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Coriolis Mass Flow Meters in Batching Applications – The Good, the Bad and the Ugly

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ABSTRACT

Coriolis mass flowmeters are the most accurate of the industrial flow measurement technologies, and the only flowmeter that claims to measure true liquid mass flow directly. They are widely used in both continuous and batch processes. They are often used in batch processes as a less-expensive alternative to load cell weighing systems (the good). As with any other flow metering technology, Coriolis has its own application "watch outs," including a requirement that the flowmeter be totally and completely full of non-aerated liquid during the measurement.

Coriolis mass flowmeters have dynamic response characteristics that require careful investigation for applications requiring short batches, such as are typical in bottle filling applications. In addition, the accuracy of Coriolis mass flowmeters is difficult to verify, compared to the relative ease of verification of weighing systems (the bad). Insuring that these application requirements are met can be an extremely challenging task, often resulting in complex piping system requirements (the ugly).

This paper will discuss in detail the good, bad, and ugly aspects of using Coriolis mass flowmeters in batching applications. In addition, an end-users perspective on how manufacturers can improve their Coriolis mass flowmeters to perform better in batching applications will be presented.

Coriolis mass flowmeters are the most accurate of the industrial flow measurement technologies, and the only flowmeter that claims to measure true liquid mass flow directly. They are widely used in both continuous and batch processes. They are often used in batching processes as a less-expensive alternative to load cell weighing systems.[1] As with any other flow metering technology, Coriolis has its own application "watch outs," including a requirement that the flowmeter be totally and completely full of non-aerated liquid during the measurement.[2] A tabulation of some of the advantages and disadvantages of Coriolis mass flow meters in batching applications is given in Table 1.

TABLE 1: ADVANTAGES AND DISADVANTAGES OF CORIOLIS MASS FLOWMETERS IN BATCH APPLICATIONS

Advantages	**Disadvantages**
• Cost is generally lower than a load cell system • Easier to retrofit into existing applications than load cell systems • Measures pounds mass (vs. other flowmeters which are volumetric devices) • Allows for simultaneous multiple feeds • Precise measurement over a broad range • Immune to the effects of tank agitation	• Device is difficult to calibrate compared to a load cell system • Meter must be totally full of liquid while metering, which often requires complex piping arrangements • Coriolis meters do not deal very well with aerated fluids • Cannot meter dry materials • Have dynamic response limitations, cannot measure extremely short batches accurately • Short batches with pumps that cause large flow pulsations (i.e. positive displacement lobe, diaphragm and piston pumps) are not accurately measured

TABLE 2: ADVANTAGES AND DISADVANTAGES OF LOAD CELL WEIGHING SYSTEMS IN BATCH APPLICATIONS

Advantages	Disadvantages
• Works with dry materials (which flowmeters cannot handle) • Relatively straightforward (but time consuming) to calibrate accurately • Conceptually easy to understand how load cell weighing systems operate	• Measure pounds force (not pounds mass), so buoyancy effect (difference in density of calibration weights vs. density of fluid measured) must be considered for highest accuracy[3] • Must consider fluid agitation, splashing, vibration from various sources, etc. • Dribble feed often used where high accuracy and high fill time is desired. Dribble feed systems are expensive to purchase and difficult to maintain • Calibration can drift over time due to friction and mechanical binding • Can only meter one fluid at a time into a load cell tank

Background on Coriolis Sensor Technology

Note: This paper is not intended to be a tutorial on the basic operation, selection, installation and troubleshooting of Coriolis mass flow meters. For an overview of these basic items the reader is directed to the excellent literature that the Coriolis mass flow meters have made available on these subjects.

To be able to properly apply Coriolis mass flowmeters in batch applications, it is important to understand the basic operational concept of the Coriolis meter. It is also important to recognize what the meter *is not.* Unlike that presented in much of the literature, a Coriolis mass flowmeter *does not* directly measure mass flow – there is no mass flow sensor internal to a Coriolis meter. Likewise a Coriolis meter does not measure Coriolis forces – there is no Coriolis force sensor internal to the meter. Unfortunately, the operation of a Coriolis mass flowmeter is not easy to explain. A simplified way of thinking about the operation of a Coriolis mass flowmeter follows. Fluid flow through the meter generates Coriolis forces that are generally proportional to the mass flow rate, at least for single-phase fluids. (Saturated steam, aerated liquids, slug flow and other examples of two-phase flow are generally problematic for Coriolis meters). These Coriolis forces generate a movement within the meter that is generally proportional to the Coriolis forces – vibration of a tube by tube twisting induced by the Coriolis forces, for example (see Figure 1). This movement is measured by some type of sensor, such as an electromagnetic detector. The signal from these electromagnetic detectors is then processed by sophisticated electronics, which have their own impact on signal accuracy and signal speed of response and latency. There are many references available to those desiring a more theoretical description.[4]

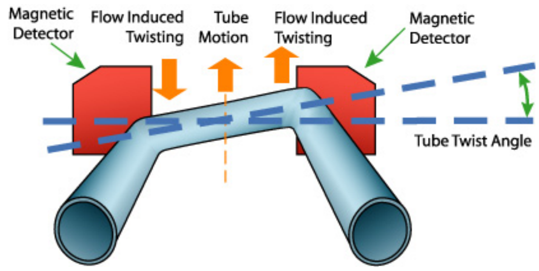

Figure 1. Operational Principal of a Coriolis Mass Flowmeter

The point of this is to realize that Coriolis mass flowmeters *do not* directly measure mass flow, any more than strain gauge load cells directly measure weight. By understanding the basics of the measurement principals, what the technology can and cannot do, one is apt to be more successful in applying the technology.

Later in this article I will address some of the watch outs associated with Coriolis mass flow meters in more detail.

Coriolis – A Less Expensive, More Flexible, and Complimentary Option to Load Cell Weigh Tanks

Coriolis mass flow meters generally are less expensive than load cell weigh tanks, especially when considered from a total installed cost perspective. Load cell weigh tanks are complex systems requiring in-depth knowledge in load cell system electronics, piping systems, and structural/civil engineering disciplines. All of this means fairly high engineering costs. In addition, construction/installation costs for load cell systems are high. The structural/civil requirements for load cell systems are stringent.[5] The structural steel required to properly support a load cell weigh tank can be substantial, and on retrofit jobs it can be extremely challenging just to get the required strength designed into the structure.

Coriolis meters are somewhat expensive themselves, and do require some level of care in piping. Coriolis meters generally do not require any civil/structural considerations, and overall the installed cost for Coriolis meters is substantially lower than that for weigh tanks.

In addition to the cost advantage, Coriolis meters offer several other advantages over weigh tanks. Coriolis meters give us the ability to handle multiple feeds at the same time, and give us the ability to handle very low batch additions that the load cell tank itself cannot accurately measure.

Coriolis meters give us the ability to handle multiple feeds at the same time, something that weigh tanks cannot do by themselves. For example, a weigh tank may be weighing the direct addition of a dry material via a screw feeder. By adding flow meters to the system, the system can concurrently measure the addition of multiple liquid feed streams. The concurrent measurement of the dry material is kept track of by subtracting the totals of the liquid feeds from the change in the weigh tank reading, resulting in a measurement of the dry material addition itself.

Coriolis meters are complimentary to weigh tanks for accurately adding small weighments. Lets consider the following example. We have a 1500 kg weigh tank, to which 900 kg of product is added. During the addition of this product we also want to add 10 grams of a highly concentrated perfume. Because of the resolution of the load cell system, it would be impossible to accurately weigh the 10 grams of perfume. Enter the complimentary ability of the Coriolis mass flow meter, and we can accurately and concurrently add the required perfume.

Coriolis Meter Application Considerations

To insure success, certain application considerations must be taken into account for Coriolis mass flow meters. These considerations include the requirement that the tube be completely full of liquid, that the liquid be non-aerated, and that the batch time be commensurate with the capabilities of the meter.

Completely Full of Liquid

It is a well-known fact that traditional Coriolis mass flow meters must be completely and totally full of fluid while measuring, or significant errors will occur.[2] Achieving this requirement in industrial piping installations can be challenging, especially in systems where product line cleanouts between batches result in empty pipelines. At startup of systems that are subject to beginning with empty pipes, sometimes elaborate systems are installed to insure that the Coriolis meters are completely filled before they begin their totalization. In other cases, the meter inaccuracy during its empty/partially full period is accepted, or sometimes not even recognized. Recently at least two of the Coriolis meter manufacturers have introduced meters that claim to be able to accurately operate in batching situations when starting from empty – and you can bet that the other meter manufacturers have development programs in this area.

Figure 2 below gives an example of the type of complex piping system that is sometimes required for accurate batching systems. To insure accuracy, the automated cutoff valve (E) and the mass flow meter must be located physically as close to the receiving vessel as practical. Long lengths of piping between the cutoff valve and the vessel can result in a significant quantity of liquid dribbling out of the pipe over time, a problem that will negatively affect batch accuracy and batch speed. Coriolis mass flow meters have the ability to measure flow in both the forward and reverse directions – therefore any reverse flow through the meter that occurs after the closing of the automated cutoff valve (E) must be minimized since it will negatively impact system accuracy.

Often *goosenecks* are installed at the tank to insure quick and consistent drainage of liquid from the pipe to the tank (see Figure 3).

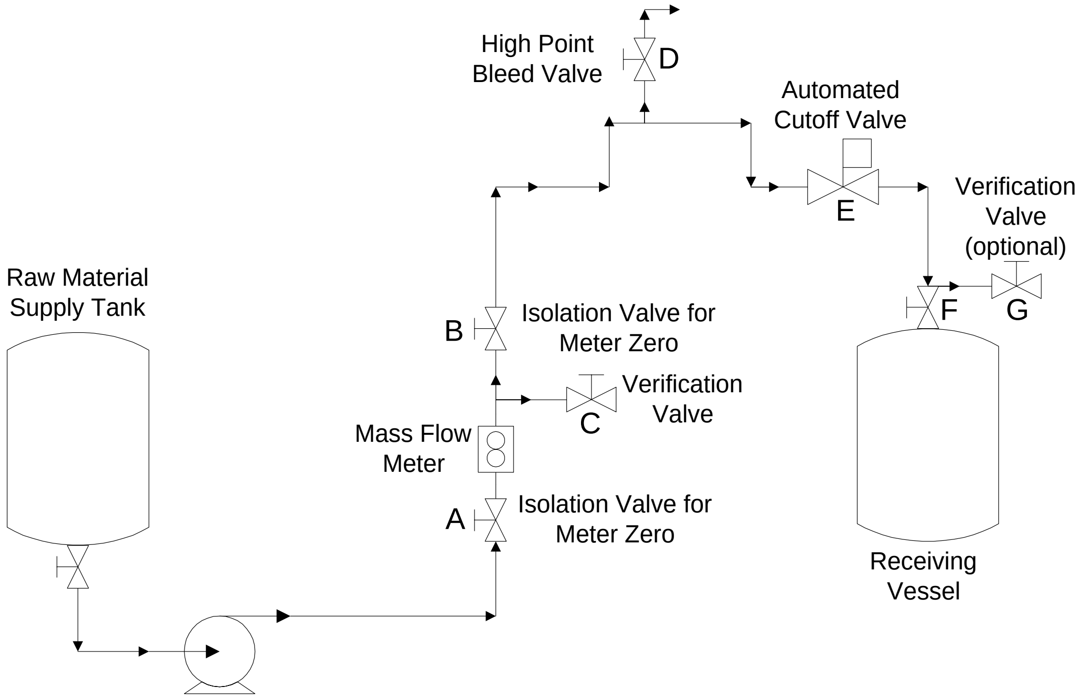

Figure 2 – Coriolis Meter Typical Piping

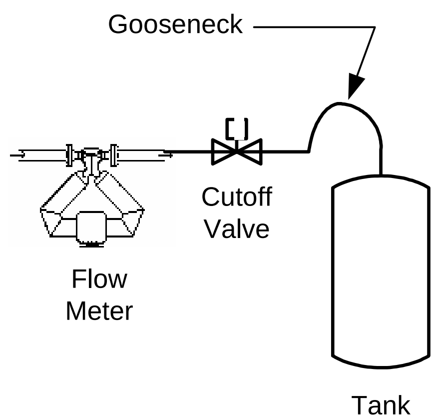

Figure 3 - Gooseneck

Aerated Liquids / Two Phase Flows

It is fairly well known that traditional Coriolis mass flow meters cannot accurately measure two-phase *slug flow*.[2] Slug flow is the condition where a slug of liquid is followed by a slug of gas, generally in rapid succession – see Figure 4.

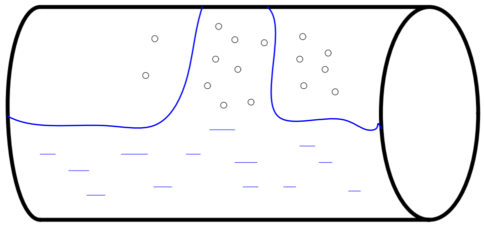

Figure 4 – Slug Flow

What is less commonly understood is that Coriolis meters have difficulties dealing with aerated liquids – see Figure 5.

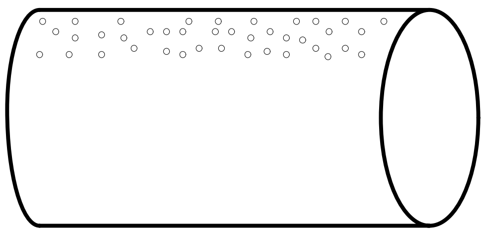

Figure 5 – Aerated Liquid Flow

Errors as large as 58% have been reported, and in one test 2 to 4% aeration caused meters from eight manufacturers to respond well outside of their stated specifications.[6] At least two of the Coriolis meter manufacturers have products available that they claim have addressed this issue.

Meter Latency, Response Time, and Batch Time Considerations

Latency will be simply defined here as the time it takes for the flow meter output to start to respond to a change in flow. Response time indicates how fast a device can respond to periodically changing flow rates. (Technically there is a lot more to it, but we won't get into those details here). It is often believed that Coriolis mass flow meters are fast-responding devices, but research shows otherwise.[7,8,9,10] Latency and response time are critical parameters for flow meters used in batching applications, especially in batches of short durations such as bottle filling. If a flow meter is used to fill a bottle, and that bottle is filled in one second, to be accurate that flow meter better have a very low latency and fast response time. It is generally regarded in industry that the very best currently available Coriolis mass flow meters have difficulties dealing with batch times shorter than ½ second, and many meters have difficulty with batches as long as 20 seconds. Our experience indicates that batch times as short is 1 or 2 seconds can be accomplished, depending on the accuracy requirements, but that for any batch time of 10 seconds or less trial runs are recommended to insure that the application requirements can be met.

The topic of Coriolis meter response time is significant enough that the Universities of Oxford and Brunel (both in England) have a joint grant program "to push Coriolis metering technology to its dynamic limit." [9] Several US patents have been issued for a Coriolis meter that is claimed to operate faster than conventional technology.[11,12,13]

One area of interest for the dynamic response of Coriolis meters is in their use with pulsating positive displacement pumps. Positive displacement pumps are traditionally used for pumping the more viscous liquids that are often metered with Coriolis mass flow meters. Many types of positive displacement pumps create substantial flow pulsations – specifically lobe, diaphragm and piston pumps.[14,15] Some work has been published on the subject.[16,17,18,19] In industry, larger pumps with slower but more violent pulsations have proven challenging for Coriolis mass flow meters to accurately measure, especially when used in short batches. Smaller pumps and faster pumps find their flow pulsations to be effectively averaged by the relatively slow dynamic response of the Coriolis meters. Patents describe times where, because of this problem, Coriolis mass flow meters are used as density measuring devices and pump rotation is used as a volumetric measurement.[20,21]

Difficulty of Calibrating Mass Flowmeters

Conceptually, calibrating a strain gauge load cell weigh tank is straightforward. One places traceable test weights on the vessel and records the reading on the scale display. Weights may be put on and taken off to generate a hysteresis curve for the system. Problems with the installation, such as friction, binding, out of plumb, insufficient support structure, etc. are resolved until the system performs to the requirements. Anyone who has ever calibrated a 3000 pound load cell system by carrying sixty 50 pound test weights and placing them multiple times on the vessel understands that although straightforward conceptually, in practice it requires a lot of physical effort.

Calibrating Coriolis mass flowmeters for *flow rate* measurements is a very difficult exercise, specifically because there is no traceable standard for flow rate. You cannot purchase a "pound per hour" anywhere. In general, such calibration of the *flow rate* for Coriolis mass flowmeters is best left to the manufacturer, who have the sophisticated lab systems required to do this calibration. Fortunately, in batching systems *flow rate* is not the important variable, rather total *quantity of flow* is the variable of interest. The most typical method of calibrating Coriolis mass flowmeters for use in batching systems involves batching a fluid over a given length of time into an accurate weigh tank, and then comparing the reading of the weigh scale to that from the totalizer on the Coriolis meter. Various issues arise with this method.[22,23] First, time must be accurately measured, and hand-held stopwatches are not sufficient for the task. Dribble after valve closure, valve speed of response, valve consistency, weigh scale accuracy and many other variables enter into this equation.

Desired Improvements to Coriolis Mass Flow Meters

Coriolis mass flow meters are a wonderful technology advancement over earlier flow meters. Their high accuracy, wide rangeability, and mass-flow measurement qualities make them the “meter of choice” for many industrial applications. Coriolis is still a new and developing technology, and as such, has areas for improvement.

Below is a list of improvements that end-users wish to see in future Coriolis mass flow meters:

- **Ability to “batch from empty”**
    - Since many batch operations require cleanouts between runs, batching from empty (the condition where the pipelines and system are empty or at least less than totally full of product at the beginning of the batch) is an important area of improvement for Coriolis.
- **Ability to accurately measure aerated liquids and two-phase flow**
    - Coriolis meters are widely used to meter viscous fluids – fluids which tend to keep air entrained in them. Improving Coriolis meters so that they can handle aerated fluids will greatly enhance the industrial fluid applications that these meters can be used in, and minimize end-user scrapped batches due to flow meter errors caused by entrained air.
- **Faster response time, less latency – ability to do very short batches of ½ second or less, even with pumps with pulsating flows (lobe, diaphragm and piston pumps)**
    - Bottle filling machines are moving to mass flow control using Coriolis meters – and away from volumetric fill using magnetic flow meters or pistons. Coriolis offers many advantages in such applications – wide rangeability to handle bottles of varying sizes, high accuracy, mass flow measurement ability. End-users desire ever-faster bottle filling times, and the desire to accurately fill a bottle with a fluid in ½ second or less – accurately with a Coriolis mass flow meter – is a desire of end users.
    - Pumps that create pulsate flow – for example, positive displacement lobe pumps – generate high-speed flow variations that have proven difficult for larger Coriolis meters to accurately meter, especially in short batching applications. Development of faster response time Coriolis meters will help end-users to meet this currently unmet need.
- **Meters that are easier to calibrate / verify accuracy**
    - Load cell weighing systems are conceptually easy to calibrate – just use traceable calibration weights. Calibration / verification of Coriolis meters is a little more difficult. For continuous flow applications, one issue is that a “pound per hour” is not a standard that can be purchased. For continuous and batch applications, the fluid being metered *does* have an impact on the calibration of Coriolis meters. So, especially with hazardous fluids, simply calibrating the meter by running water into a scale tank will not adequately calibrate the meter. Simple methods for the end-user to verify that the meter’s performance is per its specifications for the actual fluid being metered is important. This verification of metered accuracy is especially important for industries where verification of meter accuracy is required and regulated by a governmental agency such as the Food and Drug Administration (FDA) in the United States. ISO 9000 and other international standards similarly require verification of flow meter accuracy – something that is quite difficult to accomplish with today’s Coriolis meters.

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