LOW COST DIGITAL FLOW METERS FOR INDUSTRIAL PROCESS APPLICATIONS

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Abstract

Variable area flow meters or rotameters have been widely used for flow monitoring of industrial process, particularly where the cost is the first priority. However, with the constant demands for process digitization, remote data transmission, data log, flow level register and alarm triggered automation have been highly demanded. These characters are not available for the rotameters while the low cost barrier prevents other existing technology to provide the same solution. MEMS mass flow technology on the other hands, is ready to emerge for these applications. In this paper we present the working principle, design and performance of a series of MEMS flow meters that can be used to replace the rotameters. The all new digital flow meters meet all current digitization requirements while excel in performance at a very competitive cost.

Introduction

The most commonly used flow meters are the variable area flow meters, particularly those made with glass or plastics, *aka* the rotameters that was originated from Deutsche Rotawerke in Germany about 100 years ago. [1] This type of meters is easy to install and operates without external power, and it reads flow rate directly and proportionally to the scale markers on the meter. It is extremely cost effective depending on the requirements. Some models are even priced at less than ten US dollars per unit. However, the rotameters are volumetric metering apparatus without compensation to the variation of gas pressure and temperature. The meters usually have large measurement errors with low resolution in readings, particularly at low flow rate range wherein the configuration introduces additional parallax errors. It is also difficult to have the capability of remote control as the conversion of mechanical reading to digital signals would be costly and unreliable. In addition, the installation also requires a vertical configuration that makes the small form factor becomes unrealistic, and the construction of the meter also has the fragile materials that sometimes it creates safety concerns in the industrial environments. With today's increasing demands for automation and control in industrial process, new metering technologies for better data accuracy, data transmission or networking and data safety would be needed. A new series of thermal mass flow meters (Mass-View) are released recently by Bronkhorst (www.bronkhorst.com) aiming to remedy the undesired features of the rotameters, but its cost is substantially higher than those for the commonly used rotameters on market. In this paper, we present a new series of digital meters made with MEMS (micro electro mechanical systems) flow sensing technology. [2] The meters are very cost effective while incorporated with advanced features that outperform in all aspects than rotameters do. The meter structure, technical features, and performances are discussed in details.

Meter design and configuration

MEMS sensor design and fabrication

The MEMS mass flow sensors were fabricated on a silicon substrate based on the calorimetric measurement principle. The fabrication of the sensor starts with deposition of a 1.5μm thick low stressed silicon nitride on a silicon single crystal wafer substrate by low pressure chemical vapour deposition, and the silicon nitride was used as the membrane support under which the thermal isolation cavity was realized by etching away the bulk silicon materials using deep reactive ion etch process. The micro-heater thermistor deposited on the silicon nitride membrane was made of platinum via electronic beam evaporation. And two temperature sensing elements in the form of thermopile were deposited symmetrically with respect to the micro-heater with a distance of 8 μm. Another thermistor was deposited on the silicon substrate for measurement of the environmental gas temperature providing the feedback to the micro-heater which is operated at the constant temperature mode. The micro-heater provides the sources for flow medium that shall carries away the heat from the micro-heater to the downstream thermopile. The differences of the measured temperature field between the up and down stream thermopiles shall be proportional to the mass flow rate of the flow medium. And the variations of the sensor chip positions and other mechanical variations during the assembly of manufacturing can be effectively removed by calibrating each meter with a standard reference. In this configuration, the sensor could be employed to measure the bi-directional flow as well. The surface of the sensor was passivated with a 350 nm low stress silicon nitride prepared by plasma enhanced chemical vapour deposition. The passivation shall prevent sensor circuitry shortage due to the contact of any conductive materials in the flow medium as well as to enhance the mechanical robustness of the sensing component.

MEMS meter design

Unlike the other current metrology configuration, the MEMS mass flow sensing has the capability of integration, which can result in a large dynamic measurement range with a single chip. The signal conditioning circuitry can also be integrated onto a single ASIC (application specific integrated circuitry) chip. And both of the chips can be made in a mass production process. The cost of the chips can be dramatically decreased at the similar volume of the rotameters made today that could lead to a sub-US dollar cost structure for the meter electronics. Therefore, the proposed new MEMS meters would have a huge potential to replace the current rotameter applications in many areas.

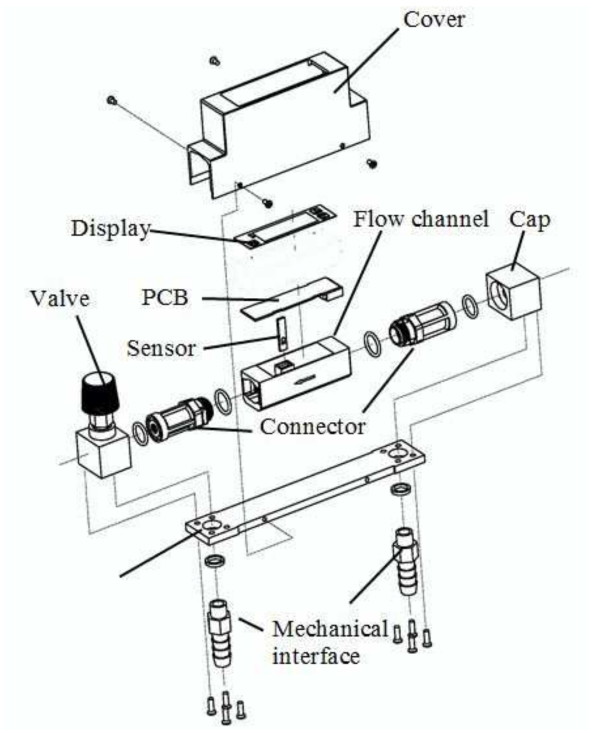

Figure 1. The explosive view of the meter

As the design target is for a direct replacement of the rotameter, the mechanical installation and connection configurations in the present design is a replication of those by rotameter. However, since the MEMS meter does not have the gravitation requirements as it does for the rotameters, the MEMS meter shall not require a necessary vertical disposition for installation, which provides additional freedom for the services and system design. The obvious advantages of an all-electronic MEMS mass flow meter are the ability for digital data transmission over the network for remote process management in the industrial applications. The data measured from the process lines not only can be transmitted to the control centre but also stored online or locally for the data safety and management as well as for the traceability that have increasing importance for product quality management. The data process capability of the MEMS meter will also provide both the instant flow and totalized flow rate simultaneously while the user can set the flow level or rate alarm trigger that can be indicated locally with sound and light while transmitted to the process control centre via the network. The electronic LED display can be bright and clear even in a much dimmed place; therefore it shall also improve the readout capability as compared to that with rotameters. The designed meters have digital readout instead of a bar graph as the digital figures shall be more direct and accurate for data readout. In Figure 1, the explosive view showed the proposed mechanical structure of the MEMS meter. The local push buttons on the display shall enable the users to program the meter for flow level alarm, gas type (several different gas calibration can be stored in the meter for user to select), as well as set the meter response time for the specific applications that may need a faster or slower response. The response time is usually can be programmed from 50 mini-seconds up to 5 seconds that shall also serves as a digital filtering for a slower response.

As the MEMS meter does not have the constrain of plastic or glass materials for reading of the floater positions, the enclosure is constructed with a casting aluminium and the flow channel can also be made of a metal materials such as stainless steel or copper. These mechanical advantages also extend the applications of the meters into high pressure regime, and enhanced the safety of the meter during the installation and operations. The current design enables a maximum working pressure of 10 bars.The needle valve shown in the figure is an option for the process control as it is often attached to the rotameter applications.

The calorimetric MEMS meters can automatically compensate the variations of pressure and temperature of the flow media which is often critical and required for the process lines since the final process or products shall depend on the mass delivery instead of volumetric delivery of the materials. Because of the large dynamic range for the MEMS meters, the reading accuracy of the MEMS meters are also substantially better than those full scale accuracy provided by rotameters, particularly in the low flow regime. However, the major drawback of the electronic meter compared to rotameters is the external power requirements. This shall not be an issue for meters required remote data transmission or control as the digital interface shall readily supply the required power. For the standalone model, the power requirements for the MEMS meter shall be a disadvantage, but due to the state-of-the art low power electronics and the thermopile applications, the MEMS meter can be operated using battery power for a reasonable long period of time. For example, a 2Ah rechargeable battery can provide a continuous operation for over 90 days.

Meter performance

Figure 2 shows the comparison of the uncertainties measured from a MEMS meter, the designed uncertainty band (dashed lines) to that of a typical 2% full scale rotameter uncertainty band. The common full scale uncertainties for most of the rotameters will normally be only good for the monitor purposes or the set-point repeatability on condition that the accuracy requirements shall not be very stringent. The actual measured data for the MEMS meter uncertainties as shown in Figure 2 are well inside the designed uncertainty band that indicated a significant improvement in particular for the flow rate at the lower end in the measurable dynamic range. This shall also demonstrate that the MEMS meters have a much wider turn-down ratio, typically achievable to over 50:1 at the low cost calibrations.

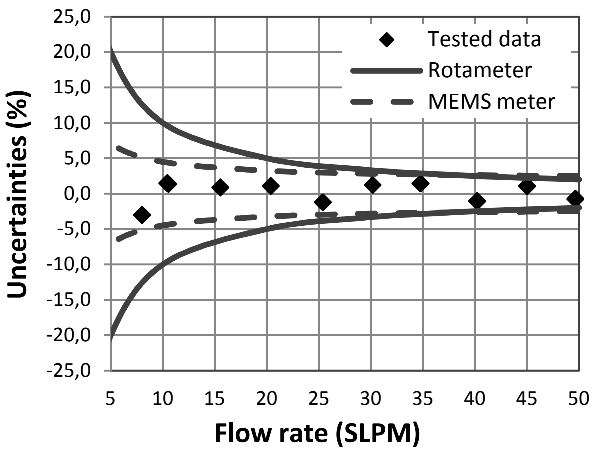

Figure 2.Comparison of uncertainty band

The multi-gas selection function of the MEMS meter can be achieved via the two approaches. The high precision approach shall require the real gas calibration and store the each calibration into the meter. For the common gases, the MEMS meter can also automatically sense the change of the gases through the measurement of the gas thermal properties such as thermal conductivities. For the low cost approach, the gas conversion factors [3] can be used while the gas type sensing capability can still be applied as it is embedded in the MEMS calorimetric measurement principle.

Concluding remarks

With the dramatic reduction on the cost for manufacturing a MEMS mass flow meter, it becomes competitive and feasible to apply the MEMS mass flow metering technology for applications where rotameters are dominated. The MEMS meters provide benefits not only for a higher accuracy, but the digital data adding many advantages for the remote process control, online data process, data safety, alarm triggered process automation, and enhanced pressure rating. The enclosure materials remove the safety concerns during installation and services, and in addition to the form factor advantages, the installation also does not require a conformation to the gravity directions. With the current advanced ultra-low power technologies for both the MEMS sensing chip and the control electronic circuitry, a battery operated standalone model is also readily available. Consequently, even for the local display of a standalone meter, the electronic digital display not only provides the options for both the instant and totalized flow information, but the LED brightness assists the distant readout even at a dimmed area without the approximation for the real scale readout on the meter body. Therefore, it is expected that the vast applications of the new technology shall be emerging in the coming years.

References

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