DOI 10.5162/SMSI2020/B2.2

A hermetic sensor concept for measuring fluid flows

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Summary:
We present a novel, fully encapsulated sensor concept, which is especially suitable for the measurement of condensing gas flows. The sensor concept is based on the Magnus forces working on a magnetically levitated and rotated cylinder at high speeds. Our first experimental results have successfully shown the feasibility of this sensor concept.

Keywords: Magnus effect, flow sensor, condensing gas flow, high humidity, hermetic sensor

Introduction

Robust gas and liquid flow measurement is a crucial requirement for the production-related industries as well as in medical applications. Despite the wide range of available sensors, in applications where condensing or corrosive gas flows are to be measured, the range of available sensors narrows down significantly. Water droplets that accumulate on a sensor element i.e. of MEMS or dP-Sensors often negatively affect accuracy or lead to complete malfunction of the sensor. In this paper, we present a novel flow sensor concept based on the Magnus effect. A major advantage of this approach is that the sensor element is in constant rotation and thus robust against influences of a condensation on the sensor surface. In addition, it allows a fully encapsulate construction of the sensor with a single-use sensor element with magnetically coupled driver and read-out. With this features, the sensor concept is suitable for medical applications and for the use in corrosive media.

Materials and Methods

Measurement principle:

Figure 1 illustrates a gas flow from bottom to top through a tube and around a cylinder, which is rotating at an angular velocity ω. This results in the two forces F_D and F_M that work on the cylinder. The first is in the direction of the flow caused by drag. The second is due to the Magnus effect that acts orthogonally to the flow velocity vector and can be described as:

$$F_M = S(\omega \times v)$$

S is the air resistance coefficient across the surface of the cylinder. Both forces would lead to a displacement of the cylinder off its rotating axis. The aim is to drive the cylinder and measure these forces with our proposed sensor concept.

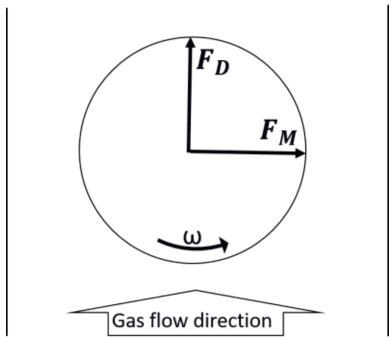

Fig. 1. Magnus (F_M)and drag (F_D) forces on a rotating cylinder with angular velocity ω

Sensor concept:

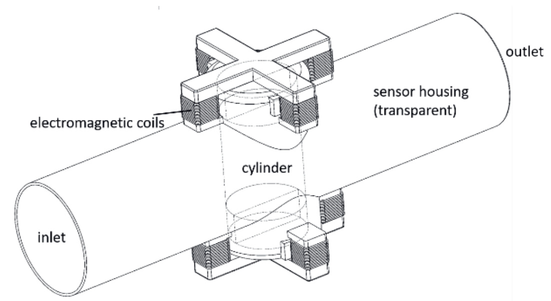

Fig. 2. Magnus sensor concept (overview)

Figure 2 and 3 illustrate the sensor concept. The sensor element consists of a cylinder that has two magnets integrated on either ends. This cylinder is fully encapsulated by a sensor housing, which guides the gas flow from the inlet around the cylinder to the outlet. The cylinder is being levitated and rotated by multiple electromagnetic coils that are placed around the poles of the cylinders permanent magnets. Additional sensors measure the current angle and displacement of the cylinder. The individual coil currents are controlled such that the cylinder is levitated in the center and driven at a variable angular velocity.

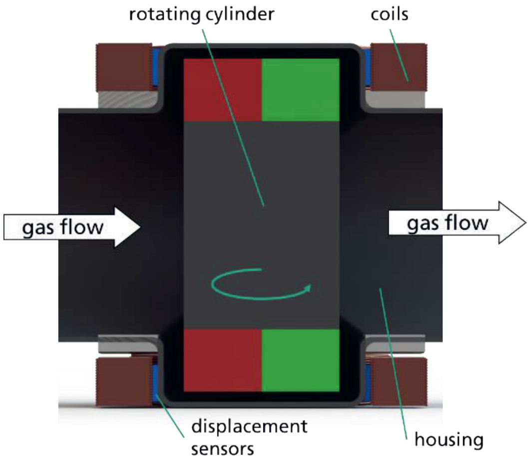

Fig. 3. Magnus sensor concept (cross-section)

Experimental Setup:

We used an existing medical rotary pump with displacement sensors and electromagnetic coils. We replaced the pump impeller by a 3D-printed cylinder and pump housing accordingly. We built a custom electromagnetic driver and implemented a custom PID-controller on an embedded microcontroller (TI, TMS320F28379D). This system controls the levitation and rotation of the cylinder. The inlet of the Magnus sensor was connected through a reference flow meter (Sensirion, SFM3000) to a gas source (pressurized air). The sensor signal is derived from the force that is necessary to counteract the respective Magnus and drag forces.

Results

First results in Figure 4 show the forces at two rotational speeds of the cylinder at 2500RPM and 5000RPM for varying volume flows. As expected, due to the Magnus effect, there is a clear dependency on rotational speed for the measured forces.

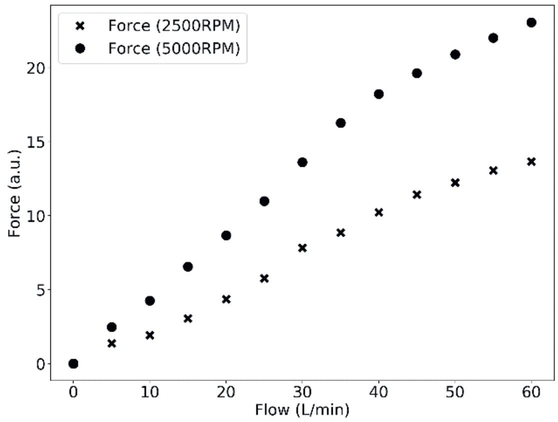

Fig. 4. Force signal for varying volume flows of 0-60 L/min

Discussion

Our first experiments have successfully shown that it is possible to measure the forces imposed on a cylinder by a gas flow with the proposed setup. The achievable sensitivity and resolution of the sensor is currently limited because of the relatively large dimensions of the setup. A dedicated coil geometry is expected to increase resolution and linearity significantly.

The presented sensor can be constructed as two separate parts. The more expensive driver electronics can be reused and have no parts prone to failure because none of them are mechanically moving or in contact with the fluid. The second unit is a low cost, fully encapsulated, single-use unit consisting of the rotating cylinder and housing. This enables the elimination of any possible cross contamination and maximizes sterility. Many applications like biological and chemical processes as well as the measurement of respiration gases of ventilated patients would benefit from such a sensor.