Advances in Thermal Dispersion Mass Flow Meter Accuracy

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Advances in Thermal Sensing Designs

Thermal flow measuring technology has come a long way since the introduction of thermocouple technology and early hot wire anemometers. Thermal technologies depend on heat transfer and traditionally operate on differential temperature measurements between two temperature sensitive materials to generate a signal directly proportional to the temperature differential and mass flow rate. Over the years, Thermal type flow sensors have been utilized across a very wide spectrum of applications and feature an assortment of performance limits. Modern Thermal flow sensor designs have greatly evolved from laboratory devices to rugged process instruments with each new generation representing a breakthrough in sensing performance.

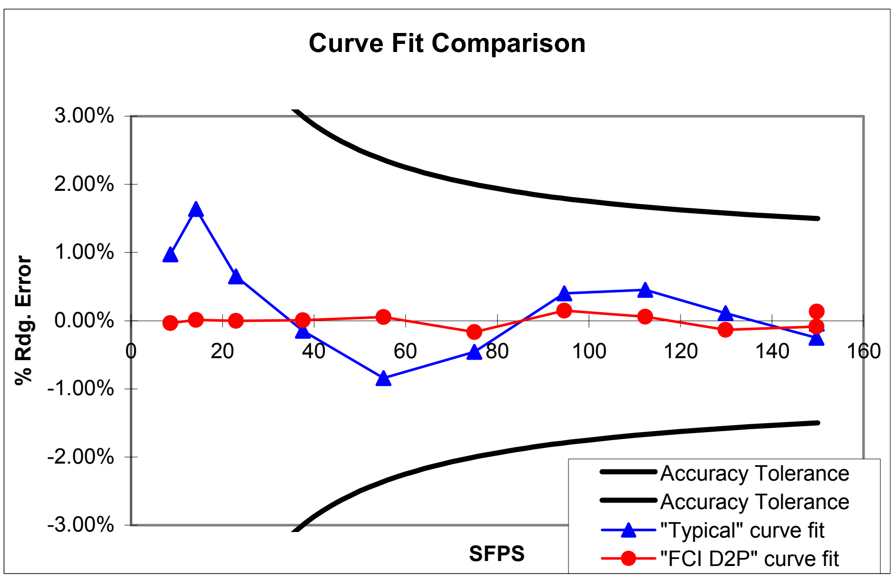
Early Thermal designers' experienced many challenges associated with maintaining manufacturing tolerances, temperature tracking, and meeting industrial packaging demands. That led designers to adopt the use of more robust and more consistently manufactured (RTD's) Resistance Temperature Detectors. RTD-based flow sensors were quickly categorized and associated with earlier delta temperature devices and became part of the Thermal flow sensor design family. As RTD's improved, manufacturers migrated toward precision platinum wound, low mass designs. Over time, production techniques evolved to enable closer tolerances, which made matching two RTD's a more tightly controlled process.

As most modern Thermal designs operate on a differential between RTD's, it is critical that the RTD construction be consistent. Early on, FCI and others recognized this need and then FCI developed the first Equal Mass sensor configuration. This sensor design ensured that the sensor element would consistently track process changes at identical rates and magnitudes. The Equal Mass design was a critical breakthrough that greatly broadened the utility of Thermal sensing technology and made it applicable to a wide range of process applications.

Incrementally, performance continued to improve as manufacturing techniques, potting methodologies, heat path aging and materials optimization became available. Today, companies such as FCI and others have adopted state-of-the-art RTD manufacturing techniques that feature lithography etched chip RTD's, which have virtually eliminated production tolerances between RTDs and made RTD trimming a simple and reproducible step. The result is a much higher pedigree RTD that is ideal for matching and available at dramatically lower costs. This achievement directly resulted in driving thermal technology towards higher performance and lower costs.

Microprocessors Drive Performance Improvements

While Thermal sensing technologies have greatly evolved in terms of consistency and stability, there have been equally important breakthroughs in signal processing and firmware. FCI has developed improvements in calibration data collection and signal processing that have led to step change performance improvements with advanced curve fit algorithms. The figure below is representative of curve fit breakthroughs pioneered by FCI to drive instrument performance and eliminate uncertainty. The graph in Figure 1 represents traditional product limitations as represented by conventional error tolerance bandwidth. It compares the performance improvements associated with the introduction of FCI's D2P curve fit capabilities, which are now being utilized in current generation FCI Thermal mass flow meters. Error and uncertainty reduction have undergone nearly an order of magnitude improvement in recent years, which has enabled calibrations at 0.5% of reading and below across 100:1 turndowns.



Stand SFPS	Typical Calculated SFPS	Typical Calculated % error	FCI D2P Calculated SFPS	FCI D2P Calculated % error
8.618	8.7017	0.97%	8.615	-0.03%
14.18	14.4123	1.64%	14.1814	0.01%
22.96	23.1091	0.65%	22.9598	0.00%
37.57	37.5147	-0.15%	37.5735	0.01%
55.14	54.6758	-0.84%	55.1691	0.05%
75.03	74.6855	-0.46%	74.9039	-0.17%
94.67	95.0481	0.40%	94.8078	0.15%
112.3	112.8075	0.45%	112.3669	0.06%
129.9	130.0461	0.11%	129.7253	-0.13%
149.7	149.3245	-0.25%	149.5682	-0.09%
149.8	149.7361	-0.04%	149.997	0.13%

Figure 1. Performance improvements associated with the introduction of FCI's D2P curve fit capabilities

Calibration Methodologies & NIST Traceable Facilities Close The Gap

The advances in sensing and signal processing necessitated improvements in calibration routines and methodologies. In order to bring the pedigree of Thermal type flow instruments truly into the high performance category and match the real field conditions of users, manufacturers needed to combine the product improvements with equally competent, high accuracy calibration capability. This meant outsourcing instrument calibrations to a qualified flow laboratory or making an extensive investment in one's own calibration facilities. Doubling as both an R&D test and production calibration facility, FCI invested in and operates its own fluid calibration center capable of flowing wide varieties of inert and hazardous gases and liquids.

Optimizing Thermal sensing technology continues to require knowledge of the fluid because the cooling rate is a function of thermophysical properties, such as viscosity, density, specific heat, thermal conductivity and coefficient of thermal expansion. While newer modeling and equivalency methodologies have become effective at producing reference gas calibrations with accuracies approaching 2-3% of reading, it remains clear, for the time being, that the highest level of performance is made available through actual gas or actual liquid calibrations. Companies with facilities such as FCI can perform liquid calibrations in actual fluids ranging from basic water to juices, hydrocarbons and coolants; similarly, gas calibrations are available in inert to hazardous mixed gases to light end gases such as Hydrogen and Helium. The capability to match actual fluid calibrations with automated data collection routines and high accuracy flow reference standards such as sonic nozzles, laser Doppler and Coriolis results in instrument calibrations that are consistently better than 0.5% of reading.

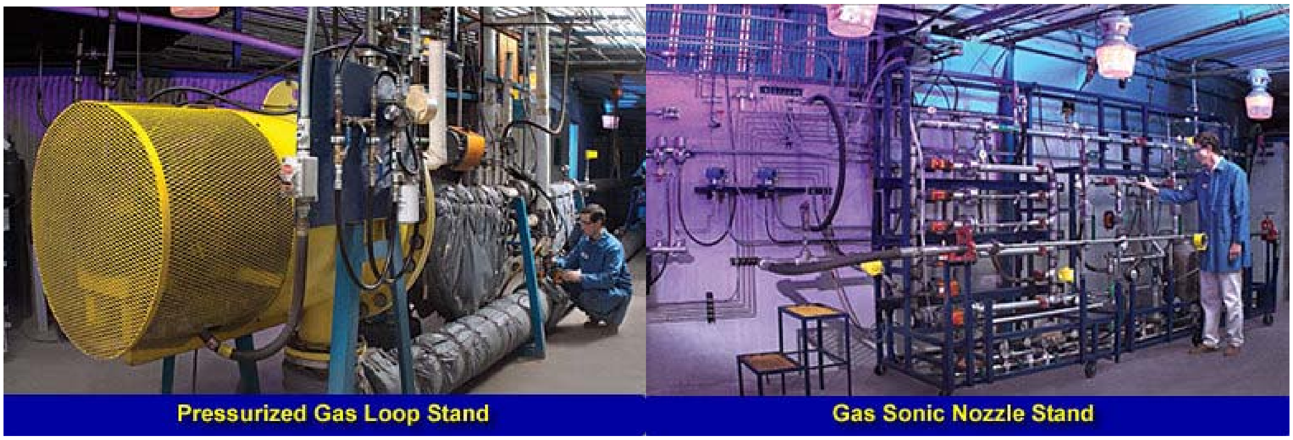


Fig 2. FCI's Calibration laboratory mixed gas and sonic nozzle flow stands

Transferring Laboratory Results To The Field

Transferring laboratory calibration performance to an actual field installation poses challenges for all flow measurement technologies. Challenges like straight run, actual instrument installation, fluid stratification, transitional flow profiles, turbulence intensity, swirl, pulsation and wide ranging process conditions can impact virtually any flow technology. As Thermal technologies are economical and accurate flow solutions from 1/8-inch lines to 30-foot stacks. The application of the technology and the proper product selection are critical to achieving the highest field installed accuracy. From 2-inch line sizes and below, most Thermal manufacturers feature "in-line" offerings that fix the sensing element in a traditional spool section. This in turn assures that any minor installation effects associated with variations of pitch, yaw, rotation or insertion depth are essentially eliminated. In addition, many "insertion" elements have evolved in such a way that most installation variables can also be eliminated or greatly reduced. Lock in place or key coded insertions, multipoint sensor assemblies, depth gages and orientation guides make for a very efficient insertion flow element installation from 4- inch lines to several meters in diameter.

Flow Conditioning Opens New Installation Opportunities

Flow conditioning is a complementary advancement that many flow technologies have adopted. FCI offers the Vortab® flow conditioners, which provide excellent isolation, swirl reduction and at virtually no pressure loss. This type of flow conditioning has dramatically opened the application universe for point sensing technologies, such as Thermal, whose normal installation guidelines recommend pipe runs of 20 diameters upstream straight run and 10 pipe diameters of downstream run. By combining and embedding flow conditioners with thermal mass flow meters they attain their published performance specifications in installations with less than 7 total pipe diameters.

Process Condition Effects And Multi-Variable Sensing

Thermal flow measurement technologies inherently utilize temperature sensing. Most Thermal flow instrument manufacturers have a reference sensor contained in the flow element that is either integrated with the delta temperature measurement or is independently placed to detect real time changes in process temperature. As thermal devices are direct mass flow measuring devices and because changes in process temperatures will directly change mass flow rates, Thermal devices are designed for automatic correction of process temperature changes. Equal mass flow sensor designs, ensure those changes are free of lag effects and thus offer real time temperature compensation. As a result, most Thermal flow meters are inherently multi-variable and also provide the process temperature as an output.

In addition, Thermal devices are largely insensitive to pressure effects except at extremely low flow rates (typically below 0.25 ft/sec) where natural convection phenomenon can produce heat rise flow effects in intrusive sensing configurations. Utilizing low power boundary layer sensing, companies including FCI have introduced non-intrusive designs that have taken both low flow and high velocity sensing to new levels.

Most manufacturer's product specifications or selection software limits use of insertion type configurations in these extremely low flow applications. Under normal operating flow ranges, independent research isolating pressure effects indicates that an uncorrected thermal mass flow meter may experience between 1-2% reading shift for every 100 PSI swing. Regardless of thermal sensor drive technique, constant delta T or constant power, they are similarly affected . Figure 3 shows a common performance curve over typical pressures swings with pressure effects producing less than 1% error.

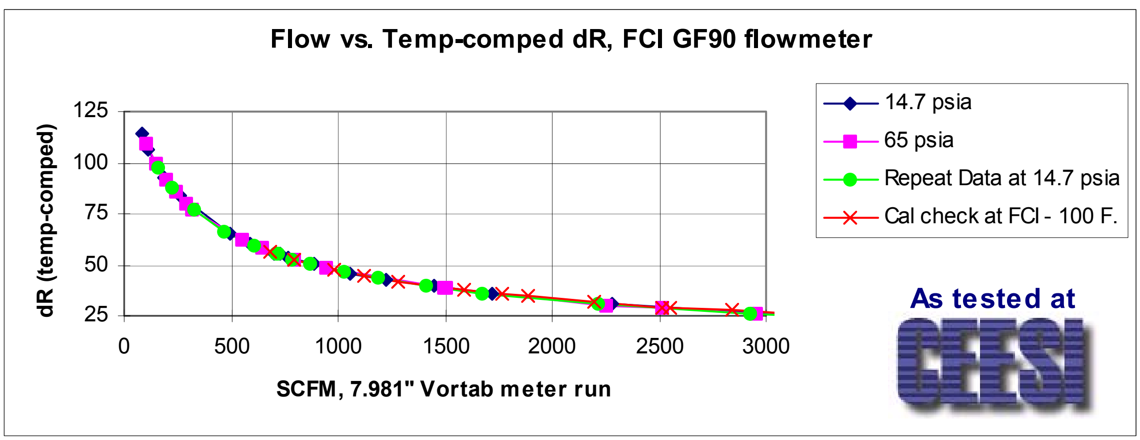


Fig 3. Typical performance curve over pressure swings with <1% error

Thermal manufacturers monitor wide process pressure swings that can produce additional uncertainties associated with gas properties breaking down. For these unique, demanding pressure applications, FCI has developed a patented Thermal mass flow sensor with imbedded pressure sensing and correction While this special configuration is not needed for most common process control applications where thermal type technologies are utilized, it does position thermal technology to approach accuracy requirements commonly reserved for custody transfer devices that are used in the wide pressure ranging conditions of natural gas transmissions.

In summary, the combination of breakthroughs from sensor design consistency, advanced signal processing, high accuracy calibrations and the ability to mitigate imperfect installation effects with flow conditioning puts Thermal-type flow instruments out on the leading-edge of technologies offering high performance, competitive price and long application life. While the marketplace offers a broad range of Thermal products in various performance and price selections, today's more advanced Thermal products can be reliably utilized in the most demanding process applications and can deliver the high accuracy and repeatability that users demand.

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About the author: With over 20 years experience in automation, process control, manufacturing and instrumentation, Dan McQueen heads the worldwide operations of Fluid Components International. His previous positions at Hughes and McDonnell-Douglas included high-level responsibility for finance and contract management on a number of key programs. He is an active member of the Instrumentation, Systems and Automation Society; TEC The Executive Committee; and serves as a Board Member with the Measurement, Control and Automation Association.

A graduate of UCLA, he has also completed advanced management and training programs at USC and the California Institute of Technology.