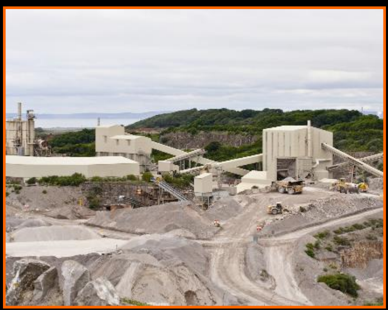
HYCONTROL
LEVEL MEASUREMENT SOLUTIONS






Achieving Reliable and Accurate Solids Level Measurement

A white paper from Hycontrol

Achieving Reliable and Accurate Solids Level Measurement

*UK-based **Hycontrol** have been leaders in the field of level measurement and control for over thirty years, with a client portfolio stretching the full breadth of modern industry. Their equipment has been trusted to measure every conceivable product from corn flakes to nuclear waste. Here, the company explains the many different level measurement technologies currently available to users and the relative merits of each type.*

The accurate and reliable contents measurement of silos, vessels, hoppers and bins plays a vital role across a broad spectrum of industry sectors. There are a diverse range of fiscal and operational reasons for measuring contents including:

- **Stock management and control**
- **Process control and optimisation**
- **Bulk out-loading**
- **Providing data for suppliers as part of a VMI (Vendor Managed Inventory) system**
- **Prevention of overfilling or over-pressurisation as part of an integrated safety system**
- **Improved Health & Safety compliance**

However, obtaining accurate and meaningful contents information is often not straightforward. Firstly, a high percentage of vessels are either not initially installed with pre-designed fit-for-purpose measuring systems or have outdated instrumentation that may already be redundant. Secondly, a complex blend of product characteristics, environmental conditions, operational parameters and budgetary constraints further complicate the situation. This means that when users need to obtain reliable data from their vessels they need to be able to make an informed decision on the best measurement solution for their particular application. The most common choices to provide this data are **level measurement meters or**

probes, retrofit strain sensors and **strain gauge load cells.** Each method has its advantages and disadvantages and, before choosing what is deemed to be the 'optimum solution', the user is faced with something of a dilemma. Consideration needs to be given to fundamental factors such as **'why are they measuring the contents?'** and **'what do they expect or want to achieve from the results?'** This might sound simple, but in many applications compromises need to be made based on a number of important commercial and engineering factors. It may be stating the obvious but level measurement and weight measurement are two very different things, and this may not be fully appreciated by the user. Although weight data can be obtained from level information the reliability of the conversion is dependent on a wide range of parameters.

Engineers installing display panels for level monitoring equipment

It is important to understand from the beginning that no sensor mounted on top of a silo actually measures level; it measures distance. It doesn't matter what technology is being used – the primary measurement is the distance between the transmitter and the material being measured. Modern top-mounted level measurement systems are quite capable of measuring a distance to within just a few millimetres, and any accuracy quoted by the instrument manufacturer is based on this distance measurement.

Level is discerned by programming the distance to the bottom of the vessel into the instrument. The instrument then automatically subtracts the distance measurement from the 'bottom' value to determine a level. For example: if the distance between the transmitter and the tank bottom is entered as 8.5 metres and the instrument itself measures a distance of 2.5 metres to the surface of the material then the material level must be 6.0 metres (empty distance minus measured distance).

This basic principle is the same across all of the available technologies that use a top-down measurement, and when used to measure liquids the accuracy quoted for the instrument will in most cases be correct.

However, when considering the measurement of solids a number of other factors that affect accuracy come into play. This white paper sets out to explain what they are and what effect they have.

In almost all applications initial purchase cost is the main driving factor in the decision process. Unfortunately this can impact negatively on the final choice, affecting accuracy, reliability, longevity, service costs and therefore overall total cost of ownership.

Retrofit Force Sensor Systems

Retrofit force sensor systems involve the fitting of special strain sensors to appropriate parts of the load-bearing structure of the vessel, effectively converting these into very large load cells. The sensors are typically welded, bolted or glued to the structure and the success (or failure) of such systems is dependent on a number of key factors. A major drawback can be the stability and magnitude of signal levels received from the sensors. Normally load cells are designed to optimise their electrical output relative to the applied bending, compressive or shear loads and their metallurgical properties are very carefully controlled via heat treatment and machining. During manufacture, the strain gauges are applied to the sensor bodies under ultra-clean laboratory conditions and temperature compensation is an integral part of the manufacturing process. Capacities are selected for specific applications and special mounting arrangements ensure loads are introduced correctly, minimising the effects of side or off-axis loads.

By contrast, vessel support structures are typically made from standard non-heat treated steels, selected to optimise system integrity and minimise bending and deflection. As a result the signal levels from the applied sensors are typically very low compared with load cells, making them more prone to structural anomalies and temperature fluctuations. A separate problem can arise where two or more vessels are mounted on a common support structure. So-called 'structural crosstalk' can mean that weight readings from one vessel can be affected by load changes in an adjacent vessel.

Although retrofit systems have their limitations, there are ones which utilise structural monitoring expertise together with data-logging techniques to provide very stable and reliable results for some applications. Retrofit sensor systems are non-intrusive and can be fitted without stopping the process.

Strain Gauge Load Cell Systems

Although the fitting of load cells may appear to be the ideal solution and provide the best accuracy, commercial and engineering restrictions significantly limit their application on high capacity vessels. Fitting load cell assemblies to existing vessels is very process-intrusive and usually requires significant and expensive engineering work to be carried out. Maintaining structural integrity is a major consideration, especially in applications subject to high winds or seismic activity. Depending on the design of the vessel and its location, in certain applications it may not be physically possible to fit load cells (for example on skirted silos or particularly tall silos).

Level Measurement Systems

Before instrument-based measurement became widely used, content levels were often determined by rudimentary mechanical means. Simple methods such as dropping weighted lengths of rope with equally spaced knots onto the surface of the material in the vessel were not uncommon. Level measuring technologies have advanced considerably over the past two decades and are now well established for measuring the contents of tanks, hoppers, bins and silos up to 100m high.

They provide a relatively non-intrusive, easy-to-fit system for products such as cement, hot bitumen, chemicals, plastics, cornflakes, limestone, aggregates, animal feed, flour and oil. Installations range from single point high- or low-level alarm systems to fully integrated multi-point and multi-technology plant-wide level measuring systems. Technologies available include:

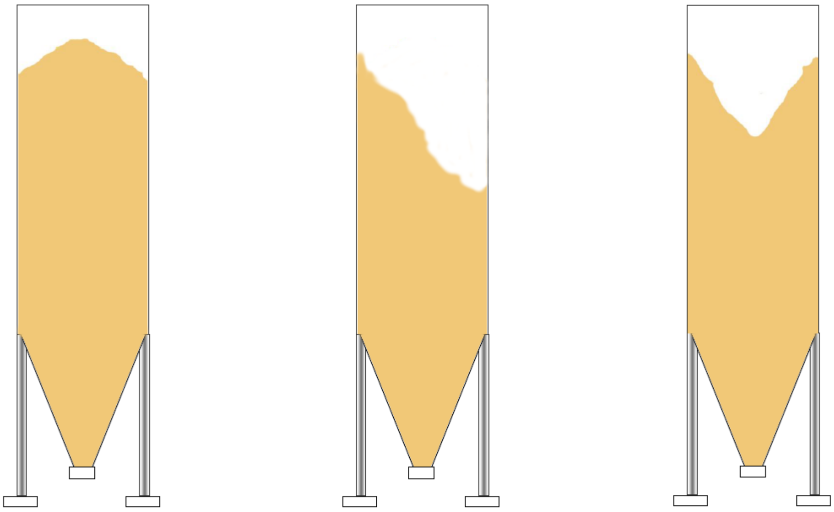
- **Ultrasonics**
- **TDR Guided Microwave**
- **Radar**
- **Microwave**
- **Paddle switch**
- **Plumb-bob/Yo-Yo**
- **Tuning Fork**
- **Capacitance**
- **Admittance**
- **Vibrating Probe**

A wide range of critical factors need to be considered when choosing a solids level measuring system, in order to ensure satisfactory results and performance. The key considerations are:

- **Product characteristics (dust, dielectric constant, bulk density, flow behaviour)**
- **Vessel environment (temperature, pressure)**
- **Size, shape and internal structure of vessel**
- **Presence of mixers, aerators or stirrers**
- **Operational requirements**
- **Filling and emptying points (location and number)**

Product behaviours within a vessel (including flow characteristics, bulk density and the tendency to absorb moisture) have a major effect on the performance of any level measuring system. The topography of the surface of the material will change as product is added or taken out of the vessel, thereby affecting the results of any measurements. As a result consideration must be given to how the product behaves inside the silo (something that would not be an issue with load cell devices). This could include:

- **Angle of repose**
- **Draw-down (opposite of repose)**
- **Rat-holing**
- **Bridging**
- **Bulk Density**
- **Dielectric value**

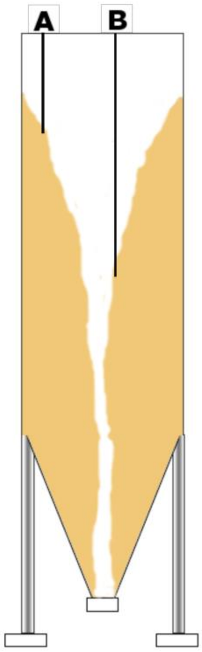


Angle of Repose / Draw-Down

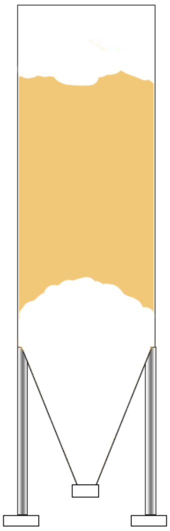
The shape the top of the material forms when it comes to rest inside a vessel is dependent on several factors: its flow characteristics, number and position of fill points and the internal surface finish of the vessel. Similarly the draw-down shape depends on the number of outlet points and positions, and the shape of the bottom of the vessel. *Some examples are shown above.*

Even geographical location can affect what the product does inside a vessel. Prevailing winds can cool one side more than the other; one side may be in direct sunlight whilst another is in the shade. This could lead to moisture or condensation forming on one inside wall causing the product to stick on that side, which may cause the angle of repose or rat-holing / bridging *as described below.*

Rat-Holing



This typically occurs when the material in the middle of the silo collapses to the empty point(s) leaving a long hole in the vessel with the remaining material stuck round the sides. Depending on the level measurement technology used and the position of the sensor, inaccurate results can occur. Contents should best be monitored to prevent rat-holing from occurring. *In the example to the right probe (A) detects 80% full, whilst probe (B) detects 50% full, leading to confusion. A solution is to use both probe positions and take an average level reading from them.*



Bridging

If product has a tendency to bridge across a silo as material is drawn off, non-contact level measurement equipment will be fooled into providing false levels until the bridge collapses. This can be caused by a number of factors including the tendency of the material to stick or clump together. *See example, left.* With product that is known to bridge, vessels are often equipped with compressed air cannons or vibrating pads to help break up the clumped product.

Bulk Density

Changes in bulk density can have a significant effect on the measured levels of powdered product in a vessel. Bulk density is both time-dependent and level-dependent. For example the level in a freshly filled cement silo will change with time as the material settles. In parallel to this issue bulk density will vary from the bottom of the vessel to the top. Any aeration used to keep the contents of a vessel fluidised will also impact on accuracy.

Dielectric Constant

The dielectric constant of a material is a measure of the extent to which it concentrates **electric flux**, and is the electrical equivalent of relative magnetic permeability. For Radar and TDR based level measurement systems the intensity of the reflection of the microwave beam is dependent on the dielectric constant of the material. The higher the dielectric constant the stronger the reflection will be: for example the dielectric constant of water is 80 meaning that it is highly reflective. However, unlike the factors above, dielectric constant does not directly influence the accuracy of the measurement but it should still be taken into consideration as it may have bearing on the choice of technology.

Vessel Design

The design and configuration of the vessel require careful consideration when choosing the most suitable level measurement technology. Common designs include:

- **Vertical tanks**
- **Skirted silos**
- **Hoppers**
- **Chutes**
- **Bins**

For symmetrical vertical tanks, measured levels are proportional to contents over most of the range. However, if it is required to accurately measure contents as levels fall into coned areas at the base of the vessel, appropriate corrections must be made. This consideration can be more relevant for smaller hoppers where any cone is a more prominent part of the design.

Internal Structure

Depending on the chosen level measurement technology, internal structures such as braces, internal ladders, grills and cross beams can affect accuracy at different points as the vessel empties and fills. The presence of mixers, stirrers and aerators will also need careful consideration as these too can have an effect on accuracy.

How Do You Decide Which Technology is Best for Your Application?

Level measurement techniques fall into two basic categories:

- **Point Measurement**
- **Continuous Measurement**

In turn, continuous measurement techniques are broadly divided into **contact** and **non-contact** technologies. Products may have unique properties which will play a role in determining the effectiveness and performance of any level measuring system and should therefore be carefully considered. In parallel, vessels differ in size and design – a typical silo can be ten metres or greater in height – whilst bins and hoppers are usually smaller and may act as intermediate product buffers between inventory and daily production.

Point Measurement

*Technologies include: **paddle switch, conductivity probes, vibrating probe, admittance and capacitance.***

Point measurement is a cost-effective solution for simple level measurement where, for example, the user may only need to know when the vessel is empty or full. A typical system for this would involve two sensor switches – one at or near the top of the vessel, the second at some point near the bottom. These provide what is often known as a simple **High-Low** level alarm system. However a fundamental issue with point level switches is that in order to function they must come into contact with the vessel's contents leaving them vulnerable to abrasion and wear, or becoming coated in product which can also damage the device or interfere with its effective operation. Self-cleaning designs and special coatings have been developed to help overcome these problems. Point measurement technology is also often used as part of a continuous level measurement package to provide a complete 'belt and braces' safety system.

Continuous Measurement

*Technologies include: **ultrasonics, TDR guided microwave, radar***

Continuous level measurement has the advantage that it provides real-time level data over the complete measuring range. Measuring liquid levels is usually quite straightforward and accuracies of 0.25% or better can be achieved under stable conditions. However it should be noted that measuring solid and powder contents can present more challenging problems. The characteristics of these technologies are outlined below:

Ultrasonics

Ultrasonic technology provides a highly cost-effective, easy-to-install, non-contact solution for many solids level measurement applications. The transducer emits pulses of high frequency sound and measures the time it takes for these pulses to be reflected back to the transducer from the material surface. As the speed of sound through air is a known constant the time-of-flight can easily be converted to distance, and from that an accurate level can be extrapolated.

Frequencies as low as 5 kHz are used on long range solids materials and higher frequencies at 40 kHz or above are used on shorter ranges. The latest low frequency ultrasonics can be used for ranges of up to 60m though a number of environmental and operational factors within the silo can reduce this range. Traditional ultrasonic devices struggled with the effects of false echoes and temperature changes but

the latest corrective software can compensate for a number of adverse operational factors relating to weak and false echoes caused by dust, internal silo structures (for example ladders or cross braces) and temperature changes affecting time-of-flight.

It should be noted that when using ultrasonics, consideration has to be given to the so-called **dead band**, a range directly below the transducer face where measurement is not possible. This area can vary from 300mm to 1500mm depending on the frequency being transmitted. This usually only presents a problem for shorter measurement ranges and can be overcome using stand pipes to move the ultrasonic transducer up from the top of the tank.

TDR (Time Domain Reflectometry)

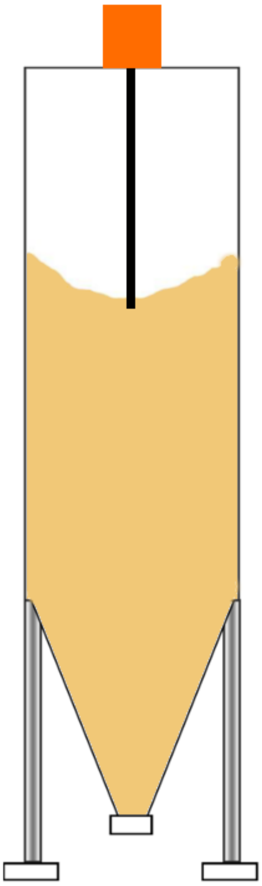
TDR guided microwave technology provides highly effective solutions for solids applications where ultrasonics are not suitable. A key issue is that this technology is unaffected by dust or changes in pressure, temperature or viscosity. The measurement principle is based around a microwave pulse that follows a guided conductor (typically a stainless steel rope or rod), suspended from the top of the silo. This pulse continues down the conductor until it hits the product surface, whereupon it is reflected back up the wave guide. The distance is then calculated using the time-of-flight measurement principle, which in turn allows the level to be calculated. The strength of the reflection is dependent on the dielectric constant of the material being measured. With measuring ranges up to 35m, TDR has the advantage of being relatively low in cost and easy to set up. The bottom of the cable is sometimes anchored to ensure it does not move around during material filling or draw down because if the cable touches the side of the silo it will report false measurements. An important advantage is that the complete system can be configured at the factory prior to fitting, saving valuable time on site. In addition this technology will continue to work even if the wave guide cable or rod becomes coated in product. The main disadvantage is that it is a contact-based technology and may not be suitable for certain applications where, for example, product contamination has to be avoided or abrasion could limit the life of the probe.

Radar

FMCW (Frequency Modulated Continuous Wave) Radar level measurement systems use high frequency microwave signals (24-26 GHz) that are unaffected by dust, pressure, temperature, viscosity, vacuum or foam. The measured level is proportional to the difference in frequency between the transmitted and the received microwaves. This technology is suitable for measurement ranges up to 80m and provides high levels of accuracy for certain applications; however the effectiveness of Radar technology is dependent on the dielectric constant of the material in the vessel.

Radar usually works better on products with a dielectric constant of greater than 2.0. Radar is more expensive than ultrasonics (in some instances up to twice as expensive), which may be a deciding factor for certain applications.

Effects of Filling and Emptying



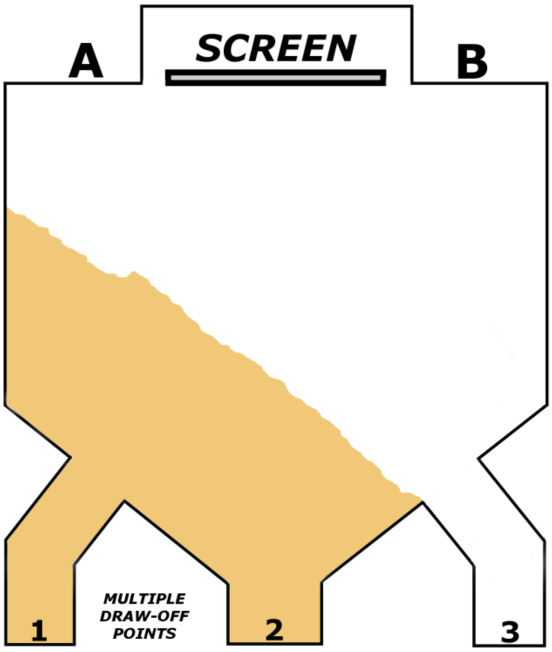
It is important to understand the way in which silos are filled and emptied when installing level measurement systems in order to optimise performance. In a normal silo with a width of less than 3 metres, with a centrally-located single fill and draw-off points, the way in which material behaves is usually repeatable. A single level probe, located away from the fill point, will provide reliable and consistent results – *as illustrated, right.*

Please note that usually the optimum position to place the probe is at distance one third radius from the outside of the vessel. This will then provide a reliable average level result.

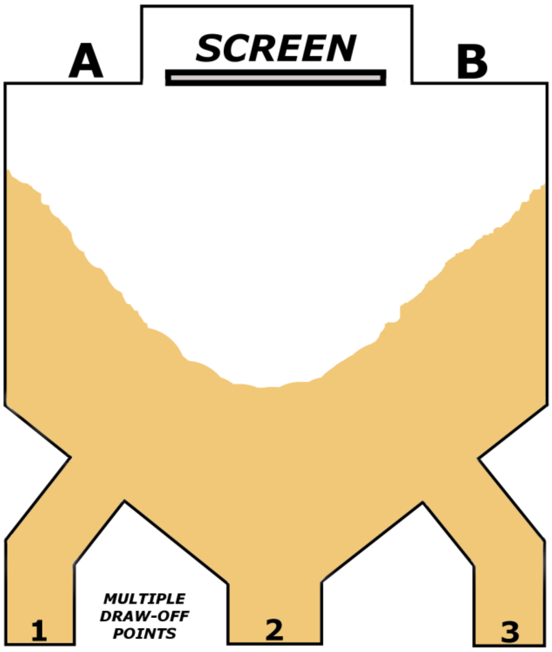
Complications can occur with vessels that have multiple fill and draw-off points - *for example in quarry screen-houses as shown in illustrations on the following page*. The three drain points at the bottom of the bin in this example will cause the product to behave in unpredictable ways. This means that a single sensor located on one side or the other of the vessel will not provide an accurate gauge of the contents – for example product may come to rest largely on one side of the bin, and a meter located on opposite side may erroneously show the tank to be empty or near-empty. Using the vessel shown in **example 1**, this would be the case for a probe located at **point (B)**.

Please note that due to the design of screen-houses, where crushed rocks are passed over a series of screens that runs down the centre of the building, it is not possible to centrally-locate a probe in a screen-house - the falling product would soon erode it away. Whilst covers could be fitted it would be totally impractical to gain access in order to service and conduct maintenance on the probe.

Example 1:



Example 2:



The most effective solution is to mount two level meters, each an equal distance from each side – in the examples *above* this would be at **points (A)** and **(B)**. The readings from each meter are then used to discern the average product height in the vessel. This is done simply by feeding the information from the two probes to to a site PLC or locally-mounted display panel where the readings from **(A)** and **(B)** are added together then divided by two, giving an average contents level for the vessel. This also provides the user with separate levels for both sides of the screen, making it easier to decide which point to draw the product from – for instance, in **example 2** above the product should be taken from **draw-off points (1)** and **(3)** to lower the product height at the sides of the bin.

In most applications filling is carried out over a relatively short period and then left until needed, however in some process applications material is continually filling and being drained from the silo. This will affect the product behaviour in the vessel, and may also cause additional wear on contact-based level equipment.

Conclusion

As we have seen, there are a wide range of level measurement equipment options to choose from, and an even wider range of material and process considerations that need to be made in choosing the right one. Solids level monitoring is, by its very nature, very different to monitoring liquid levels – unlike solid materials which will pile and fall in difficult-to-predict ways, liquids will find their own level and a meter should get consistent readings wherever it is placed in the vessel. That said, there are an equal number of factors to consider in liquid level measurement, including structural interference, vapours, temperatures and dielectric constants – these will be dealt with in a separate paper.

As was touched on at the start of this paper, the end user must ultimately has to make key decisions concerning their level monitoring and control system including the following:

- **What is the goal?**
- **What information is required? (For example – point or continuous level measurement)**
- **How should this information be implemented?**
- **Who needs to know what the vessel contents are – and can it be provided?**

Consideration also must be given to the properties of the material being measured and any elements in the larger working environment which may affect the accuracy and reliability of the technology being used.

In short, whilst there is an answer for almost every level monitoring and control question, there is no one-size-fits-all solution. The technology chosen should be tailored to the application. This is best done in consultation with experienced, competent level measurement engineers. Poorly chosen equipment selected on cost considerations alone will almost certainly lead to further headaches down the line. Correctly-chosen equipment will – if properly installed, calibrated and maintained – provide the best results both in terms of the accuracy and reliability of readings and in lower total cost of ownership for a far longer period of time.

Addendum - Product / Technology Reference Table

Technology	Mode	Product					
	Point / **C**ontinuous	Powders	Plastics	Slurries	Flakes	Aggregates	Bitumen
Paddle Switch	**P**	X	X		X		
Conductivity Switch	**P**			X			
Vibrating Probe	**P**	X	X	X	X		
Admittance Switch	**P**	X		X	X	X	X
Capacitance Switch	**P**	X		X	X	X	X
Microwave Switch	**P**	X			X	X	
Plumb-Bob	**C**						X
Ultrasonic	**C**	X	X	X	X	X	
TDR	**C**	X	X	X	X	X	X
Radar	**C**	X	X	X	X	X	

Appendix

System Accuracy / Repeatability / Resolution

*Accuracy requirements for level measuring systems vary considerably according to business and operational factors. One key issue is to establish whether the user needs to know the **LEVEL**, the **VOLUME** or the **WEIGHT** of the contents in the vessel. Volume and weight can be calculated from level data, but the accuracy of such calculations depends on a number of factors:*

- *If **LEVEL** is required, then the device accuracy will become the overall accuracy,*
- *If **VOLUME** is required the accuracy of the volume calculation will impact on the overall accuracy and*
- *If **WEIGHT** is required both the volume calculation and the accuracy of the bulk density will affect the overall accuracy.*

In all of the above cases, the overall accuracy will be affected by how the product behaves during filling and emptying.

*Repeatability is the expectation that if the product reaches the same measurement distance today as it did yesterday, the displayed value will be the same. With a liquid product this is pretty much true. However, where **VOLUME** or **WEIGHT** of a solid is required, the way the product behaves in the vessel and the position of the level device will both have a direct effect on the overall repeatability. Resolution is defined as the smallest step change in distance that a level device will respond to.*

Accuracy, repeatability and resolution are key parameters for any measurement sensor. Whilst they are very relevant to the measurement of silo contents, they are only part of the story as we have seen.

To read more of our applications in the chemical, food & beverage, nuclear, water & waste, recycling, quarrying and metals industries, please go online at hycontrol.com

Hycontrol UK (Head Office)
Orchard Street
Redditch
Worcestershire
England
B98 7DP
Tel: +44 (0) 1527 406800
Fax: +44 (0)1527 406810
Email: sales@hycontrol.com
Web: www.hycontrol.com

Hycontrol China
Room N601 Peking Times Square
Hui Zhong Li
Chao Yang District
Beijing 100101
China
Tel: +86 108 487 1101
Fax: +86 108 487 1033
Email: simon@hycontrol.com.cn
Web: www.hycontrol.com.cn

HYCONTROL
LEVEL MEASUREMENT SOLUTIONS