Sensors and Actuators A 265 (2017) 313–320

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

Reduction of power consumption and expansion of the measurement range by pulsed excitation of thermal flow sensors☆

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ARTICLE INFO

Article history:
Received 14 January 2017
Received in revised form 15 August 2017
Accepted 15 August 2017
Available online 19 August 2017

Keywords:
MEMS
Flow-Sensor
Constant Energy Excitation
Pulsed Excitation
Anemometer
Wireless
Reduced Power Consumption

ABSTRACT

A new excitation method for thermal flow sensors has been developed by powering them not continuously, but with short pulses. The impulses can be generated by a pulse generator or a capacitor circuit and can have a duration of milliseconds or less, depending on the voltage and the required resolution. Although the sensor will not reach the thermal equilibrium which is typically used for flow measurements, the dynamic heating response curve of the impulses contains enough information to determine the flow rate.

The new method was simulated to evaluate its feasibility and tested in the laboratory.

By using short impulses instead of a steady supply, the power consumption can be reduced substantially by 90% or more. Additionally, the response curve of this excitation method provides more information which can be used to reconstruct the flow rate. This expands the measurement range by a factor of 8 or more. Using a capacitor to generate the pulses provides a constant amount of energy for every single pulse, thereby reducing unwanted sensitivity of sensor signals to the temperature of the medium.

After the laboratory tests, the new excitation method was established in a wireless sensor system and tested in the field by placing a network of wireless sensor systems in a storage room to measure the air flow conditions.

1. Introduction

The progress made in the fields of battery technology such as Li-Ion or LiPoly, smarter and more efficient electronics and, not least, more cost-effective sensors paves the way for wireless sensor applications of increasing complexity.

For example, monitoring of local deviations of air flow conditions in large refrigerated warehouses is only feasible by wireless instruments for practical reasons. We have developed a wireless anemometer (WAM) for long-time measurements in such storage rooms [1]. It is shown in Fig. 1.

The WAM consists of two thermal flow sensors, embedded and orthogonally orientated in one board. This arrangement allows us to recover the air velocity vector magnitude and angle in two dimensions. Inside of the instrument enclosure, there is a circuit that drives the sensor and amplifies its signals, a transmitter unit and a battery. The antenna is mounted on the top of the cover plate.

To operate such sensor systems as autonomous units for extended periods of time, power consumption must be minimized. Hence the circuit to control the electrical heater of the thermal flow sensor is an important design issue. To optimize it, we invented a new excitation method for thermal flow sensors by driving them with short impulses. This enables reduced power consumption of the sensor and its excitation circuit and additionally provides a broader measurement range.

1.1. Conventional measurement methods

There are many different principles which may be used to detect the speed of a gas or liquid. Unfortunately, many of them are not

☆ Selected paper from EUROSENSORS 2016, September 4–7, 2016, Budapest, Hungary.

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http://dx.doi.org/10.1016/j.sna.2017.08.029
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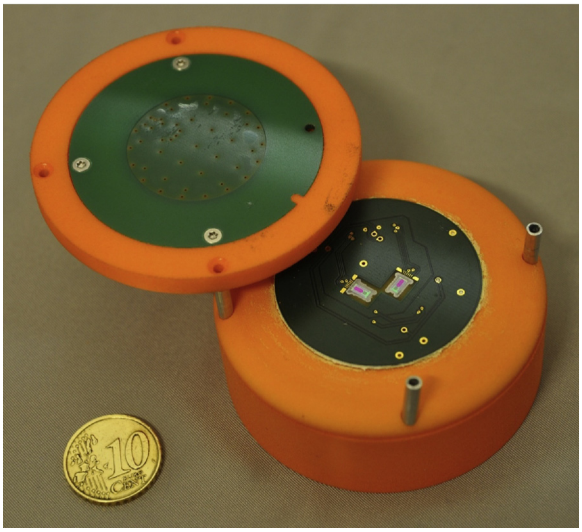

Fig. 1. Wireless anemometer (WAM) for two dimensional flow measurement with opened cover plate.

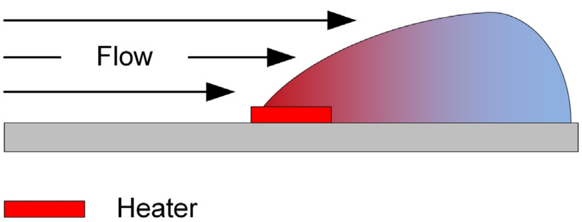

Fig. 2. Measurement principle of a hot-wire/-film flow sensor.

feasible in microelectronic mechanical systems (MEMS) technology because of the latter's structure. Some contain moving parts such as vane anemometers which require a complex technology; others, such as ultrasonic or electromagnetic sensors, need space and complex electronics.

Due to these restrictions, thermal MEMS flow sensors dominate the field because of their structural and electronic simplicity as well as their thermal characteristics [2]. They can be separated into three groups according to their working principles such as hot-wire/-film, calorimetric and time of flight [3]. For a better comprehension, it is helpful to recapitulate these common principles of flow measurement.

For the hot-wire/-film principle, a heater (wire or a surface) is heated above the temperature of the medium. If there is medium flow around the wire or above the surface it will convey some of this heat away. This transport is called forced convection or advection. The amount of transported heat is a measure of the flow rate. This principle is depicted in Fig. 2.

There are two common ways to determine the flow by this transport. If the temperature difference (ΔT) between the heater and the medium is maintained at a constant level, the power necessary to hold this temperature is an indication of the flow speed. Another method is to keep the heater power constant and measure the temperature difference. The heater wire itself is often used as a temperature sensor by monitoring its temperature-dependent resistance [4].

The calorimetric principle is based on a heater surrounded by two temperature sensing elements (thermopile, thermistors, etc.). All of these components are thermally decoupled from each other. When power is applied, the heater causes a temperature gradient in the surrounding medium. The flow of the medium causes changes in the temperature distribution that are monitored by the

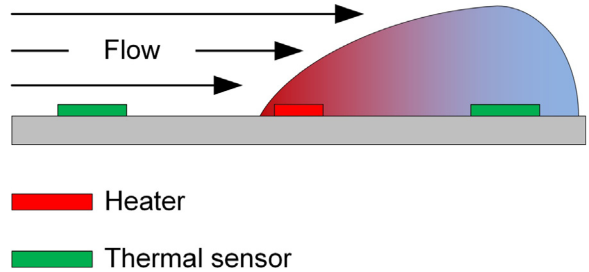

Fig. 3. Measurement principle of a calorimetric flow sensor.

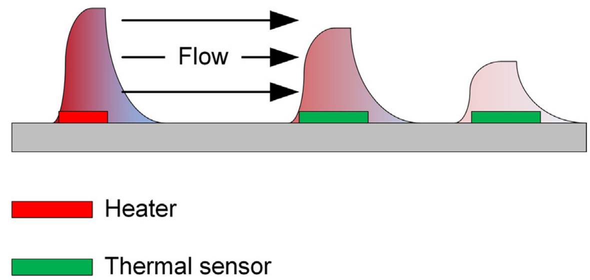

Fig. 4. Measurement principle of a time of flight flow sensor.

temperature sensing elements (thermoelectric voltage, change of resistance, etc.), as shown in Fig. 3. Usually, the difference between the sensor signals is used as a measure of flow [5]. This type of sensor also allows bidirectional flow measurement.

Time of flight (TOF) is a less widespread concept. As shown in Fig. 4 it operates with a heater, as with the previously described sensors, but in contrast it is excited with heat impulses rather than being operated continuously. One or more temperature sensing elements at a certain distance from the heater detect these impulses but instead of a temperature change, the time course of the impulses is used to determine the flow speed [6,7].

There are different excitation modes in which to operate the heater with these architectures. The hot-wire/-film and the calorimetric sensors use a constant supply and mesaure the gradient of the heat distribution; the TOF works with short impulses and measures the time that is needed for those impulses to propagate.

Both the hotwire/film and the calorimetric principle have in common that they excite the heater at least until thermal equilibrium is reached. Power is consumed during this time without yielding any useful measurement signal.

1.2. Conventional methods of thermal control

As thermal phenomena are governed by equations where quantities such as temperature, power and energy are involved, reproducible results can only be obtained if these quantities are controlled. Otherwise, unwanted sensitivity to the temperature of the medium and other parameters will occur in the system.

For the hot-wire/-film and for the calorimetric sensors, two methods are commonly used to control the thermal state of the sensor. The first one holds the heater temperature or the temperature difference between the heater and the medium at a constant level; the second does the same to the heater power. They are commonly designated the 'constant temperature' (CT) and 'constant power' (CP) modes [8].

For the CT mode, the temperature of the medium must be sensed and an electronic circuit adjusts the heater power to maintain the desired temperature or temperature difference.

The CP mode is achieved by regulating the output power of the circuit that drives the heater. This generally requires monitoring