Abstract

Accurate and reliable process measurement is critical to the ongoing productive operation of a cement plant. The key to any successful automation project is the correct application of the most appropriate field devices. Many types of instrumentation, sensors, and continuous weighing equipment that might be installed in an ordinary process plant are not suitable for the harsh environment encountered in the cement industry. In particular, the industry is recognised as having some of the most difficult level measurement applications to solve, given the high temperatures and dusty atmospheres. New technology offers better performance and reliability for some of the more problematic installations. In addition, the growing use of alternative fuels presents new measurement challenges. This article looks at the proper application, use, and maintenance of typical field devices and demonstrates these by providing specific examples from the cement industry. It

also looks at future trends in smart sensors, as well as wireless communications, which offer potential benefits to the cement industry.

Introduction
The reliable operation of field devices is critical to any successful process control system. A typical cement plant environment presents many challenges, particularly in areas with dust or high temperatures. Suppliers of instrumentation must focus on the specific needs and direction of the cement industry in order to provide the most appropriate measurement capability, as well as to interface with the plant’s control system.

Level measurement
Effective and reliable level measurement is difficult in cement plants because of the need for long-range sensing as well as the presence of dust and high temperatures. Level sensors can generally be divided into two groups, ‘continuous’ and ‘point’. ‘Continuous’
sensors measure material throughout the entire span of the vessel and ‘point’ sensors are solely for switches or alarms. Most level sensors used in the cement industry measure the empty distance from the top of the silo to the surface of the material. The device then subtracts this empty distance figure from the overall holding span of the vessel to compute material level. This section will mainly focus on continuous level measurement because it is often the most complex.

The challenges of solid level measurement

The number one problem with solids is dust. In contrast, liquids in bulk storage offer a relatively easy environment for level measurement. The liquid surface is large and flat, offering excellent reflection properties for non-contact technologies. For contacting devices, liquids present no abrasion issues or strong tensile forces that might be cause for concern. The environment above the liquid surface is typically placid. On the other hand, solids materials can present an aggressive environment with a range of unique challenges, including various surface dynamics, tensile forces and silo obstructions. The surface of solids can vary enormously. The angle of repose may be flat and smooth. More often, however, solids have a sharply sloped and irregular surface, as is typically the case with aggregate materials. Particle size ranges from very fine powders, such as finished cement, to coarse materials, such as clinker or coal.

Tensile forces further complicate solids measurement. Tensile forces in tall solids silos can reach several tons. As material is drawn from the vessel, the intense force can break off cables or moving parts within the silo. This makes contacting cable or mechanical systems problematic. Vacuum dust collectors, filling streams, aeration devices, static electricity, acoustic and electromagnetic noise are also significant factors in solids silos. This is why many cement producers worldwide have relied for years on manual measurements taken from the top of the silo using a rope/tape and weight.

The evolution from contact to non-contact level measurement

For many years, the industry installed mechanical level devices. These devices, often known as ‘Yo-Yos’, used a weight suspended by cable. This weight was lowered on a timed basis automatically into a silo to detect the surface of the material. The device computed the level by measuring the specific length of the cable required to contact the material. The technology was simple and easy to understand but it had several drawbacks. It required frequent maintenance because material got carried into the spooling mechanism for the cable. Cables would break on occasion and damage material handling components downstream from the vessel.

Ultrasonic sensors

These problems can be avoided by using non-contacting measurement technology that does not touch the material. The first non-contacting technology accepted by the industry was ultrasonic level sensing. This uses sound waves, ranging from 10 to 40 kHz, with the lower frequencies of that band often applied in long-range measurement for solids. An ultrasonic pulse is transmitted using a piezoelectric crystal based transducer. This signal is reflected by the surface of the material to the transducer where a processor computes the time of flight and converts that information into an empty distance value and subsequent material level. Many transducer setups also include an internal or separate temperature sensor to compensate for the effect of temperature on the velocity of sound (Figure 1).

Ultrasonic sensors, however, are not without their problems in environments such as cement plants. Their transmission through air can be significantly affected by dust, vapour, pressure and temperature. These can either attenuate the signal or change the speed of sound. Dust proved to be a particular problem for measurement...
during fill. In addition, some high temperature settings can exceed the specifications for the transducer. However, improvements in ultrasonic technology for dusty solids helped the sensor industry to improve level processing algorithms and better manage the influence of angles of repose. Modern ultrasonic systems now evaluate and process the entire reflected spectrum of the vessel and employ sophisticated algorithms for choosing the most probable level echo. Ultrasonic sensors remain a cost-effective and reliable solution for aggregate materials and some powders in vessels less than 15 m (50 ft.) high; for example, raw material bins. They are also very cost-effective and successful in many liquid level applications (Figure 2).

**Radar sensors**

Radar (RAdio Detection And Ranging) technology has been used successfully for level measurement since the 1970s. Initially, this non-contacting technology was applied to custody transfer applications on large storage vessels. Very high accuracy devices, with precision capabilities down to a few millimeters, were used. Custody transfer applications need this level of accuracy because small changes in level in large capacity storage tanks can yield large volume errors. However, such radar sensors were very costly and relied on a smooth liquid surface to function properly. More recently, as cost decreased and technology developed, radar devices have been simplified and introduced across a much wider range of applications, including smaller liquid bulk storage and agitated process vessels. New types of radar sensors for level measurement on solids have been developed with many being installed in the cement industry.

Radar is a suitable technology for use with solids and overcomes many of the limitations of ultrasonics. It uses electromagnetic waves in the microwave spectrum between 1 and 300 GHz. These waves travel at the speed of light and are virtually unaffected by dust vapour, pressure, or temperature, giving radar an advantage over previous technologies. However, radar instrument design has to take account of the particular characteristics of solids level measurement. Devices that work well on liquid applications often do not perform well on solids. That is because the level measurement challenge on solids is different in many ways from measurement on liquids.

**Radar frequency and processing**

Although the microwave spectrum ranges between 1 and 300 GHz, most radar level measurement systems operate between 6 and 26 GHz. It is a compromise between optimum performance and the frequencies allowed by regulating agencies. The first radar devices used 10 GHz FMCW technology and this frequency is still widely used today. Low frequency devices operate around 6 GHz, and high frequency radars function in the 24 GHz band range.

Radar propagation can be pulsed or use FMCW (Frequency Modulated Continuous Wave). Pulsed wave
Case study: level measurement in waste fuel tanks

Background

Another use for radar in the cement industry is to monitor level in waste fuel tanks. For example, one plant has 6 x 10 m (30 ft.) tanks onsite for storing waste fuels. Continuous level measurement is essential to avoid overfilling and costly cleanup. Operators also need to be able to monitor and adjust fuel-blending ratios and track inventory.

Challenges of waste fuel level monitoring

In the past, measurement was difficult because of the many chemicals stored and because each tank has a rotating agitator to keep solids in suspension. A non-contacting solution was required that could cope with multiple materials and agitation in the tank. These materials often change and could be anything from used oil to solvents like acetones, methyl ethyl ketone, or toluene. Some of the liquids had been difficult to measure because they generate vapour strata and are corrosive. An installed device would also have to meet strict hazardous area classification requirements.

The two-wire radar solution

The plant installed two-wire, loop-powered 6 GHz radar instruments designed for liquid storage applications. These devices have a polypropylene rod antenna with an integrated threaded connection that is hermetically sealed to maintain chemical resistance and impermeability. The rod material is also chemically compatible with the various types of fuels. Auto false echo suppression and level algorithms help avoid false signals created by the agitator blades. The unit also included an intrinsically safe classification that met hazardous area requirements.

case study: level measurement in waste fuel tanks

Before false echo suppression

After false echo suppression

False echo suppression for agitator blades.

radar processing is similar to ultrasonic non-contact technology, except that the radar signal is travelling at the speed of light versus the speed of sound. The FMCW technique for radar propagates at the speed of light, sending millions of signals in a short duration of time at frequencies sweeping from 24 to 26 GHz. The return signal frequencies are received and compared to evaluate how they may have changed between transmission and reception. The differential in frequency is proportional to the distance from the sensor to the surface of the material. Because the transmission is at the speed of light, microwave echoes are evaluated using a sequential sampling method, which essentially builds a profile by expanding the time. FMCW radar utilises Fast Fourier mathematics to process the large amount of data (Figure 3).

Radar signals are reflected by a significant change in dielectric constant. The relative dielectric constant of a material under given conditions is a measure of the extent to which it concentrates electrostatic lines of flux. It is the ratio of the amount of stored electrical energy when a potential is applied, relative to the permittivity of a vacuum. For example, the baseline dielectric constant of a vacuum is 1, while water is 80, and cement about 5. For a given output signal amplitude, low frequency radar requires a much larger antenna. Antennae may be constructed in a rod type design, which is common on liquids, or a horn that is suited towards solids or difficult liquid applications. For example, a 6 GHz radar device will require a 400 mm (16 in.) diameter horn to obtain the same signal as a 24 GHz radar device using a 100 mm (4 in.) horn.

Radar sensors and the cement industry

Low frequency, traditional radar devices are well-suited to liquid applications. However, to use them effectively...
on solids applications requires a large horn up to 250 mm (10 in.) dia. or even a parabolic dish antenna to capture sufficient signal. This large antenna is just not practical on most vessels. Where process connections are available, they are normally too small to accommodate a large antenna without costly modifications. If a connection must be created, it is often less costly to create a small opening, particularly if the vessel roof is concrete. With its smaller antenna sizes and ease of installation, high frequency radar offers significant advantages for solids applications.

Vessels vary in shape and size, and may contain various internal challenges. Silos assembled in sections have seams that may create false signals. Internal ladders, man-way access hatches, point level switches, and even fill streams are potential false echo signals for level measurement equipment. Silos containing finished cement are often tall and narrow, some over 50 m (150 ft.) high. For all of these situations, narrow conical beam angles are preferable to reduce sidewall path interference and reduce false signals from internal obstructions.

**Advantages of high frequency radar**

High frequency radar provides a narrower beam angle than low frequency radar. For example, a 24 GHz radar instrument has a narrow 9° conical beam angle compared to a 36° angle for a 6 GHz instrument with a 100 mm (4 in.) dia. horn antenna. This makes high frequency radar instruments more effective on solids. Smaller antenna, easier installation and a narrow beam angle are important advantages of the higher frequency radar instruments. Another substantial benefit of higher frequencies is the reflection property from sloped solids surfaces as it relates to wavelength and “skip” effect. A wave striking a sloped surface may reflect directly back or it may skip away from the sloped surface, or both. This causes the signal to diverge into two or more paths so that the receiver sees noteworthy multiple signals instead of one dominant reception. Severe “skipping” may result in the second echo being higher than the first one. This is a common problem for low frequency systems on solids and notably degrades the signal to noise ratio. This was a key issue that prevented radar being suitable for solids level measurement for some time. Using a high frequency ensures that the largest amount of signal reflects directly from the sloped surface.

Choosing the most appropriate radar technology is important for securing optimum reflection properties. Aiming the antenna towards the angle of repose will also further enhance return signals. The angle of repose will, of course, change during filling and emptying. However, aiming the antenna towards the material outlet is a good compromise that provides the highest signals possible over the full measurement range. A radar instrument designed for solids applications usually incorporates an aiming flange to facilitate alignment and commissioning of the system. Proper aim significantly increases the amplitude of the signal and reduces subsequent indirect or multiple echo signals.
Overcoming powder buildup
Dry powders may accumulate on the inside of the horn antenna system, but will generally be transparent to the instrument if it is a light coating. Materials like cement have low dielectric constants and the electromagnetic waves will pass through while still maintaining sufficient signal strength. However, if buildup is severe, particularly on the emitter, a radar device will normally produce a false high-level reading. If the problem is not regular, it may be acceptable to remove and clean the antenna perhaps once every six months. Otherwise, a self-cleaning antenna utilising an air purging system is one solution, or possibly a Teflon cap covering the horn. The purge medium can then be activated periodically, either manually or by an automatic control valve. It is critical that the purge air be clean and dry (Figure 6).

Two-wire vs. four-wire radar
Two-wire, loop-powered radar devices are good solutions for liquid bulk storage vessels. These applications are generally short range, typically less than 15 m (50 ft.), on slow moving, flat surfaces. However, problems can occur when such devices are installed on long-range solids applications. Some loop-powered devices may perform on short-range solids applications where the material rests very flat, but, in most solids applications, the return signals will be weak. Signal amplitude is reduced with beam spreading, which means that signals are weaker as the distance increases. In addition, any slope or irregular surface of the solids material will further reduce the available signal. For these reasons, a high power radar device is a more appropriate solution for solids measurement. Radar that uses four-wire AC line power to ensure sufficient signal return and accommodates the challenges for long-range solids level measurement is generally more suitable for cement applications. This also enhances the signal to noise ratio, which allows plug-n-play style commissioning.

Looking ahead – phased array technology
Future generation solids level radar may employ phased-array technology to measure and map the entire surface of material in a silo. However, the cost for such technology would have to drop significantly in order to be suitable for plant instrumentation. In the meantime, some type of gimbal-mounted single transmitter radar might be possible. However, the downside could be significant maintenance for such a unit, as it would include moving parts installed in a relatively harsh environment. Such a unit would likely need an encapsulated antenna.

Level measurement firmware
Any hardware platform for level measurement in the cement industry needs to be supported with firmware capable of learning and compensating for changing conditions and false returns. False returns can be caused by obstructions or during fill. Radar level sensors for solids and liquids generally incorporate next generation echo processing technology gathered from industry suppliers’ experience in applying ultrasonics on difficult installations. Many radar units have been successfully installed in finished cement, homogenisation, clinker, raw material, coal, pet coke, and kiln dust silos. In addition, as technology and capability increase, it will be important to maintain and develop user interfaces that are simple to understand and operate (Figure 7).

Installation
Correct installation is a vital final step to ensure reliable level measurement. Many issues with level instrumentation are associated with improper installation. Most manufacturers of instrumentation products have product manuals and application guides online and available for download. Many also offer a free applications engineering review and telephone technical support that may be used in advance to discuss installation. Suppliers typically provide a data sheet for users to complete. Experienced application engineers at the factory review this information to provide the most appropriate solution. It is good practice to include any drawings or a basic sketch of the vessel, including fill inlets, dust collector points and obstructions, as well as available sensor mounting locations (Figure 8).

Flow measurement
Coriolis technology offers a universal flow measuring principle for both liquids and gases. It offers simultaneous and direct measurement of mass flow, density, temperature and viscosity. The measuring principle is also independent of the physical fluid properties. This type of device also offers very high measuring accuracy, typically ±0.1% of rate with turn-down (flow range) generally in the 100:1 area. Some Coriolis flowmeters have the capability for up to a 1000:1 turn-down ratio.
Case study: using Coriolis technology to control dosing of grinding additives

Background
The continuous improvement of product quality, productivity and safety are the main goals of one privately-owned cement producer. The company is constantly investing in the expansion and modernisation of its two European production facilities. Key process goals are to reduce energy consumption, minimise emissions and optimise the use of raw materials. Recent process improvements included modernising the process control system. However, even a highly advanced control system is reliant upon correct and dependable information from the field. For this reason, the company decided to automate traditionally difficult areas, such as the metering of milling additives, using the latest generation of field devices.

Grinding additives
Cement operations mill clinker together with materials such as gypsum, slag and lime to make the finished product. Grinding additives ensure smoothness of milling and accelerate the process. The addition of metered quantities of these agents gives the cement a finer granulation and better flow properties, which in turn means lower handling costs. Grinding additives thus improve the quality of the cement. These substances also make it possible for the clinker to be partially supplemented by inexpensive substitutes, such as slag, light ashes, or fillers such as limestone. The company utilises glucose to increase the grinding output of the mill and improve productivity.

The challenges of accurate dosing
Adequate dispensing of the grinding additives can be a difficult task. Using too little of the grinding additive means that the mill does not run at optimum performance. Dosing too much, however, means that the material runs through the mill without being sufficiently ground. The grinding agents are also non-conductive, rendering traditional magnetic-inductive flowmeters ineffective. In addition, very small quantities of the grinding agents have to be accurately dosed. An 80 m length of the connected pipe causes pressure drop issues and the aggressive medium makes stainless steel piping necessary.

The Coriolis technology solution
The cement producer installed mass flowmeters utilising Coriolis technology to ensure correct and reliable measurement. A dosing pump dispenses grinding additives at varying rates depending on the type of cement produced. Stainless steel construction is generally a standard for Coriolis flowmeters. The diversity of cement blends produced by the company stipulates that the flowmeter must be able to cover a very wide measurement range and, in this case, a 20:1 turn-down. Turn-down is defined as the capability for accurate measurement from the highest to lowest flow rate.

How does Coriolis technology work?
If a moving mass is subjected to an oscillation perpendicular to its direction of movement, Coriolis forces occur depending on the mass flow. A Coriolis mass flowmeter has oscillating measurement tubes to generate such effect. Coriolis forces are produced when a fluid flows through these oscillating tubes. Sensors at the fluid inlet and outlet register the resultant phase shift in the tube’s oscillation geometry. The processor analyses this information and subsequently computes the rate of mass flow. Furthermore, the specific oscillation frequency of the integral measuring tubes is also a direct measure of the fluids’ density. The temperature of the measuring tube is recorded to compensate for thermal influence.

Coriolis technology is also an effective solution for flow measurement of waste fuels. It functions well even when a variety of materials are measured. Producers consider fuel density an important parameter and such information is available using this technology. The downside to Coriolis flow is that it is more costly than other technologies and should be isolated from significant plant area vibration. Manufacturers can provide more information specific to particular models and installation guidelines (Figure 9).

Dynamic weighing
Demand for tyre-derived fuels has grown significantly because of rising fossil fuel costs. Some 50 to 60 million tyres are burned annually by the US cement industry, accounting for just over 40% of all tyres used as fuel (estimates from the US Environmental Protection Agency and the Rubber Manufacturers Association).

The cement industry often burns scrap tyres as fuel in kilns used in the production of Portland cement. Some cement kilns will accept whole tyres. This is advantageous since it avoids the extra costs of creating tyre chips and avoids the removal of the steel in the tyre. It is critical to weigh tyres as they are fed into the kiln in order to control the added BTU value, control gases and maintain balance in the process.

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The cement industry needed a weighing platform of rugged design proven in the field. Therefore, a heavy-duty dual idler conveyor belt scale design was modified to weigh tyres, as well as to provide the control system with a tph feed rate and ongoing total weight of tyres delivered into the kiln. The belt scale incorporates four stainless steel parallelogram load cells to weigh the tyre span within an accuracy of +/- 0.5%. Parallelogram load cells substantially reduce horizontal influences from the belt movement by only responding to vertical forces. The system also employs a belt speed sensor mounted to the tail pulley shaft and a processor for integrating both speed and load signals to continuously compute mass rate (Figure 10).

Field device management

A growing trend in instrumentation is the application of systems to programme, diagnose and recommend maintenance for field devices. Such systems are integrated into the plant’s process control system and may communicate with field devices using an adopted industry standard protocol, i.e. Profibus, Foundation Fieldbus. These systems are often termed process or field device managers (Figure 11).

They allow the user to access any instrument or field device digitally connected to the process control system. Process device managers allow the plant to back-up parameters as well as access programming information or diagnose potential problems from a workstation connected to the central control system. In some instances, a visual inspection of the device might be required, but there are many occasions where an instrument specialist might save time by not needing to visit the installation to gather data.

Process device managers can also work independently of the control system. Stand-alone versions are typically available that may be installed on a notebook style computer. The technician can connect the process device manager directly to the instrument using an industry standard protocol. This allows the user to obtain and display much more diagnostic information from the instrument. Plant personnel also have the capability to send this diagnostic and programming information to factory technical support for review and analysis.

Process device management better integrates the field level throughout the entire system by enhancing the availability of information and access to instruments. It is an important part of the foundation for totally integrated automation (Figure 12).
New developments in field devices

**Intelligent field devices**

Some capability currently exists within instrumentation for self-diagnostics, although it is limited to very basic information. This information may not be available for transfer into the plant's control system and, even if it were, it might be difficult to understand or ambiguous from a user's point of view. Field devices will be available within the next ten years that can better sense and identify a particular problem. An intelligent device could transmit varying levels of alerts to designated areas of the process control system, such as the maintenance program.

For example, in the case of material encrustation on a sensor, the device could begin warning areas of the process control system that it is getting close to failure because of material buildup. This could be integrated into a management system to recommend or even designate a maintenance person to clean the sensor within an upcoming time-frame (Figure 13).

**Wireless communication for field devices**

Wireless communication is a development and growth area for field devices. End users and suppliers realise there is an opportunity and a need in the cement industry. Both sides are evaluating how best to apply wireless technology through product development, as well as to address concerns about reliability and security.

One area of interest is remote inventory management. Existing wireless technology would allow a producer to monitor finished cement levels in all their silos, including terminals for inventory management purposes. Monitoring capability exists to measure all the silos nationwide and even worldwide in the future. Remote inventory management often uses cellular or satellite-based communications. It is already being implemented in other industries. For example, some suppliers of bulk chemicals use this technology to monitor material level in their customer's tanks in order to improve delivery planning.

Wireless communication for instruments is also applicable at the plant level. It offers a low-cost method compared to cable for transferring data back to the plant's control system. For example, a cement producer had eight cement storage silos where they wanted to measure level. AC power was available at the top of the silos. Cabling costs for transferring level data from eight sensors back to the plant prohibited the project from moving forward. Instead, transmitting the level information using wireless technology eliminated the need for costly installation of fixed cable and, thereby, solved the problem.

**Conclusion**

Instrumentation will continue to become more reliable and user-friendly for the cement industry. Smart sensors, as well as advances in communication capabilities, will allow users to obtain much more information from field devices in addition to the process measurement. Programming options using process device managers will enable plant personnel to better maintain field instrumentation. Measurements in the cement process will always tend to be rather difficult because of the aggressive environment. Solutions will improve as field device suppliers focus on the specific needs of the cement industry.