[Considering Hysteresis in Mass Flow Meter Selection](http://www.alicat.com/alicat-blog/accuracy-and-repeatability/considering-hysteresis-mass-flow-meter-selection/%22%20%5Co%20%22Considering%20Hysteresis%20in%20Mass%20Flow%20Meter%20Selection)

Alicat’s mass flow meters and mass flow controllers are renowned for their speed and accuracy, but how important is our speed to your accuracy? In this article, we look at hysteresis and its effects on common types of mass flow instruments.

Hysteresis reduces your measurement accuracy by causing your meter to respond differently to repeated identical inputs. What is hysteresis? In simplified terms, hysteresis is the tendency of a system to react differently to the same input based on its history of past inputs. For example, most of us have eaten a chocolate bar at room temperature. Yum! But anyone who has used chocolate in cooking also knows that once chocolate has been heated and melted into its liquid state, it can remain a liquid as it cools back down to room temperature. The same input (temperature) yields different results (solid vs liquid) based on the chocolate’s history (heating or cooling). This is the hysteresis effect, and it can throw a big wrench into getting repeatable results.

Hysteresis in Coriolis Mass Flow Meters

Now that we’ve defined hysteresis, let’s look at how different kinds of mass flow measurement technologies exhibit hysteresis. Coriolis flow meters operate by vibrating curved tubing through which the gas flows. Increasing the flow rate adds mass to the system and induces second-order oscillations that are directly correlated to the density and mass of the fluid flowing through the tubing, which is called the Coriolis effect. Just as increasing mass via a faster flow rate increases these oscillations, reducing the flow decreases the oscillations. However, moving quickly from one flow rate to a much lower flow rate results in hysteresis as the second-order oscillations require time to dampen out until they correspond to the new lower level of mass flow.

You can visualize the effect of hysteresis on Coriolis meters by setting a clock pendulum in motion. Now, tap the pendulum from a perpendicular direction. You’ve induced a second-order motion to the pendulum’s swing, and even though you did this for only a moment, it will take some time before the effects of that additional motion dissipate. If you tap the pendulum a second time before it has settled down, you will again induce sideways motion, but it will be somewhat different than your first tap.

Hysteresis in Thermal Mass Flow Meters

Thermal mass flow meters provide indirect measurements of mass flow based on the thermal properties of the gas stream. Rather than detecting individual molecules of matter that pass by, they detect the effects of the heat on the passing matter, a principle called thermal dispersion. There are several types of thermal meters, but typically a small portion of the gas flow is diverted through a heated capillary tube that is equipped with multiple temperature sensors. As flow rate increases, the molecules of gas are heated by the tube and then carry that heat further down the tube until their temperatures return to their previously unheated state. Higher flow rates move the heat plume further down the tube, and lower rates shift the plume only marginally. How much heat is carried down the tube also depends on the thermal properties of the gas molecules, their concentration (pressure) and their ambient temperature before undergoing heating. A high flow rate that moves the heat plume further down the tube will require some settling time when the flow rate has dropped. This is because the high thermal conductance of the tiny capillary tube necessary to sense low flow rates also makes it very good at retaining that elevated temperature after the flow rate has dropped. Some thermal flow meters employ averaging or predictive algorithms to overcome this hysteresis, which is a good solution if you only require an estimated flow rate.

The hysteresis effect on thermal mass flow meters is easy to visualize at your home electric stovetop. Before you turn on the electric burner, touch it with your hand briefly, and then take it away. Now, turn on the burner dial to high for one second, and then turn it off right away. Put your hand over the burner; does it feel hotter than it did initially? The heat you feel is residual heat that does not accurately reflect the current state of no voltage going into the burner. If you again turn the burner dial to high for one more second before the burner has fully cooled, now the temperature of the burner in its no voltage state is even higher. When adding voltage, heat increases quickly, but when removing voltage, heat dissipates much less quickly; this is the hysteresis effect.

Hysteresis in Pressure-Based Mass Flow Meters

There are many kinds of pressure-based flow meters, but they all in some way measure flow in accordance with Bernouli’s principle, which states that pressure within a moving fluid decreases. In fact, it is pressure differentials that induce flow in the first place, so this kind of flow measurement is closest to the source. A differential pressure-based flow meter simply measures the pressure differential that is generating the flow in the first place. Like thermal flow meters, pressure-based meters also do not directly measure individual molecules of gas; mass flow measurements are  calculated from the recorded differential pressures using non-ideal gas laws.

Alicat’s differential pressure sensors employ membranes that are deflected in one direction or the other based on the direction of flow. This feature marks a critical difference among the flow measurement technologies. If you quickly reverse flow direction in a thermal flow meter, you could get yourself into a situation in which both the downstream and upstream sides of the capillary tube have been heated to some degree. Likewise, reversing direction in a Coriolis flow meter does not cancel out the previous oscillations but instead adds a new direction to them. Both of these situations suffer from hysteresis. In contrast, a membrane cannot at the same time be deflected forward and backwards, so switching flow direction occurs without hysteresis. However, the membrane can oscillate forward and back as the pressure differential changes, and this is what gives the Alicat its 5 millisecond speed of response.

You can visualize the limited hysteresis of a membrane-type pressure sensor by hitting a drum. Harder hits (more pressure) deflect the drum’s membrane further, compressing a bigger mass of air against the second membrane, which results in the sound you hear. The taut membrane returns quickly to an undeflected state, but it does require a very small amount of time to do so, which is its hysteresis. The tightness of the membrane determines the degree of this hysteresis. Loose membranes respond more slowly and take longer to stop vibrating. Properly tightened membranes dampen very quickly; in the case of a drum, it can be impossible to hit a second time before the hysteresis effects of the first hit have dissipated.

Likewise, an Alicat’s fast measurement speed and minimal hysteresis directly results in improved accuracy for every mass flow measurement. Low hysteresis means that you can be confident that your current measurement is not artificially building upon the residual effects of your last one, even if that one was just 10 ms ago. This quality also makes an Alicat highly adept at measuring transient phenomena, like the brief bursts of pneumatic actuators at oil and gas wells or attitude adjustment nozzles in sounding rockets.