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SMARTLINE TRANSMITTER - LEVEL ALGORITHM

Executive Summary

The level algorithm used by the Smartline"; Level Transmitter SLG700 series provides exceptional level identi·ication and r-eliabilityof level tracking. This isbased on an advanced correlation algorithm which compares the measurement signal with an intema. model of the expected level reflection. locking onto the correct level reflection. and providing reliable level tracking.

In addition to-::he core correlation algorthm. the instrument uses auto-amplitude tracking and dynamic background functionalitywhich enhance the long term performance of the instrument in demanding process applications.

White Paper

The Theory of Operation for Guided Wave Radar Measurement

Distance to Surface calculation:

$$d_s = \frac{t * V_{wg}}{2 * \sqrt{DCv}}$$

Where:

d, = distance to surface

t = time for the pulse to travel distance ds

Vwg= speed of light in a vacuum on the probe

DCv = dielectric constant of the material in the head space above the level (for air, DCv = 1)

In case there is a second liquid in the bottom of the tank, with a dielectric constant DCL, a second reflection would appear from the boundary between the first and second liquid. This second reflection would allow to calculate distance di to this boundary and the Interface position. The calculation is not provided in this document.

Guided wave radar (GWR) provides level measurement based on the Time-Domain Reflectometry (TOR) principle. Electromagnetic measurement pulses are guided to the measured material by a metallic probe. When the pulses reach a product surface or interface (boundary between two liquids), a portion of the pulse will propagate through the surface and the rest will be reflected backwards. The same probe transports the reflected pulses from the measured material back to the transmitter.

The electromagnetic measuring signal (pulse) travels at the speed close to the speed of light in air. If the atmosphere above the surface of the medium is filled with gas other than air, the pulse speed will be less than the speed of light in air by an amount which can be calculated knowing the 'dielectric constant' of the gas.

The transmitter measures the time of travel of the reflected signal and calculates the distance to the reflection point. The level of the material can be calculated based on the distance from the transmitter to the material and the dimensions of the container as illustrated in Figure 1.

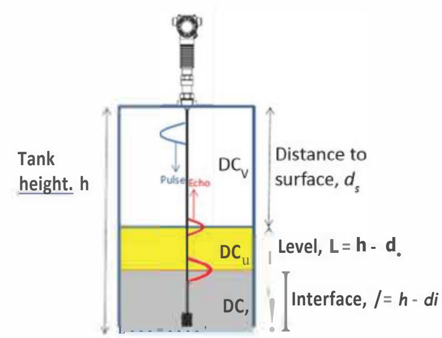

Figure 1: **Level measurement.** This figure shows the Guided Wave Radar instrument mounted on a tank. The blue curve represents the electromagnetic measuring Pulse sent by the instrument. The measuring Pulse travels through a vapour above the liquid in the tank. The vapour has a dielectric constant equal DCv. The red curve represents the reflected Echo from the surface of the measured liquid. The measured liquid has a dielectric constant equal DCu. The figure also shows the Distance to surface ds. In case there is a second liquid in the bottom of the tank.with a dielectric constant DCL, a second reflection would appear from the boundary between the first and second liquid. This second reflection would allow to calculate distance di to this boundary and the Interface position. The calculation is not provided in this document.

Benefits of the GWR Technology

The Guided Wave Radar technology is based on sending and receiving of an electromagnetic signal. This feature makes the measurement more immune to the influence of mechanical properties of the atmosphere in the tank than measuring technologies relaying on mechanical waves, for example ultrasonic measurement. The mechanical influences in the tank could be vapors, dust, changes of temperature and pressure, or foaming.

GWR technology is also immune to changes in the density (specific gravity) of the measured liquid, which normally affects measurements based on hydrostatic pressure or buoyancy methods.

Another benefit coming from the GWR technology is a strong signal focused around the metallic waveguide. This allows reliable measurement in small, tall and narrow, or busy tanks.

Correlation Algorithm - a Method to Find the Right Distance to Surface of Product

SLG 700 series level transmitters employ advanced signal processing techniques in order to get the most accurate measurements possible. This techniques allow the instrument to extract signals in the presence of interferences caused by thin interfaces, probe ends, in-tank obstacles, build-up, etc. Whereas all competitors use a simple peak-finding algorithm, the SLG700 instrument uses a correlation algorithm which helps to discern the true reflection peak from unwanted reflections. A typical echo curve representing the reflection of the measuring signal in the tank is shown in Figure 2 *(refer page 7)*. A reference reflection pulse represents reflection of the measuring signal in the process connection. It is used as a reference for the distance measurement. A Surface reflection pulse represents reflection of the measuring signal from the surface of the measured liquid in the tank. The distance measured between these two reflections (including a calibration factor) is the distance to surface ds described in the previous section.

The method by which the correct Surface reflection pulse is identified is based on the correlation between the shape of the measured echo curve and the shape of an internal reflection model, stored in the memory of the radar instrument. The specifics of the internal model are explained in the following section. The algorithm slides the model across the echo curve, and at each step calculates the difference between the model and the echo curve. This difference is known as the Objective Function. Complete pulse-shape information including amplitude, width and side-lobe attenuation is used in this process for level detection in order to minimize the influence of signal interferences. This method is further illustrated in Figure 3 *(refer page 7)* which shows the DTM display used for configuration of the algorithm. The blue curve in the upper graph represents the echo curve which is the signal received by the instrument from the tank. The brown curve represents the internal model of the reflection. The objective function is shown in the lower graph in brown with the threshold line in red.

Typically the smallest value of the Objective Function corresponds to the level selected by the sensor algorithms but the values must be below a user defined threshold. In case of multiple local minima, there is additional logic to select the best candidate. The final best candidate is used to calculate the distance to the product surface.

The Internal Reflection Model for Radar Impulse

The correlation algorithm implemented in the SLG700 has an internal model of the predicted shape of impulse reflection from the measured surface. The model is compared with the real reflection curve, to find the best correlation using the objective function, to detect the level. The model is a damped cosine function that can be adjusted with a few parameters: gain, width, and attenuation. The model and its main parameters are illustrated in Figure 4 (refer page 7).

A good match between the internal reflection model and the real reflection from the tank is important to discern the true level signal from that caused by obstacles near the probe or secondary reflections.

The sensor is pre-programmed with default values for all parameters defining the internal reflection model, determined by the dielectric constants of the materials being measured. These parameters can be adjusted, either through the advanced display or the Honeywell DTM, to match the measurement conditions, if needed. Typically, the gain (also referred to as amplitude) of the model is the only parameter that needs to be adjusted if the programmed DC value of the material does not match its true DC. Each time a change in the algorithm parameters is needed (for example, when moving the instrument to another tank) the detailed parameters can be automatically calculated by the instrument, based on the basic parameters entered by the user.

Benefits of the Correlation Algorithm

The use of Honeywell's Correlation Algorithm allows reliable detection of the correct surface reflection. The identification of the whole shape of the reflected pulse is more reliable than relying only on the amplitude of the reflections as is typically done by other level-finding algorithms. The Correlation method allows the transmitter to reliably distinguish between the true surface reflection from the measured liquid and other stray reflections in the tank: from obstacles, mounting features, product build-up, and double reflections of the radar signal. Additionally, the Correlation method allows to selectively follow small reflection from the surface of liquids with small dielectric constant (for example liquefied gases like LPG and light hydrocarbons).

When the instrument is following the level of two liquids in the tank, for example hydrocarbon and water, the use of correlation algorithm allows to obtain best in class precision and to detect a very thin layer of the upper liquid.

Auto-Amplitude Tracking

Auto-Amplitude Tracking is an innovative feature allowing improved level tracking under difficult conditions or when the material attenuation is not well known. The amplitude tracking feature enhances the user specified pulse model information using historic measurement data. Once the sensor has locked onto a correct level, it will track the amplitude rather than use the initial (user specified) model amplitude.

This feature improves the quality of the match when there are varying conditions, such as temperature variations, vapor density changes, turbulence or even dirt buildup on the probe. Amplitude tracking helps track signals that can be up to 35% different in amplitude from those initially expected.

Benefits of the Auto-Amplitude Tracking

This innovative feature allows the instrument to automatically adopt to changes in the amplitude of the reflected signal caused by changing conditions in the tank. This could be changes in the conditions in the tank such as temperature variations, vapor density changes, turbulence or build-up of a film on the probe. Also, this feature is helpful when the dielectric constant of the measured liquid changes with time, or between batches. Standard GWR algorithms used for level detection purely based on amplitude evaluation, have limited tolerance to changes in the amplitude of the signal reflection from the liquid in the tank. They require adjustments and maintenance, when the conditions in the tank vary. The Auto-Amplitude Tracking feature of the SLG700 allows to save time on maintenance, and provides continuous level measurement even under changing process conditions. One of examples here may be chemical production, where additives are selected based on recipes and fast readiness of the production line is critical for efficiency of production.

Dynamic Background Functionality

The physical components used to mount the transmitter to the tank will always cause some reflection of the radar pulse as the pulse leaves the confines of the process connector and starts to travel through the medium in the region near the reference plane. Depending on the configuration, these reflections may appear very similar to the reflections from the products in the tank and therefore should be ignored. In addition, obstacles close to the wave guide can cause reflections that mimic level.

Unwanted reflections can also occur from deposits on the probe or from interfering structures near the probe such as an inlets, outlets, and ladders. Interferences near the top and bottom of the probe can be eliminated by configuring the top and bottom blocking distances in which these interferences occur. In addition to this, the SLG 700 transmitter utilizes means of ignoring these static background reflections before processing the data for reflections from the product(s). There are two types of background echo acquisition modes available in the instrument, and either can be operated statically or dynamically.

The Field Background is meant to reduce the effect of the process connector reflection created when the radar pulse traverses between two regions of different impedances. This background is targeted for easy removal of interferences related to instrument mounting. It works best in large tanks with sufficient free space around the waveguide.

The Obstacle Background can be used in place of the Field Background and is intended to both suppress process connector reflections as well as any false echoes generated by obstacles in the tank (ladders, pipes, valves) in the vicinity of the probe. There is no limit on the length that can be specified by the user.

Both of the above Backgrounds can be automatically updated by the instrument. The intent of this feature is to provide enhanced immunity against changes in measurement conditions. With dynamic backgrounds enabled, the sensor periodically schedules automatic updates to the background. Echoes are only collected if the level is outside of the transition zones and the signal is of good quality.

The most recently updated background is stored in permanent memory and is applied after a sensor reset if dynamic background is enabled. At all times the sensor maintains a copy of the original user acquired (static) background echo and will revert to this if the dynamic background feature is once again disabled. It is recommended that this feature is turned on in all installations where build-up is expected on the probe or on the internal components of the tank, or when large ambient temperature swings over 30˚ C are expected.

Benefits Provided by the Dynamic Background Functionality

This functionality helps save maintenance time in applications where the medium or process causes changes in the tank, by building up on internal structures or instrument waveguide. This is often the case in water based media, solutions, mixtures, or melted products in chemical processing. The feature allows to update the background as often as every hour, providing worry free level measurement.

Summary

The presented level algorithm allows for reliable and robust level determination and tracking. This benefit comes with an automated setup of parameters, based on application data, so that the end user may profit from the robust measurement with very easy setup. Auto-amplitude tracking and dynamic background functionality enhance the long term performance of the instrument in process applications with varying temperature, pressure, changing characteristics of the measured liquid, or build-up inside the tank.

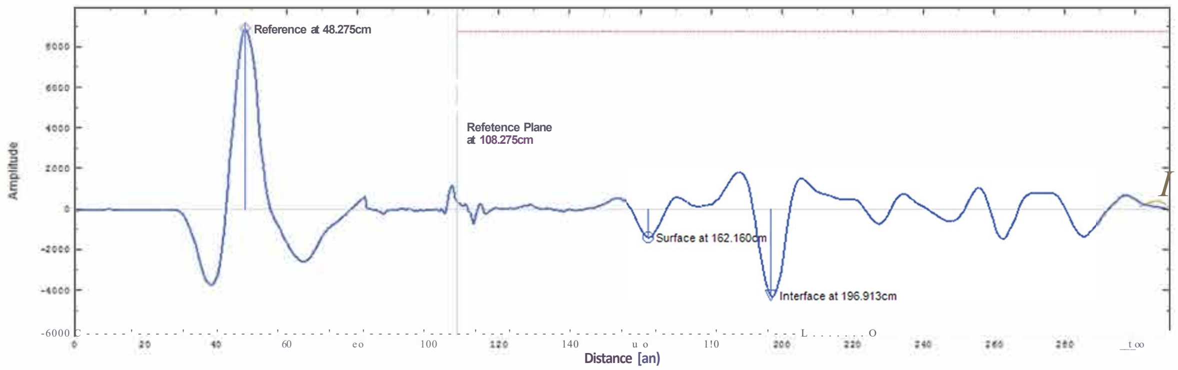

Figure 2: **Typical echo curve.** This figure shows a typical echo curve (signal reflection) as obtained by the instrument. Starting from the left, the large peak represents internal reflection of the electromagnetic wave in the process connection. The position or Lhis rerlecLion is consLanl, and il is regarded as a rererence, ror lhe rneasuremenl. Nexl. Lhere is a peak lhal represenLs reflect'1on from the surface of the liquid in the tank It is marked as Su1·face. The following peak represents reflection from the interface. between two liqu·1ds in the tank. This peak exist only in case of interface measurement (for example. hydrocarbon liquid above water in a storage tank). Another peak may be visible on the far right side. representing reflection from the end of th8 probe. It can b8 setJn when the tank is 8mpty or when th8 tank is filled with one liquid with small d·1el8ctric constant This peak is not shown in this figum.

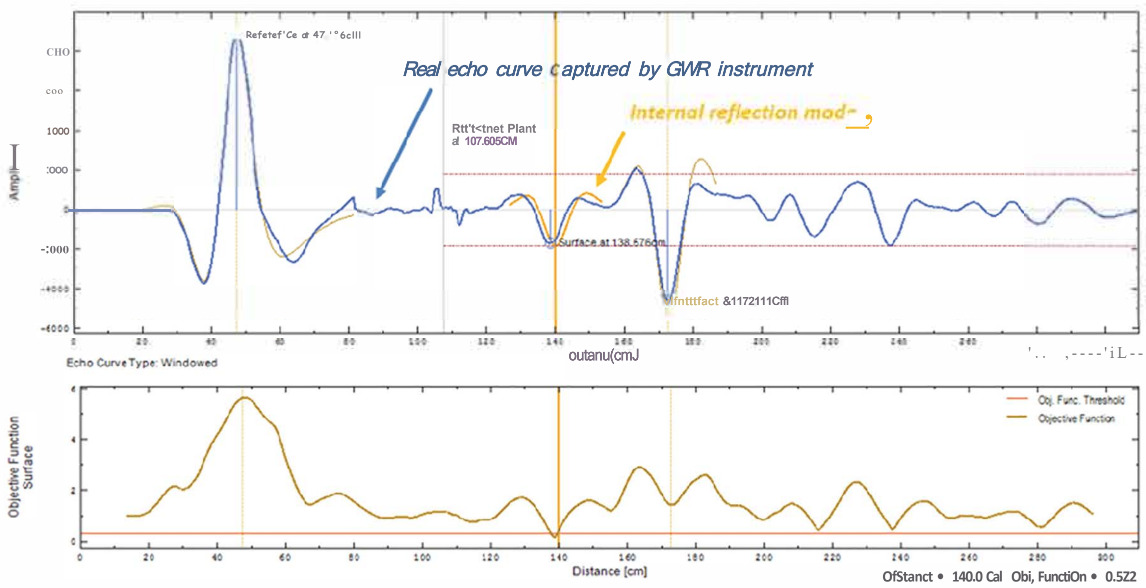

Figure 3: **Representation of the correlation algorithm.** This figure shows the □TM display used for configuration of the algorithm. The blue curve in the upper graph represents the echo curve which is the signal received by the instrument from the Lank. The brown curve represenls Lhe inlernal model or lhe reflection. The objective runclion is shown in Lhe lower graph in brown with the threshold line in red. Typically the smallest value of the Objective Function corresponds to the level selected by the sensor ulgorithms but the vulues must be below il user defined threshold (represented by the red line). In cuse of multiple locul minimil, there is cl1ddition1ll logic to select the best c,mdidc1te. The fincl1 best cc1ndidc1te is used to cc1lculc1te the distilnee to the product surface.

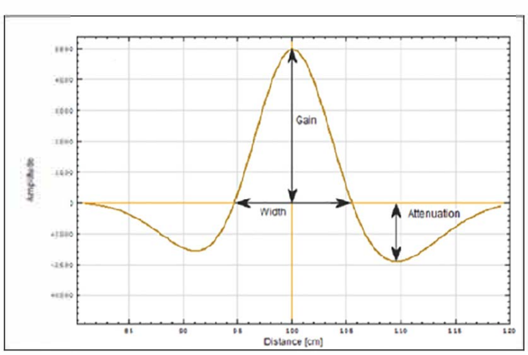

Figure 4: **Internal Impulse Reflection Model.** This figure shows the internal model or lhe rerleclion. which is used by lhe correlation algorilhrn Lo calculate the objective function and find the best match with the reflection of the surface in the tank.

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