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Progress in Process Tomography & Instrumentation System

Series 9

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CONTENTS

PREFACE

This book is an introduction to many of the topics that an engineer needs to master in order to successfully design experiments and measurements systems. In addition to descriptions of common measurement systems, the book describes computerized data acquisition systems, common statistical techniques, and guidelines for planning and documenting experiments. More comprehensive studies of available literature and consultation with product vendors are appropriate when engaging in a significant real-world experimental program. It is to be expected that the skills of the experimenter will be enhanced by more advanced courses in experimental and instrumentations systems design and practical experience.

The design of an experimental or measurements system is inherently and interdisciplinary activity. For example, the instrumentation and control system of a process plant might require the skills of chemical engineers, mechanical engineers, electrical engineers and computer engineers. Similarly, the specification of the instrumentation used to measure the haemoglobin status in dengue patients will involve medical doctor, electrical engineers and computer engineers. Based on this fact, the topics presented in this book have been selected to prepare engineering students and practicing engineers of different disciplines to design instrumentations projects and measurements systems.

Experimental methods are not unimportant, but analytical studies have, at times, seemed to deserve more emphasis, particularly with enormous computing power that is available. Laboratory work has also become more sophisticated in the modern engineering curricula.

This book is generally suitable as an accompaniment to laboratory sessions oriented around the specific experiments available at a particular institution.

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8

ANEMOMETERS FOR MULTI-APPLICATIONS

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8.1 Introduction

The history of anemometers traced back to the 14^{th} century, when the Italian Art Architect Leon Battista Alberti invented the first mechanical Anemometer, which consists of a disk placed perpendicular to the wind that rotates by the force of the wind, and by the angle of inclination of the disk the wind force momentary showed itself. Years later in 1846 John Thomas Romney Robinson invented the hemispherical cup anemometer and consisted of four hemispherical cups. The cups rotated horizontally with the wind and a combination of wheels recorded the number of revolutions in a given time, till today the hemispherical cup is still been used. Ever since then we have had the invention of the fundamental basic type namely the *laser Doppler anemometer* with a laser beam that split into two separate beams, One of the two beams is transmitted out from the centre of the anemometer. Movement in the air causes a Doppler shift in the laser light. Scientists analyze the Doppler shift to calculate wind speed. *The sonic anemometer* determines instantaneous wind speed and direction (turbulence) by measuring how much sound waves is travelling between a pair of transducers are speed up or slowed down by the effect of the wind. *The windmill anemometer* has its axis of rotation parallel to the wind the velocity of the windmill is translated into wind speed. This anemometer can indicate wind direction and wind velocity.

Based on these aforementioned types of anemometers, researchers have developed numerous type of anemometer based on necessity in various applications where previous methods adopted have proved adoptive. This paper focuses on four of these newly developed anemometers in the following areas namely; in high voltage transmission, Bread-baking industries, water flow measurement calibration and breeze sensor applications.

In the high voltage, transmission Guo-ming et al. [1] developed a Passive optical fibre anemometer from the hotwire anemometer, owing to necessity that Electric transmission lines often affected by the amount of ice accumulation on them during the cold weather, which often causes disconnection of the line or results in tower failure and many other problems. Hence, in other to prevent loss / disconnection and disasters of any kind there is a need to effectively and efficiently monitor overhead transmission lines properly, and since wind plays an important role in ice accumulation on the transmission lines thus the need for this anemometer.

In the industrial bakery, Nantawan et al [2] developed a new form of anemometer from the hot wire anemometer in quest for a device that is sensitive to low velocity at high temperature in order to measure airflow rate in the industrial bread-baking oven.

Wen-Tsai et al [4] designed a portable anemometer called the breeze sensor capable of displaying two-elemental direction and data as well as measure variation in small wind speed and instantaneous wind speed based on wireless sensor network by the use of negative voltage to ionize air.

Furthermore, Uchiyama and Ide [3] developed another anemometer based on the principle of the hot-film technique used as a calibrator in the water flow measurement.

8.2 Literature Review

8.2.1 Principle and design of FBG anemometer

The typical traditional anemometer works efficiently in normal condition of environments. However, when used on high voltage transmission lines suffer two main problems. First is the inability of the anemometer to withstand electromagnetic interference (EMI). This is due to that fact electrical components are most often sensitive to EMI and its can affect the reading of the anemometer. The second problem is the power supply condition as all anemometers is an active device. Thus to overcome this problems, passive anemometer is required for long term monitoring. Based on their intrinsic invulnerability against EMI, Fiber Bragg Grating (FBG) sensors are considered as a good approach on electrical engineering monitoring [1]. The FBG sensors have success recorded on them on many applications for measuring temperature or strain in generators, cables, and wind turbines.

This wind-monitoring system for overhead transmission consists of FBG anemometer, an optical fiber-composite overhead ground wire (OPGW), an interrogator and computer as shown in figure 8.1. Through a fibre in the OPGW, the FBG passive anemometers mounted on different towers are connected to the wavelength interrogator located at the substation. At first, wideband light is transmitted from the interrogator to the FBG anemometer and then, the particular wavelength light reflected by the FBG will be transited back to the interrogator, from which the Bragg wavelength shifts of the reflected light could be demodulated. Finally, these outputs of the interrogator are turned into forms of wind condition that are able to be visualized in the computer [1].

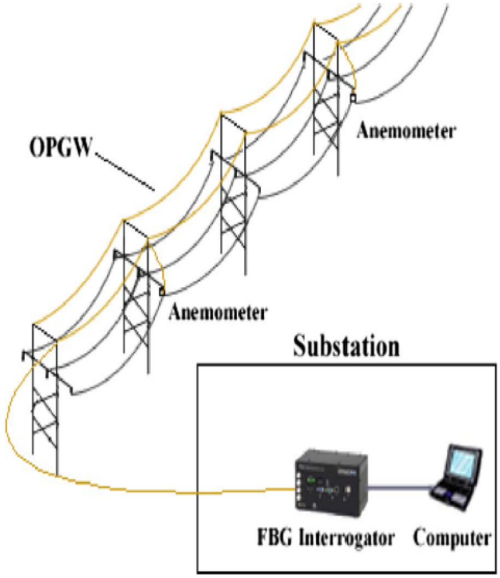

Figure 8.1: Structure of the FBG Wind monitoring system of overhead transmission lines

The important part of the system is the design of the anemometer, where from figures 8.2 and 8.3 we can view the design and structure of the anemometer. The principle of FBG is that the FBG anemometer will measure the force generated by the wind (figure 8.2). When the wind is applied on the circular plate, counter force will cause the speed of the wind on the plate to reduce to zero. Based on this concept the relationship between the wind speed and force can be found [1].

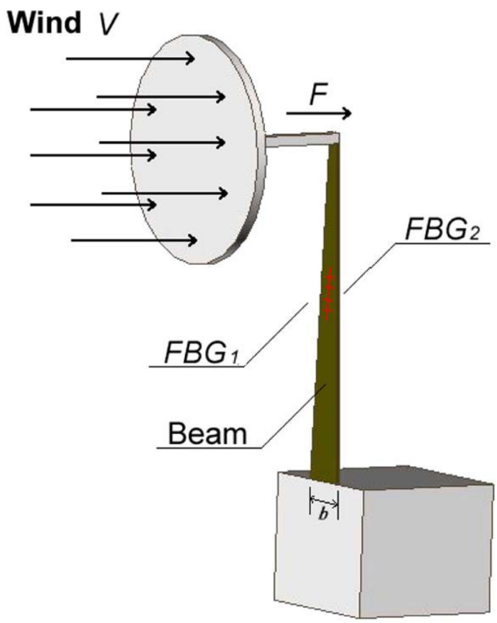

Figure 8.2: The principle of wind sensing on the FBG Anemometer

In anemometer structure shown in figure 8.3, The principle of operation is based on measurement of the force generated by the wind on the circular plate of the FBG anemometer, the wind speed at normal to the circular plate reduces to zero with a force generated simultaneously, the force is then transmitted to the top of the beam of uniform strength, with the lower stand withstanding the press, of the pull exerted by the upper end resulting in a strain. Furthermore FBG responds to both strain and temperature changes, in order to eliminate this cross effect, two FBG are symmetrically glued together on the beam surface, and whenever the wind is incident on the FBG there is a cancellation of temperature effect and hence the speed can be monitored by the shift on the FBG.

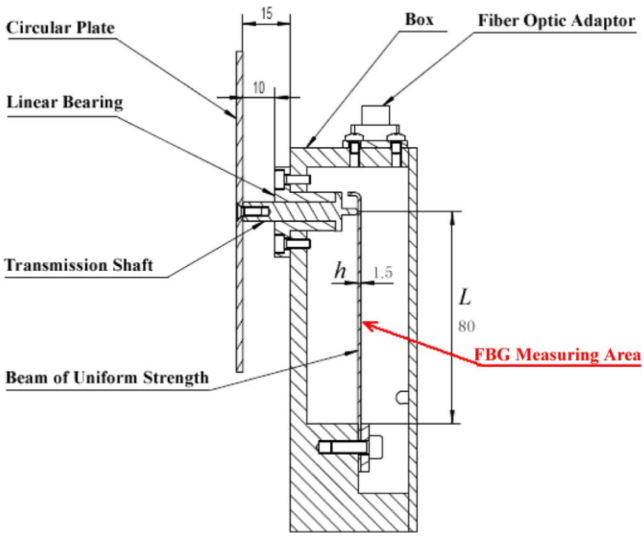

Figure 8.3: The structure of the FBG Anemometer.

8.2.2 Principle and design of anemometer for industrial Bread-baking

Owing to the requirement for a sensitive at low velocity and high temperature device to measure the airflow in industrial ovens Nantawan et al [2] developed the new type of anemometer. As shown in figure 8.4 the sensor has two probes made of a heated element and thermocouple. The Heated element made of Ni-Cr wire and for the thermocouple, a K type thermocouple measured the temperature of the heated wire. The probe connected to data logger to record the temperature profile. In order to improve the probe sensitivity, surface contact between heated wire and thermocouple is adjusted. The sensor works on the concept of temperature of a heated wire dropping proportionally to airflow velocity. Based on this condition, data profile on the temperature are mapped to endure the condition or value of the airflows.[2]

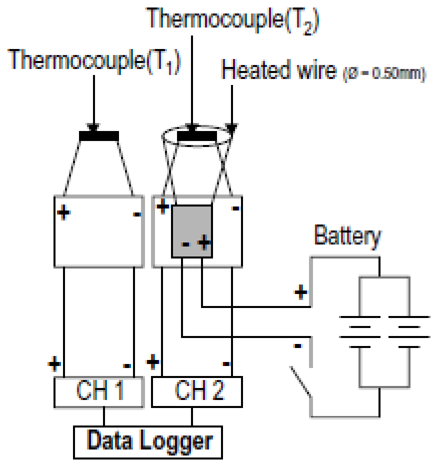

Figure 8.4: The prototype Industrial bakery Anemometer

8.2.3 Principle and design of hot film anemometer for water flow measurement calibrator

The calibrator for water flow measurement designed using the hot film anemometer, with the objective of designing a hot film anemometer with a contraction nozzle and investigating the applicability of computational fluid dynamics in designing the calibrator. A schematic diagram of hot film anemometer is shown in figure 8.5. The calibrator is made of transparent acrylic resin. The liquid is ejected through the nozzle and into a receiver. The flow is control by a liquid level controller. In order to know the linear output voltage of hot film anemometer and the volumetric flow rate of liquid, the calibrator is investigated using an L-type Pitot tube. Hot film anemometer measurement was done using hot film anemometer system and a sensor, where the sensor tip is made of quartz glass coated platinum. Sensor is connected to an L type connector as shown figure 8.6.[3]

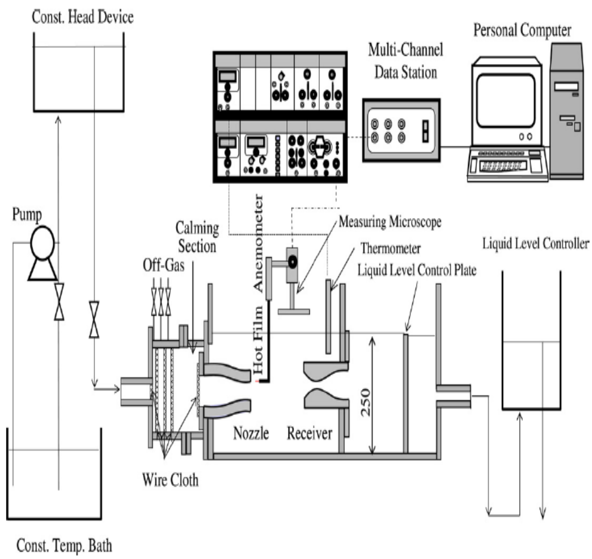

Figure 8.5: Schematic diagram of the experimental apparatus

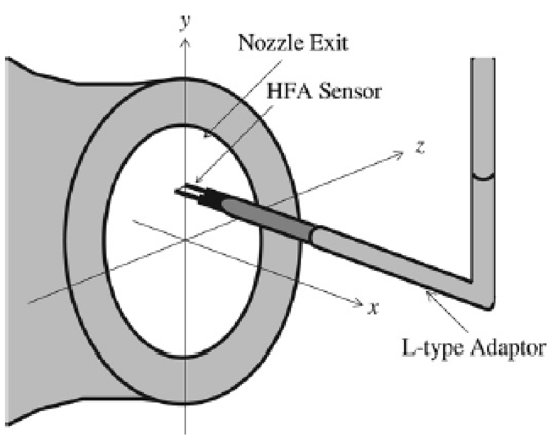

Figure 8.6: Co-ordinate of the Pitot tube measuring system

8.2.4 Principle and design of breeze sensor system based on electric field via two elemental direction

The breeze sensor designed based on the use of gas molecules of negative high voltage free air to form equip-potential field which will offset as it's affected by wind, the voltage difference measured will represent the value of the wind and its direction. The design is as shown in figure 8.7. The Sensor operation is based on the principle that input two electrodes in one conduit with high voltage connected to create electric field and polarize the air forming a charged cloud as shown in figure 8.7. Charges will move from the positively charged plate to the negatively charged plate and whenever there is disruption in the motion an offset is created. At no wind there is zero speed in the time taken from positive to arrive to negative plate. When there is a wind condition, time arrival of iron cloud will varies and the time different is calculated as the wind speed.

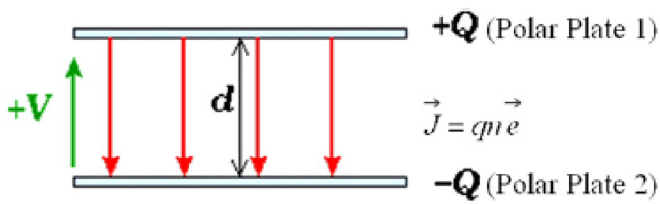

Figure 8.7: The principle of operation of the breeze sensor

For two-elemental electric field breeze anemometer to be used to measure wind speed and multi-direction measurement, it will require 2 groups of sensors of receiving end and filter circuit with vertical placement and an input point of high negative voltage in the middle. This will create a two-elemental sensing circuit capable of detecting wind direction as shown in figure 8.8 [4].

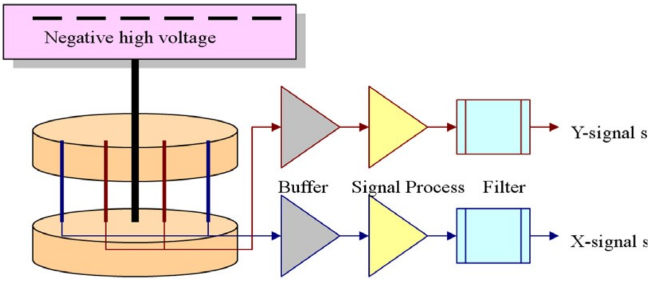

Figure 8.8: The 2- elemental electric field breeze anemometer

8.3 Result

8.3.1 Anemometer for High Voltage Overhead Transmission Lines

The developed FBG anemometer was tested using wind tunnel experimental setup to validate the performance of the sensor. The anemometer was placed at the center of the wind tunnel and connected with the interrogator by using an optical fiber. The relationship between force and wind can be known in equation 8.1.

$$F = \frac{1}{2} pV^2 C_d A \tag{8.1}$$

where,

p = density in air,
C_d = drag coefficient
A = reference area

and the shift of the wavelength separation that are used that measured the speed of the wind is defined by equation 8.2.

$$\Delta\lambda = 2\lambda_1 (1 - p_e) \Delta\varepsilon. \tag{8.2}$$

in which $\Delta\varepsilon$ = the strain of the beam of uniform strength.

The Bragg wavelength demodulated by integrator and displayed at the computer monitor. In order to test the reliability of the anemometer the speed of the wind was increased proportionally from 0 to 15 m/s during the test. The Bragg wavelength of the anemometer is recorded and the result is as shown in figure 8.9.

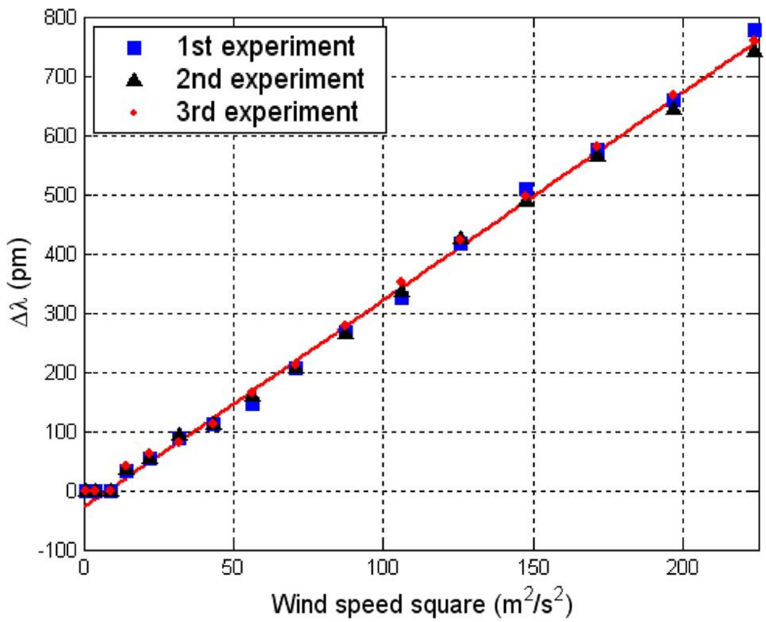

Figure 8.9: Result of the wind tunnel experiment

Based on the obtained result the wavelength is almost zero for wind speed below 3 m/s due to friction. For the condition where velocity is 3 m/s, it can be seen that the wavelength shift $\Delta\lambda$ varies linearly with wind speed [1].

8.3.2 Anemometer for industrial bread baking

The sensor designated to measure an airflow velocity in the industrial bread-baking oven. The effectiveness of the anemometer is tested using an actual industrial oven. The anemometer was designed so that changed in the airflow will caused changes in the temperature of the heated source. Based on this condition between temperature difference and airflow velocity mathematical model is established in equation 8.3.

$$Y = f(x_1, x_2) = -4.2523 + 0.8394 \times 10^{-3}(x_2)^{3/2} \times 3.172e^{100/(x_1-x_2)} - 0.4601 \times 10^{-3}(x_2)^{3/2}\, e^{100/(x_1-x_2)} - 01416 \times 10^{-6}(x_2)^3 - 0.1998e^{200/(x_1-x_2)} \tag{8.3}$$

where,

x_1 = Sensor temperature (^{o}C),
x_2 = Air temperature (^{o}C)
Y = Airflow velocity (m/s)

Based on equation 8.3, the result is obtained as in figure 8.10. The sensor tested in actual baking oven which consist of four zones with different temperature profile and airflow velocity. Based on this testing the result is as shown in figure 8.11 , where when compared to actual result is coherent to the result.[2]

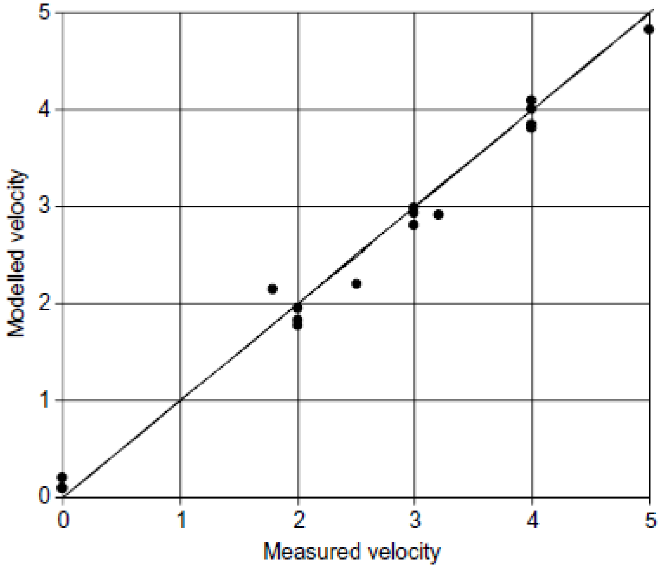

Figure 8.10: The model performance

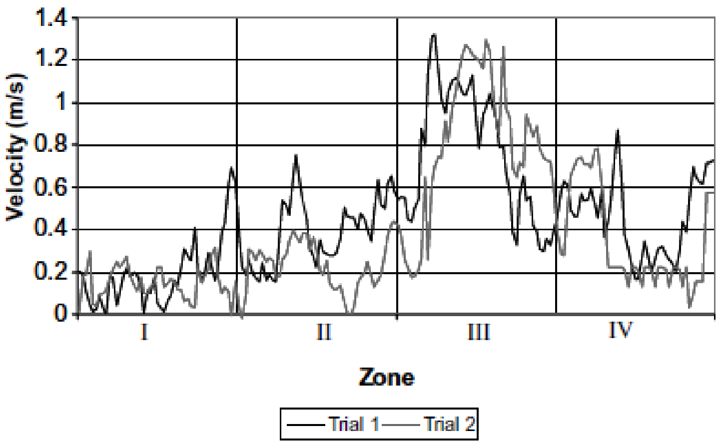

Figure 8.11: Velocity profile in an industrial bread-baking oven.

8.3.3 Anemometer as calibrator for water flow measurement

The application of hot film anemometer as calibrator, the measurement result is done near the Pitot Tube, where the hot film anemometer and laser Doppler anemometer are placed in front of the 10 mm Pitot tube. Based on the flow of the velocity of the output of the Pitot tube, the flow will produce linear output voltage on the hot film anemometer. The result of the linear output voltage and linear velocity is as shown in figure 8.12, figure 8.13. Where when compared of the distribution of velocity reading between hot film anemometer, Laser Doppler anemometer and computational fluid dynamics, all of the three reading show almost the same result where the result is shown in figure 8.14 [3].

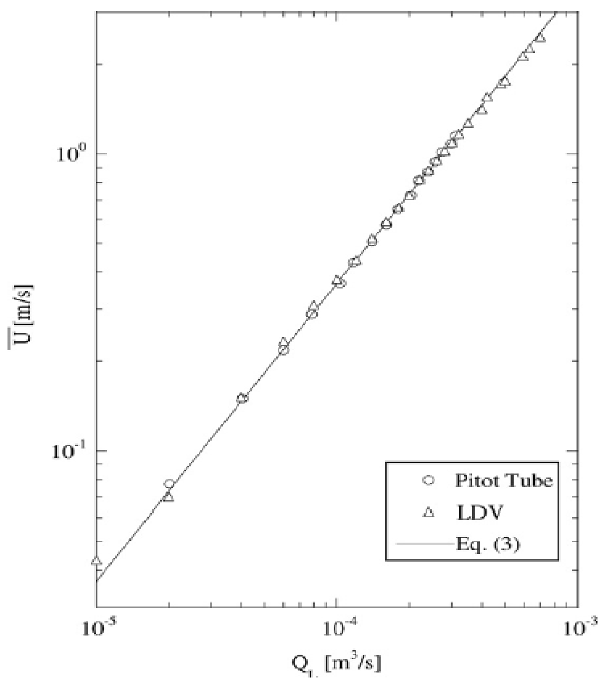

Figure 8.12: Comparison between the values observed using Pitot tube and those from LDV

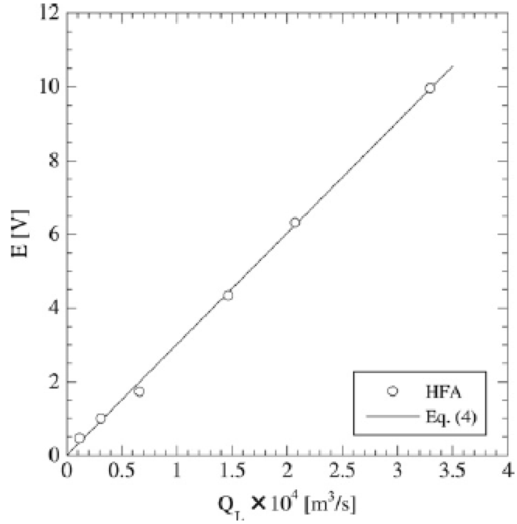

Figure 8.13: Relationship between the linearizer output voltage and the linear velocity

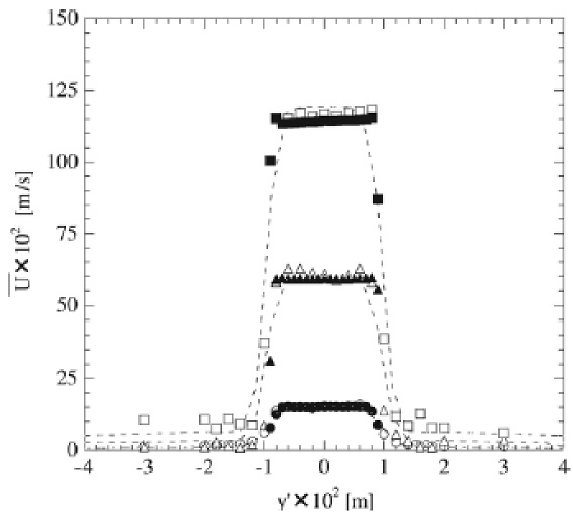

Figure 8.14: Comparison between the x component velocity distribution in the y direction for the HFA, LDV and CFD.

8.3.4 Anemometer for breeze sensor detection

In order to determine the wind values of the anemometer, an experiment was carried out by adjusting the wind speed generator. The experiment is conducted under four conditions no wind, wind from A axis, wind from B axis and wind in between A axis and B axis. In order to set the direction of the wind, Ai and –Ai is set as x axis, while Bi and –Bi will set as y axis. , Ai refers to east, –Ai refers to west, while Bi refers to north and –Bi refers to south. This is to ease the detection of wind direction as shown in figure 8.15. From graphs of figures 8.17 and 8.18 show that when the values of wind increases the output voltages from A0 or B0 also increase. But Initial condition the value is not linear due to wind speed is weaker of gravity, friction and viscosity of air effect.[4]

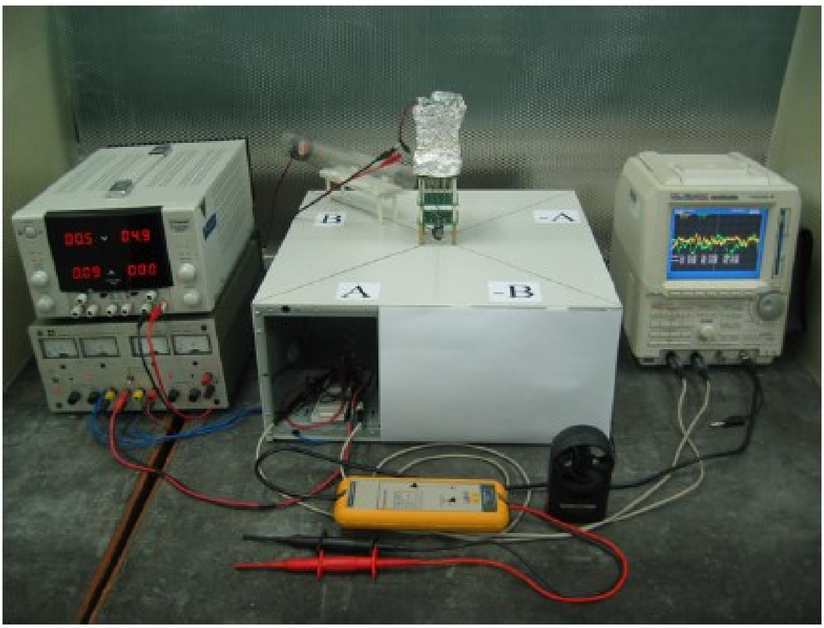

Figure 8.15: The experimental setup environment

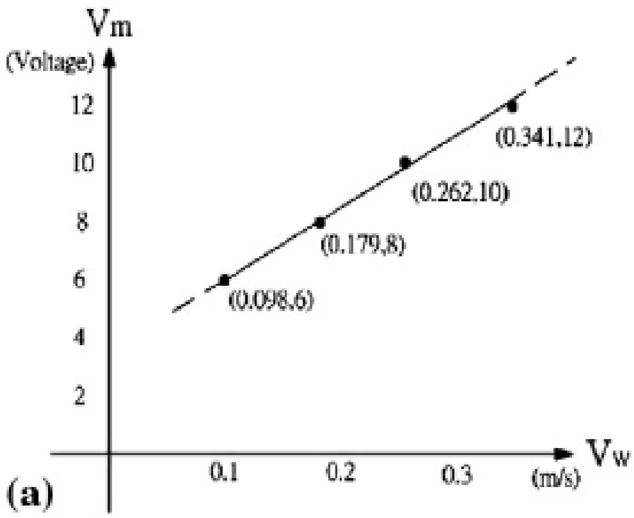

Figure 8.16: Relationship between generator speed and wind speed

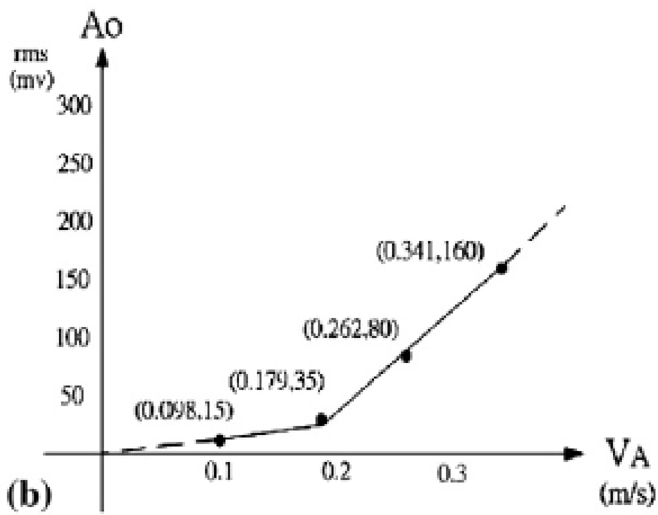

Figure 8.17: Relationship between wind speed and output voltage Ao

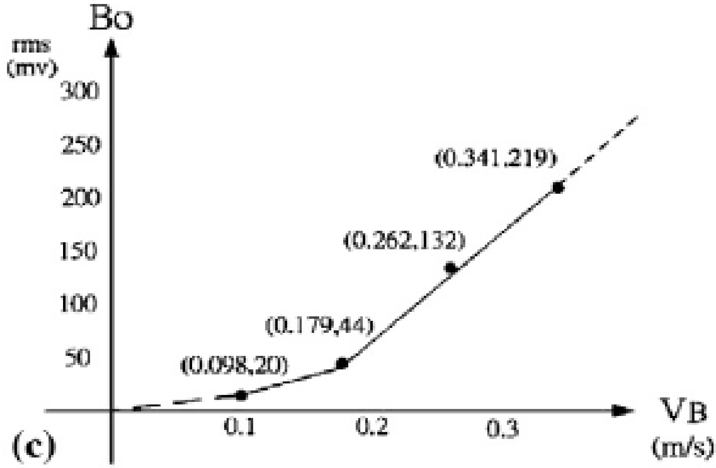

Figure 8.18: Relationship between wind speed and output voltage Bo

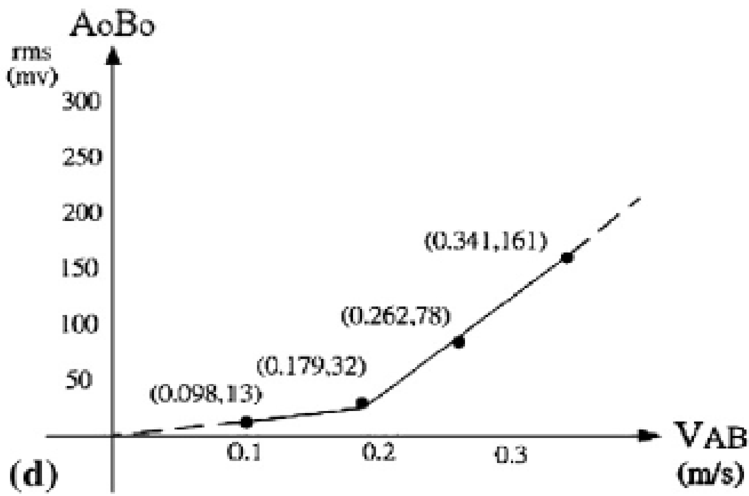

Figure 8.19: Relationship between wind speed and output voltage AoBo

8.4 Conclusion

In this paper the following conclusion can be drawn from the four different area of application of the discussed Anemometers. Although the basic function of the anemometer is to measure, the speed of the wind, however due to the limitation of the conventional anemometer new design of anemometers are developed. The design of FBG anemometer in monitoring the High Voltage Transmission Lines has high resistances for EMI deterioration, as it is made of passive elements. The design can also detect the condition of the wind loading efficiently.

The Anemometer designed for the bread bakery use, proved efficient due to its sensitivity to changes under low velocity at a high temperature. The calibrator for water flow measurement developed using the hot film anemometer was tested and result compared with that of the CFD show its efficiency and effectiveness. The hot film anemometer used in the water flow calibrator and the bread-baking application shows the versatility of the anemometer to various application based on the extent of modification.

The Breeze sensor anemometer designed using high negative for the charge ionization, measures the speed and direction of small amount of wind. This method is suitable for application that needs to measure any small movement of wind as the system can detect even the slowest changes of wind.

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