The Problem with Measuring Levels

By Joe Lewis, BlueLevel Technologies Inc.

Why do we measure the level of powder and bulk solid materials in bins and silos? I'm not talking about material presence or absence detection for high- and low-point detection. I am referring to measuring the level or height of the pile of material in the vessel. What we really want to know is the amount of material by volume or mass because that is how the material is purchased, in terms of cubic feet, pounds, tons, etc.

Measuring volume and mass in a large bin or silo, many greater than 30 ft in height, is not inexpensively nor easily done if you are attempting to accomplish it after the silo has been erected. Load stand systems are expensive and come with their own set of installation, setup, and operating challenges. Bolt-on weigh systems are not as accurate, while being lower in cost than load stand systems, and they also have installation and operational issues. Measuring the level of the pile of the material and converting it to volume or mass appears to be a cost-effective and simpler option to implement. Therefore, there really is no choice, right? How else are we to know how much material we have in the silo or bin if we do not measure the level of the pile?

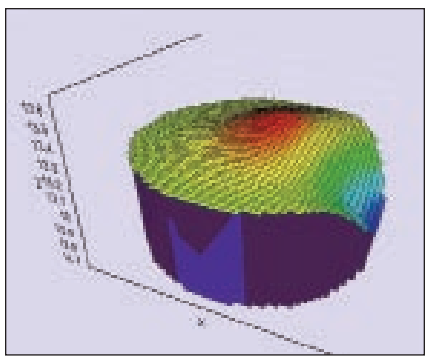

Figure 1 -Volume map of corn at ethanol facility (photo courtesy of BinMaster)

The Problems

When measuring the level of a powder or bulk solid material in a vessel, both the material and the vessel characteristics impact what sensing technology should be used and whether its application and use will be successful in meeting your objectives. The characteristics that most affect the accuracy of the resultant calculated volume and mass are as follows:

Bulk Density - Most continuous level sensors measure the empty space distance in the silo at a single point on the material surface. These sensors or their receiving devices, such as a PLC, PC, or digital indicator, perform calculations to convert the distance measurement to material level, volume, and weight. The accuracy of the bulk density value for the material impacts the accuracy of the conversion calculation from distance to mass. Variations in density within the pile of material due to packing and any variations in the material from batch-to-batch or season-to-season will affect the accuracy of the calculated mass. Determining an "average" bulk density through empirical testing that provides the best resultant mass accuracy should be considered if your objectives require the highest degree of accuracy possible. This is the most challenging aspect of converting from distance/level measurement to mass. Moisture, particle size, and other material characteristics also impact the choice of technology, but bulk density impacts the resultant calculation to get a mass value for your accounting and finance department.

Flow Characteristics - Some materials do not flow well. This is related to material properties, such as their cohesive strength between particles and between particles and the bin walls, as well as silo design in terms of smoothness of the inside walls and shape and size of the cone area (if a cone is used). Two conditions can exist in a vessel due to poor material flow characteristics and poor vessel design (e.g. ratholing and bridging). A rathole is created when the material discharges only from one area of the mate-

Figure 2 - Acoustic volume measurement sensor measuring PE pellets (photo courtesy APM Automation Solutions Ltd)

rial pile within the vessel. This is caused by frictional coefficient between material particles and the vessel wall. Bridging is similar to ratholing, except in this case the material flows at the bottom of the pile only and then stops. This "clogged" condition is created by similar aspects of the material and vessel design as the rathole. Both ratholing and bridging can create problems for you when trying to measure the amount of material within the vessel with a sensor that measures distance/level at a single point on the surface of the material. In both situations, rathole and bridging, you may be detecting the level of material and calculating the volume of material based on large inaccuracies introduced because of the assumption of a flat surface and the absence of a great amount of material from the rathole or under the bridge. A continuous level sensor, contact or non-contact type, does not know the rathole or bridge exists, hence the inaccuracies in any volume/mass calculation can be huge.

Angle of Repose - The item that most affects the accuracy of the conversion from the level measurement to mass is the angle of repose or shape of the surface of the material pile. This is a big problem that occurs most for materials that do not flow freely and for vessels with off-center fill and discharge, side inlet and discharge, and vessels with multiple inlet and discharge locations. The import of this is due to continuous level sensors only measuring the distance between the sensor and the material surface at only a single point on the material surface. Where that point of measurement is on the material surface directly impacts the volume calculation/conversion as the assumption is made that a flat surface exists, which is often far from reality.

New Technology Addresses Problems

Acoustic wave technology has recently been adapted in measurement sensor form to measure material levels and volume. Acoustic technology uses sound energy. So does ultrasonic technology. However acoustic is different because of the low frequency of the sound pulse. The lowest frequency used in ultrasonic sensors is about 15 KHz, with minimal exception. Acoustic technology frequency is as low as 3 KHz. The low frequency is the reason for much of this technology's claimed success for penetration of dust--a serious problem in many powder and bulk solid applications.

In this adaptation acoustic technology uses an array of three sensors that are not in contact with the material being measured, though the sensor is invasive to the bin. The theoretical measuring range is up to as high as 70m.

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That's over 210 ft tall. And the maximum vessel diameter can be just as large. They provide excellent solutions for very large concrete slip-form silos and large grain bins in addition to providing improved accuracy by volume.

The technology maps the surface of the material pile, thereby improves the accuracy of the volume measurement. The volume measured is not dependent on a single point-level measurement like ultrasonic, guided wave and through air radar, weight and cable, and other "level measurement" technologies. Refer to Figure 1 for an image of a material surface as measured and created by the acoustic volume sensor.

The three-sensor array and the sensor's proprietary firmware are the keys to the functioning of these instruments. Simply stated, the sensor transducer emits low-frequency sound energy in three directions, X, Y, and Z. The return acoustic wave response from all directions is captured and processed by the device firmware.

Case Studies

Examining real world examples is essential to determining if a sensor technology is right for your application. Let's review briefly two examples here. For more information on these or other real world applications you may contact the author or the referenced manufacturer/supplier as noted in the figure captions.

Measuring Volume of Polyethylene Pellets - This is a common application. A plastic converter uses polyethylene pellets stored in several silos that are 9.8 ft in diam and 39.4 ft high. The plastic converter tried multiple types of continuous level sensor technologies including ultrasonic, radar, and yoyo types. Complaints over accuracy and repeatability persisted. Using single point continuous level sensors meant that volume and mass calculations were "estimates". The result was that the plastic converter, trying to be precise in their inventory management and production control, always ordered additional material to ensure continuous availability of product. This meant extra inventory investment and decreased inventory turns.

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The solution came when the plastic converter installed acoustic technology based sensors. After installation (Figure 2) the plastic converter quickly realized improved accuracy of volume and mass. This resulted in being able to order replenishments of the material in the exact amount needed, exactly when it was needed. Because the "hedging" was eliminated, inventory was reduced. The volume accuracy improvement came from precisely knowing the material surface shape and that yielded a volume value of higher accuracy.

Measuring Calcium Carbonate - In this application the processor of calcium carbonate tried various leading brands of through-air radar technologies to measure the inventory of silos containing calcium carbonate. However, the material is very sticky and necessitated cleaning of the radar antennae after only 24-72 hours. The silos are 85 ft high and 26 ft in diam. They are pneumatically filled with two inlet locations. Discharge is from the cone bottom with three outlets. The material surface is irregular.

Acoustic technology from APM Solutions Ltd. was installed. The facility technicians indicated at the onset that if the unit lasted 72 hours they would be surprised. Almost two years later the acoustic volume sensor continues to work in this application, even with the coating on the transducer elements (Figure 3). The sensor manufacturer indicates there has been no maintenance, thereby saving the facility owner many hours. The acoustic sensors are also said to be working during filling and emptying, even with the dust inside the silos, thereby providing the user with true continuous measurements. The final positive result came from the volume surface mapping capability of the acoustic sensor which provides an image of the material surface and allows the facility personnel to be aware of material build-up and blockages that occur periodically due to the flow characteristics of this difficult-to-handle material.

Measuring Corn at Ethanol Production Facility - The difficulties in this application are dust, volume accuracy, and sensor reliability. The concrete silos are 150 ft high and 75 ft in diam. Filling of grain is done by gravity from the top at 580 tn/hr creating dust. Multiple discharge locations and empty rates of 150 tn/hr mean that the material surface is irregular. Plant personnel had used guided wave radar sensors, but due to long cable lengths and the weight of the material the

Figure 3 - Acoustic sensor transducer after one year of service in calcium carbonate (photo courtesy APM Automation Solutions Ltd)

cables would break, resulting in shutdown of operations until the cable was recovered and the sensor repaired. Acoustic sensors were supplied by BinMaster as a solution. Four sensors have been in service for over a year. These volumetric acoustic sensors were installed and optimized to track the material inventory during filling and emptying allowing the ethanol owner to optimize schedules and railcar traffic. Previous

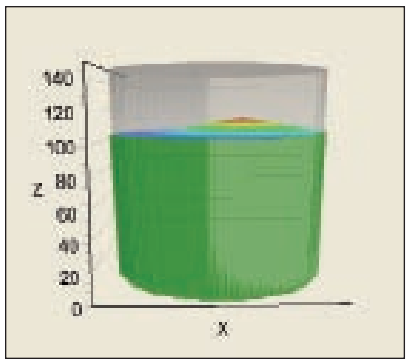

Figure 4 - Acoustic volume measurement sensor measuring PE pellets (photo courtesy APM Automation Solutions Ltd)

sensor maintenance problems were eliminated as the acoustic device is non-contact. Inventory accuracy is also reportedly improved.

Conclusion

We are privileged to be seeing the commercialization of sensor technology that is finally beginning to affordably address some long-standing problems when it comes to bulk material inventory measurement. I specifically do not use the "level measurement" phrase because we are entering a new era, one where directly measuring volume with acceptable precision and accuracy is at our doorstep. Whether using acoustic technology or something else for measuring the volume of bulk solid inventory, the next five years should prove very interesting.

Joe Lewis is the managing director of BlueLevel Technologies Inc. (Rock Falls, IL) and has 35 years of experience in process measurement and control instrumentation. He is a published author and holds a BS in electrical engineering from Roger Williams University and an MBA from Bryant University. He can be reached at 888-262-2662 or joe@blueleveltechnologies.com

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