Poster Summary

Title: Design and Testing of a Nanoparticle Spectrometer

Authors: Simon Box, Nick Collings
Institution: University of Cambridge Engineering Department

This poster presents work carried out as part of a PhD project, at the University of Cambridge Engineering Department. The project was to design build and test a Nanoparticle Spectrometer based on a novel concept.

The spectrometer is designed to identify the size distribution of aerosol samples containing particles with diameters ranging from 5-300 nm. The instrument consists of a unipolar diffusion charger that charges particles by corona discharge. A differential mobility classifier that separates particles out according to their electrical mobility, and an array of electrometer filters, that catch the particles and measure the electrical current associated with the particle landing on them.

Novel aspects of the design include:

- 2-Dimensional shape.- Allows ease of manufacture, and modelling
- Reducing cross-section.- Allows flow to be drawn out of the classifier, through the filters while marinating a constant flow velocity within the classifier.
- Electrometer filters within faraday cages.- For a low noise signal.
- Look up table inversion.- Instrument output signals are compared with a large look up table of predicted signals from aerosol size distributions, and one is selected.

Presented on the poster is:

- A schematic of the instrument classifier, showing how particles are classified and counted
- A summary of how the instrument output is modelled theoretically
- Some test results comparing the modelled and measured signal outputs for three different aerosol size distributions.
- A brief explanation of the look up table inversion technique
- Plots for three different samples comparing the concentration versus diameter plots from the Nanoparticle Spectrometer, and an SMPS from TSI.

Design and Testing of A Nanoparticle Spectrometer

Simon Box and Nick Collings

UNIVERSITY OF CAMBRIDGE
Department of Engineering

Introduction

The information presented on this poster concerns the design, modelling and testing of a nanoparticle spectrometer. The spectrometer is designed to identify the size distribution, weighted by number, of combustion generated aerosol samples containing nanoparticles with diameters ranging from 5-300nm.

Fig 1 shows the concept for this design. The aerosol sample is charged in an unipolar diffusion charger before entering the classifier at the inlet shown in fig 1. In the classifier particles are subject to forces imposed by a flow of clean air in the x-dir, and an electric field acting on the particles in both the x and y directions. Particles are separated out in the classifier according to their electrical mobility (a function diameter). At the upper edge of the classifier particles are drawn, by the flow, through a screen into separate channels where they are collected on metal filters. Sensitive electrometers detect the current associated with the particles landing on the filters, and thus the particles are counted.

The triangular shape of this instrument allows flow to be drawn through the electrometer filters while maintaining a constant x-wise flow velocity in the classifier. It also lends itself to a compact size. The electrometers are housed within faraday cages, leading to a low noise signal. The multi channel design of this instrument allows the entire size range to be analysed simultaneously giving the instrument a fast response time.

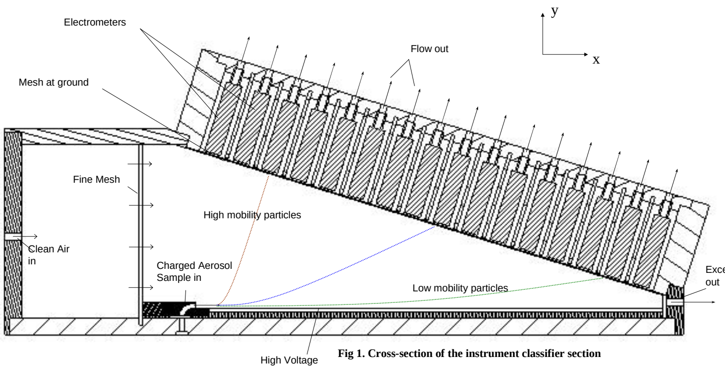

Fig 1. Cross-section of the instrument classifier section

Instrument Model

A model was created to predict the electrometer output signal for the instrument when analysing an aerosol sample with a given size distribution.

A size distribution like the one below is discretised into thin strips, which are assumed monodisperse

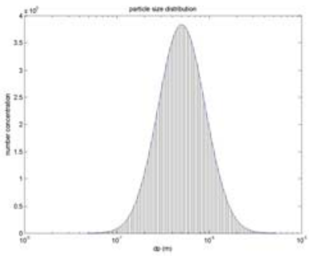

Fig 2. Sample size distribution, divided into strips

Charging Model

The effects of unipolar diffusion charging on each strip is modelled using Broisdon and Brock's "birth and death" model. This model assumes a process of charge accretion described by the infinite set of differential equations shown below.

A charge distribution, like that shown in fig 3 Is produced for each strip of the original size distribution

$$\frac{dn_0}{dt} = -\alpha_0 n_0$$

$$\frac{dn_1}{dt} = \alpha_0 n_0 - \alpha_1 n_1$$

.

.

$$\frac{dn_i}{dt} = \alpha_{i-1} n_{i-1} - \alpha_i n_i$$

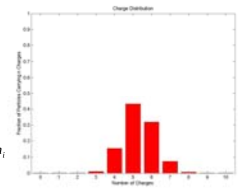

Fig 3. Charge distribution for a specific dp

Particle Tracking

A particle's electrical mobility is a function of its diameter, and the number of elementary charges it carries. Each bar in the charge distribution represents a size-charge combination for which the mobility can be calculated.

The classification of these mobilities is modelled numerically. Fig 6 shows the electric field strength in the classifier, as modelled using finite element method. Fig 4 shows particle tracks for various mobilities in the classifier, calculated using a time marching process.

When the charge and landing location of all the particles are known the current signals in each channel can be calculated, see fig 5

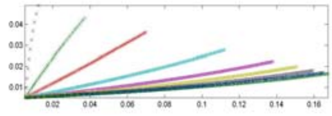

Fig 4. Particle tracks for various mobilities

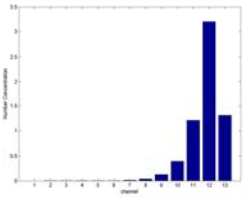

Fig 5. Predicted output

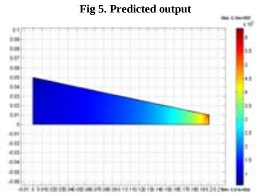

Fig 6. Electric field strength in the classifier

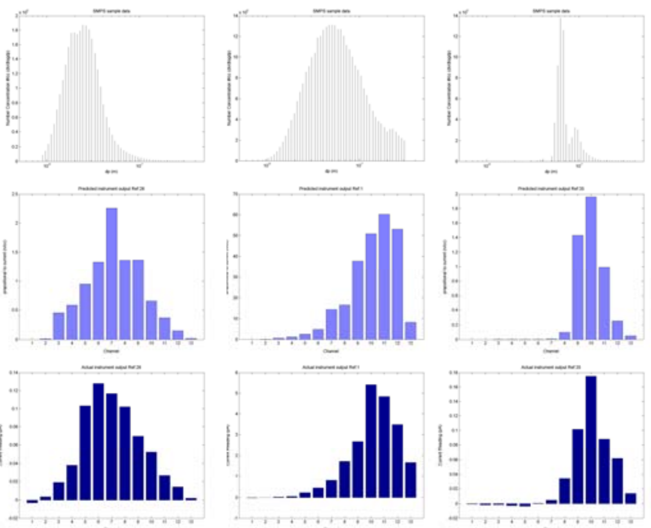

Fig 7. Experimental results showing actual, and predicted output signals for three aerosol samples

Experiments and Results

Using the theoretical model as a design aid, a prototype instrument was constructed. This prototype was then tested, details and results of some of these tests are given below.

Particles were generated using a Collison nebuliser, both salt (NaCl), and sulphuric acid (H_2So_4) particles were used. An SMPS made by TSI was used for the purposes of identifying sample distributions, and making comparison with our instruments results.

The results presented in fig 7 are from a series of tests wherein various aerosol samples were generated and analysed using both the SMPS and the prototype instrument. In the case of our instrument, only the raw current signals from the electrometers are measured.

The Physical model of the instrument, can be used, with the SMPS data, to predict the current signals in each channel. The figure shows some test results for three samples. The top line shows the (SMPS measured) particle distribution, and the light blue and dark blue charts show, respectively, the predicted and measured output signals for our prototype.

Errors

During the Course of our tests several sources of error were encountered, accounting for small differences between predicted and measured signals. These can be categorised into two groups. Firstly, loss errors: diffusion losses of particles within the instrument, and penetration losses in the electrometer filters, were both detected. These losses can be determined experimentally, and correction factors can be applied. The second group of error sources arise from shortcomings in the model. The charging model assumes a constant residence time for all particles in the charger, however in reality residence times are slightly distributed. This could account for the fact that some charge distributions that are slightly broader than predicted. Additionally the particle tracking model does not take into account diffusion in the classifier. This can result in samples with a narrow distribution appearing slightly broader than predicted.

Size Distribution Identification

It is now known that the output signal of the instrument for a specific sample can be predicted. However this is no use unless the signals for varying samples are sufficiently different that we can differentiate between them, so that signal can be converted into a particle size distribution.

In order to predict the resolution of the instrument the model was used to generate a large number of output signals corresponding to lognormal particle size distributions with various means and standard deviations. This data was used to generate error surfaces like those shown in fig 8. Here the mean squared error between signals is plotted relative to a randomly selected signal. Producing these surfaces, centred around various signals, gives us an idea of the minimum error between samples. This can be compared to the sort of error values generated when simulated noise is added to a signal.

In order to convert the Instrument output signal into a size distribution, first it was assummed that the sample distributions were lognormal. Then a large lookup table, like that used in the error surface analysis, was generated. This contained predicted signals for approximately 1000 combinations of mean diameter, and standard deviation. When a sample is generated by the instrument it is compared to all the samples in the table using the method of least squares, and a matching sample is selected. For a table this size the lookup process takes less that 1/10th of a second so does not compromise the fast response of the instrument.

Fig 10 shows results for three samples tested. The bars show the SMPS data and the line is the lognormal selected by our prototype instrument.

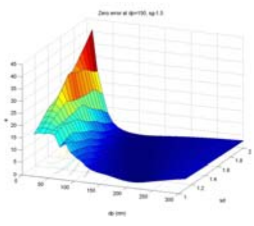

Fig 8. Error surface for signals generated by various lognormal samples

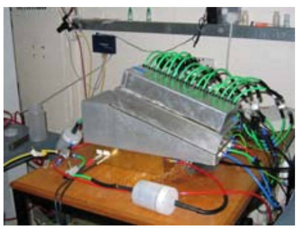

Fig 9. Photograph of prototype instrument on the test rig

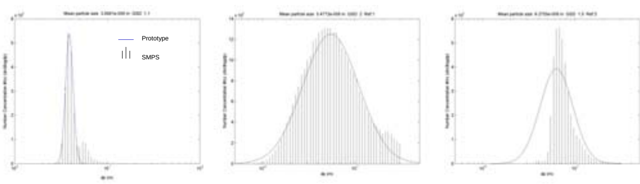

Fig 10. Graphs comparing SMPS output with that of our Instrument

1.Boisdron Y. and Brock J.R.- *On the stochastic nature of the acquisition of electrical charge and radioactivity by aerosol particles*- Atmospheric Environment V.4, pp. 35-40, **1970**

2. Biskos G. Reavell K. Collings N. – *Unipolar diffusion charging of aerosol particles in the transition regime*- Journal of Aerosol Science V. 36 pp. 247-267, **2005**

Simon Box
Cambridge University Engineering Dept
Trumpington st Cambridge
CB2 1PZ

Tel: 01223332681
E-Mail: srb42@cam.ac.uk