Application Considerations for Continuous Level and Inventory Monitoring of Powder and Bulk Solids

2ND EDITION

(Revisions from 1st Edition in Red)

Introduction

Continuous level measurement is about one thing, e.g. answering the question "how much stuff do I have". There are many applications where you need to know how much material is in a bin, silo or other vessel type. Usually the desired engineering unit is expressed in terms of volume or weight. "Measuring" volume or weight is not always the most practical approach, sometimes it isn't even viable. Take those silos you have, how do you weigh the ingredients if the silos weren't installed with load systems? Not an easy or inexpensive question to answer. So what do we do? This is where continuous level measurement sensors and systems come into play and offer a viable and cost effective approach.

The purpose of this white paper is to discuss and inform about the application considerations when you need to measure the level of material continuously or simply determine on a continuous basis how much stuff you have in your vessels.

The 2nd Edition has been updated to incorporate recent technology changes and use, including low frequency acoustic for surface mapping and volume measurement.

The Material Being Measured

When desiring to measure the amount of a powder or bulk solid material in a vessel, the material itself plays an important role on the performance of the measurement, its precision and also the choice of sensor technology best used. Here are the issues:

1. The bulk density of the material, e.g. light or heavy, does it vary?

2. What is the particle size of the material? Is it a fine micron size powder or a granular material? Smooth or sharp edges?

3. Is the material hygroscopic?

4. Does the material vary from batch to batch, load to load or are there seasonal variations?

Bulk Density: The weight of the material per volume plays an important role in monitoring the amount of bulk solids inventories or when measuring the level of a pile of material within any bin structure. Bulk density is usually given in lbs/ft^3, $grams/cm^3$ or some other metric engineering unit. Conversion between English and Metric units is as follows:

Lbs/ft^3	x 0.0160185	= $grams/cm^3$
Lbs/ft^3	x 16.0185	= Kg/m3
$Grams/cm^3$	x 62.43	= Lbs/ft^3
Kg/m^3	x 0.0624	= Lbs/ft^3

Continuous level sensors will convert from a distance measurement from the sensor to the material surface to volume and weight/mass. Accuracy of the bulk density of the material is very important to the accuracy and precision of this conversion. Any variations in density within the pile of material due to packing (such as with powders) and any variations from the source of the material from time-to-time or season-to-season can affect the precision of your mass calculation. Determining an “average” bulk density that gives you a good accurate calculated value through empirical testing, or changing the bulk density value periodically, may give you best results.

Heavy material may present problems for level sensor technologies that measure continuous level through constant contact with the material. The continuous level sensors, such as guided wave radar, have probes continuously subjected to the material and loading of the material on the probe. Long range applications with heavy material, such as cement powder, can exert tremendous pull forces on continuous level sensor cables that are suspended continuously in the silo. These forces can be exerted in some magnitude to your vessel roof.

Particle Size: The size of the particle of the material can affect the performance of some continuous level sensor technologies. Fine micron size powders will completely envelope contact technologies that may use radar or capacitance sensor techniques. However, larger particles may not contact the surface of the probe enough, such as with continuous capacitance level sensors that respond to changing dielectric constants. In addition, large aggregate particles with sharp edges can damage some continuous level sensor probes that are continuously in contact with the material.

Flow Characteristics: Some materials do not flow well. This is also influenced by silo design. Two conditions can exist in a vessel due to poor material flow characteristics of material and vessel, e.g. “ratholing” and “bridging”. A rathole (Figure 1) is created when the material discharges only from the center of the material pile within the vessel. This is caused by frictional coefficient between material particles and the vessel wall.

Figure 1: “Rathole” Build-Up of Material on Vessel Walls

Figure 2: Bridging of Material Prevents Flow

Bridging is similar except in this case material flows at the bottom of the pile only and then ceases. This "clogged" condition is created by similar aspects of the material and vessel design as the rathole. See Figure 2 for an illustration.

Both of these conditions can create problems for you when trying to measure the amount of material within the vessel with traditional continuous level measurement technologies that measure distance/level at a single point on the surface of the material. In both cases you may be detecting the presence of material and calculating a mass of material that has inaccuracies introduced because of material absence in the rathole or under the bridge. These conditions create production problems as well and material flow problems need to be dealt with in order to improve the precision of your continuous measurement system based on level sensor technologies.

Hygroscopic Material: This material characteristic closely ties in with the previous topic on flow characteristics. When a material is said to be hygroscopic it readily attracts water molecules from the surrounding environment through absorption or adsorption. An example of a hygroscopic bulk solid material is sugar. Many times the moisture absorbed/adsorbed simply comes from humidity. Combining with moisture the bulk material may become very difficult to flow and may present challenges for some continuous level sensors and measuring systems.

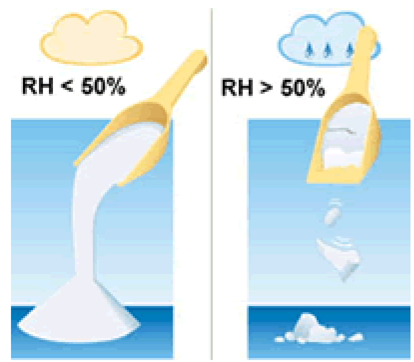

Figure 1: High Relative Humidity Combined with Hygroscopic Materials Make for Flow Problems in Vessels

Batch Variability or Seasonality: The material density is important to converting level sensor measurements to a mass value, as we previously discussed. Batch variability and seasonality are interrelated with density. Some bulk materials, such as grain, have a varying density level because of varying moisture levels from farm to farm, batch to batch etc. and this means that your average density value either needs to change or be adjusted to take this into consideration when making the conversion.

Angle of Repose: One final note about the material that affects the choice of level sensor technology as well as the precision of the conversion from the level measurement to mass. Since we are only specifically talking about automatic level control and measurement of powders and bulk solids the flow profile within the vessel is an issue. While liquids present with a flat surface in a vessel, making level sensor applications easier to handle, a bulk solid material will form a pile or create a depression. This means that the bulk material will present a sloped or angled surface to the level sensor. The angled slope is commonly

Figure 2: Angle Build-Up is Known as Angle of Repose

referred to as the angle of repose. The importance of this is due to the fact that most level sensor technologies we will discuss here measure the distance between the sensor and the material at a single point on the surface. Depending on where that point of measurement is on the angle surface, a different distance/level is measured and therefore a different mass calculation/conversion is made even though the material amount hasn't changed. This will be discussed again when we talk about real-world accuracy. Only one technology available today is considered practical for measuring level at multiple points using a single instrument and indicating the volume of the material based on an accurate mapping of the material surface.

The Vessel Containing the Material

This is all about size, shape and the accuracy of the vessel dimensions. A continuous level sensor will measure the distance/level and then convert, sometimes using off-board software, to volume and then finally converting the volume to weight. The dimensions of the vessel must be accurate if the calculation of volume is to be accurate. Having a dimension, such as the height or diameter or a cylindrical vessel like a silo, wrong by even 1" can equate to hundreds or even thousands of pounds of material that the conversion will be off. Drawings of the vessels are not always accurate with the fabricated bin or silo. Check actual dimensions versus the drawings before using them.

Filling/Discharge Systems

The method of filling and discharge of the vessel can impact your overall precision and the location, if not the choice, of the continuous level sensor. For example, pneumatic filling of a powder introduces far greater dust into the vessel atmosphere than does gravity feeding the vessel. Heavier dust can impact the performance of most through-air level sensor technologies such as ultrasonic, laser and radar.

Figure 3: Material Shape in Silo When Filled

The location of the fill inlet and discharge will impact the shape of the material surface and the location where the continuous level sensor should be installed. In addition, some bins may have multiple fill and discharge points, further complicating the shape of the surface and the choice and location of continuous level measurement technology. While acoustic technology based level measurement instruments exist that map the material surface and determine material volume, these devices still use vessel dimensions and material bulk density values that you provide. They do promise improved accuracy of volume measurement, but at high purchase prices and perhaps with some limitation or restriction. This will be reviewed later.

Environmental/Other Issues

Other issues effecting the application of continuous level sensors for measuring powders and bulk solids include the following:

1. Process Temperature: The temperature inside the bin is important to selecting the proper level sensor. All common continuous level measurement sensors are invasive, e.g. they have a sensor element sticking into the vessel. This applies to weight & cable, ultrasonic, guided wave radar, open-air radar and laser. Only weighing systems and radiometric (nuclear) level sensors are non-invasive.

   Materials of construction of the level sensor must be compatible with the minimum and maximum temperatures that the invasive element will see within the bin. Many sensors use a combination of elastomers, polymers and metals. Check to be sure that the level sensor specifications are compatible with your application. Sometimes a maximum temperature may exist “intermittently” rather than continuously. This is important to note as well. If your internal temperature is outside the limits of a chosen technology or brand, look for another or contact the manufacturer if the extreme condition is only intermittent.

   Internal bin temperatures can also affect the local ambient temperature seen by the part of the sensor external to the bin. This can impact electronic performance. Most level sensor electronics are designed for a maximum of 65-75° C (149-167° F) and a minimum of -40° C (-40° F) ambient temperature. Care must be taken to ensure that the ambient and internal bin temperature effects combined will keep the electronics within the acceptable limits as specified by the manufacturer. Refer to Figure 6 for an example of the combined effects of internal bin process temperature and ambient temperature for a capacitance point level sensor. As the process temperature at the invasive level sensor component rises, the allowed ambient temperature at the external electronics enclosure declines.

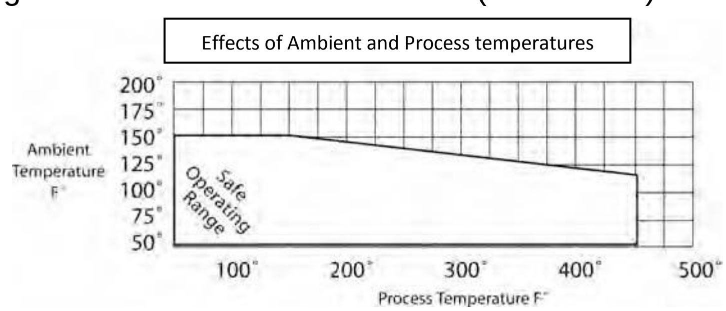

Figure 4: Ambient and Process Temperature Effect on Safe Operating Range

2. Ambient Temperature: Discussed briefly above, the ambient temperature typically refers to the temperature of the air surrounding the electronics enclosure of the continuous level sensor. This ambient temperature is influenced by environmental conditions such as outdoor temperature swings if installed outdoors. This swing can range from far below 0° F (-18° C) to above 100° F (38° C), depending on the geographic location of the level measurement sensor. Electronic components do not function properly when subjected to temperature conditions beyond their specified extremes. The result in what you may see can be anything from a substantial reduction in accuracy, intermittent or partial operation, and temporary failure to permanent fatal failure of the level sensor. Abide by manufacturers specifications.

3. Corrosiveness/Abrasiveness: Corrosion and abrasion is related to the effect the material being measured has on an invasive level sensor probe. Technologies that are "non-contact", typically ultrasonic, radar and laser, will not be subjected to as much of these problems as those level sensors that have probe elements in contact with the measured material. However, because these non-contact devices are still invasive, even vapor from the material can be corrosive in some cases. Abrasion will be related to the material contacting the probe element. Check the compatibility of the material being measured with the materials of construction of any "wetted parts" of the level sensor. Consult with the manufacturer.

4. Dust: We briefly discussed or alluded to the impact of dust in a previous section. Dust is associated primarily with powders or with granular material that are mixed with smaller particles, such as whole grains from the field. Pneumatic filling of silos when dealing with powders adds air and creates a mixture of air and particulate. This creates more dust in the internal environment of the vessel during filling. Non-contact level sensor technologies are highly sensitive to the amount of dust in the internal bin environment. The result of dust in the air can range from sensor failure to intermittent loss of signal and estimations of signal reflections to "assume" a measured value.

Figure 5: Cleaning Out of Sugar (Hygroscopic) Silo

5. Humidity/Clinging Material: Humidity can produce material that will cling or stick together (clumping) and also to the bin walls and invasive level sensor probe elements.

Figure 6: Laser Sensor Shown Inside Grain Bin, Covered with Grain Dust Even Though not in Material Flow Path or in Contact with Material Surface

This is particularly true with the more hygroscopic materials (refer to previous discussion). If material clings to vessels and level sensor probes, then a non-contact level measurement sensor may be preferred for the application. This will also depend on whether the material can come in contact with the sensor probe element by proximity of the incoming material flow and flying particles (see Figure 7). Proper level sensor location can minimize this. Traditionally non-contact sensors will not be very tolerant of any material adhering to its probe surface.

6. <u>Frequency of Measurement Required</u>: How often do you really need a measurement made? The answer to this questions helps qualify whether sensors typically intended for inventory measurement, like smart weight & cable devices and others, are applicable to your specific need. These level sensors are suitable to continuously measure the level of material with a practical frequency of 5 minutes or more. There may be exceptions to this where a shorter measurement frequency could be used, such as with short vessels of 20 feet or less. The issue is the duty cycle of the weight & cable level sensor motor. These motors are not rated for continuous duty. In addition, the travel time of the smart weight & cable level sensors are from 1 to 2 feet per second. Therefore the fastest response time in a 60 foot high silo might be every 60 seconds. This compares to a measuring frequency of every second or so with other continuous level measurement sensors.

   Most inventory monitoring applications will find a sampling rate of a few times per day or possibly once per hour acceptable. This is why longer duty cycles or slow response times are typically acceptable for these applications.

7. <u>Level v. Volume or Mass</u>: What measured value do you need, e.g. Level, Volume or Mass? This decision will qualify whether the direct mass measuring devices such as load stands and bolt-on load cells or strain gauges should be considered. If distance or level is all that is required then your level sensor accuracy is what your system accuracy will be, there is no conversion calculation to make. Usually conversion to volume or mass is needed only for inventory monitoring applications.

A Word Regarding Accuracy

This is a good time to discuss precision and accuracy of traditional continuous level measurement sensors which measure level at a single point on the material surface. First, accuracy is defined, according to Wikipedia, as the degree of closeness of a measured or calculated quantity to its actual (true) value. Accuracy is closely related to “precision”, a.k.a. repeatability or reproducibility, the degree to which further measurements or calculations show the same or similar results. A measurement system or calculation method is considered to be valid if it is both accurate and precise.

Explaining the difference can be done with an example; that of arrows shot at a target. Accuracy describes the closeness of each arrow to the bulleye at the target center. Arrows striking closer to the bullseye center are considered more accurate. If a large number of arrows are fired, the precision would be the size of the arrow cluster. When all arrows are grouped tightly together they are considered to be precise. Hence, it is possible to be precise, while not being accurate.

In determining the real world accuracy of an inventory measuring system for bulk solid materials, when using a continuous level sensor which measures at a single point on the material surface as the primary means to make the measurement, you need to consider both the accuracy stated for the chosen level sensor as well as the accuracy of the conversion. Consider the following:

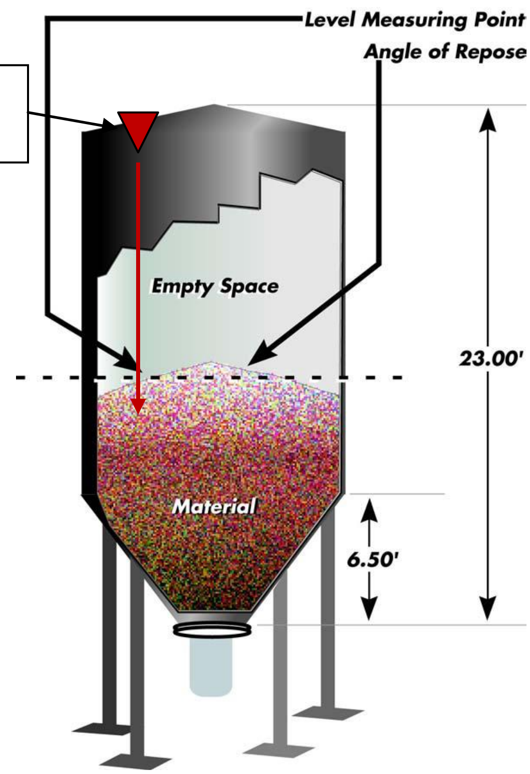

Figure 7: Sensor Location and Angle of Repose

- ✓ Converting from a measured distance into mass first requires the conversion into volume. The calculation of the volume of material is based upon the vessel dimensions and a measured level of material at a point on the material surface.

- ✓ The location of the sensor on top of the vessel determines the point on the surface where the measurement will take place. How does this relate to the shape of the material surface or angle of repose? See Figure 9.

  Many continuous level sensor manufacturers will recommend the sensor location for a cylindrical vessel with center fill and discharge to be 1/6th the diameter in from the sidewall. These are very common vessels. Square vessels can have sensors located in similar ways, but rectangular vessels and those with multiple fill and discharge locations may require further thought.

  In this example with a round vessel and center fill/discharge with the sensor located 1/6th of the diameter from the wall, if you draw a straight line across the angle of repose at the measurement point (Figure 9), the volume of material above the imaginary line and the volume of empty space below the line will be equal. The sensor location that produces this relationship of 1:1 of the material above the line versus the empty space below the line should be chosen no matter what the angle of repose is.

- ✓ Calculating volume from a distance/level measurement requires a measure of the internal diameter or measure of the vessel. Some vessel construction can create challenges. Consider a corrugated bin. What exactly do you use for a vessel measurement? The average right down the middle of the corrugation is the best dimension. The errors in the vessel dimension information increase the overall error in volume or mass calculations.

- ✓ A value to be used for the average bulk density is also required and this "average" number can reduce accuracy and possibly impact precision as well. The accuracy of the bulk density of the material being measured is important and it affects the accuracy and precision of the calculated mass. Which bulk density to use? Loose or tapped? No matter what the bulk density is in the lab or on the ticket from the transportation company, it may not be exactly accurate. In addition, remember that packing can also affect the real density at various points within the pile of material. In addition, flow aids such as aerators or vibrators may also impact the effective real density of the material.

The real world accuracy of the inventory measurement using a single point level measurement system for bulk solids applications is the stated accuracy of the level sensor, usually stated in terms of distance or level, plus the errors associated with all of the issues we previously discussed. It is not possible for the manufacturer of the level sensor system to tell you precisely what the accuracy of the calculated value of mass will be as converted from the distance/level measurement. However, most vendors will estimate that typical real world <u>accuracy of calculated mass may be between 5-10%</u> but no specification or warranty will typically be given. Continuous level sensors used in bulk solids applications to produce this accuracy of volume or mass calculation will cost between $1400 - $3000 and more.

An alternative to provide improved accuracy has always been weighing systems, though the use of acoustic technology implementation within the past few years to produce level mapping technology has emerged to challenge weighing systems. Regardless, weighing systems are not practical in some applications, especially with existing vessels. Two types of weighing systems exist, e.g. the load stand type device that is installed under the supporting structure of the vessel, and the bolt-on load cell or strain gauge device that bolts on to the supporting structure of the vessel.

Load stand systems will typically provide 0.2% accuracy or better, and this is mass accuracy. The real world accuracy is based on the quality of the calibration and the installation, but should be close to promised accuracies if done correctly. Load stand systems can cost $5000 and up, plus a significant cost of installation and calibration. The expense is certainly much more than a typical level measurement system.

The bolt-on load cell or strain gauge device is less expensive, typically around the cost of a high end level sensor ($2500) and it is easier to install than a weighing system based on load cells/stands. However, the accuracy is not anywhere near as good with the real world accuracy stated by some manufacturers being in the 1% to 5% area. This also depends on the quality of the installation and calibration, which is very challenging. With both weighing systems, the installation and calibration is often done with non-plant personnel and many times is contracted with the weigh system manufacturer.

Let's compare the level sensor with calculated volume and mass to a weighing system:

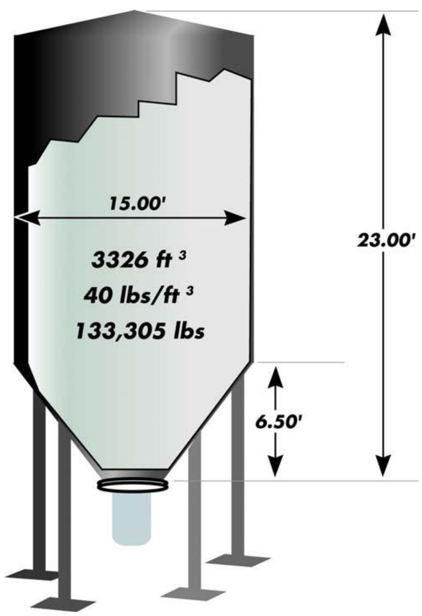

Figure 8: Sample Silo Application

Assume a vessel such as that shown in Figure 10. This silo will hold 133,305lbs of material that is 40lbs/ft^3 density. The volume of the silo is 3326ft^3 and dimensions include an overall height of 23' from top to discharge and a 15' diameter. The height of the cone is 6.5' and the discharge opening is 1' in diameter.

First, let's evaluate a weight & cable level sensor system versus both types of weighing systems. The weight & cable system has a sensor accuracy specification of 0.5% of the distance measurement. The purchase cost of this device is $1400. If a measurement is made by this sensor and the result indicates 16' of material level (calculated weight is 113,040 lbs) and the level measurement accuracy is 0.08' (0.5% maximum error). The theoretical error is 565lbs. If we assume the data used to make the calculations is "fairly" accurate, but that error in the mass calculation does exist as a result, say 3% for the mass calculation given this is a relatively small vessel, we have a real world accuracy of +/-3391lbs for this measurement.

Next, consider the weighing systems. The load stand system will be very accurate, but has a purchase cost of about $5000 and an even higher installed cost. It will measure the same 113,040lbs with an accuracy of 0.2% or 226lbs. The bolt-on load cell or strain gauge sensor would cost less, about $2500 to purchase plus calibration and installation costs, but the accuracy will only be about 2% or 2280lbs (typically between 1-5%).

In this example the level measurement system might be preferred over the bolt-on load cell system considering the approximate 44% premium in price (bolt-on strain gauges v. smart cable based sensor). And while the load stand weigh system provides more accuracy, you would have to decide whether the added expense to gain the improved accuracy is worth it. In some cases it may be, while in others it won't be. If you have an existing vessel, the level sensor or bolt-on strain gauge sensor approach will be the way to go and that is what almost everyone chooses. However, some will prefer a completely solidstate level sensor, at higher costs. It is arguable whether these more expensive continuous level measurement sensors offer a better approach than bolt-on strain gauges or smart cable based systems. Surface mapping multiple point level measurement using acoustic technology implementation may offer a better solution but the volume accuracy is variable depending upon the vessel size.

Next, we'll look at the various level sensor technologies.

Sensor Technologies / Suppliers

The most commonly used level sensor technologies for powder and bulk solids applications include the following:

- Weight & Cable, a.k.a. Plumb-bob, Yo-Yo, Bin-bob
- Ultrasonic
- Open-Air Radar, e.g. Pulse and FMCW types
- Guided Wave Radar, a.k.a. Reflex Radar, TDR, Radar on a rope
- Laser
- Acoustic

Weight & Cable: This level sensor technique has been providing level measurements in a wide variety of powder and bulk solid level sensing applications for over 80 years, and perhaps longer. The oldest patent in the USPTO archive that a quick search could locate was issued on December 21, 1926. Subsequent technological advancements by several companies took place over the following decades. Most notable are technology patents issued to Link-Belt Company in 1958, Rolfes Electronics Corporation in 1964, U.S. Steel in 1970, Bindicator Company in 1974 and Ludlow Industries (a.k.a. Monitor Manufacturing, a.k.a. Monitor Technologies) in 1979. In addition, significant contributions made by Garner Industries (a.k.a. BinMaster) have also advanced the technology.

Figure 9: Smart Weight & Cable Level Sensor by Garner Industries (Lincoln, NE)

A weight & cable continuous level sensor incorporates a power supply, motor, weight & cable system, motor control system, cable distance measurement system and an output. Upon demand from the user control system or upon automatic scheduling, the level sensor will operate its motor to lower the weight and cable system into the bin from its mounting point on top of the bin. The weight & cable system is typically a stainless steel cable (some use a chain) with a weight constructed of aluminum, stainless steel or other material. The weight & cable system will drop into the bin until it contacts the material surface. An optical measurement system is used to generate pulse counts that are read by an on-board microcontroller. The microcontroller manages the weight & cable descent and counts the pulses to determine the distance traveled. This is then relayed through the level sensor's output to a user supplied control system or a readout (user supplied or with the level sensor). When the material surface is detected the motor is reversed and the weight & cable system is retracted to its normal position. The process of measurement is repeated with the frequency determine by the user. The weight & cable system travel speed is usually 1 to 2 feet per second.

The weight & cable level sensor is one of the most economical choices for level measurement of powders and bulk solids. They are not limited to level monitoring of solids only. They are successfully used to monitor the changing level of liquids, slurries and even interface. Weight & cable level sensors provide reasonable accuracy (±0.5% or better) and good reliability. However, they are limited to applications where their intermittent nature is acceptable, hence their use primarily as an inventory monitor. Their motors are not designed for continuous duty. Most common applications are on measuring inventory levels of granular material like plastic pellets. These devices have long been an industry standard for inventory monitoring and continuous level measurement in plastics silos. The inventory monitoring frequency needs to be only a few times per day or even just daily. The level sensor accurately reflects the material level and it can be provided with displays that will interface with multiple weight & cable level sensors and convert from distance/level to volume/mass.

Table 1: Advantages and Disadvantages of Weight & Cable Continuous Level Sensors

ADVANTAGES	DISADVANTAGES
✓ No calibration required	✓ Long cycle time, long response time. Not truly "continuous"
✓ Measuring range up to 150ft (45.7m)	✓ Momentary contact of material
✓ Low purchase cost ($1400+)	✓ Moving parts, some maintenance possible in certain applications (especially heavy dust)
✓ Easy installation and setup	✓ Mechanical components can be abraded by some materials
✓ Field repairable	✓ Measurement during filling is not recommended as weight could become buried
✓ Can be used in relatively high process temperature conditions (300° F)	✓ Low pressure conditions (≤ 30psi)
✓ Good accuracy (± 0.5% of reading)	✓ Fair accuracy for ranges > 30ft (9m)
✓ Wireless sensor interface available	✓ Measures level at single point on material surface, requires calculated volume and mass
✓ Advanced PC or Internet applications available for inventory management	

Today's weight & cable level sensor is ideal for inventory monitoring where the frequency of measurement update is periodic, perhaps no greater than ever half hour (30 minutes) and the material level changes rather slowly. They are especially reliable for use on granular materials like plastic pellets and have been effectively used in many powder applications as well. Consult with manufacturers or a level measurement expert about your specific application if you have questions. Suppliers to consider:

Bindicator	www.bindicator.com
BinMaster	www.binmaster.com
BlueLevel Technologies	www.blueleveltechnologies.com
Monitor Technologies	www.monitortech.com

<u>Ultrasonic</u>: These level sensors are also a mature technology, although they have not been around anywhere near as long as the weight & cable level sensors previously discussed. Ultrasonic level sensors date back at least to the 1970's and early 1980's as far as use for level measurement of powders and bulk solids. Ultrasonic level sensors are solid state devices without mechanical moving parts other than the piezoelectric components used to generate the sound waves. Their principle of operation is measurement of distance by relating a measured time-of-flight of sonic echoes from the material surface to distance based on the speed of sound through the vessel atmosphere. They are differentiated from their cousin "acoustic" by the frequency. Most ultrasonic transducers operate at a frequency of 12 KHz and up. Acoustic operates mostly in the low frequency range of 3 KHz.

Figure 10: Ultrasonic Continuous Level Sensor System for Liquids

While these level sensors have been applied to measure the level of powders and bulk solids for years, problems have included the inability to make measurements in applications with any dusty conditions within the bin or silo environment. In addition, pressure fluctuations, changing angle of repose, large particle sizes, internal vessel obstructions and coating or the formation of deposits on the internal vessel surfaces have all presented serious challenges and problems for ultrasonic level sensing technology. Some of these issues affect the accuracy of measurement while others present disruptions in measurement due to the creation of false echoes that confuse the sensor and mask the true level measurement signal.

However, the latest generation of ultrasonic level sensor electronics has been developed to deal with some of these challenges. Temperature fluctuations are no longer a problem because most sensors of this type now incorporate a temperature sensor and their electronics compensate for its effect on the speed of sound.

But unlike today's smart weight & cable level sensors that have overcome virtually all their past application problems and objections, ultrasonic users continue to be dissatisfied with performance involving airborne dust and obstructions. It remains a growing perception that ultrasonic continuous level sensors applied in powder and bulk solid applications require periodic adjustments and are "fussy" in on-going use when used in dusty environments. In fact, there is heavy evidence that the continuing decline in price and the performance of open-air radar in dusty applications is quickly eroding the application base of ultrasonic continuous level measurement technology in solids applications.

Table 2: Advantages and Disadvantages of Ultrasonic Continuous Level Sensors

ADVANTAGES	DISADVANTAGES
✓ Non-contact	✓ Sensor signal affected by changes of angle of repose
✓ Moderate cost, ≈ $1600-1800	✓ Performance affected by dust and internal obstructions
✓ High temperatures (generally up to 300° F)	✓ Setup requires careful aiming and manufacturer personnel may be required at consumers' expense
✓ Long ranges for clean liquids	✓ Range limits for solids limited, especially with dust where performance degrades quickly
✓ ±0.1 to 0.25% accuracy	✓ Measures level at single point on material surface, requires calculated volume and mass
✓ Fast response to changing level	
✓ Sensor surface is generally self-cleaning	
✓ Typical small size makes installation in tight spaces possible	

There is little doubt that manufacturers of ultrasonic continuous level sensors have advanced the performance of these sensors in powder and bulk solids applications and eliminated many problems associated with earlier designs. However, not all problems have been resolved and may be beyond the practical use and application of the technology. Time will tell, but for now this technology remains in the list of problematic technologies when used for continuous level measurement of powders and bulk solids. Much factory support is typically required for start-up and on-going in many applications.

Use of ultrasonic continuous level sensors should be limited to measuring liquids/slurries, not powders and other bulk solids. Suppliers to consider:

Milltronics/Siemens	www2.sea.siemens.com/Products/Process-Instrumentation/Process-Sensors-Transmitters/Ultrasonic-Level.htm
Nivelco	www.nivelco.com

Guided Wave Radar: These devices were first commercialized for use in process level measurement applications during the early-mid 1990's based on research first developed in the late 1980's for level measurement. However, TDR technology has been around since the 1930's when it was used in the geological surveying area and again in the 1950's when it was employed to detect breaks in telecommunication cables. However, one should note that this technology as employed as a continuous level sensor for powder and bulk solids is not as "plug-and-play" as manufacturers might have you believe. The purchase of these units should be accompanied by a commitment to have consumer personnel to set them up, or the consumer should purchase start-up assistance from the manufacturer.

Figure 11: Technician Performs Start-Up Adjustments on GWR Device Measuring Flyash

There are also critical installation requirements for this technology, e.g. mounting method, sensor location, and silo/bin roof strength. In addition, material dielectric constant is a critical parameter to consider. The lower the dielectric constant, the more microwave energy is absorbed rather than reflected by the material surface. This equates to a reduction of accurate measurable range the lower the dielectric constant of the material is. When manufacturers' guidelines are followed, theses units work extremely well even in dusty powder applications during pneumatic filling.

Guided wave radar generally uses Time Domain Reflectometry (TDR) and measure the time-of-flight of microwave pulses guided to the material surface by a wave guide (cable or rod). The vast amount of radar energy is absorbed by the material. The lower the dielectric constant, the more is absorbed and the shorter the measurable range will be with acceptable accuracy. I know I repeated this statement, but it is a critical issue to bear in mind when considering guided wave radar technology as your level sensor choice.

Wave-guide cable traction strength needs to be matched to the application. Some manufacturers have information that provides guidance regarding the traction (pull-down force) loading effect from various materials. The heavier the material, the more load. The larger the diameter of the cable, the greater the friction and loading on the cable. Most suppliers can supply a choice of large and small diameter flexible cables for use as waveguides in powder and bulk solids applications. Here is a guiding table from one manufacturer:

Table 3: Wave Guide Cable Traction Loading

Material	Probe Size	33' (10m) Distance	66' (20m) Distance	98' (30m) Distance
Cement	0.1" (8mm) diameter	2200 lbs (1.0 metric ton)	4410 lbs (2.0 metric tons)	6620 lbs (3.0 metric tons)
Flyash	0.1" (8mm) diameter	1100 lbs (0.5 metric ton)	2200 lbs (1.0 metric ton)	3300 lbs (1.5 metric tons)
Wheat	0.1" (8mm) diameter	660 lbs. (0.3 metric ton)	1320 lbs (0.6 metric ton)	2650 lbs (1.2 metric tons)

You must consider the traction loading on the cable and the maximum rating when you consider installation and make sure your roof structure can tolerate the load. You must follow manufacturers' guidelines and instructions specifically.

Table 4: Advantages and Disadvantages of Guided Wave Radar Continuous Level Sensors

ADVANTAGES	DISADVANTAGES
✓ Rapid response to changing level, good for process level control applications	✓ Continuously invasive and in contact with material
✓ Unaffected by airborne dust, angle of repose and other process conditions	✓ Material dielectric constant limits range, for 20'+ dielectric must be >1.6 for best accuracy
✓ Great accuracy when dielectric constant and range is compatible	✓ Maximum range limited by dielectric constant, rang limit typically 70-80 ft for moderate dielectric constant material like cement, etc.
✓ Purchase price has been declining, now average price around $2000	✓ Measurement deadzones require alternate mounting methods
	✓ Very installation and material sensitive
	✓ Measures level at single point on material surface, requires calculated volume and mass
	✓ Low dielectric constant material (<1.8) require alternate processing method that provides variable accuracy unless dielectric constant remains stable

Guided wave radar is a promising continuous level sensor technology. It should be used only when you closely and accurately follow the manufacturers' guidelines and instructions. The energy field around the cable from the mounting point to the underside of the counterweight should be perfectly clear of any possible obstructions. Range requires manufacturer assessment based on material dielectric constant and particle size. Know your material well. Factory trained start-up personnel may be needed for successful use of this technology. Suppliers to consider:

Endress & Hauser	www.us.endress.com
Monitor Technologies	www.monitortech.com
Vega	www.vega.com/en/index.htm

Open-Air Radar: A close sister to guided wave radar is the open-air radar continuous level sensor. These devices use similar technology and measure the distance by determining the time-of-flight of radar energy return pulses off the material surface. In open-air designs this is referred to as pulse radar, which is similar to the guided wave radar type of level sensor. However, another successful open-air radar approach used in powder and bulk applications is the FMCW type, or Frequency Modulated Continuous Wave.

In the late 1940's altimeters came in use that were based on radar technology. This is really somewhat of the predecessor of the open-air radar continuous level sensor. At that time radar equipment was very bulky, extremely expensive and used lethal kV voltages. In the mid-1960's semiconductor technology took a huge leap forward allowing much higher radar frequencies to be attained. The new potential for building smaller, lighter systems for fighter aircraft was first explored and developed by Saab Aerospace. This technology was "spun-out" and the first radar device used for tank gauging was introduced in 1975.

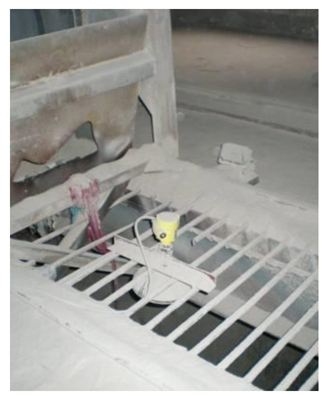

Figure 12: Open-air radar continuous level sensor measuring sintered powder

The open-air radar continuous level sensing transmitter constantly emits a swept frequency signal and the distance is calculated by the difference in frequency between the emitted and received signal at any point in time. One advantage with FMCW is that higher accuracy can be achieved.

Open-air radar technology remains highly specialized and requires a tremendous investment on the part of the manufacturer to develop and continue to support over its life cycle. Therefore, fewer suppliers exist for this technology than for most others. Both FMCW and Pulse radar types have been successful in continuous level sensing of powders and bulk solids, however, brands vary widely and this technology requires careful installation and factory trained set-up assistance. Range, like guided wave radar, remains dependent on the dielectric constant of the material as this impact the amount of radar energy absorbed by the material rather than reflected.

Open-air radar level sensors are sensitive to material clinging on their antennae and this is to be avoided. It is thought that FMCW are more sensitive to this than the Pulse Radar type. All open-air radar level sensors are not self-cleaning and need protection or cleaning.

Table 5: Advantages and Disadvantages of Open-Air Radar continuous level sensors

Advantages	Disadvantages
✓ Non-contact	✓ Material dielectric constant typically is required to be > 1.8
✓ High temperature applications ≤ 700° F	✓ Set-up requires factory training personnel
✓ High pressure	✓ Not self-cleaning sensor, sensitive to build-up of material on sensor antennae
✓ Rapid response to changing level	✓ Relatively high purchase cost ≥ $2500
✓ Success in long range dusty application such as cement powder at distribution terminals	

This technology continues to evolve and improvements are made. While still costly the purchase price has dropped over the past ten years and should continue to decline somewhat as the market gets more competitive.

Suppliers to consider include:

Vega	www.vega.com/en/Level_measurement_radar.htm
Siemens	https://pia.khe.siemens.com/index.aspx?nr=14655
Endress & Hauser	www.us.endress.com/

Laser: This technology has come a long way in the past several years. This is primarily due to the one viable supplier that exists today. They have invested heavily. The primary basis of operation uses a laser and measures the distance to the material surface by determining the time of flight of the laser emitted and reflected off the surface of the material. Because we are dealing with an optical technology (light) the color of the material can impact performance and reliability. Laser level sensors are viable in some clean applications or with much effort and assistance on the part of the manufacturer.

Laser level sensors designed for long ranges are still pretty pricey, in the area of $2500-$6000 including accessory items to keep airborne dust at bay. In the end, they are still not reliably viable in dusty applications such as cement powder, flour , powdered resins etc., especially not without costly installation and set-up services from the manufacturer. The laser light beam is narrow, it doesn't scatter. It is therefore relatively easy to aim. Accuracy of the distance measurement is superior to other technologies when the range is > 50ft.

Table 6: Advantages and Disadvantages for Laser Level Sensors

Advantages	Disadvantages
✓ No calibration	✓ Installation setup in dusty environments will require special fixtures and assistance from the manufacturer
✓ Long range potential in clean environments (≤ 250 ft.)	✓ Limited temperature and pressure ratings
✓ Distance measurement not affected by angle of repose	✓ Not really practical for use in very dusty environments unless measuring during filling is not needed and time for dust settling is allowed
✓ Non-contact technology	✓ More expensive than alternative technologies
✓ High accuracy of distance measurement	

Lasers offer pinpoint accuracy and the cost of units have come down. Dusty airborne environment in vessels with powders are still problematic and this technology should be avoided until such time that manufacturers develop it further to make the technology less expensive and more "plug-and-play" in these dusty applications. Suppliers to consider:

KTek Corporation www.ktekcorp.com/dnn20/Default.aspx?tabid=54&productTypeId=3

Weighing Systems

A quick word about weighing systems, both load stand systems and bolt-on systems, is in order. We will review each briefly.

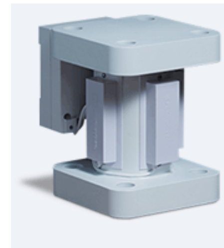

Figure 13: Load Stand Weighing Sensor by Kistler Morse

Load Cell/Stand Weighing System: This measuring system consists of the load cell and the receiver/operator interface. The load cell is packaged to be mounted beneath the structure. They fully support the weight of the vessel. Load stand systems are expensive and cannot be easily installed on existing vessels by your personnel. Calibration by factory trained personnel will be required.

Table 7: Advantages and Disadvantages of Load Stands

Advantages	Disadvantages
✓ Non-intrusive and non-contact with material, all external to vessel so very good for sanitary applications	✓ Very high purchase cost (≥ $5000)
✓ Works with even severe material flow problems	✓ Installation and calibration expense is high and requires factory intervention
✓ Not affected by dusty environment or material build-up	✓ Difficult and very expensive to retrofit existing silos
✓ Safe for handling hazardous materials since you do not have to breach the vessel	✓ Potential accuracy problems if material load is less than weight of the vessel
✓ Higher accuracy of mass measurement versus converting level to mass	✓ Structures connected to vessel can affect overall performance as can anything that impacts load of vessel
✓ Wide measuring range from 100 to 1,000,000 pounds	

Load cell systems are used when you must have high accuracy of a mass weight measurement and you can justify the expense. They need to be considered prior to installation of the bin or silo and then be installed with the vessel. Retrofitting an existing vessel is difficult and costly. Suppliers for consideration include:

Kistler Morse	www.kistlermorse.com/
BLH Weighing Systems	www.blh.com
MTI Weigh Systems	www.mti-weigh.com

Figure 14: Kistler Morse Bolt-On Strain Gauge Sensor

Bolt-on Load Cells or Strain Gauge Weigh Systems: These weigh sensors bolt-on to the supporting structure of the vessel. They tend to be cost effective by comparison to load stands and some level measurement devices ($2,500 and up) and address the need for cost-effectively retrofitting existing bins and silos where load cell stands do not. They are cost effective by comparison and are claimed to be able to provide from 1% to 5% accuracy by mass.

Manufacturers will require a comprehensive description of the vessel so the mounting method and locations can be determined. Calibrating these sensors into a system that provides the promised accuracy is the tricky part and this will require on-site assistance by the manufacturer. You will need to apply a precise load to the vessel to determine the relationship between weight and the stress measured by the strain gauge sensor. This may not be possible and the accuracy of the system will always be a function of the quality and accuracy of the calibration.

Table 8: Advantages and Disadvantages of Bolt-On Load Cells

Advantages	Disadvantages
✓ Non-invasive and non-contact	✓ Somewhat high purchase cost ($2500+)
✓ Easier to install than load stand system	✓ Calibration is critical to performance and can be difficult; requires factory trained personnel
✓ Works in applications where material flow is a problem	✓ System accuracy no better than 2-5%
✓ Not affected by internal vessel environment	✓ Accuracy limitations if material load is very small in comparison to the vessel weight
✓ Safe for handling hazardous materials	✓ Fussing with system may be required
✓ Cost effect when high accuracy of mass measurement isn't required	✓ Other structures attached to vessel may produce accuracy problems

The real-world improvement in accuracy with bolt-on load strain sensors is not necessarily going to be justified by the expense of installation and calibration. This should be closely evaluated before a decision is reached. However, for vessels where any invasive sensor cannot function properly or where flow problems exist and cannot be resolved, these systems offer a viable solution.

Surface Mapping Systems

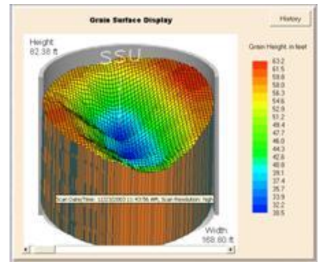

Figure 15: Grain Bin Mapping of Material Volume said to be 98.5-99.5% Accurate

In the first decade of the 21st century we have seen the market introduction of level measuring systems that are offering end users an alternative to weighing systems and the single point continuous level sensors of the 20th century. This alternative claims higher accuracy of volume than traditional single point level sensors, and perhaps comparable mass calculation values to strain gauge load cell systems without quite the same complexity of installation. Today these systems utilize wither laser or acoustic sensor technology with sophisticated software to map the surface of the material pile. Together with vessel data that the user provides, these systems calculate volume based on a profile of the surface they create from distance measurements made by the level sensors at multiple points on the material surface.

Laser-Based Systems: Surface mapping systems have been introduced commercially based on the use of laser sensor technology. One example is BinTech, a company using aerospace mapping technology and laser technology to map the surface of grain bins. Please view their website at www.bin-tech.com. Their claims of 0.5% error for volume (bushels) in large grain bins, is significant. Patented (# 6,986,294), they claim to have the "world's first tool for automated full surface high resolution measurement of large bulk inventory storage tanks".

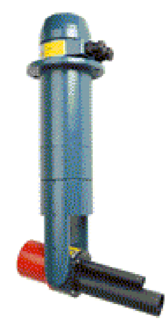

Figure 16: KTek Corporation Model LM3D Surface Mapping Laser System

Another laser based system is available from KTek Corporation and product information can be found at www.kteksolidslevel.com/productdetails.asp?vProductID=42. This product claims volume accuracy of "1% typical", not quite as substantial as that claimed by BinTech.

Figure 17: 3D Level Scanner by APM Automation Solutions in Tel Aviv, Israel

Acoustic-Based System: One final surface mapping system worthy of mention is the 3DLevelScanner from APM Automation Solutions Ltd. Here is how they describe their solution in their website. "The 3DLevelScanner employs a 3-dimensional array beam-former to transmit low frequency pulses and to receive echoes of the pulses from the contents of the silo, bin or other container. The device's Digital Signal Processor samples and analyzes the received signals. From the estimated times of arrival and directions of received echoes, the processor obtains and generates a 3-dimensional image of the surface that can be displayed on a remote screen. This unique device can then accurately determine the volume and mass of material, enabling an unrivaled degree of process measurement and inventory control."

Acoustic technology is a close cousin to ultrasonic but operates at a significantly lower frequency, 3 KHz. It is explained that this low frequency allows better performance through dust than other ultrasonic level transmitter. Case studies have been published which suggest this claim is true. It has a very wide 70° beam angle so it suggests that the technology will work best in very large silos like those found within the grain industries. While interviewing a member of their USA representative and distributor it was learned that the response time is long, perhaps as long as 3-5 minutes. This, and perhaps the other surface mapping technologies, are truly inventory monitoring devices and should not be considered for use in any process level control application. Accuracy of 1-1.5% on volume seems realistic, however, this comes at a price tag in the range of $3K-5K.

Table 9: Advantages and Disadvantages of Surface Mapping Technologies

Advantages	**Disadvantages**
✓ Non-intrusive and non-contact with material	✓ Very high purchase cost (≥ $3000-$5000)
✓ Works with material flow problems because they map the surface and bring to light potential and real flow problems	✓ Setup and calibration using factory intervention may be required
✓ Not affected by dusty environment or material build-up (acoustic)	✓ Slow response time, but generally this will be acceptable for most inventory application. Do not use for process level control.
✓ High accuracy claims from 0.5% to 1.5% is typical	

Pulling It All Together, a.k.a. Making a Decision

The bottom line is to find the device or system that best meets your needs for the lowest possible total cost. Here is a good guideline to follow for decision making:

1. What information do you need? A distance measurement, level, volume or weight?

2. What overall accuracy do you need? Error rate of <1%, <5%, 10%?

With the answers to the first two questions above you can determine whether you should be looking at a level sensor, a weigh system or a surface mapping system.

1. Choose two-three reputable suppliers and have them evaluate your application. Measure their responses and recommendations by what you know from experience and the information presented here.

2. Check their references.

3. Purchase from the supplier with the lowest total cost (installed and operating costs). Choose wisely.

Make sure your chosen supplier is going to stand behind their claims and be there to support you with on-site assistance to get their product to work the way they claim. It is always a good idea to write down your expectations and have them accept them before you purchase.

Conclusion

Continuous level monitoring is a critical application to monitor and manage materials in bins and silos. However, it is a complex task if you haven't spent decades in the level sensor industry. Understand the basics behind what you "need", level measurement, weight measurement or volume measurement using the latest surface mapping technologies. Develop your core requirements that you must have and then evaluate the alternatives. Purchase the lowest cost system that best meets your needs.