Functions need to be considered for Batch Material Transfer Controls

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ABSTRACT
Batch processes depend heavily on the speed and repeatability with which each material transfer is completed for every recipe executed. Each and every transfer generally requires precise cut-off control over the valves, screw feeders or pumps, as those transfers directly impact the annual profitability of a manufacturing facility. Therefore it is very important to have a cost-effective material transfer control system that consistently improves process quality and throughput while reducing raw material waste and operating costs.

This paper presents some main factors to impact speed and accuracy of batch material transfers. In addition to functions to reach the goals of speed and accuracy for batch material transfers, many other either must-have, should-have or beneficial functions are explained. Where those functions should be built? Some considerations are presented to answer the question in this paper.
Introduction
When dealing with batch material transfer control, people mainly want to deliver right amount of material at right time. That is, final control elements such as valve and/or pump should be activated to start a batch material transfer; and then deactivated when the target amount is reached. This may sound very easy. However, in real industrial applications, particularly in automatic batch control systems, a robust and flexible system for batch material transfer controls is not easy to built and maintain. A system must have proper control algorithms and functions to deal with process normal & abnormal variations and operator intervention during the transfer and between batches. Some of the functions may not appear that obvious.

This paper presents some fundamental factors which should be considered when building control strategies in order to meet both accuracy and speed requirements. In addition, some basic, important and beneficial functions for batch material transfers are explained for batch material transfer controls.

Speed vs. Accuracy
Usually main goals of controlling batch material transfers are to feed exact amount of material in shortest time except for some cases like flow ratio control, etc. However, these two goals (speed and accuracy) are generally not easy to obtain because they are contradictory in control point view. It is Ok if flow rate is big with no variations. But that is just an ideal situation and hardly to have any constant flow in any industrial applications. Flow variations can result from material characteristics difference, process equipment and dynamic characteristics changes, and control system execution time inconsistency.

Any of all these variations above would impact on determining when a stop-feed command should be issued. Why is that? Let’s consider a scale-based batch material transfer. It is almost certain that stopping the feed when the scale reading equals setpoint or target amount will not result in exact amount material that we want to deliver, or lead to the “ideal” curve in red shown in Figure 1. It is mainly because of a so-called spill as shown in Figure 2. Spill is the material amount difference between final material added and measuring device reading at the time when a command is issued to stop the feed.

An actual feed curve is more or less like the curve in blue shown in Figure 2. As illustrated in Figure 2, due to the spill, the dynamic scale reading differs from final weight at any moment during feed, in particular, the moment of cutoff. Cutoff here means an action when a command is issued to stop the
feed. More complicated is that spill normally results from compound effects. Among those effects, there are mainly five as follows.

- Material in suspension – a portion of the material which has passed through the valve can still be in “free-fall” and has not yet reached the surface of the mix. A spill amount of material in suspension depends a distance between surface of the mix in the receiving vessel (weight scaled based) and its final control element, such as a valve. The distance can vary batch to batch due to the surface height of the mix.

- Deceleration force – the dynamic force or kinetic energy adds to the scale reading until the material flow has stopped. Magnitude of deceleration force is related to the feed speed which can vary feed/batch to feed/batch, and during the feed/batch.

- Scale/Filter lag – During a feed, the scale reading at any moment can “lag” the actual weight on scale when filtering is applied to dampen vibration due to agitators or other process components. Regardless of the type of filtering (mechanical, electrical or digital), the scale weight discrepancy will increase the lag. This kind of lag results from reaction time from the measuring device, and filters configured for the measuring device and data acquisition unit. The reaction and filter time for a given measuring device may be a constant while sampling time for weight or flow data may vary batch to batch, or even within a batch process due to difference in scan rate.

- Command lag – some delays always exist between the time when a cut-off command is determined to issue and the time at which an execution command acts on a final control elements. Command lags can be related to architecture of the control system (controller, final control element, and measuring device), structure of the program logic in the controller, and scan and update rates of all the components associated to the material transfer.

- Valve “let-through” – Valves can not be closed instantaneously. Some material passes through the valve while it is closing. A spill from this effect depends on reaction time and consistency of the final control element, which may vary batch to batch processes.

Therefore, reality is that spill is inevitable and can not be measured in real time in general. In order to do the cutoff at a right time, a spill has to be predicted correctly in advance. However, we may be able to calculate what a spill was about approximately for a past feed, based on some historical data. It is hard to get very accurate data for calculations/predictions. Also, spills usually vary from batch to batch even with the same material. How can we minimize system variations in order for spills to be predictable? What is the information important and collectable for good spill predictions? Good answers to these questions must result from good control system and functionality designs and implementations.

Usually, it would be relatively easier to make a good cutoff with a relatively good accuracy if flow rate is low. However, material transfer at a low flow rate slows down the process, which directly impact on its batch cycle time and productivity. To reduce the impact, multi-speed feeders are used in many applications today. But the multi-speed feed approach cannot run a full speed for the entire course of material transfer, which would still have some negative impact on batch cycle time. Also, using multi-speed feed approach would increase complexity in construction, system engineering, and maintenance.

Therefore, a good control strategy for batch material transfers heavily relies on its spill predictability in order to have fast and accurate feed controls. It is not a trivial task to develop a good practical algorithm/function for good spill prediction and controls.
Functions for batch material transfer controls

In addition to the spill calculation/prediction, there are many more functions either very important or beneficial to have for good practices. For most of functions for batch material transfers, if not all, three categories (Must-have, Should-have and Beneficial) of functions are described below.

Must-have functions

Functions below in this category are basic ones for any good batch material transfers in either manual or automatic systems.

Material transfer type
There are three major types of batch material transfers in industry: Gain-In-weight (GIW) feeder, Loss-In-Weight (LIW) feeder, and flow meter feeder. Function of GIW feeder is a scale-based feed system that adds material to a vessel by detecting the gain of weight of the destination vessel. LIW is a scale-based feed system that adds material to a vessel by detecting the loss of weight from the source vessel. Flow-meter feeder is a feed system that adds material to a vessel by monitoring the volumetric addition of material through the flow-meter instrument. If there is more than one type of feeders in the place, (particularly with scale-based GIW and LIW feed systems), associated feed functions should be built accordingly. It is because different types of feeders require different control functions to handle.

Control target management
As mentioned above, due to a spill, a command to stop the feed must be issued at right time. When is the right time? There must be an algorithm built in to handle when a stop feed command should be issued. A popular way is to setup a fixed bias spill. That is, a stop feed command will be issued when a filtered weight = (weight setpoint – the pre-configured spill), for most GIW feeds, for example. This might be Ok for some process while accuracy requirement and process variation are not high.

Setpoint type
There are mainly two types of setpoint: absolute and additive. Depending on recipe/formula requirement and users’ preference, a setpoint type must be defined before starting a feed. A specific function corresponding to a setpoint type should be built in the controller to calculate a cutoff time correctly. It is not unusual to have both absolute and additive feeds required in a given control system.

Tolerance check
There is no perfect system. Nor is there unlimited accuracy requirement. A function of tolerance/feed error check is necessary for any material transfer control systems.

Dump to empty management
A common problem when emptying a vessel is that the dump process may end prematurely. While the dump appears to be finished, there is still too much material left in the vessel. Obviously the more time it takes to dump, the more completeness it is. But we usually only want to take necessary time but no more for a material transfer. When is the right time for the system to declare the material from its source vessel is completely transferred out. A proper function would have to be built in the control to manage this type of batch material transfer with all required reasonability tests.

Pre-feed condition checks
Before starting a scaled based feed, for example, it is necessary to perform pre-feed condition checks. Check whether the scale is stable, etc.

Post-feed check and report
After a feed is complete, it is important to check the performance of the feed, and store historical data for analysis.
Drain time management After the final control element such as valve and/or pump are deactivated, it would generally require the system to wait for a short period of time (a few seconds in most cases) before this material transfer phase can be considered complete. That waiting time is called drain time. It is the time that the system will wait at the end of the feed for the material to completely drain into or out of the vessel before testing the scale stability and feed tolerances. One of the reasons to have this function is to handle the spill effects mentioned above.

Instrument zero shift management As the process runs, the zero point (empty point) of the vessel will drift due to material buildup, temperature variations at the sensing devices, etc. As the system is used with this function in place, this type of drift can be tracked and automatically compensated for if necessary. If too much drift is detected, the operator can be alerted to take corrective action.

Interface drivers Data to and from measuring devices such as load cells/scale and flow-meters require, in most cases, some interface driver(s). These interface drivers are designed to do some data processing, hand-shaking for data/command transfers between instrument and controller. Using these drivers, data/commands can be formatted in a way that both controllers and field devices can understand each other.

Abnormal situation management No processes can run perfectly all the time. A material transfer process may run short of material; a valve can be stuck; pipelines can be broken; power may be outage; and more and more. How should the system react to these abnormal situations? Can the operator and equipment be protected from abnormal situations? Can the system be recovered back to normal without scratching its whole batch? To minimize losses from abnormal situations, some functions for fault tolerance and emergency handling should be built into the system.

Should-have functions Functions in this category may not be absolutely necessary but should be included in the system for a good practice.

Batch-to-batch spill adaptive algorithm In many cases, spills are different from batch to batch. It could be valve characteristics deviation; process condition changes; material difference; measuring instrument drafting, etc. To adapt these changes, calculated spills should be adjusted accordingly in order to minimize inaccuracy in batch material transfers. That kind of adjustments can be carried out using a so-called adaptive spill algorithm to adapt batch-to-batch spill changes.

Reasonable checks Some conditions should be checked particularly before a batch material transfer. Hold the process and prompt the operator if associated conditions are not met. Conditions can be for human, equipment and process safeties, and product quality, etc. This function can also be designed to include some reasonable checks. For example, if a material transfer is requested and it is less than what can reasonably be added, the transfer should not be executed and the operator should be informed of the situation.

Slow Step Timer This function is to monitor the progress of the material feed and alarms when the material has been feeding for much more time (such as 150%) than the expected feed time as calculated from the material set-point and the average flow rate. The material feed can either be halted or continue if the slow step timer times out.

Command handler A material transfer action usually requires a series of commands to associated field device(s) through controller or/and HMI module(s). In order to execute the command(s) properly in
robust, accurate and traceable way, corresponding functions handshaking, error handling, status monitoring should be programmed in the controller and/or gateway module(s) if any.

**Material transfer handler** During a material transfer, many unexpected things can happen, equipment broken down, material run-out, process condition dramatically changed, power outage, etc. Any one of these abnormal situations could cause a disturbance or series disturbances in a process that could result in plant operations to deviate from their normal operating state. The disturbances may be minimal or catastrophic, and cause production losses, or in series cases, endanger human life. Therefore, some functions such as proper status checks, error handling, fault tolerance, alarm management strategies should be built in place for good batch material transfer controls.

**Weigh/flow digital filtering** When a vessel is executing a function that induces noise into the reading of the weight, such as an agitator, it is necessary to remove the noise by using some digital rate filtering functions. While it is desirable to leave these filters on in most cases, some processes require dynamic control of the filtering. Therefore, if needed, some logic program has to be built to carry out some special filtering functions.

**Built-in diagnostics for material transfer system** Some statistical approaches would be helpful to have in order to assess how a system performs on batch-to-batch material transfers. Is the system consistent, or getting worse, or better in terms of controllability, robustness and accuracy? Having some built-in fault preventive and self-diagnostic function would increase a system transparency and maintainability on its batch material transfer functionality.

**Automatic/system control** Nowadays to increase enterprise competitiveness, large-scale automatic batch control systems become more and more popular. In other words, heavy labor oriented operations on batch material transfers usually can not meet needs in high productivity and efficiency. A basic automatic material transfer control is so-called equipment module (EM) control. Some call EM control as semi-automatic control. On an EM control, the operator can input a desired set of parameters and activate a material transfer process. Then the system decides when to stop the feed without the operator intervention. To increase automation level in batch material transfers, special cares in coordination and arbitration should be taken on all modularity levels, particularly on equipment module and unit.

**Manual/Operator control** Manual control is still very important and beneficial although automatic batch material transfers are increasingly popular. A very basic manual control is for the operator to activate or deactivate final control elements such as valves, pumps.

**Reset on instrument base and system base** In system design, it is perhaps very hard to consider all the possible “paths” that the operator might go in a real operational world. Even with a thorough system design with all possible “paths” clearly defined, the operator may or may not be able to follow the correct path to get out of an abnormal situation. To prevent the operator from getting lost in “forest”, a reset function on either material path/equipment based or system based, or both is necessary. With the reset function, the operator will be able to initialize the system to a known situation.

**Beneficial functions**

Functions in this category may not fit to all the situations, but beneficial to many good practices in batch material transfer controls, as described below.

**Adaptive predictive control target management** Operational conditions for batch material transfers may change during the feed in addition to batch-to-batch variations. A direct impact on a spill amount or
material transfer control usually results from variations in its flow rate. However, a relationship between flow rate and spill are usually not linear, and hard to establish. It is because there other factors such as dynamic force on weighting measurement as mentioned above. Therefore, it is very beneficial to have an appropriate adaptive predictive spill self-adjustment function. This kind of function is particularly important to those material transfer processes of which flow rates and their variations are relatively big with high quality control requirements.

**Fast cut-off approach** In order to carry out good predictable control over batch material transfers, final control elements such as valves or pumps must perform the same from operation to operation\(^2\). This consistency includes both a command execution time and element action/reaction time. A command execution time usually depends on controller’s scan time which can be significant different from batch to batch. Element action time is mostly dependent on its mechanical and electrical structure which can vary but is relatively consistent from batch to batch. In order to reduce variations on command execution time, a command to stop the feed would better directly come from a measuring device if possible. There are two main advantages in doing this way. First, many measuring devices can directly be set up to send an output signal if a measured/delivered amount is equal to or over a target amount. Second, that kind of comparison can be carried out at a relatively fast and consistent rate.

**Low and high flow alarm management** as mentioned above, a spill heavily depends on its flow rate. A batch material transfer will most likely fail if the flow is too high or too low. Therefore, it would be beneficial to have a corresponding alarm management function built for material transfers if a flow rate is beyond its normal range.

**Overlapping feed management** To reduce batch cycle time, overlapping feed technique can be used. This technique allows delivery of a material to the destination tank using the tank’s load cells at the same time several intermediate material are being added to the destination tank from pre-weigh vessels or/and flow meter feeds.

**Instrument cross check** When there is more than one system used to measure process performance, some minor discrepancies are inevitable. These are expected and acceptable. It is beneficial if these systems are automatically used to cross check one another. This allows for an early warning when an instrument, or the process, is starting to malfunction. Furthermore, production down time, miss-formulations and scrap batches can be prevented from happening.

**Estimated time to complete** In many cases, the operator wants to know how long a feed takes to complete. This function is not difficult to build but very beneficial from operational stand point.

**Where to build those functions in a batch control system?**

If having some or all the functions mentioned above can be aligned between operational, process engineering and system control organizations, a decision has to be made on where to build these functions. A quick answer to this question would be in controllers where all the phase, equipment module and control module logic reside. That is a popular solution nowadays.

Most P&G batch control systems have most of these functions built in the controller level for more than 30 years. We realized main advantages of this solution are people/users can see the code for the functions and create/develop and modify them without too much restriction. Disadvantages of this solution become also obvious:

1. These functions occupy a lot of memory space in the controller(s);
2. Users have to maintain the code; and
(3) It is a platform dependent solution since controllers are platform dependent.

As fast development and advance of memory chips and different communication protocols, it opens a door for these functions to be located to different “homes” like down to field devices. Field devices can be scales or flow meters where material transfers are measured. However, building these functions in field devices requires a strong commitment from associated vendors, which may or may not be easy to obtain. On the contrary, having these functions built in industrial controllers can be done at users’ wish.

It seems that all the disadvantages and advantages mentioned above will disappear by building some of these functions to field devices. Another advantage to have the most functions in field devices, some variations such as logic scan rate and command paths can be minimized. Since building and maintaining the code for the functions requires good technical skills to be effective, it may or may not cost-effective to keep all skills “in house” for a long term. Therefore, if people/users do not want to know how the functions are coded and do not want to maintain the code for modification, troubleshooting and upgrades, having the most functions built in field devices can be a good solution.

P&G recently have upgraded several manufacturing batch systems with some field devices containing most functions for material transfers. Experience with this new solution is very positive. Not only do functions in the field devices well meeting all the speed and accuracy requirements, but also the size and complexity of the program in the controller have significantly been reduced.

**Summary**

Speed and accuracy are two contradictory goals for batch material transfers in many cases. Many factors can impact on a spill amount on a batch material transfer, which are not constants and not easy to measure and predict in order to make accurate feed with a full speed of material transfer. Therefore, it is not a trivial task to develop good control strategies providing with a good practical adaptive and predictive spill algorithm.

Batch material transfer control seems an easy task to carry out. But reality is that many functions are necessary and/or important and/or beneficial to have in system to accomplish just batch material transfer controls. Some of these functions may or may not be obvious. But in a good practice for batch material transfers, most of them can be essential, particularly for those processes and systems with a lot of variations. These functions usually require system integrators, control engineers and technicians to have good knowledge and skills to build and maintain.

Most functions for batch material transfer controls can be built in either industrial controllers or field devices. Building some of these functions in the controllers can be managed by the users while in field devices it requires commitment and support from vendors for field devices. Either way has its advantages and disadvantages in engineering, maintenance, and supportability.

**Reference**
