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THE 'SMART' SPHERE
Experimental Results

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The 'Smart' sphere is a small self-equipped datalogger having 25 mm outer diameter with a built-in sensor for pressure or temperature measurements. This sphere has the capability to receive commands by wireless techniques and also stores the data continuously in its internal memory. These data can subsequently be transferred by wireless transmission to a computer for detailed analysis. Test runs using the sphere have been carried out to validate accurate functioning of the pressure and temperature sensor. The surface pressure measurements were performed using the sphere with a built-in pressure sensor inside the wind tunnel, in which the air velocity was varied. A Finite Volume technique (FLUENT 6.1) was used to simulate the flow over the sphere in the wind tunnel. The overall pressure distribution and the velocity distribution over the sphere have been obtained from these computations. The experimental and numerical results are in good agreement with each other. Additionally experiments with a free moving 'Smart' sphere with built-in temperature sensor have been carried out in a liquid column with a temperature gradient. It has been found that sphere has the capability to measure the temperature gradient rapidly and accurately as it passes through the column. The temperature measured by the sphere is compared with the reference temperature measured by 16-channel temperature datalogger and found to have good agreement with each other.

Keywords: sphere; data logger; pressure; temperature; wireless.

INTRODUCTION

Almost all particulate products are manufactured, processed, stored and transported in fluids. In processes like mixing and transportation, particle–fluid interactions are difficult to understand because the motion of both the particle and the fluid have their own characteristic time and length scales which can vary enormously in magnitude. Thus it is essential to have the thorough knowledge of the aerodynamic forces acting on the particle to improve the design of the systems handling such processes. Similarly in the food processing industry food solid fractions are conveyed in a number of operations. During this process there is a possibility that the solid–fluid stream may be excessively heated or cooled as it travels along the axial length of the pipe, which can result in a loss of product quality. Thus online temperature measurement over the axial length of the pipe is desirable. In this work we develop the novel technique of a 'Smart' sphere used to measure both aerodynamic forces and temperature.

To measure the aerodynamic forces, two approaches are reported in the literature. The first is to use sensors (strain gauge/pressure sensors) attached to a sphere/plate, with the data transmitted through a probe fixed between the sphere/plate and the data acquisition system (Willetts and Murray, 1981; Mollinger *et al.*, 1995; Moraga *et al.*, 1999; Kurose and Komori, 1999; Svedin *et al.*, 1998). It is clear that this method of supporting the probe or wire results not only in disturbance of the flow, but also causes a severe restriction of the free movement of the sphere (linear and rotational). The second is an optical approach, based on using a camera and strobe to record sequences of images, from which the velocity of the sphere can be obtained. This approach suffers from difficulty in terms of accuracy, and in separating the effect of the different aerodynamic forces acting on the sphere. Ikushima *et al.* (1993) developed a 100 mm sphere equipped with a built-in processor to measure the drag force, acceleration and velocity acting on a free-falling sphere. Although their work eliminated the limitation of a fixed position for the probe, the instrument was however quite large to be introduced in any real system. In this work we develop the 25 mm 'Smart' sphere to measure aerodynamic forces by measuring the surface pressure and another sphere with a built-in temperature sensor to measure temperature.

The free moving 'Smart' sphere technique has been developed in this project to overcome these shortcomings and could be readily used to measure the temperature and

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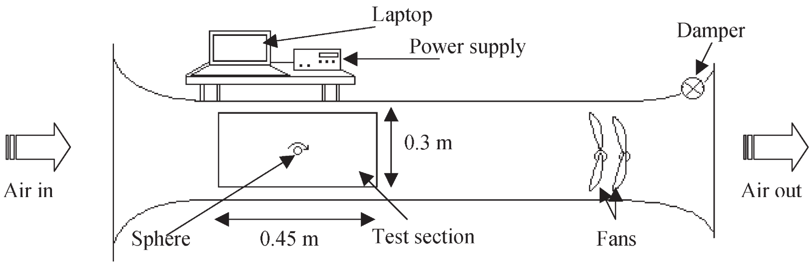

Figure 1. Pressure measurement in wind tunnel.

pressure separately. The present work deals with the development of a 'Smart' sphere with the pressure and temperature sensor and its experimental verification. Numerical verification is also done for the pressure measurements. The 'Smart' sphere of 25 mm (o.d.) has been developed with a built-in processor (pressure or temperature sensor, memory, wireless sensors, power source and CPU). In this paper we only deal with the surface pressure measurements over the sphere in the wind tunnel and preliminary temperature measurements made by a free moving 'Smart' sphere in a liquid column with temperature gradient.

The 'Smart' sphere finds its application in Food industries for measuring temperature and pressure distribution along the pipe length and to provide thermal history for perishable goods under transport etc. Thus this technique would provide a diagnostic tool for process industry and would contribute in obtaining the process data, which would be essential for improving the modelling and design of processes.

'SMART' SPHERE TECHNIQUE

The 'Smart' sphere with the built-in pressure or temperature sensor is a small self-equipped datalogger (25 mm, o.d.) completely designed and developed in-house. It has the capability to record data as fast as 10 ms per sample i.e., 100 samples/s and stores it in its internal memory. It has the built-in transmitter and receiver for the wireless data transfer to the PC and to receive the external commands given by the PC. The 'Smart' sphere has a built-in power source so it does not require any external continuous power for operation. It has the capability to store 128 000 samples of 16-bit data into its internal memory. The silicon type pressure sensor is used in the sphere with the maximum pressure range of 3.44 KPa. A high precision thermistor is used as the temperature sensor with an accuracy of $\pm 0.2^{\circ}$C over the range of 0–70°C. The sphere provides the resolution of 3 Pa/bit for the pressure measurement and 0.05°C/bit for temperature measurement. Temperature sphere is completely waterproof and can easily be used in liquids. All the above capabilities make it an ideal device to perform measurement in free moving conditions.

Further, we would briefly discuss about the experimental setup and procedure for surface pressure measurement by the fixed sphere in the wind tunnel followed by the numerical simulation of the surface pressure over the sphere. The experimental setup and procedure for temperature measurement using free moving 'Smart' sphere is discussed there after. Finally results for both experiments and numerical simulation are discussed in the Results and Discussion section.

EXPERIMENTAL SETUP FOR PRESSURE MEASUREMENT

The experiment with the 'Smart' sphere is carried out in the wind tunnel. The objective of this experiment was primarily to assess the accuracy of pressure measurement. Hence test runs were carried out under conditions in which the sphere was attached horizontally to a very fine string in the wind tunnel and rotated on its own axis to measure surface pressure over the sphere, as shown in Figure 1 (note that the Figure 1 is not to scale). The wind tunnel used in this experiment is designed to produce the uniform air velocity profile. Damper was used to vary the velocity of the air flowing through the tunnel. The pressure

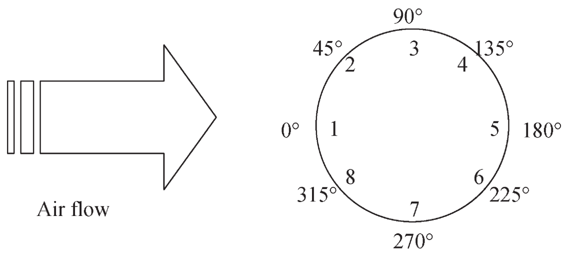

Figure 2. Points where the pressure is measured by smart sphere.

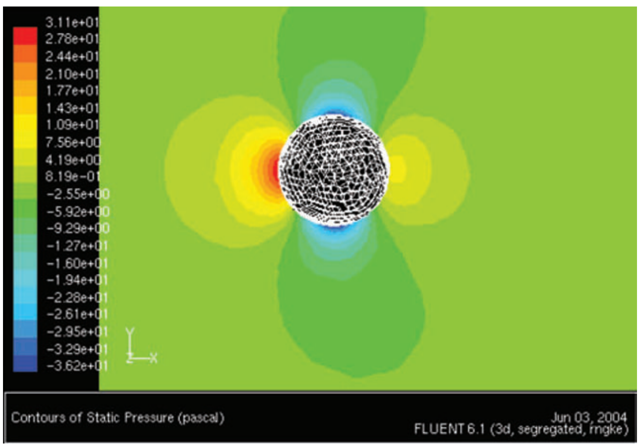

Figure 3. Surface pressure distribution at inlet velocity of 7.1 m s^{-1}.