Application Considerations for Point Level Monitoring of Powder and Bulk Solids

In The Beginning

The use of point level monitors for powder and bulk solids in modern industry dates back to 1934. This is when The Bindicator Company first used its trademarked name "Bin-Dicator"[1] in commerce to market their pressure-sensitive diaphragm point level switch. The product type is still available today. Resilient to be sure and this exemplifies the critical importance of point level monitors and their use. But what is "point level monitoring"?

"Point Level Monitoring" is the monitoring of presence and absence of material at a predetermined point within a bin, silo or other vessel containing a powder, granular or other form of bulk solid in a storage or processing application. The use of an instrumentation sensor to detect the presence or absence is commonplace today. In addition, there are many choices of technologies available. The intent of this white paper is to provide you with a basic understanding of the application considerations to assist in identifying which technology is best suited to meet your needs.

What Application Characteristics Affect Technology Choice

The choice of a point level monitoring technology can be impacted by many factors. Here are the most common to consider:

- Temperature
- Mounting Location
- Bulk Density
- Particle Size
- Dielectric Constant (E_r)
- Corrosion/Abrasion
- Adhesion

Temperature: The most common viable point level technologies are in contact with the material to be detected. Therefore, the temperature inside the bin, and the ambient conditions surrounding the sensor components external to the bin, can impact the choice of technology, which brand to buy and even the version selection within the technology category.

Temperature primarily affects electrical/electronic components and the use of non-metallic wetted parts (materials of construction in contact with the process media). Your internal bin temperature maximum and the minimum and maximum ambient temperature outside of the bin are what you will need to know. Each point level technology and brand should clearly state the limits of these conditions.

[1] "Bin-Dicator is a registered trademark of Venture Measurement Company LLC

The greatest range of internal bin and ambient temperature "out-of-the-box" will typically be the mechanical and electromechanical technologies. Refer to Table 1[2].

Table 1: Internal Bin and Ambient Minimum and Maximum Temperatures for Common Point Level Sensor Technologies

Technology	Min Internal Bin Temp	Max Internal Bin Temp	Min Ambient Temp	Max Ambient Temp
Diaphragm	-40 F (-40 C)	250 F (121 C)	Same	Same
Tilt	-40 F (-40 C)	250 F (121 C)	Same	Same
Rotary Paddle		300 F (149 C)	-57 F (-49 C)	200 F (93 C)
RF Cap		176 F (80 C)	-40 F (-40 C)	150 F (65 C)
Vibrating	-22 F (-30 C)	230 F (110 C)	-22 F (-30 C)	140 F (60 C)
Cap Prox Switch	-13 F (-25 C)	176 F (80 C)	Same	Same

This data is a generalization synthesized from the specification for standard versions of devices from a variety of brands. Generally, all of these technologies will be acceptable for 80% of the point level monitoring applications in powder and bulk solids. Other selection criteria will typically be used to make a final choice, however, the application must fit within the temperature limits of the technology chosen.

Mounting Location: This application consideration will be impacted by or may impact the size of the sensor, accessibility requirements, material flow within the bin and surrounding equipment.

Some sensors can have footprints larger than others. You will need to make sure that the sensor you choose meets your needs. Conversely, the available size of the potential mounting location may dictate the technology choice. Small bins may require a compact sensor because the mounting location is physically limited. Capacitive style proximity switches are a great choice for compact mounting, so long as they meet other application considerations.

Sensors that are top mounted and that use long rigid extensions require headroom for installation. If your mounting area headroom is limited, then you will need to check this out further. Flexible extensions may be a solution to this problem if top mounting with limited headroom is necessary. These flexible extensions are available with some rotary paddle brands. RF capacitance/admittance and vibratory technologies offer flexible extensions as well.

One last point needs to be made regarding mounting location, and that is in regards to other devices mounted on the bins in close proximity to where you want to mount the point level sensor. The most common thing to avoid is locating the level sensor close to an industrial vibrator. While vibrators are viable for fluidizing the material in the bin to

[2] Some "versions" within the differing brands may provide some improvement, but these are the ratings "typical" for entry level devices "out-of-the-box".

get the material to flow, they introduce energy onto the bin that can be very destructive to sensors mounted nearby. This is especially true, but not limited to, locating vibrators near electronic level sensors such as RF capacitance/admittance sensors and vibrating element sensors like tuning forks.

Bulk Density: This material attribute is defined in terms of weight per volume. Most commonly it is referred to in engineering units of pounds per cubic foot, grams per cubic centimeter and kilograms per cubic decimeter. Whatever the term, it refers to the same thing, density of the bulk solid material. Density of a liquid is commonly expressed as the liquids “specific gravity”. The material bulk density can impact technology choice directly or indirectly.

The greater the bulk density, the more probability there is for physical damage to invasive sensor technologies that do not easily resist side loading from shifting or flowing material or that can be damaged by falling material if the sensor element is not completely protected. Some examples follow.

Vibrating element level sensors are proven to be sensitive to both falling material and side loading. While the manufacture and design has improved over the last 15 years, this technology should still be avoided in low level applications when the material bulk density is greater than 45 lbs/ft^3 (0.72 $grams/cm^3$). Specific mounting instructions must be followed if you attempt to use vibrating element sensors in any low level application. This includes the use of a complete baffle to protect the sensor from falling material.

High level applications can also be hazardous to some technologies when the material bulk density is very high. This is because of side loads from shifting and flowing material. However, some technologies will suffer from inconsistent operation or failure of detection if the material bulk density in high level applications is very low. Consider the need to monitor for high level conditions with lightweight material such as, but not limited to, aluminum shavings, sawdust, dust collector hoppers, corn bran, various cereals, expanded polystyrene beads, potassium chloride, soybean hulls, oat hulls and untreated fumed silica. In a high level condition powders are usually very aerated due to pneumatic conveying. These low bulk densities will be problematic for most all technologies and brands.

Particle Size: The larger the particle, typically the more destruction the material can have on a level sensor. While this doesn’t diminish the impact heavy powder can have when falling directly on a sensor, if you can imagine falling or shifting aggregate material, rock like size, it will paint an appropriate picture. However, one not-so-obvious impact results from the space created between particles when the particle size is very large (rock like). Very small amount of physical contact between the material and the sensor may actually occur. This is a potential problem for RF capacitance/admittance and vibrating element devices that rely on either bulk density or dielectric of the material contacting the sensor probe.

In the opposite end of the spectrum is fine micron size powder. Imagine the difference in density between a cubic foot of wood and a cubic foot of aerated saw dust. A powder is typically a mixture of micron size material and air. The air doesn't escape until the powder settles and the impact of gravity does its thing. If you need to monitor a lightweight powder in a high level condition, like back-up protection in the hopper of a dust collector, the dust will be highly aerated and unpacked and this must be taken into consideration when selecting the point level sensor technology.

Dielectric Constant: This is a material characteristic. It is also known as a materials' relative static permittivity or E_r. This characteristic is important since RF capacitance devices look for the capacitance effect in a circuit as a result of the material being present at the sensors' probe. The lower the E_r, the lower the capacitance, the more sensitivity requirement of the sensor, the more difficult to detect the presence of the material. Examples of low dielectric constant materials are as shown in Table 2 below.

Table 2: Examples of Low Dielectric Constant Materials

Material	**Dielectric Constant E_r[3]**
ABS Resin and Pellet	1.5
Charcoal	1.5
Calcined Coke	1.5
Ground Cork	1.5
Cottonseed	1.4
Goose Down	1.2
Porous Cereals	1.6
HDPE	1.6
Milk Powder	1.7
Popped Popcorn	1.2
Rice Bran	1.4
Sawdust	1.2

How does the dielectric constant impact the performance of RF capacitance/admittance point level sensors? The lower the dielectric constant, the more difficulty the material is to detect. Refer to more detail regarding the principle of operation and dielectric constant in the point level sensor review section for RF capacitance/admittance below.

Corrosion / Abrasion: Corrosion and abrasion issues primarily are issues for the wetted parts, components that are in contact with the process material. Most point level sensors have reasonably good compatibility with the majority of materials they will come in contact with. Most sensors will be available with stainless steel, which has

[3] Actual dielectric constants may vary. This data is from commonly available industry references. Consult your chosen supplier.

reasonably good compatibility and abrasion resistance. Standard materials of construction typical for the common technologies are as shown in Table 3.

Table 3: Typical Wetted Part Materials of Construction

Sensor Technology	Typical Materials of Construction
Diaphragm	Neoprene, Teflon or Stainless Steel
Tilt	Aluminum, Nickel Plated Steel or Stainless Steel
Rotary Paddle	Bare/Painted Aluminum, PBT or Stainless Steel
RF Capacitance/Admittance	Bare/Painted Aluminum or Stainless Steel
Vibrating Element	Stainless Steel
Capacitive Proximity Switch	Thermoplastic Polyester

Good desk references for material compatibility with various chemicals and other items are found below. Both are available from Amazon.

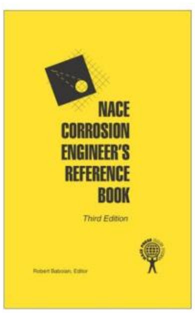

Figure 1: NACE Corrosion Engineer's Handbook

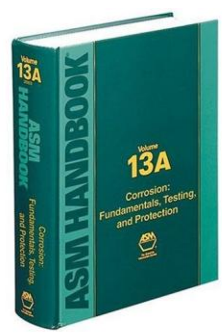

Figure 2: ASM Handbook of Corrosion

Abrasion is a more difficult issue to find any reference manual or materials on. Google this subject and you will not necessarily see an obvious answer. The reason that this subject is important in regards to point level monitors is that some materials are far more abrasive than you might expect. One good example I can give is whole corn. I have seen ½" diameter stainless steel RF capacitance probes sharpened to a point by the abrasive nature of whole corn in a low level application as the grain flows around the probe. Abrasion resistance for low level applications when dealing with most granular material and aggregate material should be considered. Consult your supplier and take advantage of their experience, as well as your knowledge of the material.

Adhesion: The tendency for a material to stick or adhere to an invasive probe element needs to be considered. Some technologies rely on the impact of material contact to activate properly. If material adheres to the probe it may result in a false indication of material presence unless it is ignored in some manner or the affect on the sensor is minimal in regards to the sensor operation. Table 4 provides some guidance in regards to the sensor technology sensitivity to material adherence.

Table 4: Sensitivity of Sensor Technology to Material Build-up on Sensor Element

Technology	Sensitivity to Material Build-Up
Diaphragm Switch	*High* (use with dry free-flowing material only)
Tilt Switch	*Low* (not typically an issue)
Rotary Paddle	*Low-Moderate* (depends on amount of material build-up on paddle; can reduce sensor life)
RF Capacitance/Admittance	*High* (Low-Moderate if active build-up immunity feature in sensor)
Vibrating Element	*High* (not tolerant of build-up; some dusting can be ignored by adjusting sensitivity of sensor)
Capacitive Proximity Switch	*High* (not tolerant of build-up and moderate dusting)

Consult with your chosen supplier about material adherence issues if this is of concern. Any technology with "High" sensitivity as shown in Table 4 should not be used for applications with sticky material unless the manufacturer can prove how their device will ignore or deal with the effect from material build-up. Vibrating element and diaphragm switches should be avoided in these applications.

Point Level Sensor Review

We will briefly review the six most popular and common technologies for use in monitoring point level applications with powder and bulk solids. These include:

- Diaphragm Switch
- Tilt Switch
- Rotary Paddle
- RF Capacitance/Admittance
- Vibrating Element
- Capacitive Proximity Switch

Each technology review will include a brief principle of operation and the advantages and disadvantages of their use. We will finish with our final table that will illustrate, generally speaking, the proper selection based on common application characteristics.

Diaphragm Switch: These point level monitors are simple mechanical devices that activate and deactivate an electrical switch in response to pressure on the switch diaphragm. This pressure is a result of the presence of material at the diaphragm.

The diaphragm level switch is installed from inside or outside of the vessel and the diaphragm is exposed to the inside of the bin and its contents. As the material in the bin contacts the external diaphragm, the force exerted on the diaphragm activates an electrical switch through some mechanical mechanism located behind the diaphragm inside the level switch. The changing state of the electrical switch as it responds to presence or absence of the material on the diaphragm surface is monitored by your control system or is used directly to engage motors, starters and simply to signal material condition through an annunciator, light or sound.

Table 5: Advantages and Disadvantages of Diaphragm Bin Level Switch

ADVANTAGES	DISADVANTAGES
✓ Low profile mounting – minimal invasiveness	✓ Use with dry and free-flowing material only
✓ High current rating of switch output (15A)	✓ Mechanical with moving parts
✓ No power required, just through switch output	✓ Diaphragm is sensitive to abrasion
✓ Low cost	✓ Used for material that is ≥ 15lbs/ft^3
✓ Easy to install and operate	✓ Non-pressurized applications only
✓ Hazardous location designs available	✓ Relatively low process temperatures
✓ Good life when installed correctly	

Application and use of the diaphragm level switch must follow some basic rules, including 1) must be dry free-flowing materials, 2) avoid sharp materials that can damage the diaphragm, 3) no lightweight materials because switch sensitivity is general limited.

Tilt Switch: The tilt switch is used primarily for high level detection by monitoring the tilt angle of the probe assembly from its plumb position. These devices are typically activated when tilted 15° from plumb. Activation is accomplished either by mechanical movement, a mercury switch or a non-mercury element. Most tilt switches uses a two component architecture consisting of the probe element and a control unit. However, some probe elements can be used for direct input to a control system. The control units will provide power conditioning for the probe and also a output with higher current ratings. Materials of construction range from bare aluminum to nickel plated steel, plastic or stainless steel for use with a wide variety of materials.

Table 6: Advantages and Disadvantages of Tilt Level Switch

ADVANTAGES	DISADVANTAGES
✓ Low cost	✓ High level only
✓ No power required, just through switch output	✓ Mechanical with moving parts
✓ Easy to install	✓ Materials ≥ 15lbs/ft^3 only
✓ Relatively good current rating of switch (10A)	✓ Use in open piles and vessels not pressurized
✓ Hazardous location approvals on some brands	✓ Relatively low process temperature ratings
✓ Typically low maintenance	✓ Can experience physical damage if not properly applied and installed

Tilt switches are used for high level detection in sand and gravel yards for open piles under belt conveyors, concrete plants for similar applications and high level in grain elevator silos. In addition, tilt switches are commonly used for plugged chute detection in open vessels filled by belt conveyors and are also used to detect the presence of material on belt conveyors. They are not typically used for low level detection or in closed pressurized silos. They can be used in many aggregate materials with large bulk density. They are rugged sensors capable of withstanding large aggregate material with sharp jagged edges. Actuators installed on the underside of the tilt switch probe enclosure ensure the tilt switch does not get buried.

Rotary Paddle: The rotary paddle bin level indicator is an electromechanical point level monitor that is very universal in its application and use. It operates by using a small drive motor within its enclosure to turn a “paddle” that is attached to the enclosures output driveshaft, which extends into the vessel. The paddle will rotate freely in air. When material is present and impedes the rotation of the paddle, switches internal to the sensor enclosure will change position and indicate material presence. When material falls away from the paddle it begins to rotate again and the electrical switches will revert to their previous position indicating the absence of material at the point where the paddle is within the vessel.

The drive motors used are small synchronous motors of either the permanent magnet or hysteresis types. The use of the former requires deactivation of the motor when material impedes the paddle rotation. The hysteresis type motor will stall when the paddle rotation is stopped. In both cases, when paddle rotation stops the output switches reverse state from their previous position when material was absent.

Rotary paddle level sensors can be side or top mounted on bins and silos. Top mounted units can include shaft extensions to place the rotating paddle at the point where a high level detection is needed. Both high, low and intermediate level monitoring can be done with rotary paddle units. Plugged chute detection is also a somewhat common use for these devices.

Table 7: Advantages and Disadvantages of Rotary Paddle Bin Level Indicator

ADVANTAGES	DISADVANTAGES
✓ Relatively low cost	✓ Drive motor failure is most common maintenance issue; some brands more prone than others
✓ Rugged construction	✓ Electromechanical, moving parts
✓ Low bulk density handling of ≥ 5lbs/ft^3	
✓ Easy to install	
✓ Wide range of power supplies and accessories	
✓ Hazardous location ratings	
✓ Most universal in bulk solids application	

Whether your material density is 5lbs/ft^3 or >100lbs/ft^3, a rotary paddle unit will work. High level, low level, intermediate level, plugged chute detection, foodstuffs, plastics, powders, aggregate, feed, grain, and even difficult materials like carbon black, plastic regrind, powdered chemicals, flour and many other materials can be handled with a rotary paddle level sensor. When you combine its relatively universal nature, good reliability, fairly economical cost structure and a 70 year history of success and improvements, the rotary paddle bin level indicator is a leader in point level monitoring for powder and bulk solids.

<u>RF Capacitance/Admittance</u>:

The RF capacitance point level sensor will detect the presence of liquids, slurries, powders and granular materials. In regards to material type it is a very universal technology. The RF capacitance/admittance sensor is based on the formula for measuring dielectric constant where $E_r = C_x / C_o$, where C_x is the capacitance value of a specific material based on its dielectric, and where C_o is a measured capacitance of a vacuum or air.

The RF capacitance point level sensor applies a radio frequency to the probe and monitors the capacitance at the probe compared to its calibrated reference capacitance value. When the dielectric at the probe changes due to the presence of material, the capacitance effect is enhanced and this changes the impedance of the application.

The formula C = KA/d is used, where C = the capacitance effect, K = the dielectric constant (air = 1.0; material = > 1.0), A = area of the capacitor plates (active probe section and vessel mounting) and d = a fixed distance of separation between the two plates. As air in the vessel is replaced by the material to be detected, the capacitance is increased thereby changing the impedance of the circuit. The sensor output is activated as the condition changes. This measured value is compared to a reference impedance as determined by the sensitivity setting of the sensor.

Many RF capacitance/admittance level sensors will include an active feature for build-up immunity, thereby allowing these devices to be used with materials that can coat the probe. The principle of this technology is called a "driven shield". The driven shield is a section of the sensor probe that enables the electronic circuitry to ignore product build-up that would otherwise cause false indication of material presence. This driven shield section of the probe is activated with the same radio frequency as the active probe section. Since current cannot flow between identical potentials, the driven shield blocks current flow along the probe between the active section and the vessel wall. This provides immunity to the effect of material build-up between the probe and the vessel wall.

Table 8: Advantages and Disadvantages of RF Capacitance/Admittance Point Level Sensors

ADVANTAGES	DISADVANTAGES
✓ No moving parts, all solid-state	✓ Requires calibration and sensitivity adjustment to tune the sensor to the specific application
✓ Wide range of applications including powders, granular materials, liquids and slurries	✓ Dependent on the dielectric constant of the material
✓ Wide variety of accessories and options	✓ Light materials may be problematic because of usual low dielectric constant
✓ Wide range of power supply options, often universal power supply	✓ Some brands or applications require periodic recalibration
✓ Hazardous location areas are okay	✓ More expensive than electromechanical and mechanical level switches
✓ Easy to install	

RF capacitance/admittance level sensors can be used to detect many different types of materials. Some typical applications include many liquids and slurries, plastic pellet and resin materials (depending on dielectric constant), feed and grain, aggregate, cement, foodstuffs, specialty powders and many others.

Vibrating Element: This type of level monitor detects material by monitoring the dampening effect of the material as it contacts the vibrating probe. Most devices vibrate the probe using piezoelectric crystals. When electrically excited a piezoelectric crystal will deform and vibrate at the resonant frequency of the probe element. A second crystal receives the vibration and deforms which results in an electrical signal. This is monitored. When material comes in contact with the vibrating element it dampens the vibration and this frequency change affects the electrical output of the second crystal and the electronic circuitry interprets this as detection of material at the sensor point. A relay output is then activated. When the material falls away from the sensor probe the vibration restarts and the output reverts to its material absent state.

Table 9: Advantages and Disadvantages of Vibrating Element Point Level Sensor

ADVANTAGES	DISADVANTAGES
✓ No moving parts, solid state	✓ Material build-up will result in false sensing
✓ No calibration required, just a sensitivity switch setting	✓ Moderately expensive from RF capacitance/admittance sensor price level and greater
✓ Technology proven and matured since late 1980's	✓ Sensitive to damage from mechanical impact or from falling/shifting material
✓ Many brands very sensitive and can detect very lightweight materials	
✓ Easy to install	

Vibrating element level sensors are available as single element rods or tuning fork style. The tuning fork devices are best for liquid and slurry applications. When used with powder and bulk solids the tuning fork unit is sensitive to bridged material between tines. The single element rod sensors do not have this problem and because of this they are well suited for powders as well as granular materials. In either case the vibrating element sensor should be used with dry free-flowing materials as they are not tolerant of build-up or heavy dusting.

Conclusion

Point level monitoring is a critical application in many instances. High level detection is used to prevent overfilling and fill shutoff. Low level monitoring ensures timely re-ordering of material to avoid material outages and production shutdown. Several viable technology choices exist, and several characteristics to consider before deciding on the best device for your need. Refer to Table 5 for a summary of these choices.

Table 10: Technology Selection Guide Based On Common Application Parameters

	Diaphragm	Tilt	Rotary	RF	Vibrating	Prox
Material						
Powder	Y	Y	Y	Y	Y	Y
Granular	Y	Y	Y	Y	Y	Y
Slurry	N	N	N	Y	Y[4]	N
Liquid	N	N	N	Y	Y[4]	N
Density						
Very Low 1.5-5lbs/ft^3	N	N	CF	CF	Y	CF
Low >5lbs/ft^3	CF	CF	Y	CF	Y	CF
Medium >15lbs/ft^3	Y	Y	Y	Y	Y	Y
High >40lbs/ft^3	Y	Y	Y	Y	CF	Y
Moisture						
Low	Y	Y	Y	Y	Y	Y
High	Y	Y	Y	Y	Y	Y
Process Temperature						
>200 F (93 C)	Y	Y	Y	CF	CF	N
>300 F (150 C)	CF	N	CF	CF	CF	N
Material Coating						
Minimal	Y	Y	Y	Y	CF	CF
Heavy	N	CF	CF	Y	N	N

[4] Some tuning fork versions only