Coriolis MEMS-sensing technology for real-time fluidic measurements

Advancements add to the fastest growing flow sensing technology.

By Nader Najafi, Richard Smith & Michael Putty, Integrated Sensing Systems

A new technology brings real-time measurement of physical properties of fluids to a higher performance level by using silicon as the sensing material, microelectromechnical (MEMS) technology for fabrication and a balanced Coriolis technique for measurement. Balanced MEMS Micro-Coriolis (BMC) technology allows fluidic measurements of density, concentration, viscosity, temperature, mass flow and volume flow. The technology offers 6.5 digits of resolution after the decimal point [5x10-7 gram/cubic centimeter (cc)] for the measurement of density. This allows detection of hydrogen concentration changes in nitrogen at low pressures in real time with better than 0.1 percent concentration resolution.

Traditional (stainless steel tube) Coriolis-based meters are the most expensive density/flow sensing products, yet they represent the fastest growing flow sensing technology over the last 20 years. This is because of the unique attributes of Coriolis sensors, such as being the only technology capable of directly measuring mass flow; imperviousness to secondary parameters such as temperature, pressure and viscosity; and being able to measure density. Limitations include high cost, large size/weight and complicated tube drive and sense systems (magnetic resonation or laser detection of flow tube twist [flow]); low-resolution density measurement, vibration sensitivity and high power consumption.

Recent silicon MEMS Coriolis sensing products offer most traditional Coriolis sensors advantages while overcoming some of their shortcomings.[1-7] These devices are, however, not balanced and thus share some of the problems such as sensitivity to stress and installation mass and material. BMC technology attributes that have resulted in its advantages can be divided into three major groups: device, system and balanced sensor.

Device

At the device level, silicon MEMS devices offer several advantages: small and lightweight, long life, high reliability, high stability, low power consumption, high performance and low cost at high volumes.

These device-level advantages stem from two important facts: MEMS is a branch of microelectronics and silicon is a superior sensing material. MEMS technology offers advantages such as

Image 1. (Top) An intrinsically safe BMC multiparameter fluidic meter

All graphics courtesy of Integrated Sensing Systems high-precision, high reproducibility of miniature three-dimensional microstructures.

BMC sensors utilize single-crystalline silicon as the sensing material. Silicon is among the best materials in the world for highly reliable, long-term sensors and actuators because of its excellent mechanical properties. For long-term applications with high reliability requirements, the most important advantage of silicon is that it is a crystalline material and stays elastic until it breaks, without plastic deformation. A metal tube or diaphragm will plastically deform over time when exposed to creep and fatigue factors. This results in performance drift, which is a liability. If a silicon structure is bent, it either goes back to its original position or breaks but never deforms. As a result, silicon sensors could be practically free of fatigue, hysteresis and drift. Therefore BMC products provide advantages for demanding, high-cycling applications such as resonating tubes that face billions of vibration cycles.

System

While the MEMS device-level features are important, a more important advantage of the MEMS technology is in the systems integration. One of the most important contributions of BMC disruptive technology is that the entire mechanical Coriolis fluidic sensing system is integrated into a single microchip that requires only low-voltage electronics for its full operation. The system includes resonating flow tubes, flow in/out ports and low-voltage electronics circuits for its entire operation (tube vibration, sensing tube frequency/density, sensing tube twist/mass flow and sensing fluid temperature/viscosity).

Balanced sensor

BMC products utilize a "balanced vibrating tube" sensing technology versus unbalanced vibrating tube. When an unbalanced Coriolis tube resonates, it creates an equal and opposite force to the substrates on which it is mounted, which places limitations on its packaging and installation. BMC sensors use a balanced structure with lightweight tubes, resulting in no inserted force as well as lack of sensitivity to the sensor package, and masks the installation substrate from the sensor vibration. The balanced structure overcomes major practical problems, the most important of which are the ability to operate without requiring a mass from or having any dependency on the overall sensor package and compatibility with a variety of assembly techniques. The balanced structure is impervious to stress from the sensor package, installation or other sources and it is resistant to temperature changes of ambient, sensed fluid, package and installation substrate. The structure is unaffected by the installation environment and any crosstalk, and therefore multiple BMC sensors can be installed side by side.

End-user priorities are stability, accuracy, resolution, speed, initial cost and cost of ownership, which the new technology supports with several features:

Imperviousness to ambient noise/vibration

- Stainless steel tube Coriolis sensors are vulnerable to environmental vibrations since the resonant frequency of their tube is low (<1,000 Hz).
- BMC microtube resonant frequency is high (>20 kilohertz) because of several parameters including small size, silicon superior physical properties and microtubes' light weights.

MEMS devices

Attributes of silicon material for MEMS devices include:

- Mechanical properties
- Precision (submicron) micromachining
- Batch fabrication
- Extensive technology base
- Low-cost and high-quality of supplies of silicon wafers
- Potential for corrosion-resistant applications

Reliable against shock

- Because of light weight of the microtubes (micrograms).

Low fluid dead volume

- The small size of the microtube (microliters) creates orders of magnitude with lower dead volume than the tubes.

Rapid fluidic measurement response (density/viscosity/temperature/flow)

- High resonant frequency results in a fast response to fluid's properties (can be <1 millisecond).
- Low dead volume of the tube (microliter) results in fast fluidic step response.
- Rapid and accurate fluid temperature measurements caused by small mass, embedded temperature sensor and silicon's high heat conductivity.

High resolution, repeatability and accuracy in real time

- Because of high resonant frequency, high quality factor, balanced-tube measurement technique, low silicon density, silicon's properties, imperviousness to environmental parameters and high-performance electronics.
- Resolution of 5X10-7 gram/cc in real time with flow through the sensor.

High reliability and stability

- Silicon properties and lack of plastic deformation stage. Operation is based on electronics (no magnetic vibration or laser detection). Custom electronics further compensate many secondary parameters and the potential for failure and drift caused by these electronics mechanisms is extremely low.

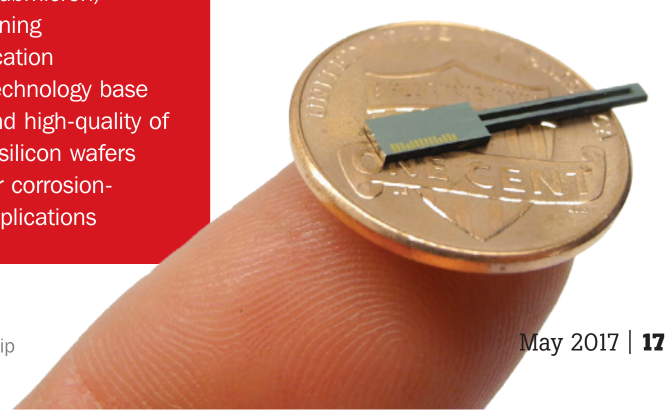

Image 2.
A BMC MEMS sensor on a penny on a fingertip

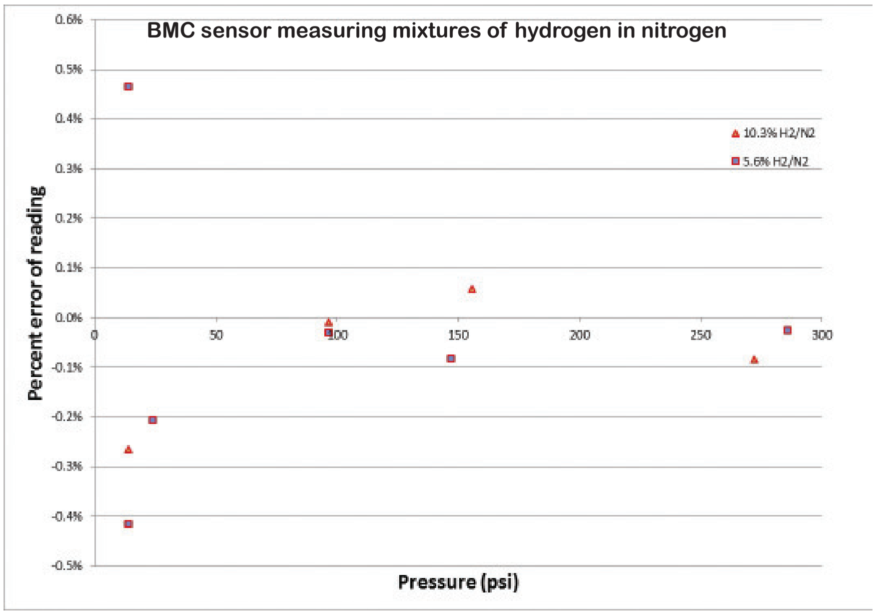

Figure 1. BMS sensor error in the measurement of hydrogen concentration in nitrogen at different pressures

Capability to measure multiple parameters with a single sensor in real time

- Density, viscosity, mass flow, temperature and associated parameters such as specific gravity, concentration, comparison to a reference, API, PLATO, Brix, etc.

System-level feature optimization

- Small size
- Low power
- Intrinsically safe
- Low cost
- Battery operation

Capable of measuring all types of fluids

BMC technology can be used in many markets and applications. High-end applications include processing and manufacturing; fuel custody transfer; fuel production and quality monitoring; methanol production; natural gas monitoring and custody transfer; propane-air blending, liquefied petroleum gas monitoring and transfer; fuel cell sensors; beverage manufacturing; gas concentration sensors; measurement of the energy content of gases; real-time monitoring of gas molecular weight; aerospace sensors; and small-size, inline, embedded sensors.

High-volume applications include advanced drug delivery pumps, automotive sensors, urea/diesel exhaust fluid sensors and mobile fuel cells. FC

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Nader Najafi, Richard Smith and Michael Putty work for Integrated Sensing Systems. Visit mems-iss.com or metersolution.com for more information.