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Feedrate deviations caused by hopper refill of loss-in-weight feeders

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ABSTRACT

Continuous powder processing requires accurate and consistent feed streams of the raw materials which makes loss-in-weight feeders invaluable. Periodic hopper refill of the feeders, which is needed for continuous operation, can lead to inconsistent and poor feeding performance. This paper presents both a method for measuring the feeding performance during hopper refill as well as several methods for quantifying the resultant deviations from feedrate setpoint caused by refill. The main results show that hopper fill level is the most significant factor that can be used in mitigating the deviations effects during refill. The use of discharge screens also showed a small improvement in feeding accuracy. Another potentially useful method of reducing deviations during refill is to use refilling systems that have a lower more controlled rate of refill that gently replenishes the feed hopper rather than the high rate refill of some refilling systems.

1. Introduction

Continuous processing is considered a profitable choice in many industries because of the many advantages over batch processing. The main advantages of continuous manufacturing are improved process control, reduced labor costs, smaller equipment footprint, and more uniform product quality. A significant difference between continuous and batch operation is the necessity to control flowrates of material as opposed to measuring an amount of material without time dependence. In powder processing this requirement is often met with loss-in-weight feeders which gravimetrically control the feedrate of material [1].

Under its standard gravimetric mode of operation, a loss-in-weight (LIW) feeder's controller compares the observed gravimetric feedrate to the user defined setpoint. Depending on the deviation from setpoint, the controller may send a new signal to the feeder to change the speed. This is beneficial to the performance of the feeder, as it allows the feeder to adjust for many known and unknown causes of feedrate inconsistency that would affect volumetric or constant drive speed operation [1]. To keep the process continuous and uninterrupted requires occasional refill of the feeder hopper. During refill it has become common practice to replenish the feeder when it reaches the lowest level that the manufacturer would recommend for operation. It has been common practice to begin the refill process around 20% and continuing until the hopper fill level reaches 80% [2,3]. However, during this refill time and a short post refill delay (typically about 10-15 seconds) [2,4–6], the feeder operates in volumetric mode and does not monitor nor control the gravimetric feedrate, opening the possibility for deviations from setpoint. One potential source of deviation occurs when the incoming material compresses the bed of powder within the hopper, thereby increasing the density in the hopper causing over-feeding [7]. Another source of deviation occurs when the material becomes aerated by the refill procedure. When this occurs, the powder behaves like a liquid and floods through the screws uncontrollably [5].

There have been a few patents created by manufacturers as well as a recent journal article that attempt to address this caveat of using a continuous feeder that will eventually require refill [7,10]. In US Patent 4524886, Wilson and Loe use values stored during the emptying of the feed hopper to control the screw speed during refill [7]. This is also the current method used in the K-Tron manufactured feeders. Although this is a method that can potentially work in a slow refill process, this method has problems when refill times are very short. This is briefly mentioned in the K-Tron operations manuals for their twin-screw feeders suggesting that the “Refill Array” feature only be enabled for refill methods that are longer than 15 seconds in duration [4].

US Patent 6446836 by Aalto and Bjorklund, addresses the problem by using redundant replenishment hoppers instrumented with load cells [8]. When the gravimetric feeder requires replenishment, one of the hoppers receives a signal to refill. The other replenishment hopper remains isolated from the gravimetric feeder, and is replenished with material from a pneumatic refill system. The subsequent feed hopper refill will be handled by this recently refilled replenishment hopper. The loadcells connected to each isolated replenishment hopper pass the rate of refill signal to the dispensing gravimetric feeder's controller. This removes the uncertainty of the rate of the refill stream from the replenishment hopper, enabling the feeder to operate in gravimetric mode throughout the refill process. Similarly in a journal article by

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Cologni *et al.*, uses an instrumented refill hopper to monitor the refill feedrate, which allows the controller of the feeder to be controlled throughout the refill [10].

Wilson and Bullivant discuss in US Patent 4579252 a method that bypasses the issue altogether. They use a second feeder to feed while the original one is refilled [9]. Although this method may have the best results, it also has the disadvantage of the expense of a secondary gravimetric feeding system and the additional space required around a downspout that may already be crowded by other feeders supplying different components.

All the methods or systems mentioned above may work to reduce or eliminate the issue. However, these patented techniques do not always eliminate the problem and often involve purchasing extra equipment in addition to access to the internal programming of the controller. With commercially available feeders, the ability to implement many of these control strategies is limited, due to the closed design of the PLC programming.

This work focuses on using pre-commissioning testing of commercially available feeders to observe the effects and issues during refill as well as developing a method for quantifying the effects so that it can be used for optimizing refill scheduling. By using a gain-in-weight catch scale, which collects and weighs material as it is fed, deviations from the feed setpoint can be monitored during hopper refill even when the internal feeder loadcell is not reliable. It has been observed that size of refill has a significant impact on feeder consistency and performance.

2. Equipment

2.1. Loss-in-weight feeders

For continuous manufacturing, the ability to feed a powder steadily and continuously can be one of the most important parts of the overall processing. If a powder feeder cannot sufficiently dose at a desired rate, then it will pass composition and flowrate variability issues on to subsequent unit operations, such as mixing [11]. There are two main principles used for controlling the feedrate of a feeder: volumetric and gravimetric. The volumetric feeding principle sets the speed of the feeding mechanism to a constant rate, which keeps the volume per unit of time consistent. Feedrate from a powder feeder can be described by the following general equation:

$$\dot{m}= \rho_{bulk}\,\dot{V} \tag{1}$$

where ρ_{bulk} is the bulk density and $\dot{V}$ is the volumetric feedrate. In order for volumetric feeding to maintain a constant mass feedrate ($\dot{m}$), the bulk density must remain constant. This is acceptable where density does not vary. However, powders have a variable density depending on the state of consolidation [12–14], environmental factors (such as moisture [15]), and changes in powder properties (such as particle size [12], through segregation or attrition). To compensate for changes in powder density, the gravimetric control or loss-in-weight principle can be used to directly regulate mass feedrate [1].

All loss-in-weight feeders consist of three parts: volumetric feeder, weighing platform (load cell), and gravimetric controller (see Fig. 1). The volumetric feeder is mounted on top of a weighing platform that measures the mass of the feeder, its powder hopper, and the material contents. As the feeder dispenses powder the gravimetric controller acquires a signal from the loadcell in the weighing platform as a function of time.

Using the difference in weight measured by the platform divided by time, the controller can determine the instantaneous feedrate:

$$\left(\frac{\Delta w_{feeder}}{\Delta t}\right) = -\dot{m}_{feed} \tag{2}$$

This feedrate is compared to the desired setpoint by the controller which adjusts the speed of the screw in order to maintain the feedrate setpoint. However, this equation is not true when the feeder undergoes hopper replenishment.

2.1.1. Operation during hopper refill

Eventually, as the hopper empties the powder needs to be replenished. See Fig. 2. In order to maintain continuity of operation, the hopper is refilled while the feeder is operating. During refill the feeder must be switch to non-gravimetric operation where screw speed is instead controlled volumetrically. The reason for the switch in operation mode is because the change in weight with time during

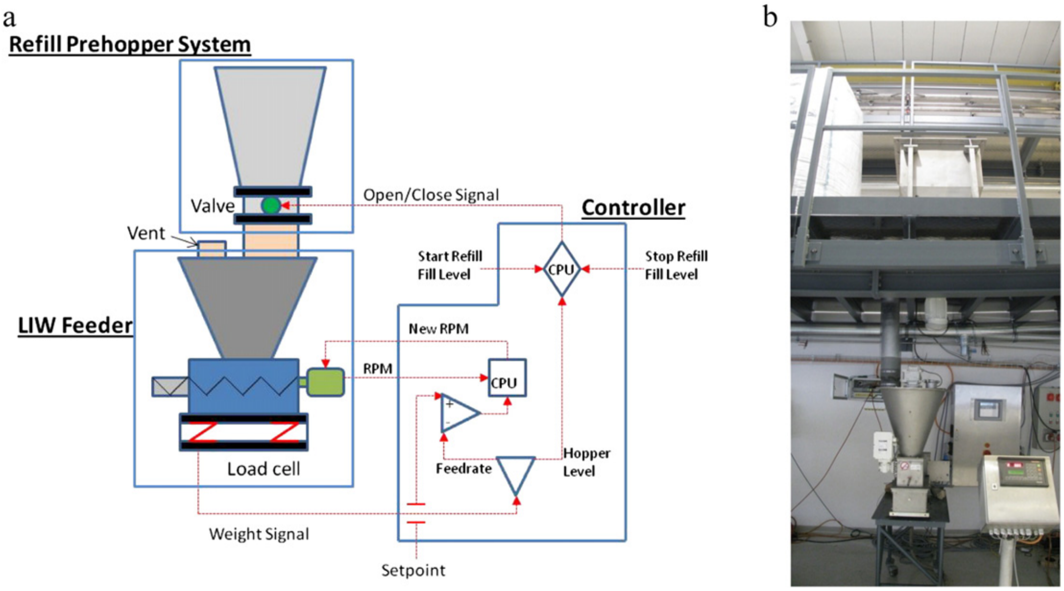

Fig. 1. a) Diagram of the main components of a loss-in-weight feeder including a refill system and gravimetric controller with labels for the main control signals. b) Photograph of a Gericke GLD87 feeder in a testing setup with an attached automatic refill system located on the platform above.