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Ask Joe! Column

Frequently Asked Questions on Feeder Performance

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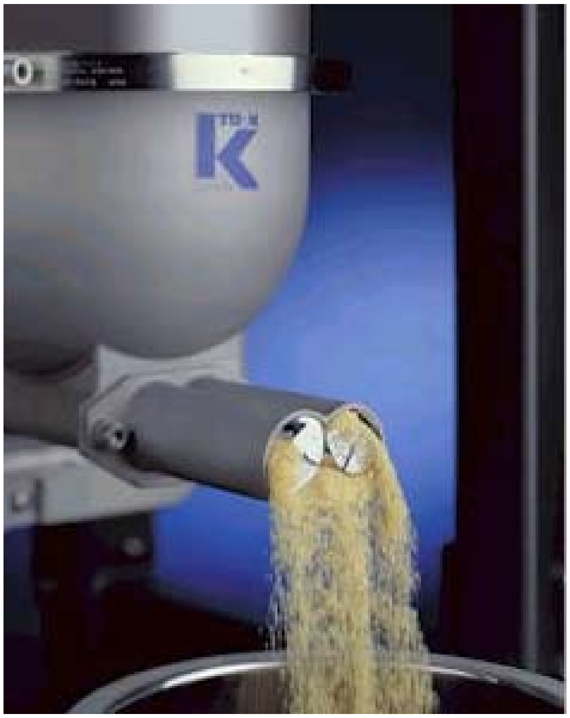


Feeder accuracy is a concern of any processor who has to control the flow of bulk solid material. This article answers some of the most common questions surrounding the area of feeder accuracy, and should serve to form a working knowledge of the basics of continuous feeding.

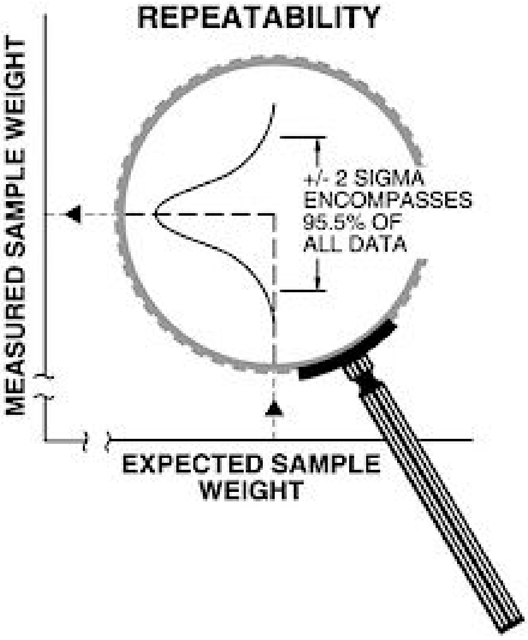
While applications can range from the simple regulation of a single material to highly complex and sophisticated, multi-ingredient blending systems involving many feeders and processing lines, this discussion will limit its focus to individual feeder accuracy.

By combining a presentation of the principles of feeder accuracy along with the practical aspects of their application to real world process operation, it is hoped a more useful and rounded understanding is achieved.

1) How is feeder accuracy defined?

Feeder accuracy is gauged by three distinct performance statistics: repeatability, linearity and stability. Repeatability reports how consistent the feeder's discharge rate is, linearity assesses how accurately the feeder discharges the requested rate, and stability indicates performance drift over time.

Repeatability

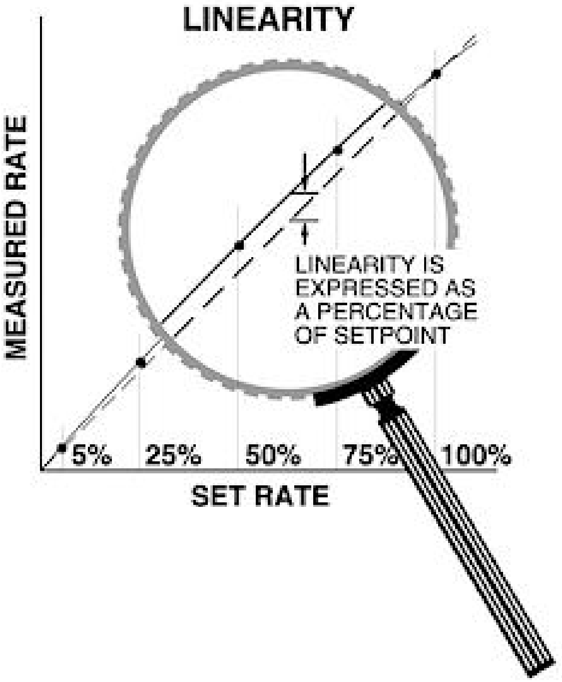


Repeatability quantifies the short-term consistency of discharge rate and is important to quality assurance because it measures the expected variability of the discharge stream, and hence of the product itself.

Repeatability is measured by taking a series of carefully timed consecutive catch samples from the discharge stream, weighing them, and then calculating the + standard deviation of sample weights expressed as a percentage of the mean value of the samples taken. For example, owing to the random nature of repeatability errors, if sampling shows a standard deviation of + 0.3% it can be said that 68.3% of sample weights will fall within the +0.3% error band (1 Sigma), 95.5% will occur within +0.6% (2 Sigma), and 99.7% will lie within +0.9% (3 Sigma).

A complete expression of a repeatability statistic must contain the following elements: a + percentage error value, the Sigma level, and the sampling criteria. For example, a repeatability performance statement might take the following form: +0.5% of sample average (@ 2 Sigma) based on 30 consecutive samples of one minute, one kilogram, one belt revolution, or thirty screw revolutions, whichever is greater.

Linearity



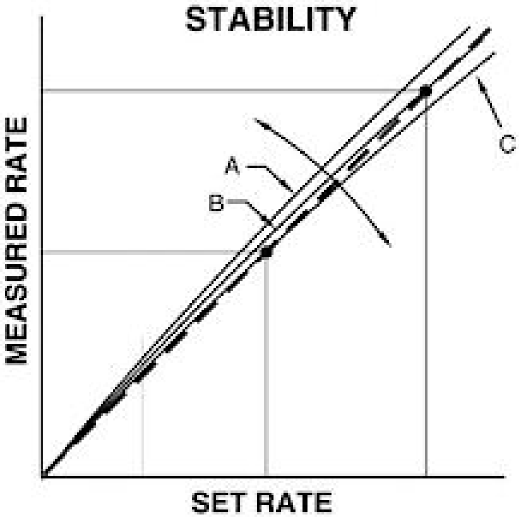
Perfect linearity is represented by a straight-line correspondence between the setpoint and the actual average feed rate throughout the feeder’s full range.

To perform a linearity measurement several groups of timed catch samples must be taken from the feeder’s discharge stream. Typically, ten consecutive catch samples are weighed at each of the following flow rates: 5%, 25%, 50%, 75% and 100% of full scale. For each of the five data sets the average sample weight is calculated, and the + deviation between the computed average and the expected sample weight is taken. Each weight-based deviation is then expressed as a percent by dividing by its expected sample weight and multiplying by 100. The result is a set of five error values, reflecting average feed rate performance over the unit’s operating range.

To eliminate any bias that could be remedied by mere calibration, and to reduce this set of five error values to a single number that characterizes the feeder’s linearity performance, the range of the error set is computed. The result expresses the feeder’s linearity performance in percent of desired operating rate.

Linearity performance is thus correctly expressed only when it contains the following elements: a + percentage error value based on set rate, the sampling criteria, and the turndown range from full scale. For example, a linearity performance statement might take the following form: +0.2% of set rate based upon ten consecutive samples of one minute, one kilogram, one belt revolution, or thirty screw revolutions, whichever is greater, over a range of 20:1 from full scale. Note that the linearity curve depicted above right is exaggerated for illustrative purposes.

Stability



A perfectly performing feeder is worth little if it can’t maintain its performance over the long haul. Many factors can potentially contribute to performance drift such as feeder type, control and weigh system stability, the handling characteristics and variability of the material, the feeder’s mechanical systems, maintenance, and the operating environment itself.

Drift is detected by calibration checks, and is typically remedied by a simple weight span adjustment. In the stability diagram above right, line A illustrates a condition in which the feeder has drifted far out of calibration. Nowhere throughout the feeder’s operating range does the measured rate equal the set rate. By adjusting the feeder’s weight span setting the linearity curve is rotated so that perfect correspondence between set and measured rate can be established at any given point (e. g. 90% full scale for line B, or 50% full scale for line C).

The user will ultimately determine the appropriate frequency of calibration checks based on operational experience, but the question of stability is worth considering when purchasing a new feeder. Significant and ongoing cost savings in maintenance labor, off-spec product, and potential process downtime can be realized by selecting a feeder designed for stable, drift-free operation.

2) How to choose between volumetric or gravimetric feeders?

By definition, gravimetric feeders measure the flow's weight in one fashion or another, and then adjust feeder output to achieve and maintain the desired setpoint. Volumetric feeders don't weigh the flow; they operate by delivering a certain volume of material per unit time from which a weight-based flow rate is inferred by the process of calibration.

Volumetric feeders are open-loop devices in that they cannot detect or adjust to variations in the material's density. For materials whose density does not vary significantly, volumetrics may perform acceptably. However, the density or flow properties of many materials varies significantly enough to warrant gravimetric feeding if accuracy requirements are at all demanding. Most feeder manufacturers have the resources to determine whether a given material can be fed volumetrically at the required accuracy, or if a gravimetric feeder is required.

Since volumetric feeders are open-loop devices from the viewpoint of discharge rate, headload variations and material buildup on the flights of a feed screw change the volume-per-revolution relationship, throwing off calibration without any outward sign. Gravimetric feeders automatically detect and adjust to these conditions.

Data capture and communications is becoming an increasingly important consideration in many processes as automation and plant wide integration become the norm. Gravimetric feeders hold the advantage in that they actively measure the flow rather than inferring it, and most feeder manufacturers now offer full-featured PC-based communication interfaces compatible with PLCs and other plant wide data acquisition or monitoring systems (SCADA).

3) How does a loss-in-weight screw feeder work and what issues impact its ability to perform accurately?

A loss-in-weight feeder consists of a hopper and feeder that is isolated from the process so the entire system can be continuously weighed. As the feeder discharges material, system weight declines. The loss-in-weight feeder controller adjusts feeder speed to produce a rate of weight loss equal to the desired feed rate setpoint.

Owing to their high gravimetric accuracy, strong material handling capability, innate material containment design, and ability to feed precisely at very low rates, loss-in-weight screw feeding has become the preferred feeding method in a broad range of industries and applications.

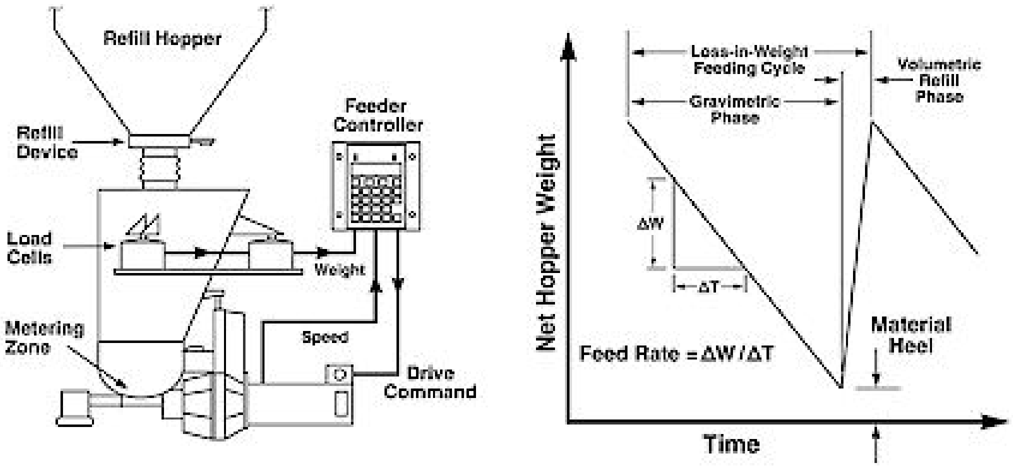


Figure 2 - Loss-in-Weight Feeder Components & Operating Principle

Assuming a properly selected and sized volumetric feeder, accurate performance hinges on several factors. To achieve high accuracy the weighing system must be able to quickly detect very small changes in total system weight. This requires a responsive, high-resolution yet stable weighing system that is unaffected by environmental variations.

In-plant shock and vibration act to corrupt the weight measurement, destroying the basis for feed rate control. Flexible connections and the possible use of shock mounts help isolate the feeding system; however, both the weighing and control system must be designed to discriminate between meaningful weight readings and the spurious forces associated with residual shock and vibration.

Another factor focuses on refill management. During hopper refill, system weight increases and cannot be used to control feed rate. Early loss-in-weight feeders held feeder speed constant during refill until replenishment was completed and a declining weight was sensed, at which time feeder speed would be controlled again.

Two problems are associated with this approach. First, during refill the feeder acts as a constant-speed volumetric feeder. Second, upon re-entry to loss-in-weight control, abrupt changes in feeder speed frequently occur resulting in flow control errors until the feeder settles at the new, proper speed. These abrupt speed changes occur because screw fill efficiency changes during refill, and material density at the bottom of the hopper can be somewhat higher than it is prior to refill owing to increased headload.

To remedy this, it is necessary to invoke control measures during refill to smoothly compensate for the increasing density or headload of material about to be discharged. This can be accomplished by gradually altering feeder speed in such a manner as to precisely mirror the effects of increasing density and headload. To determine the appropriate speed at any given hopper level in the refill process, the relationship between flow rate and feeder control output is memorized during the entirety of the preceding gravimetric feeding phase. Then, during refill, reference is made to this data set, and the appropriate motor speed can be applied based on sensed system weight as the hopper is filled.

4) When should a weigh belt feeder be selected and what factors affect its performance potential?

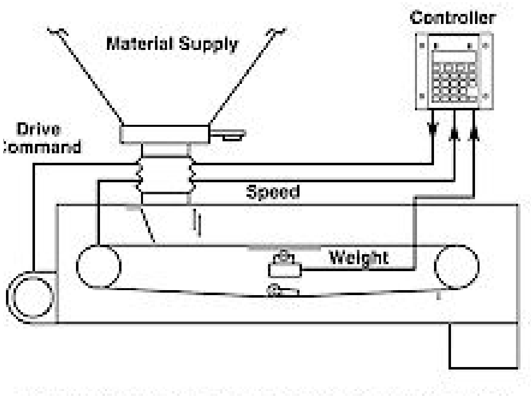


Figure 3 - Weigh Belt Feeder Components

Due to their operating principle weigh belt feeders are often a good choice when feeding relatively free flowing materials not requiring containment. Weigh belt feeders operate by continuously weighing a moving bed of material on its short conveyor, and controlling belt speed to result in the desired flow rate at discharge. Weigh belt feeders can achieve high rates while remaining compact, simply through a combination of manipulating material bed geometry and operating at higher belt speeds.

Factors affecting the performance potential of a weigh belt feeder include the consistency of the material bed (formed as incoming material is sheared past an adjustable inlet gate), the resolution, responsiveness, and environmental sensitivity of the weighing system, and the effectiveness of the feeder's various mechanical and electronic systems designed to permit accurate weighing through the belt.

Regarding material bed consistency, a stable, properly formed bed minimizes the need for corrective belt speed variation, resulting in improved overall accuracy. Based on the material's properties and intended range of flow rates, the feeder manufacturer typically determines the proper bed geometry and range of permissible inlet gate adjustment.

Weigh system resolution must be high (though not as high as in loss-in-weight feeding), especially at higher belt speeds where material may pass over the short weigh section in a small fraction of a second. The system must also be able to accurately weigh in a process environment where unknown levels of shock and vibration occur.

Precisely weighing material through a moving belt requires that belt tension be maintained within limits at all times. Variation in tension produces a weighing error due to a catenary effect and may also result in belt slip. While static belt take-up tensioning devices may still be found on some feeders, the preferable solution is a dynamic tensioning device that applies constant tension regardless of belt load, wear and stretch.

Taring or zeroing is a major concern when weighing through the belt since any error in tare produces a systematic error in feed rate. Sources of tare error include belt wear, impregnation of material into the belt, and adherence of material on the belt. Changes in belt weight due to material buildup are often inevitable. The use of a belt scraper at discharge and elsewhere within the feeder minimizes but, for many materials, cannot eliminate the concern. Thus, periodic taring is usually required.

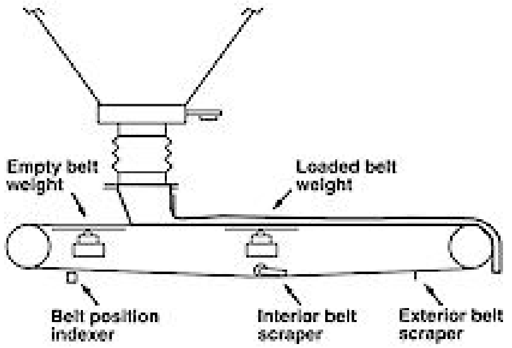


Figure 4 - Continuous Automatic On-Line Weigh Belt Taring

Many modern weigh belt feeders include a self-tare feature that, upon user demand, cycles the (empty) feeder through a single belt revolution and automatically computes an average tare value correction. If the application requires improved short-term accuracy an available indexing feature records inch-by-inch tare variation along the belt's length. During process operation, indexed belt segment tare values are invoked as the corresponding belt segment passes over the weighing section. The most advanced taring capability adds a second weigh sensor upstream of the material inlet, permitting continuous, automatic on-line taring without emptying the feeder.

5) Compared to other process weighing applications how does a gravimetric feeder's weighing system differ?

The performance demands placed on a gravimetric feeder's weigh system far exceed those required of a static weighing system. To illustrate, consider the following scenario. A loss-in-weight feeder handles a powder and is to feed at a maximum rate of 100 kg/hr with a turndown range of 20:1. The feeder and hopper together weigh 100 kg and can accommodate 50 kg of material. Assume the measurement range of the feeder's weigh system to be 200 kg and all sources of feeding error apart from weighing are ignored.

To achieve a 2 Sigma weighing accuracy of +0.25% at the feeder's maximum rate of 100 kg/hr over a 5-second interval the weigh system has to detect an expected weight loss during that period of a little less than 140g with a standard deviation of only 0.17g! At maximum turndown where the feeder operates at a rate of only 5 kg/hr the weigh system must measure an expected 6.9g weight loss during that same period with a standard deviation of less than nine one-thousandths of a gram.

Weighing performance such as illustrated above requires the highest possible measurement resolution. And when it is realized that weighing must take place in a process environment frequently hostile to such precision, the true scope of the weighing challenge becomes clearer.

In both loss-in-weight and weigh belt feeding, weight measurements must also be taken very quickly. This need underscores the importance of a highly responsive weigh system that does not rely on deflection and that exhibits no significant hysteresis or creep. Also, it must display strict linearity if it is to perform accurately over its full operating range. And finally, a weigh system appropriate for application in continuous feeders must also display a very high level of measurement stability to avoid drifting off calibration, regardless of temperature, humidity or other environmental factors.

6) How can the effects of shock and vibration be minimized in gravimetric feeder applications?

As if the challenges described in the previous question were not enough, the impact of shock and ambient plant vibration on a continuous feeder's weigh system deserves separate treatment. At first glance it may seem fruitless to even attempt precision weighing in a plant environment where vibration is the rule and occasional bumps, hits, and jostles can likewise be expected.

However, in this age of smart machines, the traditional measures of flexible connections and shock mounts are being augmented by innovations in sensor design and powerful real-time signal processing techniques that are able to reliably extract meaningful data even in an apparently chaotic weighing environment.

Advanced weight sensor technologies designed to minimize signal contamination during the measurement are combined with highly sophisticated post-measurement processing techniques to minimize the effects shock and vibration transmitted to the feeder from its environment. While beyond the scope of this presentation, two examples should suffice to illustrate the power behind these innovations.

For example, two vibrating wire scales, each carrying a 10 kg static weight, were subjected to +0.025 G vertical vibration at frequencies ranging from 3 to 100 Hz. One scale employed non-digital filtering; the other scale employed digital filtering. Half-second weight measurements were recorded at 0.25 Hz intervals throughout the test range. A five-second interval was allowed between measurements at each frequency step.

Significant signal contamination and resonance effects associated with the sensor employing non-digital filtering would occur. Digital filtering would suppress these vibration effects. While effective throughout the test range, digital filtering has been specially configured to suppress vibrations most characteristic of the typical plant environment: 10 Hz vibrations are diminished by a factor of 20,000, and 20 Hz vibrations by 200,000.

7) How do I measure feeder accuracy in my plant?

Whether performed automatically or manually, precise sampling is crucial to accurate performance measurement. Today, realizing the importance of sampling accuracy, more and more processors are automating the sampling procedure. Automated sampling eliminates human errors associated with manual sampling such as inconsistent sampling durations, and streamlines the process of data handling. Automated sampling involves the use of a precision scale with output to a computer. Software controls the acquisition of weight data as the feeder discharges material onto the scale.

The sampling procedure our company employs exclusively is called differential dynamic sampling. This highly accurate method involves outputting the weight reading as frequently as once per second, and automatically computing the difference between successive 'micro-samples'. These values are then totalized over the desired sampling size or period to form a single 'macro-sample'. This process is repeated until the desired thirty macro-samples (for repeatability measurements) or ten macro-samples (for linearity measurements) are obtained.

Note that automated sampling is the only means available to reliably determine feeder accuracy over timescales shorter than one minute. When taking short duration samples, human error in timing the samples becomes too great a factor to produce a meaningful result.

While the trend is toward automated sampling, manual sampling is still frequently employed when calibrating a feeder in the operating environment. Tools include a watch, two containers, a sampling scale, a record keeping worksheet, and a calculator. Whether testing for linearity or repeatability, the procedure is basically the same.

With the desired setpoint value dialed in and the feeder running under gravimetric control, material flow is channeled from the process by a flap-type flow diverter (or similar means) into one of the containers. At the start of the timed catch sampling period the sampler quickly slides a clean, empty container into the material stream, positioned so that all material is discharged into the container. At the end of the timed sample interval the sampler cycles the other container into position and, while it is receiving material, records the weight of the contents of the first container.

The sampler proceeds in this fashion, weighing one sample while the next is being obtained, until the desired number of consecutive samples is taken. Conventional statistical computation is then performed to determine repeatability performance (standard deviation) or linearity (average sample weight).

To minimize errors in manual sampling several safeguards must be observed:

- Since there will probably be a difference, however small, between the weight of the two empty catch sample containers, each container should be tared separately. If the scale being used to weigh the samples does not have provisions for storing two tare values, the heavier container should be tared out and weights affixed to the lighter one to bring its weight up to that of the heavier one.
- The sample weight must be large enough to make human error in sampling negligible. Most feeder manufacturers specify that samples should be a minimum of one minute in duration or one pound in weight, whichever is greater. Other limitations may apply.
- To minimize variations in sampling technique, the same individual should catch all samples.
- Samples must be taken consecutively.
- The resolution of the sampling scale must be one order of magnitude greater than the smallest sample deviation. Thus for example, if samples are to be measured to 0.01g, the resolution of the sampling scale should be 0.001g.

Experience will dictate the required frequency of calibration checks for any given feeding application. Thus, it is recommended that processors consider the use of run charts to trend calibration data over time.

7) What are the most common feeder troubleshooting and maintenance issues?

Assuming the feeder was properly selected and engineered for the application, and that upstream and downstream equipment is operating properly, most problems arise from improper installation, inadequate maintenance, lack of training of operating and maintenance personnel, and changes in the process material, or operating conditions and requirements.

Thus, many problems can be avoided at the outset simply by assuring proper installation, and thorough training of operating and maintenance personnel. Especially for more complex feeding systems, contracting for installation service is cheap insurance against potentially costly problems and start-up delays. And operator/maintenance training not only familiarizes plant personnel with the equipment itself, but also can be invaluable in improving problem solving skills through exposure to the methods and practices of troubleshooting.

Given the fact that a feeder is engineered and configured to handle a specific material over a specific range of rates, changes in the process material and/or operational requirements are also significant sources of

unanticipated problems. In more than a few cases, merely changing the material supplier has resulted in feeder problems due to subtle differences in the physical characteristics of the new material.

And, if a feeder is required to operate at rates outside of its initial design range, performance difficulties should not be unexpected. Some feeders have been designed to be easily re-ranged in the plant-a fact worth considering at purchase if such a need can be anticipated. Also, if process conditions such as ambient or material temperature, or vibration levels change significantly and a change in feeder performance is noted, it is prudent then to consult with the manufacturer.

Certainly, not all problems can be attributed to the causes addressed above. Aside from mechanical or electronic failure of feeder components, some problems arise from the feeder's operating principle itself. Since volumetric, loss-in-weight and weigh belt feeders operate on different feeding principles, each will be treated separately.

Volumetric Feeders

Simplest in principle, speed-controlled volumetric screw feeders are usually the most easily diagnosed when problems arise. Again assuming a correctly configured feeder for the application, the most likely causes of problems are the integrity of the speed control and a change in the volume-per-revolution relationship.

If the feeder's speed sensor does not perform accurately (or at all), control is not possible. Depending on the specifics of the sensing mechanism, cleaning or replacement is required according to the manufacturer's recommendation, but first confirm that the problem is not with wiring or electrical connections.

If screw speed control is not the problem, a change in the feeder's volume-per-revolution relationship is the likely cause. Such changes typically occur due to material buildup on the screw or a blockage above the screw that prevents a consistent supply to the screw. Immediate but temporary remedies include cleaning the screw, discharge tube, and/or hopper. A permanent solution to repeated episodes may require a change in screw design, bin design or agitation, or other measures.

Loss-in-Weight Feeders

Typically employing a screw feeder to handle bulk solid materials, the problems addressed above in regard to volumetric feeders also apply to loss-in-weight units. Note, however, that since a loss-in-weight feeder controls primarily to declining system weight rather than screw speed, screw buildup or partial blockage will be compensated for automatically until, at some point, the feeder reaches an alarm condition. If this condition is observed, first check for buildup or blockage.

Since loss-in-weight feeders rely on an accurate weight measurement of the entire feeding system, it is important that the system be isolated from the process's vibration environment. While mainly an issue to be dealt with at installation through stable mounting, avoidance of strong air currents in the feeder's vicinity, and the use of shock mounts and flexible connections, difficulties can arise due to causes ranging from the installation of new equipment near the feeder to improper refitting of flexible connections during maintenance. If repeatability problems appear to be correlated with the operation of nearby machinery, or performance erodes after maintenance, increased vibration may be reaching the feeder. Note that some weighing systems available today provide built-in vibration protection.

The weigh system, arguably the most critical element in a loss-in-weight feeder, can also be the source of performance problems. Great advances in weighing technology have been made over the last twenty years, but there continues to exist a real diversity in the quality and capabilities of weigh systems in use today.

Thus, in light of this diversity, issues such as resolution, stability, responsiveness, weigh signal integrity, sensitivity to vibration, reliability, and data communications must be carefully evaluated by the processor before committing to equipment purchase. After installation, a program of regularly scheduled calibration checks is the best way to monitor system performance and reveal problems such as drift as early as possible.

A final source of typical loss-in-weight performance problems has to do with conditions at inlet and discharge. At inlet, if refill is performed automatically through the use of a refill feeder, any leakage in the shut-off device will produce a feeding error. And when discharging to a non-ambient pressure environment, any leaks or pressure pulses reaching the feeder will likewise produce a feeding error. These problems are usually easily fixed but may be difficult to detect. The best solution is to periodically check for positive and complete sealing.

Weigh Belt Feeders

Assuming a properly applied weigh belt feeder, most of the typical problems encountered with this type feeder center around the mechanical systems associated with managing the belt itself-keeping it clean, tracking properly, and in constant tension. Each manufacturer takes a somewhat different approach to achieving these ends, so a complete presentation of remedies to potential problems is beyond the scope of this paper. However, it is important to mention that, regardless of the systems employed, most problems stem from lax maintenance, cleaning and monitoring of belt management systems. The best solution here is prevention through regular monitoring and replacement as required according to manufacturer’s recommendations.

For proper feeder operation the inlet gate of a weigh belt feeder is set to produce a material bed of a certain height and width for the given material. If a different material is handled, or if the density of the original material is changed significantly, adjustment to the inlet gate geometry is usually required to a) avoid material spilling off the belt or coming in contact with the channeling side skirts, and b) establish the proper belt loading (e.g., lb/ft) value. Ignoring this consideration sets the stage for problems.

Belt slip occurs when insufficient frictional force exists between the belt and its drive pulley. Slip causes a direct error in feed rate, and is due to insufficient belt tension and/or the accumulation of process material on the inside of the belt. Proper maintenance of the belt and tensioning system will help avoid belt slip, but if the condition persists the feeder may have to be re-configured to operate at a lower belt speed. Belt slip detection is available from most if not all manufacturers.

Finally, due to their operating principle of weighing material through the belt, accurate and frequent taring is a concern. As discussed, continuous, automatic, on-line taring is now available. However, until it is the norm, processors must make weigh belt taring a regular activity.

In Conclusion

Today misformulations, wasted material, and rejected product are too expensive to be called unpreventable. Ensuring feeder accuracy is central to guarding against these process pitfalls. And developing a familiarity with feeding's principles and practices is a good first step. But what else does the user need to guarantee a correct, reliable and cost-effective solution to his feeding problems?

The answer lies in selecting the best supplier, and making the fullest possible use of available support services, both before and after purchase. Check out the supplier carefully, gather references and talk to current customers. Evaluate the supplier's experience, application expertise, and systems engineering capabilities. Learn about the supplier's testing program, service and spare parts programs.

In short, communicate and investigate early on in the process. The time and effort invested will surely pay handsome dividends for years to come.

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