

Technical Paper

Smart Refill Technology in Loss-in-Weight Feeding

Recharging a loss-in-weight feeder doesn't have to harm performance. Smart Refill Technology combines several strategies to overcome the problem.

Loss-in-weight feeders have evolved from mechanically ponderous devices to the sophisticated microprocessor controlled instruments of today. Weighing and control advancements over the years have made loss-in-weight (gravimetric) feeding the preferred method wherever the combination of high gravimetric accuracy, ingredient containment, and material handling capability are needed.

However, loss-in-weight feeding does possess some shortcomings, especially at higher feed rates. First, during the feeder's required hopper refill phase, weight-based control must be temporarily suspended and replaced with volumetric control. It is in this refill phase that significant feed rate errors can occur due to volumetric control inaccuracies. And second, higher feed rates have historically meant physically large and expensive systems. In some cases required space could only be obtained at the cost of significant structural changes to the plant itself. These refill challenges are especially great when feeding tough to handle powders.

Feeder manufacturers have taken varying approaches to the challenges present during refill of the feeder's hopper. K-Tron

utilizes an approach called "Smart Refill Technology (SRT)." Smart Refill Technology ensures that intermediate to high rate loss-in-weight systems do not have to suffer from feed rate inaccuracy during refill and can use a more compact hopper offering a more economic solution to fitting into tight locations in the factory.

SRT combines a refill control concept called the Refill Array with precision digital weighing to deliver improved feeding accuracy during hopper refill, substantially reduced headroom requirements, the elimination of material handling problems associated with large feeder hoppers, smooth and quick transitions into and out of hopper refill, and lower total installation costs.

The Loss-in-Weight Principle

Loss-in-weight feeding achieves rate control by weighing the entire feeder, hopper and the material contained in it. The speed of the metering device is controlled to result in a per-unit-time loss of system weight equal to the desired feed rate. In this way high accuracy may be achieved, and nearly any metering device appropriate to handle the material at the desired rate may be selected. See Figure 1.

As an integral part of loss-in-weight feeding the weighed hopper must be resupplied with material. To continuously resupply the hopper would destroy the very basis for control, the declining weight value itself. Hence, the hopper must be resupplied periodically rather than continuously.

Lacking any basis for gravimetric control during these brief but periodic refill phases, flow control is achieved volumetrically. Traditionally, a constant metering speed is maintained throughout the refill phase – a speed corresponding to the metering



Smart Refill Technology maintains high levels of loss-in-weight feeder performance during hopper refill.

speed associated with gravimetric control just prior to entering the refill phase. If, for example, metering speed averaged 60 rpm just prior to the system sensing the need to refill the supply hopper, screw speed would be maintained at that 60 rpm for the duration of the refill operation. After refill is completed, material has settled, and the feeder senses an appropriately declining system weight, the feeder is returned to gravimetric operation where metering speed once again becomes the parameter of control.

Figure 2 plots hopper weight versus time, and shows the declining weight signal, the

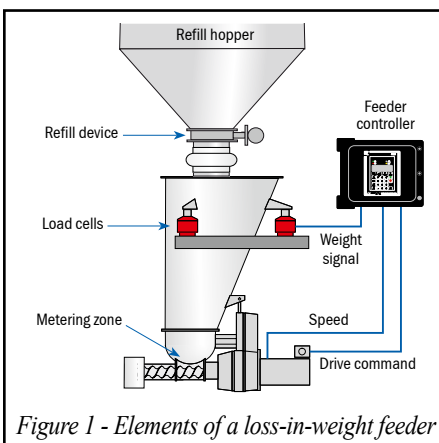


Figure 1 - Elements of a loss-in-weight feeder

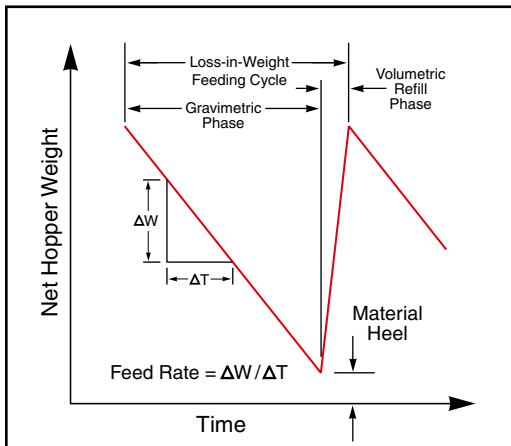


Figure 2 - The loss-in-weight feeding cycle slope of which is the feed rate (change in system weight per unit time). Note that the hopper does not empty completely before the refill phase is triggered. The prime reason for this is to assure an ever-present supply of material at the metering device so feeding may proceed without interruption. Additionally, if a sufficiently large material heel is not present, the increasing pressure applied by the impact of the incoming, possibly aerated material during refill may cause uncontrolled flooding through the feeder.

Even with an insulating heel of material in place, density within the metering zone will rise somewhat as the hopper fills. Given a constant metering speed during refill (60 rpm in our example), this increase in density causes progressive degradation (overfeeding) in feeding accuracy as more and more material enters the hopper and compacts the material in the hopper's lower regions. How severe is this inaccuracy? The answer hinges on hopper size/geometry in addition to the compactability of the material itself. Laboratory tests and field experience involving many hundreds of materials show that, in practical terms, headload-related loss-in-weight overfeeding may range anywhere between +1% for relatively constant density materials to +10-15% for powders and other materials whose density can vary substantially.

The Smart Refill Concept

To minimize feed rate errors during refill, Smart Refill Technology discards the

approach of maintaining a constant metering speed. Instead, SRT enables metering speed to be gradually lowered during refill to precisely counterbalance the effects of increasing material density occurring in the metering zone as hopper weight increases. The slower rate is determined by storing in the controller's memory an array of indices, called feed factors. These values correspond largely to material density and its mechanical behavior within the feeder, and are computed during the entirety of the gravimetric feeding cycle.

Then, on the basis of sensed hopper weight at each array point during refill, material density within the metering zone may be inferred, and a metering speed corresponding to its feed factor array value may be invoked. In this way gravimetric feeding accuracy during the brief refill may be maintained.

The SRT approach is most easily illustrated by considering Figure 3. The graph at the top plots net hopper weight versus time. Beginning with a full hopper (where net hopper weight equals refill complete weight), gravimetric operation is in effect and the feeder operates normally, according to the operating principle explained above. As feeding proceeds and net hopper weight declines, the controller also determines and stores a set of up to 100 feed factors, each of which is an index of the average density of material discharged at the hopper weight associated with the feed factor. A low feed factor indicates that a higher number of screw revolutions were required to discharge a given weight, implying a reduced material density.

Conversely, a high feed factor reflects higher density since fewer screw revolutions were required to deliver the same material weight.

The middle plot shows motor speed versus time. During the early portion of the gravimetric feeding phase, motor speed is relatively constant since density within the metering zone of the feeder, while higher than at later times in the feeding cycle, does not vary substantially. This is because material in the upper portion of a typical hopper is largely supported by the material below and, in turn, the tapering walls of the lower portion of the hopper. As feeding proceeds and hopper level declines, headload in the metering zone begins to lessen, resulting in a reduction in density and a corresponding increase in motor speed required to maintain feed rate. When hopper weight reaches the refill request threshold, the refill phase begins. During refill SRT begins with the motor speed that was in effect at the time of refill request, and then modifies that speed by applying the corresponding feed factor as each hopper weight 'slice' is encountered. Without SRT, motor

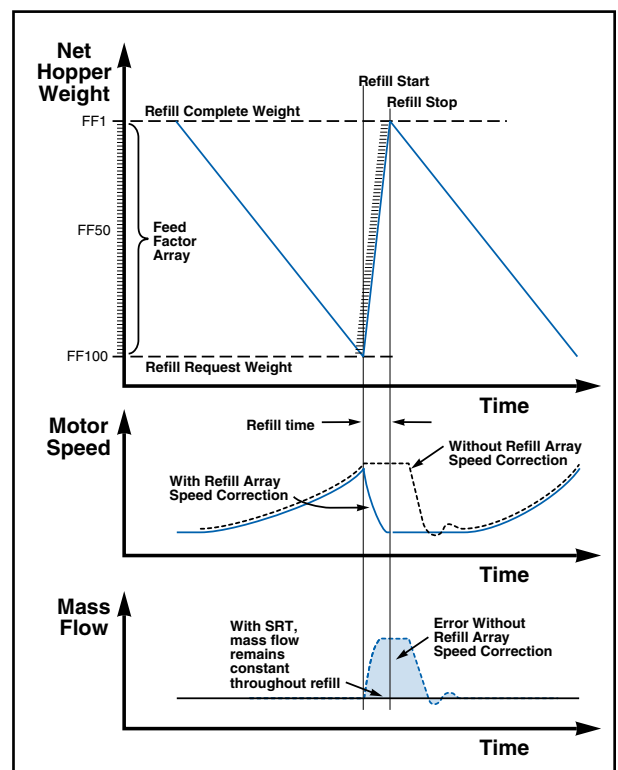


Figure 3 - Dynamics of the refill operation

speed remains constant throughout the refill cycle, which results in overfeeding.

The mass flow error associated with constant metering screw speed during refill is shown in the bottom illustration of Figure 3. Note that metering speed is shown to remain constant for some time after refill completion. This undesirable effect is typical for conventional loss-in-weight systems that require several seconds for their weighing systems to stabilize before reverting to gravimetric control. Fast response digital weighing technology, such as K-Tron's Smart Force Transducer (SFT) single vibrating wire, is needed in order to produce a low stabilization time without a big delay. Note also that when speed is held constant during refill an abrupt change in metering screw speed is required upon re-entry to gravimetric operation. SRT, in contrast, exhibits no such discontinuity, resulting in a smooth transition from refill to normal gravimetric operation.

Low or High Refill Frequency?

SRT provides another valuable benefit: the opportunity to substantially reduce overall feeder size and cost by enabling refill to occur at a much higher frequency than before.

In earlier loss-in-weight systems a low frequency refill approach was taken as pictured in Figure 4. In that approach a relatively lengthy gravimetric feeding phase is followed by refill whose duration

should not exceed 10% of the cycle, which results in overfeeding. The hopper must, of course, have a capacity greater than the amount of material fed during the entire gravimetric phase. In low rate applications this requirement is not a problem; however, as feed rate increases, so must the capacity of the hopper. As a result, high-rate loss-in-weight systems have historically been large and bulky with hoppers often in the hundreds-of-cubic-feet capacity range. This, in turn, necessitated a much larger range (and hence less sensitive) weighing mechanism. The low frequency refill approach therefore translates directly into the high initial cost associated with purchasing and installing a physically large feeding system, in addition to the high continuing costs of the inefficient use of plant area and headroom.

Consider alternatively a comparably high rate loss-in-weight system with a high frequency of refill as shown in the same diagram. The metering device itself remains the same so as to provide the desired feed rate, but the hopper and weighing mechanism may now be much smaller. Both the gravimetric feeding phase and the volumetric refill phase are much shorter in

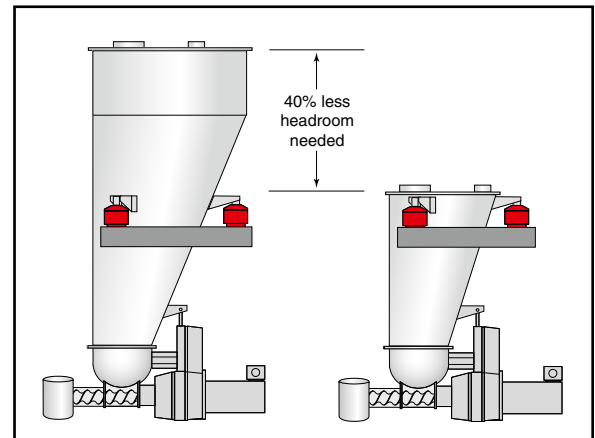


Figure 5 - The low-frequency refill loss-in-weight feeder (left) delivers 2,800 kg/hr (6160 lb/hr) with a 180 dm³ (6 ft³) hopper at 10 refills per hour. But with Smart Refill Technology the same feeder (right) delivers the same discharge rate using only a 50 dm³ (1.8 ft³) hopper at 40 refills per hour at no loss in feeder accuracy. Significant savings in headroom are possible, and the smaller sized feeding system costs less.

is required to resupply the weighed hopper more frequently, there is no difference in the rate at which it must deliver material.

The analogy of driving a car with your eyes closed highlights one of the most significant benefits of the high frequency refill approach: much shorter periods spent in volumetric control. In high frequency refill the feeding system operates volumetrically for a much shorter period before returning to true gravimetric control. This is analogous to blinking your eyes normally during driving. It is easy to stay in control. However, in the case of low frequency refill, volumetric control persists for a much longer time before re-entering gravimetric control. This is akin to closing your eyes for a dangerously long time when driving. By refilling more frequently, there is less of an opportunity for feed rate to deviate from setpoint before gravimetric control is re-established.

Another compelling benefit to the high frequency approach comes in the form of a smaller and more compact feeding system. Costs connected with purchase cost, installation and plant area/headroom are all cut. Specifically, depending on the application, savings on equipment costs of up to 30% are typical. Also, significant plant space savings are possible when planning a new

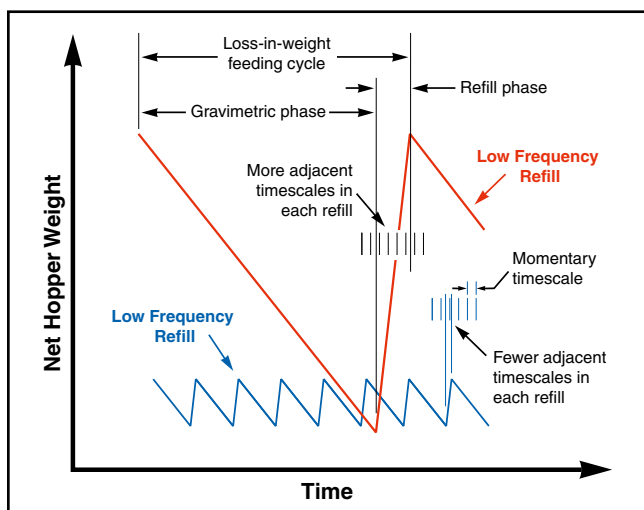


Figure 4 - Refill frequency

duration – even up to ten times shorter than they would be under the low frequency refill approach. Note, however, that while the duration of the feed and refill cycles are much reduced, the total time spent in these cycles is the same as in the low frequency approach... the cycles are simply more finely divided than before. Similarly, while the refill device

process line or upgrading and old one. See Figure 5.

Refill Device Selection

There are several choices on the type of refill device utilized above the feeder hopper. Options include knife gates, modulating butterfly valves, rotary valves, or in the case where extreme control is required, such as in microfeeding, the use of alternate metered devices such as volumetric screw feeders or vibratory tray feeders (see Figure 6). If the material is free flowing but extremely friable, the vibratory tray might be the better choice, due to its gentler action on the metered material. In addition, the use of pneumatic loaders above the butterfly valve or rotary airlock is often employed to transfer the material to a receiver above the feeder hopper.

A knife gate or a slide gate might be acceptable if the feeder hopper is large and consumes most of the vertical space between the weighed hopper and the refill hopper, and if modulation of the gate valve is feasible for the given bulk material flow characteristics. Problems arise when the refill system does not take into consideration the capacity of the feeder hopper, the flow properties of the bulk solid, and the distance and potential storage volume of bulk solids that can occur between them.

For example, in refilling a feeder hopper from an IBC (intermediate bulk container),

super sack, or large hopper, the volume of the product in these vessels will often times exceed the volume of the feeder hopper. Clearly, it is impossible to control the refill without overflowing the feeder hopper, unless a time window is established for the opening and closing cycle of the refill valve. This time window can be calculated based upon bulk density of the material, the angle of repose which dictates the settling leveling the feeder hopper, and the flow rate through the refill device. It should also be noted, that when discharging from bins or IBC's which may be equipped with flow aid devices (e.g. vibrators or live bottom bins) special care must be made to isolate the vibration of these devices from the feeder hopper to ensure there is no contamination of the feeder's weighing system.

In the case of using a screw feeder as a refill device, bulk material flow may continue from the screw feeder even when stopped. A plug or shutoff valve at the end of the screw feeder may be necessary to guarantee positive shutoff when the refill feeder is stopped, preventing unintentional flow.

A rotary valve can also be used to isolate pressure zones from the weighed hopper. When using a rotary valve, the vanes must be tightly sealed and at least eight to twelve vanes used. If this is the case, an additional refill valve is usually not required. The rotary valve is a good choice for handling floodable and free-flowing powders, since

it meters them in a controlled manner to the weighed hopper. However, special care should be taken if the powders are not free flowing or cohesive, as they may tend to agglomerate or pack in the rotary valve vanes.

As mentioned above, the flow rate from the refill device must be sufficient to avoid exceeding the 10% refill time limit. Additionally, the flow cutoff action of the selected device must be quick and sure. A slow tapering off of the refill flow needlessly lengthens refill time, and any leakage of the refill device may cause an unavoidable weight disturbance, but will always result in a flow error in the positive direction.

As mentioned above, pneumatic receivers operating under a dilute phase vacuum transfer principle are often used as refill devices, particularly for continuous operations. Pneumatic receivers use negative pressure to suck the material required for refill into a separately mounted and supported vacuum receiver. The receiver is filled to a pre-determined level and then holds the material charge until the feeder below requests a refill. The level of fill in the receiver is determined by level sensors. When the feeder requests refill, the discharge valve opens and the receiver contents are discharged into the feeder hopper. For loss-in-weight feeding, this discharge valve is always a pneumatic butterfly valve in order to prevent any chance of dribbling. At the time of refill discharge, a gas pulse is sent through the receiver's filter to release any entrained particulate or material which may have accumulated. Filter material can vary, including options on laminated membrane type materials, for quick release and easy clean properties.

After dumping the material into the feeder hopper, the valve is shut again and the receiver vacuum cycle immediately begins, preparing for the next refill request.

The use of pneumatic receivers as refill devices allows for an uninterrupted source of refill from either bags, drums, IBC's or supersacks.

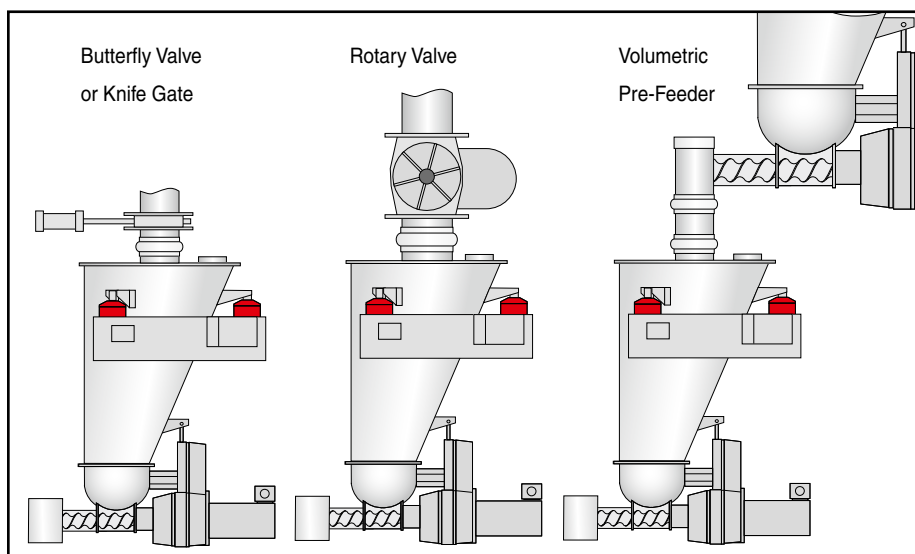


Figure 6 - Various examples of refill devices

System Dynamics

Let us now consider the more practical side of the issue, both from the point of view of system dynamics and the concerns of the application itself. First, system dynamics.

Precision loss-in-weight feeding is a true exercise in dynamic control. To achieve control on a moment-to-moment basis the weighing system must accurately discern the constantly declining system weight, and then the controller must, in turn, compare that weight to the known target weight at that instant, and then issue an adjusting command to the metering device. In intermediate/high rate loss-in-weight units, this dynamically based control loop may occur many times per second, placing demands on the responsiveness of the weighing system and controller alike.

During normal, constant-rate gravimetric feeding, control adjustments are typically small, and thus most loss-in-weight systems are fully capable of reasonably accurately tracking the smoothly declining weight. However, for loss-in-weight systems employing deflection-dependent weighing mechanisms, problems can arise during the attempted transition out of the refill phase. Reverberations of the dynamic loading changes encountered during refill act to delay resumption of gravimetric feeding. Deflection-dependent weighing systems characteristically exhibit high stabilization times, and no loss-in-weight system will allow itself to re-establish gravimetric operation until a valid and credible weight signal is present. It is primarily for this reason that conventional, high-deflection loss-in-weight systems have historically been developed as low frequency refill devices, utilizing large hoppers. To adopt a high frequency refill approach while using a deflection-dependent weighing system would mean that an excessive amount of time must be spent under volumetric rather than gravimetric control.

Today, with essentially deflectionless vibrating wire weighing technology, extremely high resolution and low stabi-

lization times are possible even under the severe loading changes that occur during refill. This advancement, along with more sophisticated control, has enabled the design of high rate loss-in-weight systems capable of fast and smooth transition form refill. Up to 60 feed/refill cycles per hour are possible, minimizing feeder size with no performance penalty.

Application Concerns

Turning to the application itself, four points deserve specific mention. First, as already mentioned, the maximum refill time should not exceed 10% of the total feed/refill cycle time. This consideration is largely irrelevant in low rate systems where cycle times are long and where hoppers are small and can be refilled quickly. However, in many intermediate-to-high-rate systems this 10% limit will dictate the required delivery rate of the refill device.

Second, adequate venting of the hopper must be provided. As material drops into the hopper during refill it becomes aerated to one degree or another, and it also displaces the air in the hopper. Adequate venting will assist in material settling and a quicker return to true gravimetric operation.

Material considerations form the third area of concern. The high-frequency refill approach with its characteristically smaller hopper capacity requirement will reduce the opportunity for material segregation. However, the smaller insulating heel of material may cause some highly floodable materials, aerated during their drop from the refill device, to surge uncontrolled through the metering device. This is normally not a problem, however, because material drop distances are significantly less with high frequency refill systems and therefore material impact is less. Proper selection of the metering element and/or the use of baffle plates within the hopper will resolve flood-through if and when it arises. Given the vast diversity of materials and their equally diverse flow characteristics, it is strongly recommended that laboratory tests be conducted to determine the best method of handling the material, regardless

of whether high- or low-frequency refill is selected.

The fourth and final concern focuses on the refill device. Largely the material itself will determine the particular type of refill device. Freely flowing pellets may require nothing more than a knife gate, while more stubborn powders and other materials often require a screw or auger. The flow rate from the refill device must be sufficient to avoid exceeding the 10% refill time limit. Additionally, the flow cutoff action of the selected device must be quick and sure. A slow tapering off of the refill flow needlessly lengthens refill time, and any leakage of the refill device will cause an avoidable weight disturbance.

Conclusion

A much-improved approach to higher-rate loss-in-weight feeding is made possible by the development of Smart Refill Technology in combination with advances in weighing and control systems. High-frequency refill affords substantial cost reductions at purchase, at installation, and throughout the life of the application. Intermediate-to-high-rate loss-in-weight systems can now be offered with compactness in mind with no loss in performance. When feeding tough powders that may have large variations in bulk density, this technology can be especially valuable.



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