A Comparison of Gas Mass Flow Controller Measurement Technology

Mass Flow Controllers are devices that measure and control the flow of gas by utilizing a measurement technique, an on-board PID control and an integrated or close-coupled control valve. Most commonly they are used in small bore instrumentation tubing systems and for the purposes of this article they are considered to be in-line with a maximum of 2" line size. The measurement techniques can be sub-divided into four main groups; Thermal By-Pass, Laminar Flow Differential Pressure sensors, Through-Flow Constant Temperature Anemometry, and MEMS/CMOS sensors commonly known as "chip-flow" sensors.

Thermal by-pass instruments are, by far, the most common across the world, following their introduction into the Semiconductor industry decades ago. Their wide adoption is largely based in their capacity for wetted parts in 316L stainless steel, with high end elastomers and/or metal to metal seals. They are capable of measuring relatively low flow rates at hundredths of a millilitre per minute all the way through to just over 8000 litres per minute—albeit across many increasing body sizes. They are also well suited to high pressure applications with 700 bar being possible, although in reality the majority of instruments are subjected to no more than 20 bar. They do, however, have several challenges. Commonly, thermal by-pass instruments are calibrated using air or N2, with correction factors being applied when controlling other gases. These correction factors add measurement uncertainty in addition to the stated calibration errors. For many gases, the physical properties relevant to the thermal flow measurement process change substantially with pressure and temperature. These changes often invalidate the 'K-Factor' approach for switching calibrations between gasses. Real gas calibration does circumvent these problems, however there is both a commercial impact—especially for the more exotic gases—and a safety impact in terms of corrosive or toxic gases. Other challenges can be seen with their general usage: they tend to only offer 50:1 turndown on measured range, are relatively slow with settling times of between one and two seconds, and can be sensitive to installed orientation – especially with low molecular weight gases such as Hydrogen and Helium. Lastly, due to their construction and measuring technique they do take quite some time to reach thermal equilibrium with "warm up" times of 30 minutes being common.

Laminar Flow Differential Pressure mass flow controllers utilize the basic laws of physics (*i.e.,* Poiseuilles' Equation involving temperature, pressure and viscosity/compressibility of gases) and, by differential pressure, provide the user with a mass flow measurement. In addition—and directly related to the sensor technique—measurement of volumetric flow, pressure and temperature is also provided. Furthermore, a capability of their on-board electronics is that the user can change the control parameter from mass flow to volumetric flow to pressure control and back again all at the press of a button. The relevant gas properties for this measurement technique, viscosity and compressibility, may be stored in the device as functions of the measured pressure and temperature parameters. The same laws of physics eradicate the need for conversion factors so there are no uncertainty additions over and above the calibration standards. Other strengths include control settling times of between 50 and 100 milliseconds, a standard turn-down of 200:1 on the measured range, attitude insensitivity, negligible pressure loss and virtually immediate warm up. Low flow rate measurement is significantly better than with by-pass thermals with thousandths of a millilitre per minute being measurable. As above, however, Laminar Flow Element mass flow controllers do have their limitations. Flow control above 20 bar requires special configurations and use with some of the more extremely aggressive gases is not recommended.

Through-flow Constant Temperature Anemometry brings us back to thermal techniques. This sensor is based upon two probes being inserted into the straight flow path within the base-block of the instrument. The first probe is a variable heater, the second probe acts as a temperature sensor with the aim being to always maintain the same differential temperature across the two. As flow increases, more power is required by the heater to maintain this constant ΔT and it is this change in power requirement that is correlated back to mass flow. Again, materials of construction are a strength with 316 stainless steel being possible throughout and pressure loss is generally very good. Pressure rating, at 30 bar for stainless versions, offers a good median between by-pass thermals at the top and chip-flow sensors being capable of withstanding only the lowest pressures. As a result of the open flow channel being somewhat less controlled in terms of flow regime, the best calibration accuracies tend to be 1.5-2% and the lowest flow rate capability is relatively high. To this the effects of Conversion Factor Error should be added as these instruments are also commonly calibrated on air or N2, even when used on other gases. Other challenges are consistent with thermal techniques; only 50:1 turndown on controlled range, slow settling times at two seconds and a 30 minute “warm up” time to reach stated calibrated accuracy.

MEMS and CMOS “chip-flow’ are also thermal devices although they operate by averaging the temperature change, induced by a constant power “heater”, across the whole of the chip. The size of the sensor and the miniaturization of the control package defines their greatest strength – they can be very small in size. Similarly, and also linked to their design and construction, their power consumption is also very low. The sensor itself has fast response although it is the application of the various control packages available from different manufacturers that defines the control response. Some manufacturers offer 50 ms control response. The concept of Conversion Factor Error is not applicable to these sensors as they need to be calibrated on the actual gas. This potential short-coming is often minimised by offering multiple calibrations – up to a maximum of 10 – as standard. Flow rate capability is primarily related to the physical size of the instrument with miniature versions being limited to a maximum of 20 LPM. Larger variations are available but these tend to be limited to the mid-hundreds of litres per minute. The design and materials of construction limit their use to dry, non-corrosive gases at pressures no more than 10 Bar.

All of these measuring techniques offer benefits unique to themselves yet, each have limits to their use. Their application, or perhaps more accurately their selection, within the great many opportunities available across the flow control market depends upon the correct identification and understanding of the process conditions, the effect of such a device within the whole system and the control response characteristics for both current and possible future requirements.

Alicat Scientific is a manufacturer of both Laminar Flow Element (Differential Pressure) and “Chip-Flow” Mass Flow Controllers. Their LFE/DP range offers :
• Four instruments in one – mass flow, volumetric flow, pressure and temperature • User selectable control mode to control on either flow or pressure • Multi-gas calibration: 98-130 gases preloaded, plus COMPOSER™ gas composition firmware • No conversion factors – accuracy

statement remains true for each gas species or gas mix • Bi-directional flow measurement and control capability • User selectable engineering units and standard temperature conditions • 50- 100-ms speed of control response • Numerous valve designs enhanced by customization service for orifice size and configuration • User accessible PID valve tuning to optimize in-situ speed of response and stability • No warm-up required: ready to measure in one second • Stand-alone unit: use with or without a computer or PLC • All flow data visible on one screen (flow, pressure, temperature) • 200:1 linear turndown • Flow measurement capability from 0.0025 mln/min through to 5000 Ln/min.

The Alicat “Chip-Flow” range offers :
• Designed for stress free integration into OEM products in an economical package • Six pre-loaded gases or He or H2 • Very small footprint • 50 to 100 ms speed of control response • No warm-up required: ready to measure in 70-ms • 200:1 linear turndown (100:1 turndown on 20 ln/m models) • Flow measurement capability from 1 mln/min through to 20 Ln/min.

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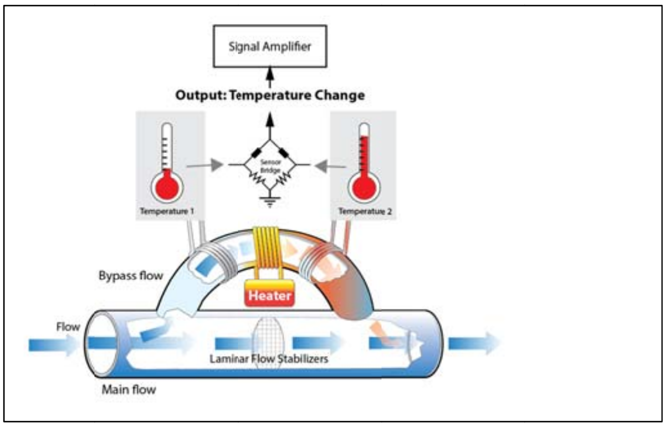
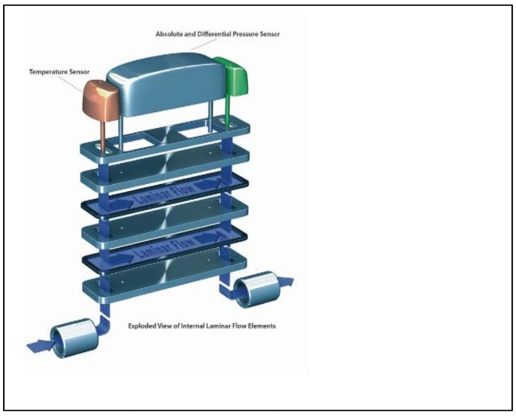
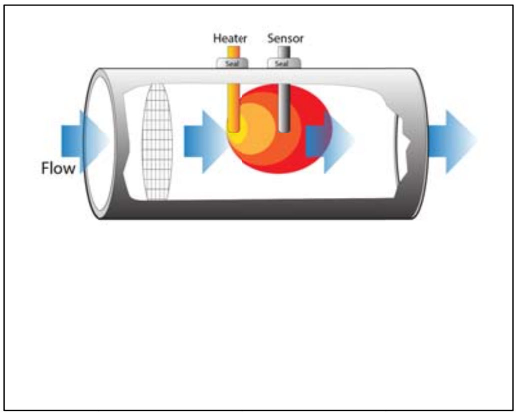


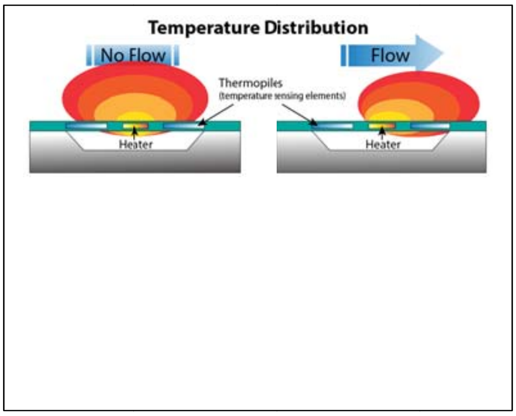
Thermal By-Pass Sensor



Laminar Flow Element Sensor



Through-Flow CTA Sensor



“Chip-Flow” Sensor