Micro Fluidic Flow and Pressure Control Modules for Integration Into Compact Systems

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The footprint of mass flow and pressure sensors can be substantially reduced using MST/MEMS

Equipment manufacturers are looking for compact solutions to monitor or control the gas flow or pressure within their systems. As these systems are getting smaller and smaller, the incorporated flow and/or pressure control units need to be miniaturized.

For example, the dimensions of a conventional gas chromatograph (GC) are approximately 1 x 1 x 1 m. The latest generation of (portable) GCs may have dimensions down to circa 25 x 25 x 25 cm. In a GC, usually 3 to 6 mass flow and/or pressure controllers are applied. Conventional mass flow controllers (MFCs) and pressure controllers (EPCs) have dimensions of circa 2.5 (w) x 7.5 (l) x 12.5 (h) cm, making it impossible for manufacturers to further decrease the dimensions of their equipment. Moreover, the use of individual instruments introduces potential leak points.

Until now, conventional mass flow and pressure sensors and controllers have needed a footprint of 1.5” (ca. 40 mm), as for instance specified in the NeSSI™ [1] system. Due to micro system technology (MST/MEMS), Bronkhorst High-Tech has been able to halve this dimension to 0.75” (ca. 20 mm), enabling the realization of ultra compact flow and/or pressure measurement and control instruments and systems.

In this article, a new generation of instruments is presented that meets the size and other requirements imposed by compact equipment manufacturers. Furthermore, due to their modular construction, compact manifold solutions can be built, thereby reducing potential leak paths and ensuring space efficiency.

Flow sensor structure and basic operating principle

The actual flow sensor chip consists of a thin square membrane with two heaters and two temperature sensors (T-sensors) on its surface. The membrane is suspended in a frame around it and can withstand 200 psi (15 bar).

The measurement principle is as follows: the two heaters are heated to a temperature ΔT over the medium temperature by providing them with constant power. From each T-sensor, the hot side is located on the membrane, and the cold side is on the frame around the membrane. The temperature difference between the hot sides of the upstream and downstream T-sensors is proportional to, and a measurement of, flow.

At zero flow, the heaters are powered in such a way that the differential output voltage of both

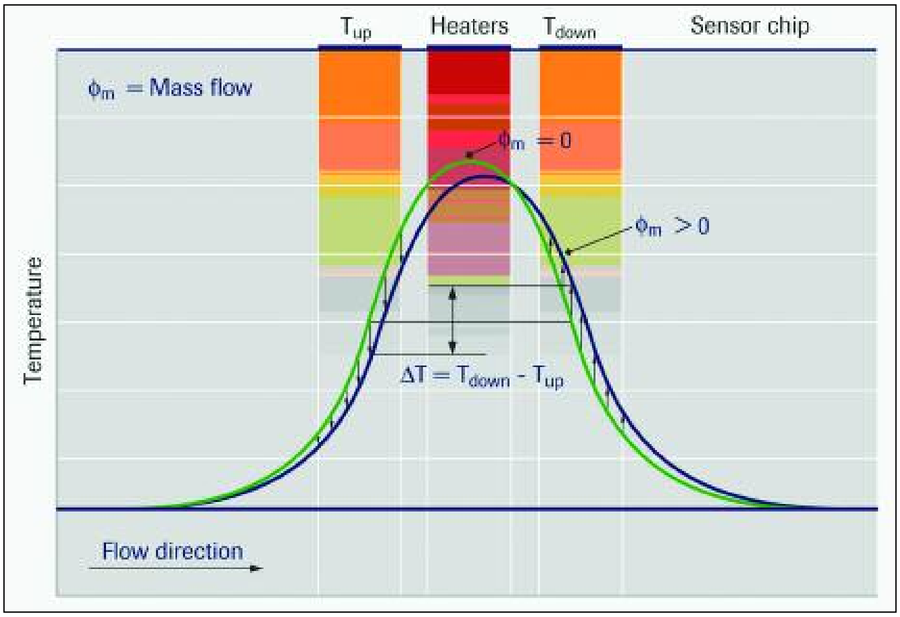

Figure 1. Basic operating principle of flow sensor chip

Figure 2. Exploded view of the flow sensor (left) and control valve (right) module

T-sensors equals zero. The resulting temperature distribution on the membrane is shown in Figure 1 (the green line, indicated with $\Phi_m = 0$). When a flow occurs, the temperature of the upstream T-sensor decreases, and the temperature of the downstream T-sensor increases. The resulting temperature difference ΔT [°C] is the measurement for the flow, as shown in Figure 1 (the blue line, indicated with $\Phi_m > 0$).

Unfortunately, the transfer function between mass flow Φ_m [kg/s] and resulting temperature difference ΔT [°C] is not a simple expression. The temperature difference ΔT is dependent on the dimensions and physical properties of the membrane material and on the physical properties of the gas that is applied.

The exact relation between mass flow Φ_m [kg/s] and resulting temperature difference ΔT [°C] has been determined using finite-element method (FEM) simulations. Using this exact relation, the behavior of the flow sensor for different gases can be predicted.

Micro fluidic modules

The flow sensor chip is mounted in a modular housing with a 20 mm footprint. Additional modules with this footprint, necessary for the realization of miniature flow pressure control systems, are:

- Flow sensor; typical flow ranges from 20 ml_n/min through 2000 ml_n/min (full scale values)
- Pressure sensor; typical pressure ranges of the order of 100 psi
- Control valve
- Electronic circuitry
- Three-way valve
- Shut-off valve
- Filter
- Mixing chamber

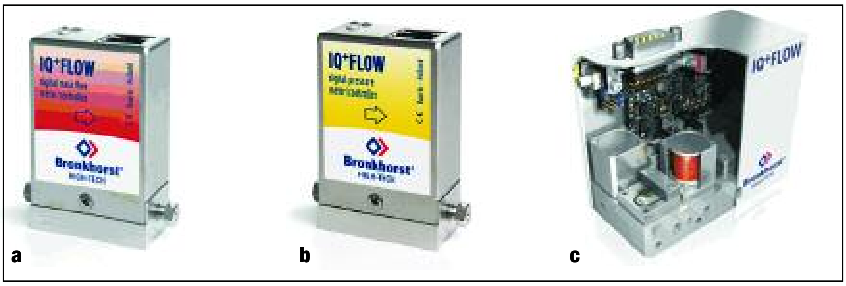

Figure 3. (a) IQ+Flow mass flow controller; (b) IQ+Flow pressure controller; (c) customized manifold flow pressure controller based on IQ+Flow modules (chip flow sensor, chip pressure sensor, control valves, electronic circuitry, three-way valve)

Both individual instruments and customer specific designs can easily be configured with these modular "building blocks", as shown in Figure 3.

Due to these small-sized modules, we have manufactured mass flow and pressure controllers (as shown in figures 3a and 3b) with the dimensions 20 (w) x 40 (l) x 60 (h) mm which, to our knowledge, are the smallest manufactured instruments.

Experiment

A sample group of mass flow controllers utilizing the chip flow sensor, control valve and electronic circuitry modules were subjected to the same test (see Figure 3a). The output signal of the instruments was measured for flow ranges varying between 20 and 2000 ml_n/min. nitrogen, hydrogen, helium and argon. Furthermore, the dynamic behavior of each of the instruments was measured by performing various set point variations. The resulting mass flow sensor response was measured by a digital oscilloscope.

The measured output signals as a function of the mass flow are shown in Figure 4a. The measured dynamic behavior of the mass flow controller is shown in Figure 4b.

The measured curves, as displayed in Figure 4a, correspond well with the theoretically expected values as obtained with the FEM simulations. The measured response times, of which a typical example is shown in figure 4b, are all within the value of $t_{98\%} = 0.5$ s.

Example of an analytical application

A miniature flow pressure control unit can be applied at the injector of a GC, as shown in Figure 5. The carrier gas flow is controlled by the MFC and fed through the injector to the analytical column and thus to the detector. It is vital that the carrier gas flow is highly stable under all circumstances, since the analytical result is very much dependent upon the stability of the flow velocity through the analytical column.

The pressure within the injector is kept constant by the EPC. When a liquid sample is injected it immediately evaporates due to the high temperature in the injector and the resultant pressure pulse is directly vented by the EPC. It is very impor-

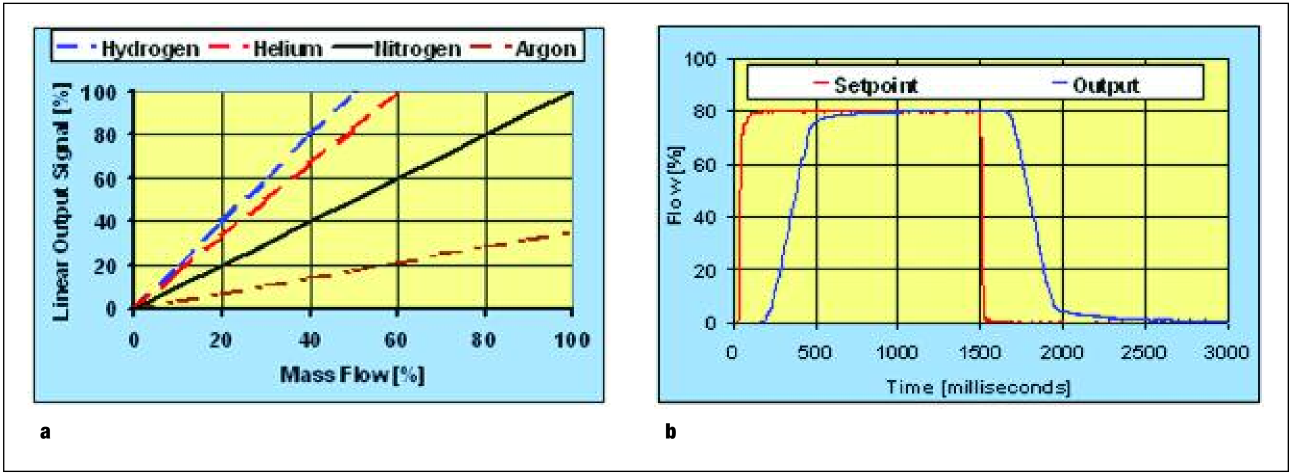

Figure 4. Measurement results obtained with an IQ+Flow MFC, adjusted for N_2: 500 ml_n/min ∫100 % (a) response to different gases: N_2, H_2, He and Ar; (b) response to change in set point (gas: N_2)

tant that the pressure in the injector is stable under all circumstances since the analytical result is again very much dependent on the stability of the flow velocity through the analytical column (which is affected by pressure variations on the column).

Therefore, stability and fast response are important features for both the MFC and the EPC. Moreover, both controllers should be independent of each other's behavior.

The system as described above has been realized with the miniature flow pressure control modules, built both as individual instruments (as shown in Figure 5b) and as a customized manifold (as shown in Figure 3c). Both versions of the miniature flow pressure control unit showed excellent performance.

Conclusions

In this article, a new generation of micro fluidic flow pressure control modules has been presented that are capable of meeting the special needs—and more importantly, the size constraints of analytical and other markets. Due to the use of micro system technology (MST), we are able to halve the size of functional modules thereby enabling the realization of ultra-compact flow pressure measurement and control instruments and systems.

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References:

1. New Sampling/Sensor Initiative;
www.cpac.washington.edu/NeSSI

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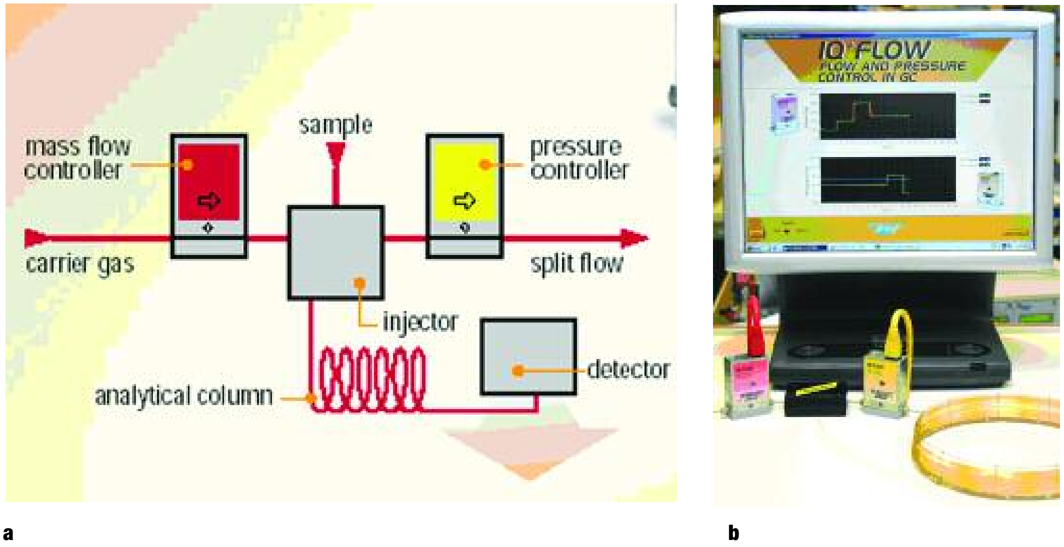

Figure 5. (a) Schematic and (b) realised miniature flow pressure control unit at the injector side of a GC