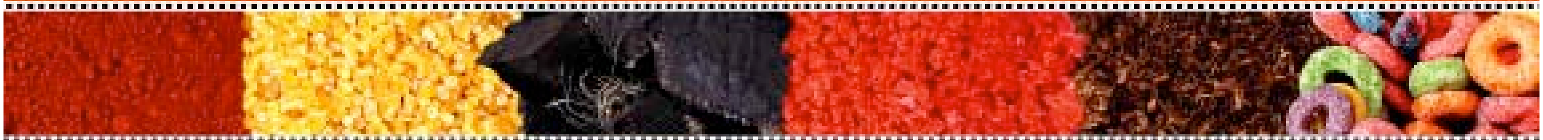

Technology Review
Level Measurement of Bulk Solids in Bins, Silos and Hoppers

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Technology Review – Level Measurement of Bulk Solids and Powders in Bins, Silos and Hoppers

Introduction

Trying to measure the level of bulk solids or powders in a bin or silo can be difficult for several reasons. Many of these reasons are related to the need to convert level to volume and mass, as well as the nature of the material itself which often behaves in a manner that makes obtaining a level measurement difficult, or makes the accuracy of the measurement questionable. Let's take a closer look at these reasons:

1. The material can be extremely light or very heavy.

2. Bulk solids can be fine micron size powders or large with sharp edges.

3. Many materials produce large amounts of dust during filling and discharging.

4. Some materials are hygroscopic and readily absorb or trap moisture, and moisture can combine with solids to cake or clump inside a vessel making material flow difficult and presenting challenges to some of the available level measurement technologies.

Ratholing

5. Solids stored in a vessel do not have a flat, horizontal surface like virtually all liquids. The surface of powders and granular materials has an angle of repose. This angle of repose, or shape of the surface, can vary with filling, discharging, the location of filling and discharging, angled or multiple fill points, multiple draw points, etc.

Angle Buildup

6. The coarser the material, the more likely it is to clump, bridge, leave voids and pile up.

Bridging

7. Pneumatic conveying systems aerate material. The bulk density changes in storage as the material compacts with time.

8. It may be difficult to know an accurate value for the bulk density for materials like corn and flour that vary from season to season, and are dependent on specific crop and blend.

9. It also can be difficult to know the exact dimensions of the silo the material is stored within.

These issues are just the tip of the iceberg in regards to the problems that can be encountered. They can have a major impact on selecting a technology to measure how much material resides in the vessel at any given time.

There are several technologies that can be used to determine the material level or amount of bulk solids within a storage silo. These technologies are sensitive to the specific application, some more so than others. The selection of the wrong device can waste time, money, manpower, and generate a good deal of frustration for all involved.

Manufacturers of level measurement technologies are often asked to recommend a technology for measuring bulk solids in vessels. We feel that an objective review and understanding of the technologies available will be advantageous to anyone needing to speak with manufacturers in their search for an answer to the question of "what to do".

After reading a great deal of material, and investigating the options with several manufacturers ourselves, we have created a list of pros and cons for all the major technologies to help objectively make a selection of the best technology for a given application. We are presenting the results of our review in hopes that it will prove helpful to you, should you be involved in such applications.

To begin our review let's first identify the technologies typically available for these applications.

Who Are The Players?

Continuous measurement of the level or amount of solids in bins, hoppers and silos is dominated by the following technologies:

- Weight & Cable (plumb-bob, yo-yo, etc.)
- Ultrasonic
- Guided Wave Radar
- Thru-Air Radar
- Laser
- Load Cells
- Strain Gages

Please note that Weight & Cable systems, while not really continuous, are used in applications where level measurement updates as frequent as once every 15 minutes are acceptable. These devices are used to measure the changing level of material and calculate volumes and weights, and are therefore included in our review.

The first four technologies on the list all measure the distance from the sensor location to the surface of the material and consequently the height of the material in the vessel. Load cells and strain gages infer the mass of material by measuring the force exerted on a sensing element.

If you read most technical journals, or surf the Internet, you will find that newer technologies (like radar and laser) promise to eliminate the frustrations users may have experienced with the more mature technologies (like weight & cable and ultrasonic). However, after closer examination we also find that those same mature technologies have made significant design advancements in recent years, and promise to be vastly more reliable than earlier generations of products.

Our purpose, as stated previously, is to objectively review the pros and cons of each technology as it is important in assessing a technology's compatibility with a specific application, and in making a cost effective decision on what to use. This is true whether you are looking to buy an instrument for a new application, or looking to replace a device previously in service.

To keep this discussion at a reasonable length, we will not perform an in-depth review of individual operating principles, as they are well documented elsewhere. Only general information is presented, intended to be objective and not reflect a particular manufacturer's design. We also will provide a list of leading manufacturers in each technology area. Anyone interested should refer to manufacturer's literature to review product features and the full range of specifications.

The comments we make here for each technology are based on what we have been able to ascertain as being the current state-of-the-art. The end user must discern whether a product has sufficient design features, especially on the tougher applications, so as to obtain the full performance benefits that technology has to offer.

The Starting Point

Before getting into the pros and cons of the various technologies, and before you start to check out prices and features, it is necessary to clearly define the application and what you are trying to accomplish. From an application engineering perspective we recommend you answer the following questions:

1. Do you need continuous or intermittent (as frequent as every 15 minutes) measurement? If the latter, what frequency of measurement do you need?
2. Do you need to measure during filling?

3. Do you need to know just the level of the material, or also the volume or mass of the material in the vessel?

4. What "real world" accuracy are you looking to achieve? Is this in terms of the level of the material or volume/mass?

5. What are the vessel dimensions and construction? How accurate is this information and how accurately can you calculate the internal vessel volume?

6. What are the physical properties and flow characteristics of the material(s) being measured? How accurate is this data? Will these parameters be constant, or can they change?

7. What are the process conditions (temperature, pressure, etc.) and how can they vary?

8. How is the vessel being filled and emptied? What are the fill/empty rates? What are the fill/empty distances?

9. What is the anticipated angle of repose? How will this change during filling/emptying?

10. Where is the sensor to be located? Are there any special conditions, like tight spaces, non-intrusion, sanitary requirements, etc.?

11. What kind of display, operator interface, and outputs are required? Do you want the electronics to be integrally mounted to the sensor or mounted remotely?

12. How much can you afford to spend for this functionality?

Even if you don't know all the answers, and you probably don't, it's still a good idea to review these questions and keep them in mind when looking at the pros and cons of a specific technology.

Important Considerations Regarding "Real World" Accuracy

Accuracy is a very important selection consideration because it directly affects the purchase price of the instrument you choose to accept for your application. As stated previously there are two ways to determine how much material is present:

1. Find the location of the surface of material with a level measurement system (measures distance/level). Some applications require this reading be converted into a calculated volume or mass. The volume or mass can be calculated by the level measurement system, or in external equipment (e.g. PC, PLC or DCS).

2. Directly weigh the material in a vessel using load cells or strain gages attached to, or placed under, the vessel supports.

The printed accuracy for level measurement systems is a statement of how accurately each measures the distance from the sensor to the solids surface. It does not typically include potential errors for converting this measurement into a volume or mass.

The printed accuracy for a mass system is a statement of how accurately it measures the changes in force exerted on the sensor, which is directly related to the mass of the solids in the vessel.

In determining the **"real world" accuracy** for a level measurement system when conversion to volume or mass is desired, you should consider the following:

1. Converting a distance into a volume requires an assumption of the relationship between the point on the surface of the material where the level measurement sensor will make its' measurement and (given the angle of repose) the "theoretical" surface height for that same volume of material if the surface were flat and horizontal.

   Manufacturers generally recommend that a level instrument be located on the top of the vessel 1/6 of the diameter in from the sidewall when there is assumed to be a symmetrical angle of repose (this typically exists with center fill / center discharge vessels). In this situation, if a straight line were drawn across the angle of repose at the measurement point (Figure 1) the volume of material above the imaginary line is equal to the volume of the empty space below the line. The sensor location that will produce this 1:1 relationship (volume of material above the line : volume of empty space below the line) should be chosen, no matter what the real angle of repose. If not, error will be introduced in the volume and mass calculations.

   When necessary and justifiable it is possible to use multiple sensors across the diameter of the vessel to limit error in the volume calculation by using an average surface height, but this adds to the purchase price of the system.

2. The conversion of a distance measurement into a volume also requires an algorithm for the internal cross section of the vessel. Corrugated wall construction, internal structures, non-flat bottoms and odd-shaped vessels (non-cylinders and non-rectangles) need to be accounted for accurately in this algorithm or additional error will be introduced into the volume calculation.

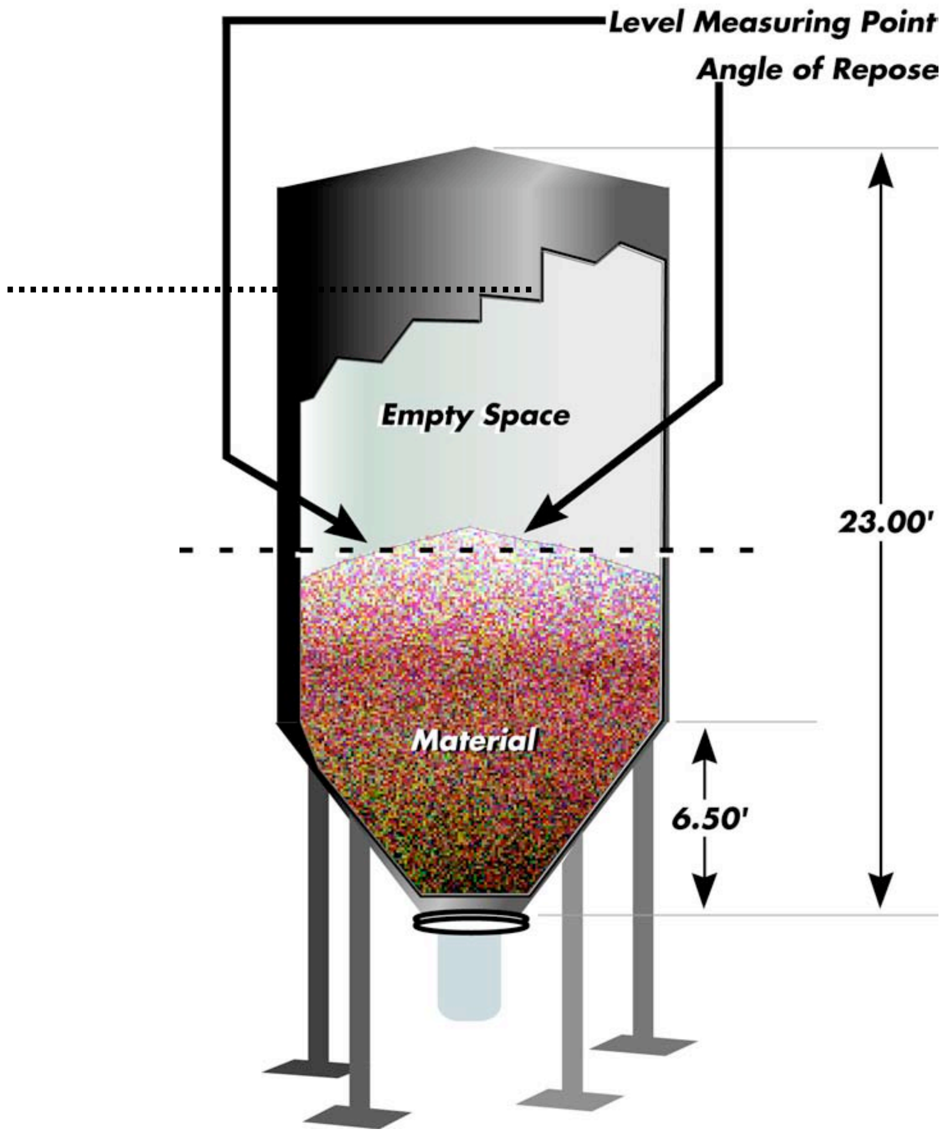


Figure 1: Angle of Repose and Level Sensor Location

3. A value for the "average" bulk density of the material is needed to convert the calculated volume into a calculated mass. Again, the amount of error added into the mass calculation depends on how accurately this average bulk density represents the true bulk density of the material in the vessel.

Remember that the accuracy of the average bulk density is important and affects the precision of the mass calculation. No matter what the bulk density of the material is in the lab or on the weight ticket from the material vendor or shipper, the density on the bottom of the pile is greater than the material at the top of the pile due to packing. Packing factors are unknown. In addition, aerating devices and flow-aids can impact this value as they add air into the material in order to aid material flow during discharge.

The "real world" accuracy of a level measurement system for bulk solids applications is the stated accuracy of the manufacturer, usually stated in terms of distance or level. Level, the inverse of distance once the maximum height is known, can be directly used to estimate the amount of material in the vessel. The "real world" accuracy of a level measurement system providing a calculated volume or mass reading is the sum of the level system error and the errors previously described that affect the conversion of level to volume or mass.

Most vendors estimate that typical "real world" accuracy can be between 0.5% and 1% for calculated volume, and 1% to 5% for calculated mass. "Real world" accuracy can be better than these typical figures, or worse, depending on the specific conditions of the application and the specific level measurement technology chosen.

Level measurement systems typically vary in purchase price from $1300 to $5000 or more. Purchase price generally increases with higher accuracy. You must determine if it is really cost effective to pay more for a technology that measures distance more accurately if you are really interested in a volume or mass measurement (given the potential errors induced by the required calculations).

Weigh systems come in two types:

1. Load cells that are placed under the supporting structure of the vessel.

   The material compresses the sensor and this compression produces an output proportional to the changing weight of the vessel. The stated accuracy is typically +/-0.2% or better. "Real world" accuracy is based on the calibration of the system after installation and the effects of ambient temperature swings on the load cell output, but should be close to the stated accuracy. A load cell system has a purchase price of $4000 and up. Installation and calibration cost can be significantly more than for a typical level system.

2. Strain gages that attach or bolt on to the supporting structure of the vessel.

   This system is lower in cost, approximately $2000 and up, and easier to install. The sensors measure changes in stress in the vessel support member and provide an output in proportion to the weight of material. The calibration is critical because a relationship must be defined between weight of material and the equivalent stress created in the support member. Two manufacturers state typical "real world" accuracy as being in the 1% to 5% range, depending on the quality of the system calibration, the mass range being measured, and other installation conditions.

So which type of system do you choose to use, level or mass? In choosing between a weight system and level system, the answer depends on whether the higher "real world" accuracy of the weight system provides a payback (or other advantage) to offset the higher initial purchase and installation costs. The answer is typically "yes" for custody transfer or internal accountability applications where knowing the exact amount of material in a vessel is very critical. However, the answer may be "no" for the majority of other applications where accuracy is not as critical, and the lower cost of level measurement systems present a more cost effective solution. This is reflected in market research data that suggest that weight systems account for only approximately 23% (based on dollars) of all bulk solids continuous level applications.

Let's consider a simple example based on the vessel shown in Figure 2. This silo has a volume of 3,326 cubic feet, and holds 133,305 lbs. of material.

We will consider a weight & cable level measurement system versus the two types of weighing (mass) systems. A weight & cable system has a purchase cost of approximately $1300 and will measure distance with an error of 0.5% or less. It would measure a material level of 16ft. (a weight of 113,040 lbs. of material) with an accuracy of +/-0.08ft (0.5% maximum error).

Assuming no errors in the volume or mass calculations, this equates to a theoretical error of +/- 565 lbs. out of 113,040 lbs. If we assume the data used to convert from distance/level to volume/weight is only "fairly" accurate, and that a small error of 1% exists for the mass calculation given such a small vessel, we arrive at a "real world" potential error of +/- 1130 lbs for this measurement value (16ft = 113,040 lbs.). This "real world" accuracy would be the same for any other level measurement technology that has the same accuracy of the distance or level measurement. The accuracy in the volume or mass calculations is constant, no matter what the technology used.

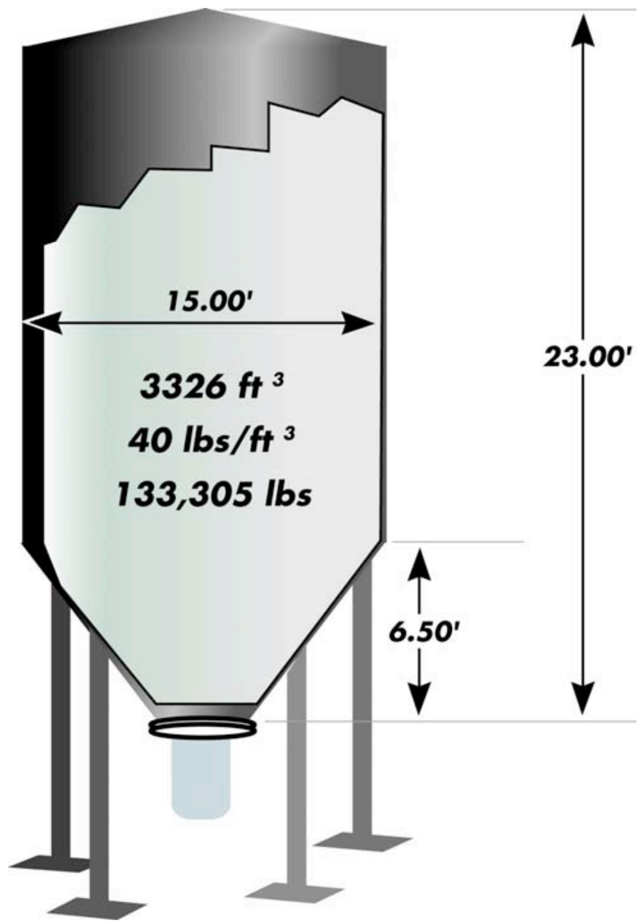


Figure 2: Example Silo – "Real World" Accuracy

A load cell weighing system would have a purchase cost of about $5000 and will measure 113,040 lbs. with an accuracy of +/-0.2%, or an error of +/- 226 lbs. A bolt-on system would have a purchase cost of $2500 and have an assumed accuracy of +/-2%, or an error of +/-2260 lbs.

It appears as though the level measurement system would be preferred to the bolt-on weight system on both price and performance for this simple example. The load cell weight system would be preferred over the weight & cable system <u>if</u> the added $3800 in purchase cost can be justified by the gain in "real world" accuracy.

Such a comparison will vary from application to application, and the results will differ depending on the specific conditions encountered. The thing to remember is that there is no universal answer as to what to use. You must look at level versus weight systems, and even level versus level system for each individual application to make a cost effective decision.

LEVEL MEASUREMENT SYSTEMS

We will now begin our review of the individual technologies for measuring the level of bulk solids and powders in vessels. Pros and cons will be listed for each technology in table form. Information on the key issues concerning the selection of that technology will follow. As mentioned previously, the method of operation, and explanation of product features can be found in manufacturer's literature and is not included here for brevity.

All the technologies reviewed are generally offered with several sensor types, and many options and accessories to allow manufacturers to provide an engineered solution for a wide range of applications.

Weight & Cable Level Systems

PROS	CONS
Not affected by process conditions or material properties – no calibration.	Does not respond instantaneously to a change in level.
Distance measurement not affected by angle of repose (ranges ≤ 150 feet).	Momentarily Intrusive
Low purchase cost (≥ $1300).	Periodic maintenance may be required on extremely dusty applications
Easy installation and set-up.	Mechanical parts can be abraded by some solids
Field repairable.	Measurement during filling not always recommended. Care must be taken not to bury weight during filling.
New designs are very durable for many applications.	Low pressures (≤ 30 psi).
Can be used on dusty powders.	Moderate accuracy for ranges > 30 feet.
Can be used with signal absorbing materials.	
Can be used for high temps (≤ 500o F).	
Explosion proof designs available.	
Good accuracy (±0.25% to ±0.50%) for ranges ≤ 30 feet.	
Wireless interface of sensors and operator interface is available.	
Advanced PC software available. Easy use for supplier managed inventory applications.	
Multiple outputs available.	

Weight & cable systems are one of the most economical choices for measuring the level of solids in vessels. As stated earlier, these systems do not make second-to-second continuous measurements and are not generally recommended when the frequency of continuous measurement is less than 15 minutes.

A high percentage of current users seem satisfied with both the economy and performance of these systems and continue to use them. In fact, the dependability and performance of weight & cable designs has improved significantly over the last few years.

Weight & cable systems offer very good accuracy for vessels 30 feet and under in making the distance measurement, even compared to newer technologies. In longer ranges other level systems offer higher accuracy of the distance measurement, but at an increased purchase cost.

The weight & cable sensor has a few moving parts and therefore may sustain part wear and require some maintenance on severe applications. Recently published articles in print and on the Internet suggest that non-intrusive level systems are replacing weight & cable systems for this very reason.

Key Question - Therefore, it is not performance but rather durability which is the key question concerning weight & cable technology. Is it wise to pay more initially for a system that is non-intrusive and/or that has no moving parts based on the allure of reduced maintenance and downtime in the future? I am not referring to maintenance and down time of weight & cable systems caused by misapplication or misuse (such as exceeding the maximum allowed measurement frequency, ordering the system with an improper length of cable for the empty tank measurement, or burying the sensor by demanding frequent measurements during filling, etc.). I am referring to maintenance and downtime on applications approved by manufacturers and after following their guidelines.

Today's state-of-the-art weight & cable systems are significantly advanced compared to previous designs not only in performance, but also in mechanical durability. Laboratory tests have shown that today's designs can withstand in excess of 150,000 cycles without any mechanical failure. Using the system to update the measurement every 20 minutes, 24 hours a day, and 7 days a week, for 5 years would equate to approximately 130,000 cycles. The actual average measurement rate is significantly less. Field experience has shown that when used properly on a simple application, like plastic pellets, users can expect 5 years or more of maintenance-free service.

Using weight & cable systems on more difficult applications, like cement and flour, that produce copious amounts of dust during filling/emptying, may require periodic preventative maintenance. Field experience has shown that maintenance may be required approximately every 5000 cycles on such service. This equates typically to every 6 to 8 months. The maintenance involves cleaning the system, and replacing a part that mechanically cleans the cable as it is being retracted. This is a $5 to $8 part. The motor, cable and electronics should not need replacement for many years.

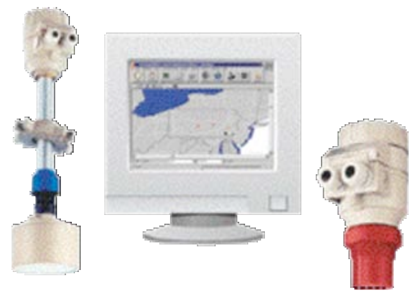
According to manufacturers, the required maintenance should take about 30 minutes, and does not require factory personnel or any special tools or training. If we assume a maintenance frequency of every 8 months and a burdened labor rate of $50 per hour for your personnel, the total estimated maintenance cost over 5 years amounts to under $250. This does not take into account any cost associated with the approximate 3.8 hours of downtime due to the maintenance.

You should consult the various manufacturers for their specific recommendations on the application of weight & cable systems and any maintenance requirements. Here is a short list of the leading manufacturers in the USA:

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

Conclusion - The increased durability of the state-of-the-art weight & cable designs, added to the low purchase cost of the weight & cable system, makes this technology a very cost effective solution, compared to other level measurement devices, for a wide range of applications.

Ultrasonic Level Systems



MONITOR TECHNOLOGIES — PROS	CONS
Non-intrusive / Non-contact.	Sensor signal may be affected by changes in the angle of repose.
Attractive purchase price (≥ $1700)	Low pressures ≤ 40 psi.
Auto-compensation for temperature changes.	Set-up requires care in aiming the sensor and mapping the vessel to eliminate false echoes.
High temperatures (≤ 300o F).	Performance may be affected by very lightweight aerated material due to sound absorbing nature of material.
DSP (digital signal processing) techniques improve performance.	Performance may be affected by heavy dust during filling/emptying.
Long ranges (≤ 260 feet).	Dead zone prevents material selection immediately in front of sensor.
±0.10 to ±0.25% accuracy in measuring distance.	Negative perception that devices need to be continually “fussed” with.
Instantaneous response to changes in material height.	May not be recommended for angle of repose $\geq 45^{o}$ unless particle size is greater than 1 inch.
Relatively easy installation in tight spaces.	Performance on large particles may be affected due to uneven shape of the solids surface.
Sensors are self-cleaning.	

Like weight & cable systems, ultrasonic continuous level systems are a mature technology. And like weight & cable, today’s state-of-the-art ultrasonic systems offer greatly improved performance and reliability due to advances in technology, primarily in the transducer and in the signal processing techniques embedded in the electronics of the instrument via software.

Problems surrounding the use of ultrasonic systems have included the inability to make measurements in applications with dusty conditions, pressure fluctuations, changing angle of repose, large particle sizes, internal vessel obstructions, and coating or formation of clumps on the internal vessel surfaces. Some of these conditions can affect the way the sound wave reflects off the surface and/or the generation of “false” echoes that mask the true level signal.

Temperature fluctuations, once a problem for ultrasonic systems, are no longer an application issue because most modern systems measure ambient temperature and compensate for its effects.

Unlike today's state-of-the-art weight & cable system, a higher percentage of ultrasonic users have not been satisfied with performance on applications involving the above issues. It is for this reason that there is a perception in the marketplace that you have to spend time continually "fussing" with ultrasonic systems to get them to work. In addition, the perception is common that ultrasonic systems may not be reliable in dusty conditions. Many recent articles published in print and on the Internet indicate that use of newer technologies (like guided wave radar, thru-air radar and laser systems) is increasing at the expense of ultrasonic units.

Key Questions - Therefore the key questions concerning ultrasonic level systems are; 1) how advanced are the state-of-the-art designs in improving performance on the traditional problem applications? 2) Can you really install them and forget about them, as you can with other technologies? Most, but not all, ultrasonic system manufacturers believe that today's systems are as dependable and reliable as any other technology on the market.

How is the state-of-the-art ultrasonic system better than previous generations and designs? First, proper installation, aiming and set-up have been and remain critical to achieve maximum performance. With state-of-the-art smart systems, set-up includes not only aiming the sensor, but also identification and elimination of false echoes of the reflected sound wave. This is called shaping or mapping of the vessel and can help eliminate problems associated with false echoes.

Improvements in performance on dusty applications include the use of low frequency sensors, down to 5 kHz. However, materials can absorb low frequency pulses rather than reflect them so this may not be a universal solution. In addition, auto-gain (varying the amount of amplification) and/or auto-power (varying the strength of the pulse) circuits help ultrasonic systems to maintain measurement if vessel conditions cause the reflected signal strength to fade during filling/emptying.

The use of digital signal processing (DSP) also provides a major improvement in performance. DSP and firmware with advanced algorithms process and analyze the return sound signal and make adjustments (increase the gain and/or power) as needed to maintain dependable measurement. DSP allows the system to take a "snap shot" of the local conditions in a vessel, record it to memory, and manipulate it. Digital filtering can average these echo profiles, and eliminate random interference sources to more reliably determine material level.

Here is a short list of the leading manufacturers in the USA:

Kistler-Morse	http://www.kistlermorse.com/
Monitor Technologies	http://www.monitortech.com/
Siemens/Milltronics	http://www.siemens.com/

Conclusion - There is no doubt that state-of-the-art ultrasonic level systems have eliminated many of the problems exhibited by earlier designs. There is still some doubt as to whether all problems, particularly heavy dust, have been satisfactorily dealt with by the new technology advances. Many ultrasonic manufacturers offer other level technologies as well, and will not approve an application if it is beyond the limits of an ultrasonic system. Therefore you should have confidence in the reliable performance of a state-of-the-art ultrasonic system that has been approved by the manufacturer for your specific application. One last piece of advice regarding ultrasonic technology; strongly consider purchasing the on-site start-up assistance that should be available from the manufacturer. It can make start-up go much smoother and it further ties the manufacturer into the application after the sale, which can help in resolving any problems that occur down the road.

Guided Wave Radar (GWR) Level Systems

PROS	CONS
Instantaneous response to changes in level.	Intrusive.
Distance measurement unaffected by dust, angle of repose, process conditions.	Material must have a dielectric constant $\geq$ 1.3.
High number of measurements taken per second.	High purchase price $\geq$ \$2300.
High accuracy, especially in short ranges.	Maximum range may be limited on heavy solids by maximum pull strength of wave guide.
Ranges $\leq$ 115 feet.	Wave guide can be damaged by large particles, heavy solids and material movement.
High temperatures $\leq$ 300o F.	Large particles may be harder to sense.
High pressures $\leq$ 580 psi.	Not used for sanitary applications.
Easy set-up.	
Ability to adapt to a variety of vessel shapes and probes can be cut to length in the field.	
No measurement dead zones.	

GWR systems offer many advantages for an ever-widening range of previously hard-to-measure applications. The most significant disadvantages are that it is a totally intrusive sensor, and the higher purchase price.

GWR systems have received a good deal of word-of-mouth concerning the ability to measure reliably in dusty applications. The pulse of the radar energy is focused and travels along the wave guide. There is very little dispersion of the signal as it travels toward the solids surface, or after it is reflected. Dust does not scatter the pulse as it can with the signal from non-contact technologies.

Most manufacturers' state that with the proper probe design, and with digital signal processing techniques, GWR systems are not affected by coatings. However, performance of the system may be affected if moisture is present, and can combine with the dust to create a clinging-type of conductive coating. This could require re-calibration of the system or periodic cleaning of the wave guide. Of course, this is a problem for most other level measurement technologies as well. The presence of a combination of heavy dust and moisture may be an application where bolt-on strain gage weight systems offer a more effective solution.

Recent articles, both in print and on the Internet, compare GWR systems to Thru-Air Radar (TAR) systems. While we will discuss TAR systems in more detail in a little while, the following are the advantages of GWR systems over TAR systems as cited in these articles:

1. <u>GWR systems are more accurate</u> because the radar pulse does not disperse, the signal-to-noise ratio of the reflected pulse is higher, and GWR must account for only one signal reflection.

    Note: The stated accuracies by manufacturers of both systems are very close. The signal dispersion of TAR and the reflection of the signal by internal vessel obstructions, as well as the solids surface, is a signal strength issue. TAR systems have different electronics features than GWR systems to deal with these issues. It is not clear whether GWR systems in fact offer any "real world" accuracy advantages over TAR systems based on item 1 alone.

2. GWR systems are easier to mount, can adapt to a wide assortment of vessels, and have the ability to operate in smaller spaces.

3. The set-up for GWR is easier, since there is only one signal reflection.

    These articles also state that TAR always requires a laptop PC to map the vessel during set-up. In our research we have found that this is not true for all systems, but does apply to many.

4. GWR takes more readings per second, which is advantageous for fast filling or emptying conditions.

5. GWR are less sensitive to coatings and build-ups.

   This refers to the fact that coatings, clumps of material on the sides of the vessel, etc. may affect the reflection of the radar signal. TAR, like state-of-the-art ultrasonic level systems, incorporate features in the design to deal with this, so it is unclear how much of an advantage this really is.

6. GWR can measure materials with lower dielectric constants.

   The specifications for both systems are close, but GWR may have an advantage for materials with dielectric constants near the minimum requirement for TAR. There is some confusion regarding the effect a change in the dielectric constant has on GWR performance. Theoretically it should have no affect, as long as the minimum requirement for dielectric is maintained. Some experts say that a change in the value after start-up may cause the radar pulse to penetrate deeper into the solid surface before it is reflected. However, most manufacturers state that any error created by this effect would be negligible.

7. GWR systems offer better resolution for longer ranges.

   The specifications for both GWR and TAR are again close. However, TAR may actually have an advantage for longer ranges on heavy solids. GWR range may be limited because of the maximum allowable pull on the wave guide.

8. GWR systems have a lower purchase price than TAR systems.

Here is a short list of the leading manufacturers in the USA:

Endress & Hauser	http://www.us.endress.com/
Krohne	http://www.krohne.com/
Vega	http://www.vega.com/

Conclusion - GWR and TAR systems have different pros and cons. One may be more advantageous than the other for specific applications, however, either should be equally reliable and dependable on any application approved by the manufacturer.

GWR is continuously intrusive, versus the intermittent nature of weight & cable systems or the non-intrusive nature of other level measurement technologies. Depending upon the height of the vessel and weight of the material this could be a problem.

GWR is truly continuous, unlike weight & cable, and is recommend over weight & cable only when the process necessitates frequent continuous measurements. In any case, choose the most economical option that fits the application and your most important needs.

<u>Thru-Air Radar (TAR) Level Systems</u>

PROS	CONS
Non-intrusive.	Requires material have a dielectric constant ≥ 1.8.
High Temperature ≤ 700° F.	Set-up requires mapping the vessel.
High Pressure ≤ 580 psi.	Installation requirements due to potential sensor size.
Ranges ≤ 130 feet.	Sensor is not self-cleaning on dusty applications.
High accuracy in distance measurement, especially in smaller vessel.	Time required to process pulse/echo limits sample rate.
Instantaneous response to changes in material level.	High purchase cost ≥ $3000.
No measurement dead zones.	Range on low dielectric materials may be limited by ability to satisfactorily reflect pulse.
As safe as microwave ovens or cell phones.	

TAR pioneered the way for the use of radar in terms of level measurement. While used widely on liquid and slurry applications in the past, it is becoming more popular for harder-to-measure powder and bulk solids applications as well.

The TAR energy diverges as it shoots down into the vessel in order to reflect off the solids surface. As with ultrasonic level systems, internal vessel obstructions, changing angle of repose, clumps of material adhering to the vessel walls, etc. can affect the reflected level signal and create reflections inside the vessel.

Proper installation and set-up is critical for good performance. State-of-the-art TAR systems allow the user to map the vessel during start-up to identify and eliminate false signal reflections. With some manufacturers, not all, the use of a laptop PC loaded with proprietary software is required for set-up. This software incorporates all the experience gained in previous applications to discern the true level signal. As stated for ultrasonic systems, TAR systems often use digital signal processing (DSP) and signal averaging techniques to successfully hunt for the level signal.

TAR systems use more power that GWR. TAR exists in two basic forms, pulsed radar and FMCW (frequency modulated continuous wave) and produces a high power energy wave that is able to blast through all vessel atmospheres, including dust, to the solids surface. The only possible worry would be if vapors or moisture combine to provide an atmosphere that has a dielectric constant higher than that of the solids material itself. GWR systems may be more energy efficient, have a radar pulse that does not diverge or create false reflections, and have a reflected pulse with a higher signal-to-noise-ratio, but, the higher strength of the TAR system, and the advanced electronics features of TAR, allow it to deliver the same degree of reliable performance for many of the same applications.

TAR systems may be at a disadvantage on low dielectric materials, which produce a weaker reflected signal and may limit the usable range. In addition, the limited sampling rate due to the extra signal processing in TAR systems may not be sufficient for reliable level measurement in applications with fast filling or emptying rates. This may be a problem in small vessels, but not usually in true storage situations.

While GWR units are highly recommended for dusty applications, TAR systems can also be used. However, TAR sensors are not self-cleaning in dusty environments. One manufacturer offers a Teflon dust cap as an option (Teflon is invisible to radar pulses). Moisture, combining with dust to produce sticky, clinging-type coatings may be a problem for TAR. Air purges may be offered as an option for the sensor to keep it clean. However, the purge air may actually create "worm holes" in the sticky build-up rather than remove it completely.

Here is a short list of the leading manufacturers in the USA:

Krohne	http://www.krohne.com
Siemens/Milltronics	http://www.siemens.com/
Vega	http://www.vega.com

Conclusion - We reviewed the advantages that experts claim for GWR systems previously. TAR offers different pros and cons and may or may not be as advantageous as GWR for some applications. Certainly non-intrusion is a large advantage for TAR on applications that can abrade and damage GWR probes, or for large vessels filled with heavy material. TAR systems should deliver the same reliability as any other level system for applications that have been approved by the manufacturer and that match the technology pros and cons. TAR has the advantage of being truly continuous versus weight & cable units, however, we still feel that the best course of action is to choose the most economical option that fits the application and your most important needs.

Laser Level Systems

PROS	CONS
No calibration.	High cost for ranges > 50 feet or high dust.
Ranges ≤ 250 feet.	Limited temperature and pressure limits for direct connection to process.
Non-intrusive.	Not recommended for high dust applications.
New systems more competitively priced for ranges ≤ 50 feet without heavy dust.	
Distance measurement not affected by angle of repose.	
Performance not affected by material or process conditions.	
Easy set-up and installation.	
High accuracy in distance measurement.	
Instantaneous response to changes in material level.	
No measurement dead zones.	

Laser level systems designed for long ranges can have a very high purchase price in the range of $2500 to $6000. They have primarily been used on extremely difficult applications where lower cost systems would not be compatible. One manufacturer has recently introduced laser systems that offer better economy for smaller vessels with very little dust, having a purchase cost in the $1500 to $2000 range.

The laser is a narrow beam that does not scatter on reflection. It is easy to aim, particularly around internal obstructions in the vessel, and easy to set-up. Laser systems can be direct connected to the vessel if the temperature is 150^{o} F or less, and the pressure is 3 psig or less. For process conditions outside this range the laser is mounted outside the vessel and shoots through an appropriate sight glass installed in the top of the vessel. Such an option increases the purchase and installed cost of the system.

Manufacturers state that lasers can penetrate dust. However, the laser lens needs to be kept clean. One manufacturer has options for a sensor dust cover and air purge. Even with such options, lasers are only recommended for light to moderate dust applications at best.

Laser systems do offer pinpoint accuracy for measuring level. Their accuracy is particularly superior to other systems in longer ranges over 50 feet.

Here is a short list of the leading manufacturers in the USA:

K-Tek	http://www.ktekcorp.com/
Optech	http://www.optech.on.ca/

Conclusion - Laser systems have not been used as widely as radar systems, primarily because of the previously high purchase cost. The introduction of more cost- effective designs for shorter ranges, having so many positive advantages, should result in wider appeal with potential users and accelerate their use. These units are non-invasive, highly accurate and respond quickly to changes in material level. If true continuous measurement is needed they are a good option. However, the trade-off is price. You should still choose the most economical option that fits the application and your most important needs.

WEIGHT MEASUREMENT SYSTEMS

Load Cell Weight Systems

PROS	CONS
Truly non-intrusive system.	High purchase cost (> $4000) plus installation cost.
Works even with severe applications involving material flow problems (ratholing, bridging, etc.)	Involved calibration procedure.
Not affected by dusts or build-ups.	Potential issues and costs retrofitting existing vessels.
Safe method for handling hazardous materials.	Potential accuracy limitations if material load is significantly lower than the dead weight of the vessel.
Multiple sensor system – can provide redundancy – leaves vessel on-line while a failed sensor is replaced.	Measurement may require extra attention to details during operation to get maximum accuracy.
Provides highest accuracy.	Structures connected to vessel may affect performance.
Ranges from 100 lbs. to 1,000,000 lbs.	
Sanitary applications – meets CIP/SIP requirements.	

Load cells, as stated previously, are generally placed under the supporting structure of the vessel and offer the highest accuracy of measurement (± 0.2% or better). They have a very high initial cost (purchase, installation and calibration costs combined), and are primarily used for "certified for trade" or internal accountability applications (where mass measurement is required), or on severe applications where other systems will not work. They are widely used in the food, pharmaceutical and aggregate industries. These are engineered systems by the manufacturer for specific applications.

Here is a short list of the leading manufacturers in the USA:

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

Conclusion - Load cell systems do not really compete with level systems. If you absolutely need accuracy in mass measurement, level systems will not be competitive except under limited conditions, as demonstrated in a previous example. The high cost of the weight system is not a factor because there are rarely any other candidates at a lower cost that offer the required performance. You should still approach your selection by choosing the most economical option that fits the application and your most important needs.

Strain Gage Weight Systems

M O N I T O R   T E C H N O L O G I E S

PROS	CONS
Truly non-invasive system.	High purchase cost (> $2000).
Easy to install – suited for retrofitting existing vessels.	Calibration critical to performance.
Works even in severe applications involving ratholing and bridging.	Typical "real world" accuracy of 1% to 5%.
Not affected by dust or build-up.	Potential accuracy limitations if the material load is significantly lower than the dead weight of the vessel or lower than 75,000 lbs.
Safe method for handling hazardous or highly abrasive materials.	Measurement may require extra attention to details during operation to get maximum accuracy.
Sanitary applications; meet CIP/SIP requirements.	Structures connected to vessel or vessel bolted to concrete may produce accuracy and reliability issues.
Cost effective means for mass measurement when accuracy is not critical.	

Strain Gage Weight Systems attach or bolt on to the supporting structure of the vessel. They are cost effective systems for providing 1% to 5% of mass accuracy. They give years of maintenance-free service once they are installed and calibrated.

The manufacturer will require a complete description of the vessel so that the method and location of sensor placement can be determined. Once this is done, the system can be installed by the user. The real trick is in calibrating the system. You need to apply a precise load to the vessel (either via material or attached weights) to determine the relationship between weight and stress applied to the sensor. This is not always possible and the accuracy of the system will be a function of the accuracy of the calibration.

Here is a short list of the leading manufacturers in the USA:

Kistler-Morse	http://www.kistlermorse.com/
Thermo-Ramsey	http://www.thermo.com/

Conclusion - Strain Gage Weight Systems, because of their lower cost (compared to load cell systems), "real world" accuracy in mass measurement, and design advantages, do compete more with level systems over a wider range of applications. As in a previous example, the advantages of a weight system vs. a level system will vary from application to application and there is no general rule of thumb on which is better to use. We recommend that you choose the most economical option that fits the application and your most important needs.

CONCLUSION

Despite the emergence of new technologies, like radar and laser, or improvements to mature technologies, like weight & cable and ultrasonic, there is still no "silver bullet" for bulk solids measurements. No single technology offers a cost effective solution to every solids application. In fact, except for the simplest, most applications generally require an engineered solution by the instrument system manufacturer.

Here is a four-step guideline to use in selecting the correct solution for your application:

- **Define the requirements of the application.** How important and necessary is high accuracy? Where does reliability and maintenance fall in your list of priorities? Are you just replacing the manual process of making a measurement or do you need custody transfer accuracy?

- **Create a list of potential candidates** by matching the requirements you have identified against the pros and cons for the various technologies as we have discussed.

- **Talk to leading manufacturers** who sell the instruments on your short list. Evaluate their offerings against your needs and look for the highest value. The material that we have presented here should be considered general information and in no way is a substitute for the years of specific application experience the manufacturers will bring to the table. Discussing the process conditions, installation requirements, nature of the material, required "real world" accuracy and cost targets (purchase, installed and long term cost of ownership) with each manufacturer will further reduce the candidates on the list.

- **Make a final selection** from your short list of manufacturers and technologies. You will have at least one, and most likely several technologies that can successfully be matched to your application. The selection from the final short list is typically influenced by one or more of the following factors:

  - ❖ <u>Personal Preference</u>: Each of us is influenced by the previous experience we may have had with a specific technology and brand. However, bear in mind that even mature technologies have undergone major advancement in design in recent years. Comparing today's state-of-the-art designs with designs available even only 5 years ago, as we have stated previously, may be like comparing a Volvo to a Model T. Don't automatically rule out any technology based on a poor performance history at first. Many brands are on their second or third generation designs. Make certain that history was not the result of misapplication or misuse of the technology, or simply limitations of earlier designs. If the state-of-the-art for that technology or brand is not cost effective, or can not solve the past problems, then look at other candidates.

  - ❖ <u>Perceived Durability and "Fussing" Required</u>: Eliminating maintenance, re-calibration, or "fussing" may seem at first to be a significant factor in making a selection. However, once the manufacturer has approved their device for your application, and assuming the pros and cons of that device meets the application needs, maintenance should not be a major concern. Any of the technologies remaining on your short list of candidates should yield a high degree of dependability and years of maintenance free service.

  - ❖ <u>Highest Accuracy</u>: Higher accuracy will be a major factor on a not so insignificant percentage of applications, as stated previously. When accuracy is a major factor driving your selection, a weight measurement system may be favored over a level measurement system. For the majority of other applications, where accuracy is not as critical, level measurement systems offer the lower cost.

- Lowest Cost: This brings us to cost as a major driver in the decision process. This is usually initial cost, which includes the purchase price of the system and the cost to install it and get it operational. Again, once pros and cons have been examined (which vary from technology to technology), and once the manufacturers have approved their technology for your application, there is no criterion besides cost. You should choose the most economical option that fits the application and your most important needs.

Regardless of which technology you finally select, remember that the most important thing is to closely follow manufacturer's guidelines to avoid problems and frustrations.