Sensors and Actuators A 257 (2017) 185–193

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

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

Corona anemometry using dual pin probe

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ARTICLE INFO

Article history:
Received 11 September 2016
Received in revised form 30 January 2017
Accepted 20 February 2017
Available online 23 February 2017

Keywords:
External flow
Ozone generation
Anemometric
OpenFOAM
Parallel pin
Corona discharge

ABSTRACT

In this paper, we present an experimental study on the anemometry characteristics of a bipolar corona discharge probe with symmetrically arranged parallel electrodes. The possibility of measuring a wide range of air flow rate/flow velocity has been demonstrated. The parallel pin probe simultaneously creates positive and negative corona discharge, decomposes air media at both electrodes while keeping them with charge balance ensured by the use of a single isolated power source. This feature is fundamentally different from other reported unipolar discharge configurations, where the decomposed gas and charge is created from single electrode. Under the existence of the air flow, the decomposed gas is redistributed towards the downstream electrode, and changes the current–voltage characteristics of the system. When the probe is in open space, the discharge current is reduced with increasing flow velocity. In constrained space the discharge current behaviour is similar at high flow rates above 25 l min^{-1}, while at low flow rates this relation is reversed. In addition, the sensitivity of discharge current to change in air flow is much higher when the negative pin is placed downstream. Both open space and constrained space characteristics are explained in terms of the influence of external flow on the ozone distribution and its effect on the discharge current. This explanation is supported by ozone measurements, with the data showing good correlation between the discharge current and ozone concentration with respect to the external flow. The role of the electrode separation and discharge voltage is also investigated.

1. Introduction

Air flow measurement is widely used for accurate and continuous monitoring of gas exchange in numerous practical applications, such as air conditioning in offices, hospitals and clean rooms. Flow measurement can be based on a variety of different principles [1], successful commercial flow meters include orifice flow meters, linear resistance pneumotachographs, ultrasonic flow meters or hotwire/hotfilm anemometers. The orifice flow meter and linear resistance pneumotachographs are based on measuring the pressure drop between upstream and downstream of the flow passing through an orifice providing resistance to the flow. The ultrasonic flow meter is typically based on the transmission of ultrasonic signal between a pair of transducers, where the flow velocity is calculated based on transit time change [2]. With advancing in micro fabrication technology, air flow meters have been improved in terms of design, minimum size, cost efficiency and complex integration [3,4].

In parallel, the investigation of electric discharges for flow velocity and pressure detection has perhaps started with the work of Thomas for microphone [5] and of Lindvall for turbulence measurement [6]. Later Werner published comprehensive investigation on the effect of pressure, velocity, temperature and humidity on the electric discharge [7]. Since then, various kinds of ion anemometers have been developed and have wide applications in different circumstances, from low velocity [8] to supersonic velocity [9–11], from normal air pressure [12] to low pressure at high altitudes [13], or from automobile injection system to a speedometer of an aircraft [14]. In recent efforts with advancing technology, the corona anemometer has attracted more interest in improving measurement resolution at the lower end of flow velocity range [15], increase of linearity [16], providing integrated sensing network [17], and wider measurement range [18]. Related studies have also been extended for pressure and temperature characterization in different environments [19–24].

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http://dx.doi.org/10.1016/j.sna.2017.02.025
0924-4247/

In general, the ion source in ion anemometer can be constructed by α rays emitted from a radioactive source [25–28], although more commonly by means of high electric field corona discharge because of its cost and higher yield of ions to achieve quicker response and better sensitivity. In an electrical discharge, the ions created through ionizing collisions have approximately two or four orders smaller mobility than electron mobility, so an ion cloud is left behind as the electrons reach the positive electrode [29]. The ion anemometer utilizes the movement of ions in the stream and detects the ion current. The air flow velocity is then calculated by either measuring the change of ion drift velocity, the deflection of ions flowing into a segmented collector, the ion-transit time over a known distance, or the combination of those [14].

The ion drift type velocity measurement relies on the fact that the mobility of ions in moderate electric fields is sufficiently low so that their paths are strongly affected by slight air movement. The ion source in this kind of device is usually from irradiation. When the air moves in the electrode interspace, some of the ions are carried away by the air flow or, alternatively, are forced to make a longer path so that they are offered a greater chance of charge neutralization, resulting in a change of ion current [8,30].

The deflection type velocity measurement is somewhat similar to the thermal anemometry device; the ion current originating from ion source is driven by electric field towards a partitioned ion collector. The collector is divided into insulated symmetrical segments so that in case of no flow condition equal ion current reaches all segments. With air flow, the ions will drift downstream and the partial currents flowing into the individual segments will vary based on the segment location. The signals are usually processed by the difference of current between pairs of segments over the total current as the reference, which in principle is similar with the Wheatstone bridge circuit in sensing technology. Obviously, multi directional flow can be detected as long as the collecting segment electrodes are properly positioned around the ion source [12,25,27,31–35]. Usually positive ions are used in deflection type flowmeters, since their mobility has smaller dependence on the air humidity compared with that of negative ions.

The ion-transit type ion anemometer utilizes ions flowing directly through a collector or ions passing near a charged electrode. The flow velocity is calculated based on the time difference of the induced current with and without the air flow. The time measurement is usually triggered based on maximum point or zero-cross point of the induced current [9,26,36].

In addition to the above presented sensor operation types, another kind of ion anemometer has also been developed for reduced flow rate detection. The anemometer is based on drift mobility increment mode, which was first demonstrated by Chua et al. [15] in a miniaturized format. It utilizes the product of ionization from corona discharge in a confined space. By igniting corona discharge in a small flow tube, ozone is quickly formed and the discharge current is suppressed [37]. With airflow the ozone concentration will decrease and thus the current–voltage curve of corona discharge will change accordingly [15]. In dry air, negative corona discharge creates ozone with concentrations several times larger than that of positive corona, and the reduction in discharge current due to ozone is much more significant [38]. Consequently, the ion anemometer is usually based on negative corona discharge.

From these studies it is well understood that the influence of geometry and discharge parameters, such as discharge electrode configuration, magnitude of discharge current, polarity and discharge mode (dark, corona or glow) is of significant importance [39]. Many authors have reported the characteristics of various electrode arrangements for ionic anemometry, typically needle-to-rod [7,14], needle-to-plane [9,15,25,30,39], wire-to-rod [17,33,35,40], plane-to-plane [11,18,34], point-grid-plane [7,12], wire-to-plane [32], and point-ring-ring [36]. The fundamental

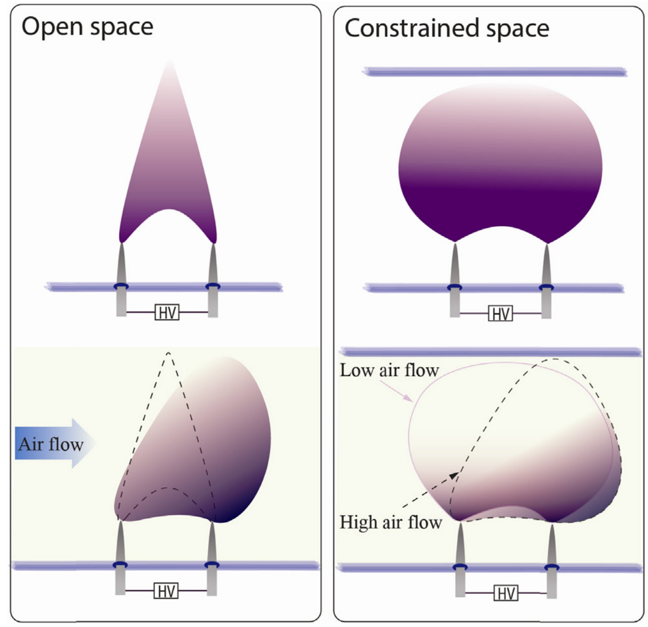

Fig. 1. Schematics of our proposed configuration in open space and in constrained space.

requirement for the above systems is a high-curvature electrode generating ions. The ions are primarily of one polarity created by either positive or negative discharge. On the contrary of the above presented corona based devices, our proposed configuration uses symmetrical electrode arrangement creating simultaneous bipolar corona discharge. This configuration has been fundamentally applied in pressure sensing and flow generation [41–46].

In this paper, we report for the first time the anemometry characteristic of a unique bipolar discharge configuration, using symmetrically arranged electrodes powered from an isolated single power source [41]. The anemometry is investigated in free/open space and in constrained space, i.e. flow channel with characteristic dimensions comparable with the electrode separation, as shown in Fig. 1. In free space, the parallel pins generate ion wind in the direction of pin axes, carrying away the charged species and discharge byproducts [46]. When the pin electrodes are exposed to a perpendicular external flow, the discharged gas will drift accordingly, affecting the discharge characteristics of the downstream electrode and consequently of the entire system due to the symmetrical arrangement of electrodes. In the constrained space, the discharged gas quickly fills the entire space surrounding the electrodes until a dynamic balance is reached, where the composition and decomposition rates are equal. A small external flow will reduce the composition rates, changing the gas composition and, consequently, the corona characteristics. A higher external flow will gradually drift the discharged gas downstream and the device will exhibit similar characteristics with that of open space.

The positive corona discharge enhances the ion deflection mode, suitable for measuring high flow velocity range, while the negative corona discharge with drift mobility increment mode is suitable for low flow velocity range. The initial momentum of corona-produced ion wind is significant in the direction parallel with the pins, resulting in weak effect of external flow in the same direction alongside the pins. On the other hand, the ion wind is negligible in the perpendicular direction and the device is sensitive to external flow perpendicular to the pins and thus suitable for use in this configuration.

The device itself is easy-to-build and can be implemented cost effectively because of its simple and commercially available com-