COMPACT MASS FLOW METER BASED ON A MICRO CORIOLIS FLOW SENSOR

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ABSTRACT
In this paper we present a compact ready-to-use micro Coriolis mass flow meter. The full scale flow is 2 g/h (for water at a pressure drop of 2 bar). It has a zero stability of 2 mg/h and an accuracy of 0.5% reading. The temperature drift between 10 and 50 ºC is below 1 mg/h/ºC. The meter is robust, has standard fluidic connections and can be read out by a PC or laptop via USB. Its performance was tested for several common gases (helium, nitrogen, argon and air) and liquids (water and IPA).

KEYWORDS
Mass flow meter, Coriolis, Microfluidic

INTRODUCTION
Microfluidic systems have gained a lot of interest in the last decade in a wide area of applications [1]. Examples of such can be found in the analytical field, (bio)-chemistry, medical and industry. These fields require in-line measurement and control over mass transport. Since often mixtures of varying composition are found, a true mass flow sensor is wanted. Haneveld et al. presented such a mass flow sensor based on the measurement of the Coriolis effect [2].

Figure 1: Micro Coriolis mass flow sensor integrated into a robust housing using a custom-made chip holder. 1/16” stainless steel tubes are connected to the chip. 1a) First design; 1b) realization.

However, to be useful in the field, the sensor should be packaged and have a simple and robust (electric and fluidic) connection to the outside world.

MASS FLOW METER DESCRIPTION
Novelty
Here we present packaging of a micro Coriolis mass flow sensor into a stainless steel housing (figure 1). Several experiments were performed to characterize the behavior of the meter. The meter is ready-to-use by integrating interface electronics and standard fluidic connections. The electrical connection is a standard Bronkhorst High-Tech connection that can be connected to a pc or laptop via USB. The fluidic connections in the current design are 1/16” Swagelok connectors.

Sensor structure and operating principle
The functioning of the Coriolis mass flow meter is described using figure 2. By Lorentz actuation the tube is brought into resonance. The movement is an alternating rotational displacement of 1 to 10 µm around the x-axis (torsion mode). A flow running through the section of the tube that is indicated by L causes an alternating force in the z-direction around the y-axis (swing mode). This force is called Coriolis force and causes a displacement of the tube roughly between 1 and 100 nm.

Figure 2. Rectangle-shaped Coriolis flow sensor. The tube is brought into resonance by Lorentz actuation at an angular velocity, $\omega$, the displacement at the corners of the tube is between 1 and 10 µm; $F_c$ indicates the Coriolis force as a result of mass flow $\phi_m$ through the part of the tube indicated by L, this force causes a displacement roughly between 1 and 100 nm.
Chip and packaging

The chip is fabricated using surface micromachining techniques. Details can be found in [3]. To protect the relatively fragile Coriolis tube a glass cover is glued on top of the chip. The combination is then glued to a PCB after which wirebonds are made to connect the chip electrically. In figure 3 a photograph of the chip and PCB can be found.

Chip holder and fluidic connections

To robustly interface the sensor chip to the “macro” world, we placed the chip into a stainless steel chip holder (figure 4). This holder forms a steady base to connect the chip fluidically using stainless steel nuts and Tefzel ferrules that connect two 1/16” stainless steel tubes with the chip.

Electronics

It is apparent that the displacement by the Coriolis force is extremely small. This places strong demands on the detection part which is done using electrostatic comb structures [3]. Here displacement of the tube causes a change in capacitance that is transformed into a voltage change. This is detected by a digital signal processor (DSP) via several analog to digital (ADCs) and digital to analog converters (DACs). The chip and the ADCs and DACs are interfaced via a charge amplifier.

EXPERIMENTAL RESULTS

Pressure tests

Several tests were performed. A helium pressure test was done at the Bronkhorst High-Tech production facility. This showed that the Coriolis mass flow meter could withstand a maximum pressure of 40 bar.

Temperature drift

The influence of ambient temperature on the zero stability was tested by placing the meter inside a climate chamber (Vötsch VC4018). The relative humidity was kept constant at 20%. A temperature sweep was made between 10 and 50 °C in steps of 5 °C. Between steps the temperature was kept constant for two hours. Results of this experiment are given in figure 5. This shows a temperature drift between 10 and 50 °C below 1 mg/h/°C.

Mass flow of water

We tested the Coriolis mass flow meter for several liquids (water, IPA) in a temperature controlled environment. In this room the temperature was kept between 20 and 25 °C. Here we present the results with water.

In figure 6 a schematic overview of the setup is given. The mass flow measurements were done by comparing the read-out value of the meter with a weighing scale (Mettler Toledo AX205). A pressure difference across the meter was generated by pressurizing a 300 ml water tank with helium. After this tank a 2 µm peek filter unit (Upchurch Scientific A-355 with a A-700 filter frit) was placed. To prevent interference by air bubbles, the water was degassed.
in-line by a Systec mini vacuum degasser. The Coriolis mass flow meter was used to control the mass flow rate by driving a normally closed valve (Bronkhorst top-mount valve) that was placed in front of the Coriolis mass flow meter. Between the valve and the meter again a 2 µm filter was placed. This second filter prevents particles, that possibly originate from the metal valve, to enter the Coriolis mass flow meter. Via a piece of peek tubing the water was passed towards a 200 ml glass beaker placed on the weighing scale. The beaker was prefilled with water and topped by a layer of oil to prevent evaporation of water during the measurement. Each point represents a measurement over a period of 4 minutes. The result for the mass flow measurement of water is presented in figure 7. For water the meter shows a zero stability of 2 mg/h and an accuracy of 0.5% reading. The full flow of 2 g/h is reached at an approximate pressure of 2 bar.

For IPA the same zero stability and accuracy was found. Because IPA mixes with oil, we were not able to reliably use the weighing scale for mass flow measurements of IPA. For this purpose we drove mass flow by a syringe pump using calibrated 100 µl syringes.

Mass flow of air

We tested the Coriolis mass flow meter for several common gases (He, N₂, Ar and air) in a temperature controlled environment. Since the meter was designed for an approximate 1 bar pressure drop at 1 g/h mass flow of water, the pressure drop for 1 g/h gas mass flow is expected to be higher. Again the temperature was kept between 20 and 25 ºC. Here we present the results obtained with air. In figure 8 a schematic overview of the setup is given.

As a reference we used a piston prover (0.1 l/min). A well-defined pressure difference across the Coriolis mass flow meter was generated by a pressure controller (Bronkhorst EL-press). The maximum pressure difference we could apply across the Coriolis mass flow meter was 8 bar. As a consequence we could not reach the nominal flow rate of 1 g/h. For the valve to operate reliably we generated a constant leak of 0.6 l/min with a thermal flow controller (Bronkhorst EL-flow). This was necessary since the volume flow through the micro Coriolis meter is extremely small. Between the pressure controller and the Coriolis mass flow meter we placed 2 µm filter (Upchurch Scientific A-355 with a A-700 filter frit) to prevent clogging. The meter was directly connected to the piston prover. For each measurement point we did at least three runs. In these runs we let the piston prover pass between the same two detection points. The result for the mass flow measurement of air is presented in figure 9. For air the meter shows a zero stability of 2 mg/h and an accuracy of 0.5% reading.
The same zero stability and accuracy were found for nitrogen, helium and argon.

![Figure 9: Measured air mass flow vs. piston prover. The envelope represents a zero stability of 2 mg/h and an accuracy of 0.5% reading. The pressure drop across the Coriolis mass flow meter was approximately 8 bar.](image)

**CONCLUSION**

We presented a compact and ready-to-use micro Coriolis mass flow meter in a stainless steel housing. It has a full scale mass flow of 2 g/h and accuracy of 0.5 % reading. Its zero stability is 2 mg/h. The meter can withstand 40 bar and operates well in an ambient temperature range between 10 and 50°C. Its temperature drift is below 1 mg/h/°C. It measures mass flow of both liquids and gasses. We tested the meter for water, IPA, helium, argon, nitrogen and air. The meter was designed to have a 1 bar pressure drop at 1 g/h water mass flow. Since our current gas setup was limited to 8 bar pressure drop across the Coriolis mass flow meter, the mass flow meter is characterized for air up to ~0.35 g/h.

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