OPTIMIZING SCALE ACCURACY FOR AUTOMATED INGREDIENT WEIGHING AND BATCHING APPLICATIONS

Powder and bulk solids applications, such as the formulation of food and pet food recipes, have incorporated automated ingredient weighing and batching systems into their manufacturing processes, which helps to streamline operations. Making certain that the scale you invest in is appropriate for and capable of precisely weighing and batching your ingredients is imperative and should be done before and after implementation. This article describes the factors that come into play concerning ingredient batching accuracy in automated weighing and batching systems.

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Automated ingredient weighing and batching systems for food, pharmaceuticals, and chemical materials such as flavorings, active ingredients, and catalysts are widely used today. These systems, such as the 12-ingredient system shown in Figure 1, have enabled manufacturers to increase production and decrease both labor and material variation. These automated systems also simplify lot tracking and production record keeping. However, with these automated systems, there’s a growing trend for the ingredients that make up a batch or mixture to be more concentrated in order to minimize related shipping and storage costs. These more concentrated ingredients have escalated the demand for highly accurate weighing systems. Quite often, there’s a trade-off between having a large enough scale to weigh the formula and a small enough scale to be accurate. A clear understanding of what automated ingredient weighing and batching systems can do is necessary to design an optimal system with accurate ingredient dosing for your application.

Knowing scale standards

What is accuracy? Merriam-Webster Dictionary defines accuracy as “freedom from mistake or error” and also as “degree of conformity of a measure to a standard or a true value.” In the case of automated ingredient weighing and batching applications, we want to make sure that if a recipe calls for a certain ingredient at a certain weight that we’re dispensing the correct ingredient amount.

There are many different methods for measuring a material’s weight, so standards have been developed. When scales are used in the US for legal-for-trade (LFT) applications (commercial applications where material is sold by weight), the National Institute of Standards and Technology (NIST) regulates how.
accurate a scale should be and how accurate a scale can be. In *NIST Handbook 44: Specifications, Tolerances, and Other Technical Requirement for Weighing and Measuring Devices*, the National Type Evaluation Program (NTEP) discusses how electronic scales can be set up, qualified, and calibrated. The handbook covers the capabilities of both the weighing sensor and the instrumentation that’s used to display and calibrate the signal from the weighing sensor. Following these guidelines is necessary when selling LFT scales, and these guidelines are certainly useful in the process of scale qualification too, but available technology for in-process weighing may in some cases be better than what the handbook’s specifications require.

**Determining ingredient requirements**

With ingredient batching automation, there will typically be a recipe or formula that you want to manufacture. The first thing any manufacturer should consider is what its own ingredient needs are in order for a recipe to be made accurately. Specifically, for each weighed ingredient think about what an acceptable amount would be above or below that ingredient’s target weight (also called the amount of error) that would still meet your recipe for batch requirements. For example, if the process calls for a 1 percent maximum error and you’re trying to weigh 1 pound of material, then the weighing system would need to be able to weigh to a specificity of ±0.01 pounds (1 pound divided by 100 equals 1 percent). If your process also requires weighing another ingredient in your formula on the same scale used for heavier weighments, then you’d want to make sure that the minimum weight wouldn’t go below 1 pound if ±0.01 pounds is the scale’s accuracy. For example, you wouldn’t want to weigh 0.01 pounds of material on this scale because your possible error could be 0.01 pounds, which could possibly be a 100 percent error in measuring that ingredient. Once you’ve established what the acceptable amount of error is for each ingredient that’s being weighed in your process, then you can look at the available automated ingredient weighing and batching systems to find one that suits your needs.

**Selecting the right system**

There are several factors that come into play when needing to achieve an accurate weight in automated ingredient weighing and batching systems. These factors should be taken into consideration when looking to purchase an automated weighing and batching system and include the weighing sensor; the weighing instrument; the number of scales, their size, and how they’re mounted; the feeder size that’s used to meter material into the scale; the control system that handles the recipe automation; the required cycle time or process speed; and the environment where the scale is going to be installed.

**FIGURE 2**

Electronic strain gauges known as load cells are used to weigh and batch ingredients in automatic systems.

**Weighing sensor.** In most modern applications, the weighing sensor, known as a *load cell*, is commonly an electronic strain gauge, like the kind shown in Figure 2. Standard strain gauge technology measures the deflection of a load-bearing element when force is applied to that element. The load-bearing element that’s deflected must have a high degree of repeatability in the degree of deflection for a given load and a high degree of repeatability in the load-bearing element’s ability to return to its original position. The typical strain gauge is bonded to the load-bearing element and as the load-bearing element bends, the gauge’s resistance changes. When a voltage is applied to the strain gauge, the change in voltage is directly proportional to the amount of load that’s placed on the load-bearing element. To make sure a load cell is accurate, the load cell must respond to a minimum and maximum amount of weight in the same fashion throughout the cell’s rated capacity. For example, when weighing 1 certified pound on a load cell that has a capacity of 100, if you put the 1 certified pound on the scale 100 times, the scale should go up by 1 pound each time. And if you take the 1 certified pound off the scale 100 times, the scale should go down by 1 pound each time.

**Weighing instrument.** According to *NIST Handbook 44*, a typical load cell should be capable of being accurate with 5,000 divisions.
Using our latest example, the 100-pound load cell could be set up to increment by ±0.02 pounds (100 pounds divided by 5,000). The degree of deflection needs to be accurately measured by an instrument that can produce an electronic signal from the strain gauge information that’s compatible with the automated weighing and batching system. This example uses a weighing instrument commonly known as a scale head, which is a machine that converts the varying voltage signal or analog signal from the load cell to a digital value that the automated system can use. For this example, the scale head that displays the weight would be set up to increase and decrease by 0.02 pounds as weight is added or subtracted to match the load cell’s capabilities. Most scale heads can exceed the load cell capability in the number of divisions. A scale head with the ability to split the load cell signal into 20,000 divisions isn’t unusual, and, in the case of our 100-pound load cell, the scale would increase or decrease by 0.005 pound increments. This number of divisions would be beyond what’s standard according to Handbook 44, but getting the scale to recognize increment changes by the smaller division of 0.005 (as opposed to the larger division of 0.02) gives our control system a better chance to anticipate the actual target value for accuracy. This target value is quite often expressed as a percentage. For instance, 1 part in 100 is 1 percent, 1 part in 1,000 is 0.001 percent, and 1 part in 10,000 is 0.0001 percent.

When we talk about 10,000 divisions (1 part in 10,000 or 0.0001 percent), keep in mind that we’re always looking at the full-scale value of the scale with the combined scale vessel weight and necessary attachments (referred to as dead load) and the weight of the material being weighed (referred to as live load). You’d be mistaken to focus solely on the live load as the scale vessel’s capacity is affected by the scale’s full-scale weight. If our process requires that we be accurate to 1 percent and we’re trying to achieve a target weight of 0.1 on the same 100-pound scale, then we must divide the desired target weight by 100 to see what the scale’s accuracy needs to be. In this case, the scale would have to be accurate to ±0.001 (0.1 divided by 100 for a 1 percent accuracy). We’ve already seen that if we divide the 100-pound scale signal by 10,000 divisions, the scale will increment by 0.01, so the absolute best we can do is ±0.01 or 10 percent of the target weight. If we’re weighing 0.1 pound and want to be within a percentage using a 10,000-division system, the application would be better suited to a 10-pound scale. The smallest amount that we can weigh is 1 pound on this 100-pound scale to be within the desired process specification of 1 percent (1 divided by 100 equals 0.01). As you can see by this example, scale divisions don’t necessarily equate to scale accuracy.

**Scale count, size, and mounting.** To determine how many scales you need for your process and what size they should be, we need to select a worst-case formula. This formula should have the largest number and quantity of ingredients that’ll be produced. The total amount of ingredients should be added together to arrive at the scale’s size. You may find that more than one scale of a rated capacity is necessary to cover the full range of ingredients’ weights. If, for example, a scale is capable of weighing ±10 grams, then we don’t want to try to weigh a 10-gram addition on the scale because our possible error is 100 percent. If the desired accuracy is 1 percent, then the minimum amount that we could weigh on this scale is 1,000 grams, since a 10-gram error would give us the desired 1 percent accuracy. You’ll also probably encounter situations where there’s a very large gap between the maximum amount of weight and the minimum amount of weight to be used for all the formulas you have. If the minimum inclusion rate is below what can be weighed accurately and the maximum inclusion rate is acceptable for the scale system, as is sometimes the case in food and pharmaceutical applications, then you may want to consider a preliminary dilution of the ingredient or contact your supplier about the possibility of buying the ingredient at a lower concentration level. If you notice that the minimum inclusion rate for the ingredient is acceptable for the scale but the maximum inclusion rate exceeds the scale system’s capacity, then the ingredient can be included on a larger scale as well as on a smaller scale, or the ingredient can be weighed in multiple drafts from the same scale. In any case, the scale should be designed so that there are no line connections, such as power or pneumatic lines, that might move around and cause scale fluctuations. The

![FIGURE 3](load_cells_mounted_at_a_hopper_s_center_of_gravity.png)

Load cells mounted at a hopper’s center of gravity
conditions that can affect a scale’s accuracy include being subjected to excessive vibration, air currents caused by doors opening and closing, differences in air pressure due to conveying systems, and temperature swings. Setting up a scale for a 10-gram accuracy doesn’t do any good if the scale is bouncing up and down by 20-gram increments due to other process equipment running in the service plant area. Make sure the system fluctuation isn’t more than the target accuracy that you’re trying to achieve for your process. In the case of cyclic vibrations, such as those caused by a mixer or other equipment, you may be able to actively electronically filter out the vibration signal. In the case of erratic scale fluctuations, such as those due to a truck driving by or someone opening and closing a door, these can be minimized if a scale is mounted on a solid structure that’s heavy and rigid enough to not be affected by nearby vibrations and if the scale’s properly protected by shrouding made from sheet metal, glass, plastic, or cloth, which will block air currents that could move the scale.

**Maintaining the system**

Having assured yourself of the previous factors mentioned, your scale isn’t out of the woods yet. There are potential problems that can crop up that could affect your scale’s accuracy and inventory levels even after installation. These potential problems include inventory justification, load cell failure, scale mounting, excessive vibrations and scale damping, insufficient scale settle time, scale gate leaking, feeder flooding, scale misapplication, feeder sizing issues, air movement, and electrical noise.

**Feeder size.** Matching the desired accuracy percentage to the scale resolution — the smallest increment in applied weight that the scale can detect or display — may not be enough to achieve or maintain accuracy. As mentioned earlier, the automated ingredient weighing and batching system should have a feeder capable of delivering material amounts that correspond to the scale’s desired minimum increment. This means we don’t want a feeder that’s too large for the desired target amount. If the feeder can deliver the minimum material scale amount in 1 second, then we can hope to stop the feeder in time to anticipate the target weight. If possible, the automated control system must be able to stop the system within 1 increment of the scale, meaning that the system quite commonly will be under or over by at least 1 increment.

**Control system.** Being able to stop the feeder within 1-scale increment is crucial to ensuring accurate weighments and can be done with a control system like the one shown in Figure 4. If the control system is overloaded with tasks however, the system may take longer to stop the feeder. An automated ingredient weighing and batching system’s scale accuracy is dependent on both mechanical and control limitations, and both are important to consider in order to have a system that’s accurate and trouble-free.

**Cycle time.** After we have completed the scale evaluation, we’ll also want to determine what kind of cycle time is possible given our worst-case (most complex) formula. If, for example, you’ve determined that you’d like to use 40 ingredients in a scale system and your worst-case formula calls for 12 of these ingredients, then we need to calculate how much time it’ll take to weigh and discharge these ingredients into the process. This is important because we want to make sure there’s enough time for the system to go into a low-speed fill mode that can increase the accuracy and make sure the scale has a sufficient amount of time to settle the material before the final weight is recorded. Ideally, we don’t want the time it takes to weigh and discharge the ingredients to exceed the downstream system’s cycle time.

**Environment.** Another very important factor that’s often overlooked is the environment where the weighing system is going to be installed. Environmental conditions that can affect a scale’s accuracy include being subjected to excessive vibration, air currents caused by doors opening and closing, differences in air pressure due to conveying systems, and temperature swings. Setting up a scale for a 10-gram accuracy doesn’t do any good if the scale is bouncing up and down by 20-gram increments due to other process equipment running in the service plant area. Make sure the system fluctuation isn’t more than the target accuracy that you’re trying to achieve for your process. In the case of cyclic vibrations, such as those caused by a mixer or other equipment, you may be able to actively electronically filter out the vibration signal. In the case of erratic scale fluctuations, such as those due to a truck driving by or someone opening and closing a door, these can be minimized if a scale is mounted on a solid structure that’s heavy and rigid enough to not be affected by nearby vibrations and if the scale’s properly protected by shrouding made from sheet metal, glass, plastic, or cloth, which will block air currents that could move the scale.

**FIGURE 4**

The control system of an automated ingredient weighing and batching system can be programed to the manufacturer’s necessary specs.
**Inventory justification.** In most automated systems, there will be some difference between the amount of material that's called for by the formula (the target or theoretical weight) and the amount of material that's dispensed (the actual weight). For inventory justification, which means reasonably defending the inventory amount on hand, the actual value should always be used. To perform an inventory justification, subtract the actual totalized weights of dispensed ingredients for a given period from the beginning inventory level for that period. The remaining physical inventory level on hand should match this calculation. If there’s excess material left over, then there’s been an inventory gain, whereas if there’s missing material, then there’s been an inventory shrink. An inventory gain can be due to the package label weights not being the same as the actual weight of material in the package. Inventory gains are quite common since most suppliers will overfill a package rather than risk shorting a customer. If there’s missing material, there are several different places where the material can be lost. Missing material can be attributed to instances of material spillage, an improperly calibrated scale, or a scale system failure, such as a system reflecting a material weight of 1 pound on the scale when really the weight is 1.1 pounds. These types of occurrences can result in lost material.

If the system’s performance is being checked, then the actual versus theoretical inventory value should be looked at. For example, if you want to know how close you were to the target or theoretical weight that you’re trying to achieve, then you’d subtract the target or theoretical weight from the actual weight and then divide the result by the target weight. This will tell you the percentage of error from the target.

**Load cell failure.** One of the most common problems manufacturers experience after installing their automated ingredient weighing and batching system is load cell failure. Check each load cell individually to make sure that the output from the cell is what it should be. On the side of each load cell, there’s a rating that tells how many volts the load cell will output at full-scale capacity. To check the output, apply a known test weight to the scale. The load cell will measure and reflect a certain voltage, and if the voltage measured differs from the number printed on the load cell’s side, then the cell is bad. If this happens, then you’ll have to replace the cell and recalibrate the scale.

**Scale mounting.** The load cell mechanical attachments need to be hooked up so that the scale can move freely. Any flex connectors, electrical lines, or pneumatic lines that are attached to the scale must be connected in a way that allows the scale to perform repeated weight measurements. This repeatability can be checked by putting minimum and maximum weights on the scale and then taking the weights off. In each weighing, the scale should return to zero, and if it doesn’t, then check for interference with the scale movement.

**Excessive vibration and damping.** Another common issue is excessive vibrations affecting the scale’s accuracy. If vibration causes the weight displayed on the scale to fluctuate so that the weight exceeds the minimum scale increment you need for accuracy, then the vibration needs to be eliminated. A common way to remove vibration is by electronically damping the scale, which absorbs the vibrations. A parameter in the scale instrument allows you to change how often the scale’s signal is sampled and averaged. This filtering can affect the scale’s accuracy by making the scale less reactive to weight. If the vibration is cyclical, such as what might be found with a motor or drive mechanism, then the vibration may be actively electronically filtered with no adverse effect on the scale’s accuracy. However, if the vibration is intermittent, such as from someone walking on the scale’s support structure or nearby equipment stopping and starting, then the vibration should be isolated by changing the scale’s mounting. Another issue that can come up is excessive scale damping. If the scale filter is adjusted too high, then the values that come back can be delayed due to averaging that’s taking place after the analog-to-digital conversion occurs. It’s better to take care of the vibration’s root problem with proper scale mounting.

**Insufficient scale settle time.** When a scale is filled, the scale can continue to oscillate for a time until the material settles. If the scale reading is taken before the scale settles, then the reading can be inaccurate. Observe the scale display after filling to verify that the scale has settled. If the display shows movement after the feeder has shut off, then the settle time should be extended to improve the scale reading’s accuracy.

**Scale gate leaking.** If the scale’s discharge gate is leaking, then material can leave the scale as material is entering it. If you’re unable to physically see the gate to check for leaking, then a scale integrity test can be performed. To execute a scale integrity test, fill the scale to a known weight and then monitor the scale for some time to make sure that the weight stays stable. If the scale loses weight during the integrity test, then the gate is leaking and needs to be fixed.

**Feeder flooding.** Free-flowing materials that have a flat angle of repose can possibly continue to flow even after a scale’s feeder shuts off. This is referred to as feeder flooding. The scale integrity test can also check for ingredient flooding. If the scale gains weight, then the scale’s feeding device might be allowing material...
to enter the scale after the feeder has shut off. This can be fixed by adding a shutoff gate to the feeder’s discharge end.

**Scale misapplication.** In this case, the scale is sized to weigh larger amounts, so smaller amounts can’t be weighed accurately. As we covered earlier, if the scale accuracy is ±0.1 pounds, then we shouldn’t try to weigh 0.1 pounds’ worth of material on the scale since the possible error would be 100 percent. So make sure you’re using the appropriately sized scale for your specific application.

**Feeder sizing issues.** The feeder should be sized so that material feeding can be controlled down to the scale’s minimum weight increment. With auger-type feeders, there may be quite a difference in the amount of material that leaves the feeder, depending on the feeder’s position. This flow pulsation can contribute to fluctuations in the scale’s accuracy. Make sure that the flowrate has sufficient turndown to allow for a slow-speed material amount to hit the desired target weight. Turndown refers to the range of flow that a feeder can accurately and repeatedly dispense. The better a feeder’s turndown rate, the closer the feeder will get to an accurate ingredient measurement.

**Air movement.** Scales can be affected by air currents and changes in air pressure. If material is being conveyed pneumatically, make sure that the scale is isolated from the positive or negative pressure that’s created by the conveyor. Opening and closing an area’s door or access panel can also possibly cause a change in pressure that’ll pull up or push down on the scale. Proper scale venting or interventing, which uses ducts or pipes to equalize the pressure between two areas if the scale transitions between floors, can take care of the pressure differential.

**Electrical noise.** Load cell signals are in millivolts or 1/1000 of a volt. The system must be properly grounded and shielded from sources of electrical noise. The cable shield wire of the load cell shouldn’t be grounded on both ends or at multiple points, or a ground loop could occur, which would raise the voltage from the ground, creating an audible hum. A ground loop is caused by two pieces of interconnected electrical equipment that are grounded by multiple paths and a closed conductive loop forms, which results in the electrical noise. Make sure to follow the manufacturer’s recommendations for allowable distances between cable shield wires to avoid a signal loss. If a longer load cell cable run is needed to get back to the scale instrument, then the system may need to be set up with sense lines, which measure the actual voltage at the load cells, to compensate for the fluctuating resistance that can take place with temperature changes that are more likely to occur the longer a cable is. Check the load cell’s excitation voltage — the supply voltage for the load sensor — using a voltmeter at the excitation plus (+) and excitation minus (-) wires on the load cell to make sure that the DC power supply to the load cell is stable. If this voltage fluctuates, then the output from the load cell will also fluctuate.

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**For further reading**

Find more information on this topic in articles listed under “Weighing and batching” in Powder and Bulk Engineering’s article index in the December 2019 issue or the article archive on PBE’s website, www.powderbulk.com.

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