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A Miniaturized 2D Solid State Anemometer Based on Thermal Flow Sensors

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Abstract

In this work a compact wind velocity and direction sensor, based on properly probing the pressure distribution generated by the wind around a cylinder surface, is presented. The originality of the approach consists in a particular channel configuration capable of deriving a flow that varies with the wind direction according to a cosine function. Optimization of the channel structure has been performed by means of fluid-dynamic simulations. A prototype, consisting of two orthogonal sections, where the derived flow is read by integrated thermal flow meters, is described and the results discussed.

Keywords: Anemometer, Integrated sensors, Miniaturization, Low power.

1. Introduction

The growing interest in non intrusive wireless sensors networks for meteorological, agricultural[1], environment monitoring[2] has urged the development of miniaturized low power sensors capable of detecting both the wind direction and velocity. Mechanical cup-and-vane anemometers still represent the simplest and less expensive solution when miniaturization and a small detection limit are not required. Ultrasonic anemometers[3] are more reliable and robust than mechanical ones but, similarly to the latter, are not suitable to be downscaled below dimensions of several centimeters. Thermal anemometers are precise and sensitive devices that, however, are marked by excessive power consumptions to be employed in battery powered network nodes[4]. Thermal flow meter with reasonable power consumptions (mW range) and dimensions in the millimeter range can be easily obtained by means of silicon micromachining techniques[5] but their intrinsic fragility prevents their direct exposure to wind streams. A possible solution using micromachined thermal anemometers to measure gas flow rates derived from the pressure differences generated by the wind around a cylindrical[6] or spherical body. In this way the micro-sensor might operate in a more protected environment, but, with the configuration presented so far estimation of both the wind direction and velocity is not straightforward.

In this work we describe an original channel distribution capable of deriving a flow that depends in a sinusoidal fashion on the wind direction. A prototype based on two orthogonal sections equipped with integrated thermal micro-flow sensors have been proven effective in estimating both the wind velocity and direction with simple and reliable calculations.

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2. Device operating principle

In order to understand the operating principle of the device, let us first consider Fig.1(a), depicting the cross-section of a cylinder exposed to a wind with velocity **u** perpendicular to the cylinder axis. The cylinder produces a disturbance on the otherwise uniform velocity distribution and a non uniform pressure distribution is generated around the cylinder outer surface. The most representative parameter is the Reynolds number (Re) given by $\rho uD/\mu$, where ρ and μ are the gas density and viscosity, respectively while D is the cylinder diameter.

It has been shown[7] that the threshold Re value for separation of the boundary layer and consequent vortex formation is only of the order of a few tens. In a Re interval of several decades starting from the mentioned threshold value, the pressure distribution along the cylinder outer surface as a function of angle ϕ is similar to that shown in Fig. 1(b). The curve is normalized to the dynamic pressure, equal to $\rho u^2/2$, indicating that the pressure differences rapidly increase with the wind velocity.

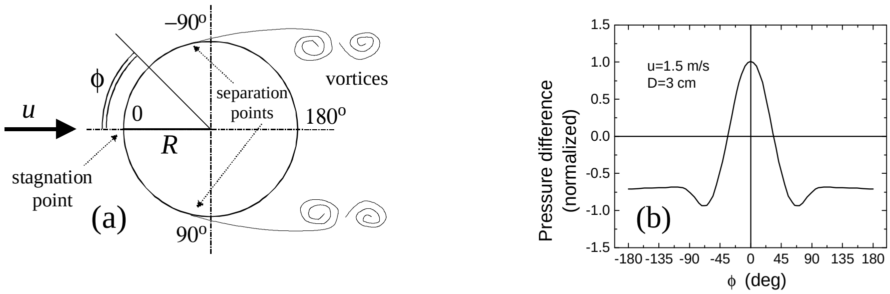

Fig.1 Flow around a cylinder exposed to an air stream of velocity **u** (a) and pressure distribution along the lateral surface (b).

The pressure distribution of Fig.1(b) has suggested the development of anemometers[8] such that schematically shown in Fig. 2(a) where a channel coinciding with a diameter is drilled through the cylinder body and the pressure difference across the two channel ends is measured. The idea is using two distinct sensors with perpendicular diameters to determine the wind direction and speed. Unfortunately, as shown in Fig.2 (b), this possibility is prevented by the non monotonic dependence of pressure difference dependence on the angle θ in the interval 0-180°.

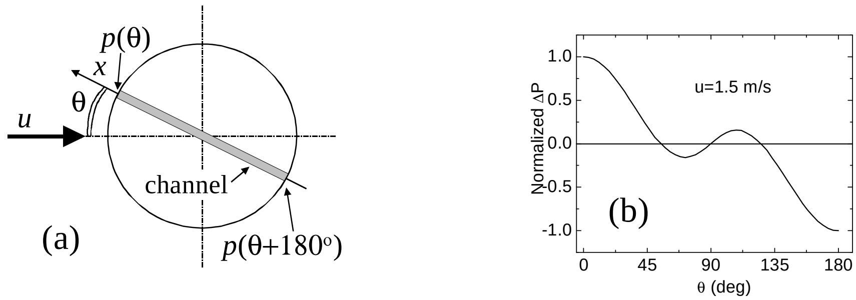

Fig.2. Single channel anemometer (a) and its response to the wind direction (b), showing a non monotonic behavior.

The device proposed in this work is based on substituting the single diametric channel with the channel configuration shown in Fig. 3 (a), where C1-C6 are channels ending on the lateral surface. The wind velocity u forms an angle θ with the symmetry axis of the channel structure, indicated with x. The pressure distribution around the cylinder, probed by the channels, produces a pressure difference ΔP across H1-H2. The structure has been simulated using the fluid-dynamic subset of the COMSOL™ finite element method solver. The angle α was varied in order to obtain the required monotonic behavior and find the value that best approximated a cosine function. The optimum a value turned out to be 40°. An example of simulated behavior obtained with the optimum structure exposed to a wind velocity of 1.5 m/s is shown in Fig. 3(b). Simulations performed at velocities in the range 1-10 m/s, showed that this empirical result is unexpectedly maintained over a large Re range.

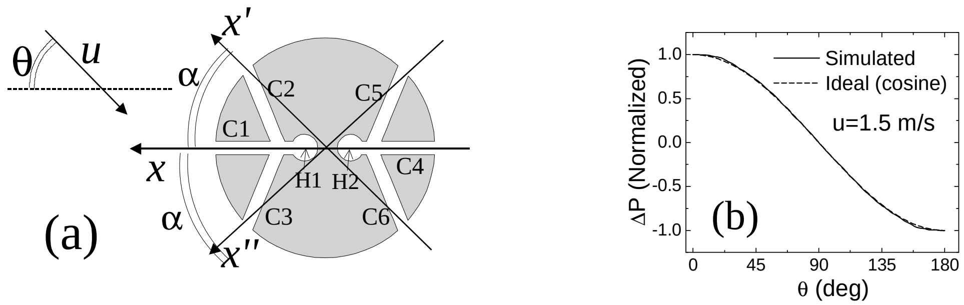

Fig.3.Proposed channel configuration (a) and pressure difference between H1 and H2 as a function of θ compared with a cosine unction (b).

3. Two dimensional prototype

The prototype, build according to the principle described in previous section, is shown in Fig. 4(a).

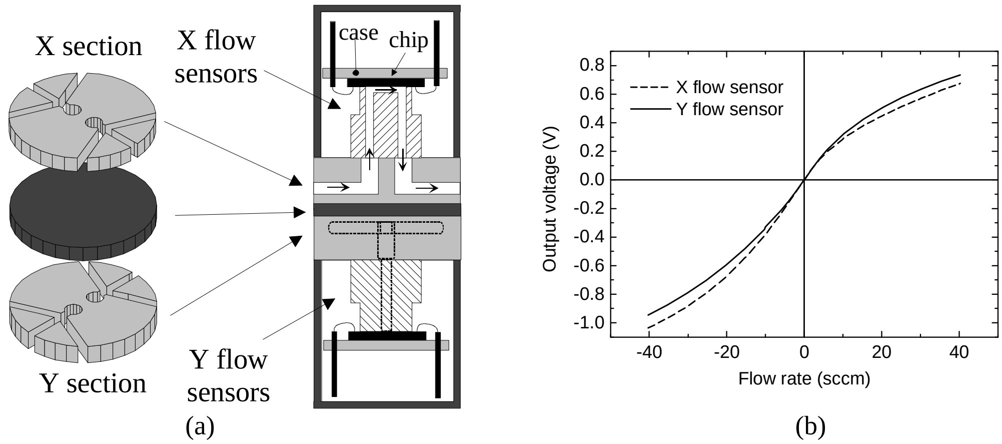

Fig.4. Structure of the two dimensional anemometer (a) and response of the X and Y flow sensors (b).

A Poly-Methyl-Methacrylate cylinder with 3 cm diameter has been obtained by gluing together a series of disks, where two orthogonal channel confifurations, *X* and *Y*, identical to that of Fig. 3(a) were precisely milled. For each section a high sensitivity integrated thermal flow meter is connected across points H1 and H2, so that the measured flow is proportional to the pressure differences to be sensed. The flow meters are based on silicon chips fabricated using the STMicroelectronics process BCD6s and subsequently post-processed to produce thermal insulation between the sensing microstructures and the substrate. The gas flow is conveyed to the chip by means of a plastic adapter as schematically shown in Fig. 4(a). Details about the flow sensor fabrication can be found elsewere[9]. The sensors are connected to an electronic circuit including two analog readout channels (X and Y), each one formed by a low noise amplifier and an 1.5 Hz low pass filter. The total gain of the amplifier-filter cascade is 150. The signal are acquired by a microcontroller (Analog Devices ADuC847), equipped with a precise multichannel ADC, and transmitted to a personal computer (PC) by means of a wireless link. The response of the two flow meters used in the prototype is shown in Fig.4(b). A linearization procedure implemented on the PC was used to estimate the flows from the senor output signals. Considering the sinusoidal relationship of the pressure difference across H1-H2 on the wind direction angle θ, the two flows Q_X and Q_Y measured by the corresponding flow sensors are such that, Q_X=f(u)cos(θ) and Q_Y=f(u)sin(θ), where f(u) is a function of the wind velocity u. Using elementary trigonometric operations the wind direction (θ) and the function f(u) are estimated.

4. Results

The experiments have been performed inserting the cylinder in a pipe of 10 cm diameter (wind tunnel) in such a way that the active sections (X and Y) fall close to the pipe axis. A flow is forced in the pipe by means of an electronically controlled fan. The flow velocity is measured by a precision mechanical anemometer while the angle is varied by rotating the anemometer. The results of angle estimation are shown for different wind velocities in Fig. 4, where the error is represented in the inset. It is possible to observe a good agreement between the actual and the estimated wind direction in a wide wind velocity range. The maximum error on the angle is 8º.

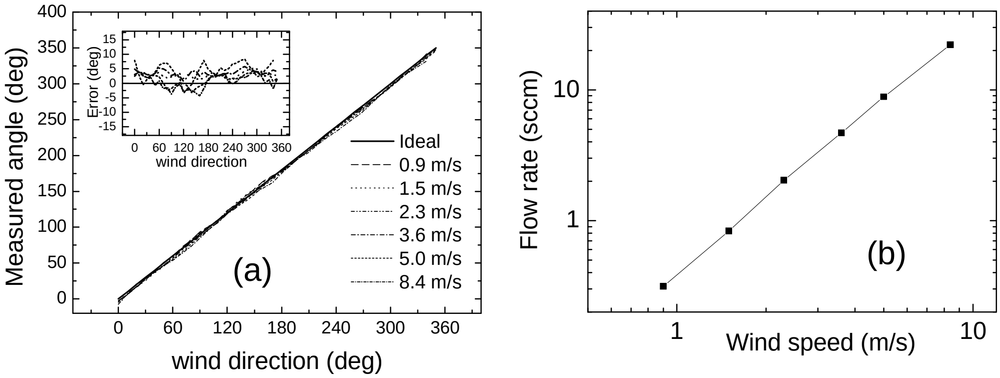

Fig.5. Estimated angle as a function of the actual wind direction (a). The inset shows the corresponding error. Dependence of the estimated quantity f(u) as a function of the wind speed.

The function f(u) is plotted in Fig. 4(b), where a power law behavior well suitable for simple estimation of the wind velocity can be recognized.

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