurate level.
A Guided Wave Radar supplied with dynamic Gas Phase Compensation will provide a highly accurate level measurement. Properly designed, the unit will operate in saturated steam conditions up to 2900 psig @ 690°F with no fear of damage to the electronics. It will also eliminate the concern of having a measured error of up to 20% or more that must be accounted for. Instead you receive a level indication directly from your GWR you can depend upon.

One additional aspect to consider in choosing your GWR is the mechanical design of the unit. In higher pressure/temperature steam loop applications the units’ ability to withstand extreme conditions must be taken into account as well. Every GWR employs an isolation material between the wave guide and electronics responsible for launching the microwave pulse and receiving the return signal. For standard units this isolation material is a polymer such as Teflon® or PEEK. At lower temperatures (approximately 300°F for Teflon® and 450°F for PEEK) these materials are great. Unfortunately they do not possess the needed durability at elevated temperatures. In high temperature steam will bypass polymers resulting in damage to the electronics and failure of the device. Higher pressure/temperature applications need more temperature resistant isolation materials such as ceramics and graphite to ensure longevity of service.

**COMPARISON TO OTHER LEVEL TECHNOLOGIES**

How does the accuracy and performance of a GWR with dynamic compensation compare to other more conventional technologies employed in steam loops?

**Direct Reading Glass Gauges**

For boiler drum level this is still the only true direct level indication per PG-60 of the ASME Boiler and Pressure Vessel Code. A Direct Reading Glass Gauge can be used in conjunction with other non-direct reading devices, but can not be eliminated. Consequently, at least one operational glass gauge must be present. There are a number of additional regulations and requirements that we will not take the time to discuss here.

Historically Direct Reading Glass Gauges were also used on other non-code vessels in the steam loop as well. Over time the numerous gaskets present on a glass gauge will wear and fail. Glass without Mica shields for higher pressure/temperature service is at risk to etching which will cause it to weaken and fail under pressure. Belleville washers are also needed to help maintain seal integrity from pressure/temperature cycling. Eventually many of these units have been slowly replaced with less maintenance intensive devices capable of being monitored from the control room.

**Displacer Transmitters**

This 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 float weight changes in conjunction with the drum water level the varying tension on the spring balance is converted to a level signal.

Issues encountered with these systems stem from wear and maintenance. Over time metal fatigue will result in measurement drift and error in your level indication. Corrosion can also impact the performance of the unit, especially if water quality is not tightly controlled. Even if none of this happens the setup for a displacer is based upon a specific water density. Should the pressure/temperature of the water vary, the level indication will be off.

**Water Columns w/ Conductivity Probes**

These devices have long been used in conjunction with direct reading glass gauges to provide a remote reading option to the control room. While not technically a continuous signal, when fully functional they do provide good control without the need to have a technician physically at the boiler drum.

A signal from the conductivity probes is typically received at a control panel. In turn this will illuminate a series of lights providing remote level indication. The control panel can also provide high/low relays as well as a 4-20 mA output.

Maintenance is the issue most commonly faced with these instruments. The conductivity probes are subject to corrosion due to contact with the process water and require regular replacement. Considering most systems have between 10 – 20 probes per column, this is not an inexpensive process.

**Magnetic Level Gauges**

A Magnetic Level Gauge is probably the most common replacement for most of the more traditional level gauges in a steam loop, including boiler drum level. However, even though a magnetic gauge has local visual level indication, it is not considered a direct reading level gauge. The level indication is dependent upon the magnetic attraction between the internal float and exterior indication device.

Magnetic gauges can be very dependable when properly maintained. However, if good maintenance is not followed problems can develop. The strength of the magnetic coupling between the float and indicator is directly proportional to the distance between them. Consequently, the radial clearance between the outside face of the float and inside face of the chamber is very small. If any dirt or debris finds its way into the chamber and between these two components it can become lodged. This will prevent the float from following the change in liquid level.

Like other displacer type devices, a magnetic gauge is designed for a specific liquid density. If the float is not properly manufactured or the density of the process changes, measured error will occur.

**Differential Pressure Transmitter**

As its name implies, this level indication device is measuring the difference in pressure between the vapor space in a vessel or chamber and the liquid height. The net result is the pressure exerted on the lower sensor independent of the pressure in the vessel. By comparing this value to a known density, the liquid height can be determined.

Initially 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 drift and the need for recalibration.

As with the displacer type instruments, a differential pressure transmitter is calibrated based upon a specific liquid density. If that density changes, measured error in the level indication will ensue.

**Guided Wave Radar**

The strength of guided wave radar is based upon the fact that it has no moving parts, has digital electronics, and a linear output. This means it is not subject to drift or calibration issues unless the unit is physically damaged. Guided Wave Radar is also impervious to changes in pressure or temperature. It is simply reacting to the change of impedance that occurs as the generated pulse contacts the liquid surface. By employing a dynamic form of Gas Phase Compensation any effect a high pressure/temperature polar media might have on the units’ signal propagation is also largely eliminated.

**CONCLUSIONS**

There is no shortage of technology choices for continuous level measurement in your steam loop. All have unique features and benefits that need to be carefully evaluated prior to selection for your individual application.

In the case of Guided Wave Radar, one of the first considerations is what the operating temperature and pressure will be. For saturated steam conditions < 400°F a standard GWR will provide excellent service. At saturated steam conditions > 400°F the impact on measured error due to the effects of steam vapors will be more pronounced. This is when dynamic Gas Phase Compensation needs to be employed for maximum accuracy along with a more temperature resilient design to protect the electronics.

Application flexibility, resistance to effects from process conditions, low maintenance requirements and dynamic compensation all combine to make Guided Wave Radar an accurate and reliable choice for steam loop applications. These features also result in low cost of ownership and tighter control over system operation.

**REFERENCES**


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<table>
<thead>
<tr>
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