Various Technics of Liquids and Solids Level Measurements (Part 3)

In part one of this series of articles, level measurement using a floating system was discusses and the instruments were recommended for each application. In the second part of these articles, level measurement with the aid of pressure instruments was discussed. In the third part of this series of articles, radar level measurement basics and parameters affecting its efficiency will be explained.

RADAR LEVEL MEASUREMENT BASICS

Radar level measurement is based on the principle of measuring the time required for the microwave pulse and its reflected echo to make a complete return trip between the non-contacting transducer and the sensed material level. Then, the transceiver converts this signal electrically into distance/level and presents it as an analogue and/or digital signal. The transducer's output can be selected by the user to be directly or inversely proportional to the span.

Pulse radar has been used widely for distance measurement since the very beginnings of radar technology. The basic form of pulse radar is a pure time of flight measurement. Short pulses, typically of millisecond or nanosecond duration, are transmitted and the transit time to and from the target is measured. The pulses of a pulse radar are not discrete monopulses with a single peak of electromagnetic energy, but are in fact a short wave packet (Fig. 13). The number of waves and the length of the pulse depend upon the pulse duration and the carrier frequency used. These regularly repeating pulses have a relatively long time delay between them to allow the return echo to be received before the next pulse is transmitted.

If we consider that the speed of light is approximately 300,000 kilometres per second. Then the time taken for a radar signal to travel one metre and back takes 6.7 nanoseconds or 6.7×10^{-9} seconds. How is it possible to measure this transit time and produce accurate vessel contents information?

A special time transformation procedure is required to enable theses short time periods to be measured accurately. The requirement is for a 'slow motion'. We mean milliseconds instead of nanoseconds. Pulse radar has a regular and periodically repeating signal with a high pulse repetition frequency (PRF). Using a method of sequential sampling, the extremely fast and regular transit times can be readily transformed into an expanded time signal. A common example of this principle is the use of a stroboscope to show down the fast periodic movements of rotating or reciprocating machinery.

Pulse radar takes literally millions of 'shots' every second. The return echoes from the product surface are sampled and averaged which is particularly important in difficult applications where small amounts of energy are being received from low dielectric and agitated product surfaces. The averaging of the pulse technique reduces the noise curve to allow smaller echoes to be detected.

Part of the pulse radar transmission pulse is used as a reference pulse that provides automatic temperature compensation within the microwave module circuits.

The benefits of radar as a level measurement technique are clear.

- Radar provides a non-contact sensor that is virtually unaffected by changes in process temperature, pressure or the gas and vapour composition within a vessel.

- The measurement accuracy is unaffected by changes in density, conductivity and dielectric constant of the product being measured or by air movement above the product.

- The echoes derived from pulse radar are discrete and separated in time. This means that pulse radar is better equipped to handle multiple echoes and false echoes that are common in process vessels and solids silos.

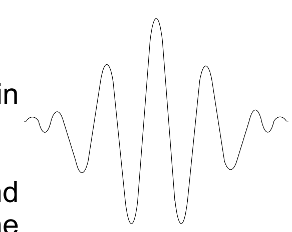

Fig. 13.
Short Wave Packet

ACCURACY OF RADAR LEVEL MEASUREMENT

The parameters that should be considered when selecting a radar level measurement instrument to achieve the desired accuracy are: range resolution (bandwidth) and frequency.

The achievable accuracy of an existing radar level meter depends heavily on the type of application, the antenna design, mechanical installation, the state and quality of the electronics and echo processing software employed. Even though the effects of temperature and pressure variations are infinitesimal, however compensation methods are also used for these parameters. Other influences on accuracy of an existing instrument include signal to noise ratio and interference.

Range resolution is one of a number of factors that influence the accuracy of process radar level transmitters. Higher accuracy of pulse radar level transmitters can be achieved by looking at the phase of an individual wave within the ‘envelope curve’. In process level applications, pulse radar works with an 'envelope curve'. The length of this envelope curve depends on the bandwidth of the radar transmitter. A wider bandwidth leads to a shorter envelope curve and therefore improved range resolution (Fig. 14). This is only practical in slow moving storage tanks. If the liquid level surface is flat calm and the echo has a reasonable amplitude, it is possible to look inside the envelope curve wave packet at the phase of an individual wave.

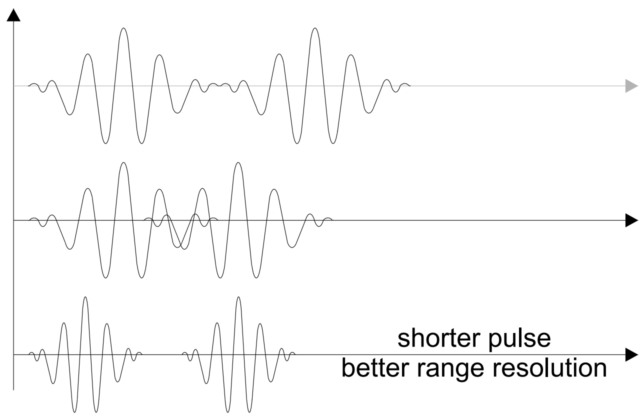

Fig. 14. A shorter pulse has a wider bandwidth and better range resolution.

Higher frequency also results in a more steeper of the envelope curve. The envelope curve of a high frequency radar with a short pulse duration is sufficiently steep to produce a very accurate and cost effective level transmitter for storage vessel applications. On the other hand, high frequency radar transmitters are susceptible to signal scatter from agitated surfaces. The high frequency radar will receive considerably less signal than an equivalent 5.8 GHz radar when the liquid surface is agitated. The lower frequency transmitters are less affected by agitated surfaces. Lower frequency radar is also better suited to solid level applications. Moreover, the high frequency radar level transmitters are more susceptible to steamy and dusty environments and to condensation and product build up on the antenna. There is more signal attenuation at the higher frequencies, such as 26 GHz. A 5.8 GHz frequency radar instrument is more forgiving of product build up.

In theory, the envelope curve of a high frequency radar with a short pulse duration produces a very accurate measurement. A better accuracy will also be achieved, because the leading edge of the envelope curve is steeper. However, very high frequency has averse affects on some applications.

WAVE VELOCITY WITHIN MEASUREMENT TUBE

The speed of microwaves within a measuring tube is apparently slower when compared to the velocity in free space. The degree to which the running time slows down depends on the diameter of the tube and the wavelength of the signal.

There are different modes of propagation of microwaves within a wave guide. However, an important value is the minimum diameter of pipe (d_c) that will allow microwave propagation.

The value of the minimum or critical diameter (d_c) depends upon the wavelength (λ) of the microwaves. The higher the frequency of the microwaves, the smaller the minimum diameter of measuring tube that can be used.

Equation 1 shows the relationship between critical diameter and wavelength. For example, 5.8 GHz has a wavelength of 52 mm and its minimum theoretical tube diameter is 31mm. In practice the diameter should be higher; at least 40 mm.

With a frequency of 26 GHz which has a wavelength of 11.5 mm, the minimum tube diameter (dc) would be 6.75 mm.

$$d_c = \frac{\lambda}{1.71}$$

Eqation 1.
Theoretical Tube Diameter and Wavelength Equation

POWER

The peak microwave power of most process radar level transmitter is less than a milliWatt. This level of power is sufficient for tanks and silos of 40 metres or more.

An increase in the microwave power will produce higher amplitude echoes. It adversely will produce higher amplitude false echoes and ringing noise as well as a higher amplitude echoes off the product surface. The average required power depends on the pulse duration and pulse repetition frequency of pulse radar transmitters.

The low power output from microwave radar transmitter means it is an extremely safe method of level measurement.

AGITATED LIQUID MEASUREMENT WITH RADAR INSTRUMENT

High frequency radar transmitters are susceptible to signal scatter from agitated surfaces. This is due to the signal wavelength in comparison to the size of the surface disturbance.

The high frequency radar will receive considerably less signal than an equivalent 5.8 GHz radar when the liquid surface is agitated. By comparison, 5.8 or 6.3 GHz radar is not as adversely affected by agitated liquid surfaces.

In highly agitated liquid surfaces, installing the radar in a bypass tube ensures a calm surface with no scattering of the echo signal.

CONDENSATION AND BUILD-UP EFFECTS ON RADAR INSTRUMENTS

High frequency radar level transmitters are more susceptible to condensation and product build-up on the antenna. There is more signal attenuation at the higher frequencies, such as 26 GHz. Also, the same level of coating or condensation on a smaller antenna naturally has a greater effect on the performance.

A 6" horn antenna with 5.8 or 6.3 GHz frequency is virtually unaffected by condensation and build-up.

STEAM AND DUST EFFECTS ON MEASUREMENT OF RADAR INSTRUMENTS

Lower frequency radars (5.8 GHz & 6.3 GHz) especially with horn antenna are not adversely affected by high levels of dust or steam. These frequencies have been very successful in application ranging from cement, flyash and blast furnace levels to steam boiler level measurement.

ANTENNA BASICS

An important aspect of an antenna is directivity. Directivity is the ability of the antenna to direct the maximum amount of radiated microwave energy towards the liquid or solid we wish to measure. Two kinds of antennas are used in the process industry: various versions of dielectric rod antenna and horn antenna.

The dielectric rod or horn antenna is connected to the tail of the instrument to ensure outstanding focusing and to direct the maximum amount of microwave energy toward the level being measured and to capture energy from the return echoes. The tapered section of the rod focuses the microwaves toward the material being measured.

The function of an antenna in a radar level transmitter is to direct the maximum amount of microwave energy towards the level being measured and to capture the maximum amount of energy from the return echoes for analysis within the electronics. No matter how well the antenna is designed, there will be some microwave energy being radiated in every direction. The goal is to maximize the directivity.

A measure of how well the antenna is directing the microwave energy is called the 'antenna gain'. Antenna gain is a ratio between the power per unit of solid angel radiated by the antenna in a specific direction to the power per unit of solid angle if the total power was radiated isotropically (equally in all directions).

With horn antennas, this allows smaller nozzles to be used with a more focused beam angle. For example, a 1 ½" (40 mm) horn antenna radar at 26 GHz has approximately the same beam angle as a 6" (150 mm) horn antenna at 5.8 GHz. However, this is not the complete picture. Antenna gain (G) is dependent on the square of the diameter (D) of the antenna as well as being inversely proportional to the square of the wavelength (λ). Antenna gain also depends on the aperture efficiency (η) of the antenna. Therefore the beam angle of a small antenna at a high frequency is not necessarily as efficient as the equivalent beam angle of larger, lower frequency radar.

$$\text{Antenna Gain} = \frac{\text{Directional Power}}{\text{Isotropic Power}}$$

Eq. 2. Antenna Gain

$$G = \eta \left(\frac{\pi \times D}{\lambda} \right)^2$$

Eq. 3. Antenna Gain

DIELECTRIC ROD ANTENNA

Dielectric rods are made of polypropylene (PP) or Teflon (PTFE) and can be used in vessels nozzles as small as 40 mm (1½"). The microwaves travel down the inactive parallel section of the rod towards the tapered section. The tapered section of the rod focuses the microwaves toward the liquid being measured. It is imperative that all of the tapered section of the rod be inside the vessel, but not a good practice to allow a rod antenna to be immersed in the product. If a rod antenna is coated in viscous, conductive and adhesive product, the antenna efficiency will deteriorate.

Rod antennas are usually used for liquids and slurries, while horn antennas are recommended for powder and granular applications.

HORN ANTENNA

The metallic horn antenna or cone antenna is well proven for process level applications. The horn is mechanically robust and generally is virtually unaffected by condensation and product build up, especially at the lower radar frequencies such as 5.8 GHz or 6.3 GHz (Indumart LTR700). There are variations in the internal design of horn antennas.

The operating principal is that the microwaves that are generated within the microwave module are transmitted down a high frequency cable for encoupling into a waveguide. The metal waveguide directs the microwaves towards a low dielectric material (PTFE) machined to a pointed cone and then the horn of the antenna. The microwaves are emitted from this pointed cone in a controlled way and then are focused towards the target by the metal horn. After reflection from the product surface, the returning echoes are collected within the horn antenna for processing within the electronics.

RADAR LEVEL TRANSMITTER FROM INDUMART

Indumart *LTR700 Series* Radar Level Transmitter is capable of monitoring virtually any short to medium range non-contact measurements of liquids and most free flowing solids (granules and powders). In applications characterized by dust, the instrument demonstrates notable stability by adjusting itself to the severity of the process. Measurement is virtually unaffected by changes in process temperature, pressure, density or gas/vapour composition within the vessel.

A dielectric rod or horn antenna is connected to the tail of the instrument to ensure outstanding focusing and to direct the maximum amount of microwave energy toward the level being measured and to capture energy from the return echoes. The tapered section of the rod focuses the microwaves toward the material being measured. Polypropylene, PTFE, High temperature with de-coupler and 2" sanitary antennas are available.

Optional RS232/RS485 communication provides both remote programming of and acquiring information from the field devices. The *LTR700* with digital communication and the configuration software, which runs under Windows®, enables remote programming of the field devices and viewing of the primary measurement values on a computer via EXCEL® application. Programmable system is usually recommended, which gives the opportunity to declare both the dielectric constant of the material and the severity of the process to optimize level measurements.

Other features of the *LTR700 Series* include: (1) fully self diagnostic system with individual error message; (2) service and test parameters read out, which reports on the operating conditions, echo profile, noise level and more to facilitate the installation and troubleshooting of the system.

The optional remote display (DIS300) may also be added to this radar level measurement system to indicate the process value on its 4-digit display and to initiate alarm contact at 2 points.

Fig. 15. Indumart LTR700 Radar Level Transmitters