Guided Wave Radar in Saturated Steam Applications

MAGNETROL®

One of the main advantages of Guided Wave Radar (GWR) over other level measurement technologies, and one that has increased its popularity in industrial process applications, is the fact that it is immune to a variety of process conditions. Specific gravity changes, dielectric constant changes, temperature, pressure and vapor space changes all have virtually no effect on the performance of GWR transmitters.

However, one application in which a process variation does affect the performance of GWR can be found in the Power industry, where the need for accurate level measurement of boilers, feedwater heaters and deaerators is important. These applications, all containing saturated steam in the vapor space, require special attention.

Measurement error can be introduced into a saturated steam system due to speed of propagation variations in the GWR signal relating to vapor space dielectric. However, the error is predictable with the high frequency, electromagnetic pulses travelling down the probe at very near the speed of light.

With the speed of light (c) in a vacuum (ε = 1.00) being 186,000 miles/second or 3×10^8 m/second, this is calculated as:

$$c / \sqrt{\varepsilon}$$

Where:
c = speed of light
ε = dielectric constant of vapor space

As the equation shows, as long as the pulses travel in a vapor space with dielectric ε at or close to 1.00, no significant variation in the speed of propagation is expected. Although this is not a consideration for GWR in the vast majority of applications, it is a considerable factor in those applications for which saturated steam exists in the vapor space.

As the temperature (and pressure) of a saturated steam application increases, the dielectric constant of the gas (steam) vapor also increases. This increase in vapor space dielectric causes a delay in the GWR signal propagation as it travels down the probe to the process medium, water in the preceding application examples. This signal propagation delay results in a measured liquid level appearing lower than actual. In other words, in a time of flight technology like GWR, the detected reflection from the liquid level will appear "farther out in time" due to the delay.

The change in the saturated steam vapor dielectric depends on temperature, and the measurement error associated with the resulting propagation delay is directly related to the equation above. For example, the air vapor space dielectric in such an application starts at ε = 1 @ 70F (20°C). However, as shown in Table 1 below, the dielectric constant of the air (steam vapor) will increase to:

Table 1

Temp. (F)	Temp. (C)	Pressure (psia)	Pressure (bar)	Dielectric Constant of Liquid	Dielectric Constant of Vapor	Error in Distance %
100	37	0.95	0.06	73.95	1.001	0.0
150	65.5	3.72	0.25	65.09	1.002	0.1
200	93.3	11.54	0.80	57.26	1.005	0.2
250	121.1	29.84	2.05	50.36	1.011	0.5
300	148.9	67.03	4.62	44.26	1.022	1.1
350	177	134.60	9.28	38.84	1.040	2.0
400	204	247.30	17.05	34.00	1.069	3.4
450	232	422.50	29.13	29.62	1.113	5.5
500	260	680.60	46.92	25.58	1.180	8.6
550	288	1045.00	72.05	21.77	1.285	13.4
600	315	1543.00	106.38	18.04	1.461	20.9
650	343	2208.00	152.23	14.10	1.816	34.8
700	371	3093.00	213.25	8.29	3.295	81.5

ε = 1.11 @ 450°F (232°C), resulting in a measurement error of about -5.5 %.

ε = 1.28 @ 550°F (288°C), resulting in a measurement error of about -13.4%.

ε = 1.8 @ 650°F (345°C), resulting in a measurement error of almost -35%.

Solution

The Eclipse® Model 706 GWR transmitter and Model 7yS Coaxial Steam probe combine to provide a unique solution to this application. In knowing that the propagation delay described above is predictable, the effects of the changing steam conditions can be monitored and in knowing that the vapor space dielectric, accurate active (continuous) compensation of the actual liquid level reading can be accomplished.

This is a patented technique with Magnetrol® holding two US Patents (US 6642801 and US 6867729) for both the mechanical target concept and the associated software algorithm.

The effects of the changing steam conditions described above can be compensated for by utilizing a mechanical target placed on the probe within the vapor space. This mechanical target is specially designed to produce an intentional, small signal reflection at a precise, known location.

Magnetrol places the mechanical steam target 5 inches (12.5 cm) down inside of the Model 7yS coaxial probe. Knowing exactly where the target is located at room temperature, and then continuously monitoring its apparent location as the saturated steam conditions change, enables calculation of the vapor space dielectric. In knowing the vapor space dielectric at any given time, accurate compensation of the delayed signal reflection is incorporated and an accurate liquid level reading is accomplished.

Figure 1 is an example of the waveform as displayed using the ECLIPSE DTM and PACTware. A typical steam target signal is shown at room temperature with the probe dry.

Figure 1: Steam Probe in an empty chamber

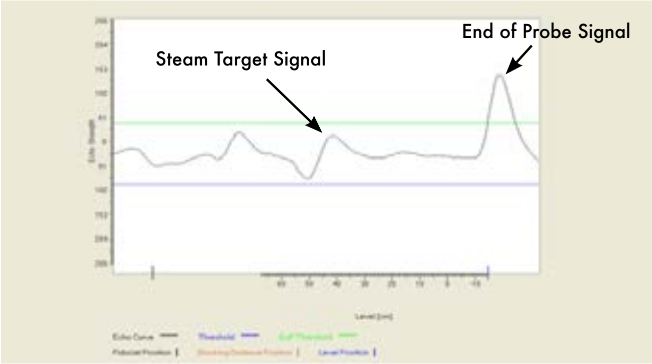
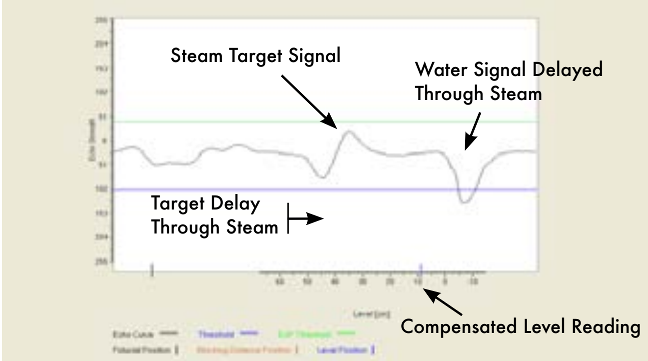


Figure 2 shows the same steam probe at process conditions with level on the probe. The signal from the steam target now appears farther out in time (farther to the right).

Figure 2: Steam Probe at process conditions



Probe Choice Is Important

Unlike their competitors, Magnetrol utilizes the coaxial probe in these applications for two reasons:

1) The coaxial probe has a predictable and consistent geometry, and therefore, a consistent and predictable impedance along the length of the probe.

Because the coaxial probe has a known, consistent impedance along its entire length, no undesirable signals occur within it. Subsequently, the very small amplitude steam target can be properly detected anywhere on the probe. This is important because active compensation provided for by the target will cease when the water level rises and its signal covers the target. Therefore, a target placed high on the probe maximizes usable probe length.

As mentioned above, the Model 7yS Steam probe has the steam target located only 5 inches (12. 5 cm) down from the top of the probe. This means that the ECLIPSE Model 706 transmitter can actively compensate for most of the entire probe length of any ECLIPSE Model 706 steam probe. This is very important in those applications where an ECLIPSE Model 706 transmitter is being retrofitted into an existing torque tube displacer chamber where small measuring ranges are required.

As a measure of comparison, GWR manufacturers utilizing a single rod probe have their steam target locations as far as 21 inches (53.3 cm) down the probe because single rod probes suffer from inconsistent impedances that depend on both the mounting and the installation. Their targets need to be located lower on the probe because the inconsistent impedances will cause erroneous signals that can adversely interact with the target signal. This dramatically decreases the active compensation area on the probe and typically requires a "spool piece" to be added to existing chambers in order to move the steam target up and out of the measuring range.

2) The coaxial probe is the most efficient GWR probe, resulting in increased signal strength.

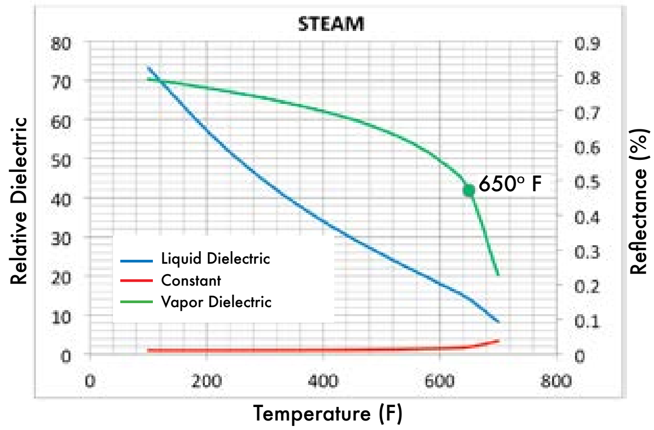
At first glance, one may not think that a water-based application would require the increased signal strength of a coaxial probe; however, as evidenced in part by the explanation above, these saturated steam applications are anything but ordinary.

Another complicating factor in these applications is the fact that the dielectric constant of water decreases with increasing temperature. As shown in the table below, although water has very high dielectric constant of approximately 80 at room temperature, its dielectric will decrease down to about 14 at 650°F (343°C).

Therefore, in these water-based applications, a liquid:air dielectric ratio that starts at 80:1 at room temperature, can actually end up at a ratio of 7.7:1 at 650°F (343°C). (Water dielectric 14.1 divided by air dielectric 1.82).

Please see Figure 3, which shows how the dielectric constant of water and steam change with temperature, along with the resulting signal reflectance.

Figure 3

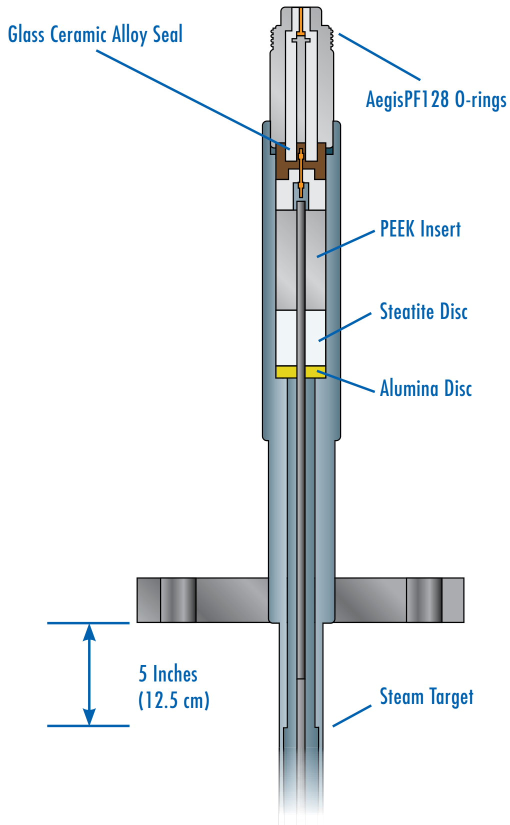


The additional signal strength of the coaxial probe is, therefore, actually very important, especially when additional adverse process conditions like boiling occur and further reduce the apparent dielectric constant of the water.

Process Seal

As saturated steam is also a very aggressive and difficult application from a material compatibility perspective, it is worth noting that Magnetrol specifically designed the Model 7yS steam probe for use in saturated steam. As shown below, the process seal utilizes a dual seal concept.

The first line of defense in this design is an alumina ceramic disk, which protects a Steatite disc and PEEK HT element above. For further protection, a hard glass ceramic alloy seal is also used. This results in a very robust seal that can withstand the harsh conditions in these applications.



Remote Mounting

In addition to the integral version, which is installed directly on to the probe, the ECLIPSE Model 706 transmitter is available with 3 foot (1 meter) and 12 foot (3.6 meter) versions, allowing the transmitter to be placed in a more convenient location due to temperature, vibration or access.

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