Measurement of Electrostatic Charge and Aerodynamic Diameter of Sub-Micron Particles by the ESPART Analyzer

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Abstract— Development of a blue diode laser based ESPART (Electrical Single Particle Aerodynamic Relaxation Time) Analyzer for measuring aerodynamic size and electrostatic charge distributions of sub-micron particles in real time and on a single particle basis is reported here. The ESPART Analyzer measures relaxation time (product of particle mass and its mechanical mobility) and electrical mobility (product of electrostatic charge and mechanical mobility) of individual particles for determining aerodynamic size and charge respectively. The improvement of sensitivity for small particle detection was achieved through the optimization of the LDV fringe pattern, by using a large angle, forward scattered light collection system, and advancing the electronic signal processing system to provide a high signal-to-noise ratio. By replacing the red laser with a blue laser and adjusting the angle of intersection in the sensing volume, we reduce the LDV fringe spacing and increase the solid angle of the receiving optics for collecting light scattered by small particles. A photo-multiplier tube is used in the receiving optics and the RF signal arising from each particle is filtered before demodulation. The signal is processed by a LabVIEW digitizer and data processing performed with a computer. This research project was supported by a grant from NSF, Grant No. IMR 0526977.

I. INTRODUCTION

The ESPART analyzer is a proven and effective method for real time measurement of charge and aerodynamic diameter of particles [1,2]. This method can be modified to reduce the characterization size of the particles into the nanometer range. By reducing the size of particles characterized by the ESPART analyzer, we can see benefits in the burgeoning field of nanotechnology and its applications. Industries such as the toner manufacturing industry have already used ESPART analyzers measuring particles in the micron range [2]. Medical applications will benefit by having a process to characterize smaller particles for aerosol and powdered drug delivery systems. Space industries will be able to use these improved methods for dust particle analysis in future missions to the moon and Mars [5,6].

The ESPART analyzer is comprised of four main components, a dual beam frequency biased laser Doppler velocimeter (LDV), a relaxation chamber, signal processing, and a modern computer [4]. The LDV process uses two Bragg cells (acousto-optic modulators) to frequency bias a laser beam that has been split into two beams by a beam splitter [3]. These two beams are recombined in the relaxation chamber to form the sensing intersection for particles passing through. At this sensing intersection in the relaxation chamber, an AC electric field or acoustic field (if they are not charged particles) is created to allow particle excitation in the sensing volume. Scattered light from this process is collected by a photomultiplier tube (PMT), and this information is filtered and passed onto a data acquisition card in a modern personal computer for data processing.

II. THEORY

Aerosol particles are introduced into the relaxation chamber at an angle normal to the plane of the LDV apparatus. When these particles enter the AC electric field or acoustic field, they will have a motion that is given by the excitation signal. This signal and the measured signal will have similar characteristics, but the measured signal will have a small phase lag due to other forces acting on this particle. When the particles intersect the LDV system in the system volume, the reflected light from the particles will have a modulated Doppler burst that can be used to determine this phase lag. We can see this phase lag, φ, characterized by equation 1.

$$\phi = \tan^{-1} \omega \tau_p \tag{1}$$

In this equation, τ_p is the relaxation time of the particle and ω is the excitation frequency. Then from the phase lag we will determine the aerodynamic diameter of particles, d_a, with equation 2.

$$d_a = \sqrt{\frac{18 \eta \tau_p}{\rho_0 C_c}} \tag{2}$$

Where C_c is the Cunningham slip correction factor, ή is the coefficient of viscosity, and ρ_o is 1gm/cm^3. The motion of the particles can be shown by equation 3,

$$\frac{V_{p(a)}}{U_g} = \frac{1}{\sqrt{1 + \omega^2 \tau_p^2}} \qquad (3)$$

where $V_{p(a)}$ is the motion of the particle, and U_g is the acoustic exciting signal.

When charged particles enter the sensing volume, we can use an AC electric field as the particle excitation signal, which also allows us to determine the charge of those particles, q, by using equation 4.

$$q = \frac{V_{p(e)}}{E_0} \frac{3\pi\eta d_a}{C_c} \sqrt{\left(1 + \omega^2 \tau_p^2\right)} \qquad (4)$$

In equation 4, $V_{p(e)}$ is the motion of the particle and E_o is the electric field.

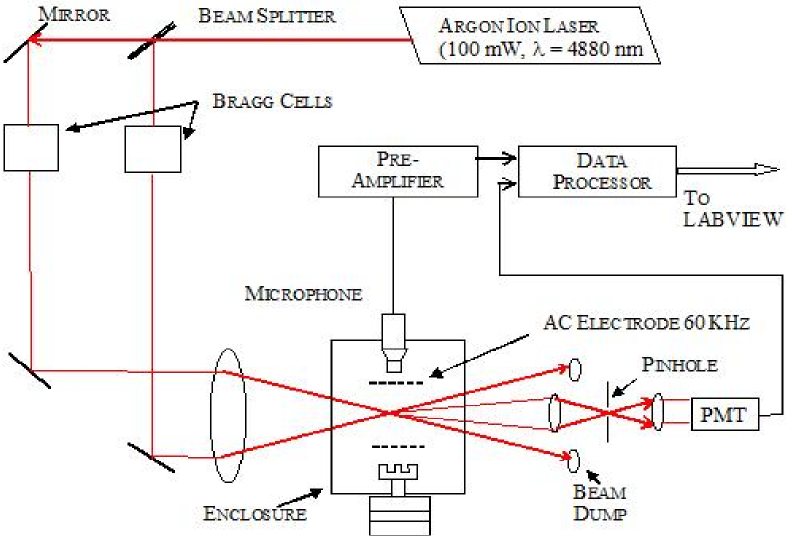

Fig. 1. The optical diagram for the ESPART analyzer, shown with two Bragg cells (BC_1 and BC_2), blue diode laser (L), mirrors, beam splitter (BS), and relaxation chamber with excitation drive and PMT.

III. SETUP AND METHODS

The modifications from the previous design of the ESPART analyzer are introduced to allow reduced particle size characterization. These changes are able to be made because of advances in laser diodes and signal processing technology that was not available at the design of the first ESPART. A blue diode laser (405nm wavelength) is being used in the new design. Shown in figure 1 is the optics diagram for the new ESPART analyzer.

In the original design a helium-neon laser (633nm wavelength) was used. The advantages of the new diode laser technology have allowed reduced fringe spacing in the LDV setup. This fringe spacing is shown by equation 5.

$$d_f = \frac{\lambda}{2\sin\left(\frac{\theta}{2}\right)} \tag{5}$$

In equation 5, d_f is the fringe spacing, λ is the wavelength of the laser source, and θ is the angle of intersection shown in figure 1. Using a large angle of intersection, 30°, and the wavelength of the blue laser, 405nm, we have a fringe spacing of approximately 0.78µm. It can also been seen that the large angle of intersection contributes to the small fringe spacing, as it is inversely proportional to d_f.

The laser beam is split using a standard beam splitter cube that is non-polarizing. The beams then travel to two Bragg cells (acousto-optic modulators), one being driven at 39MHz and the other at 41MHz. This creates a 2MHz frequency bias in the LDV system. Focusing lenses are then used to focus the beam at the sensing volume. At the sensing volume we have an AC electric field or acoustic field exciting the particles. The motion of the particles relative to the excitating field causes a phase lag that can be shown win figure 2.

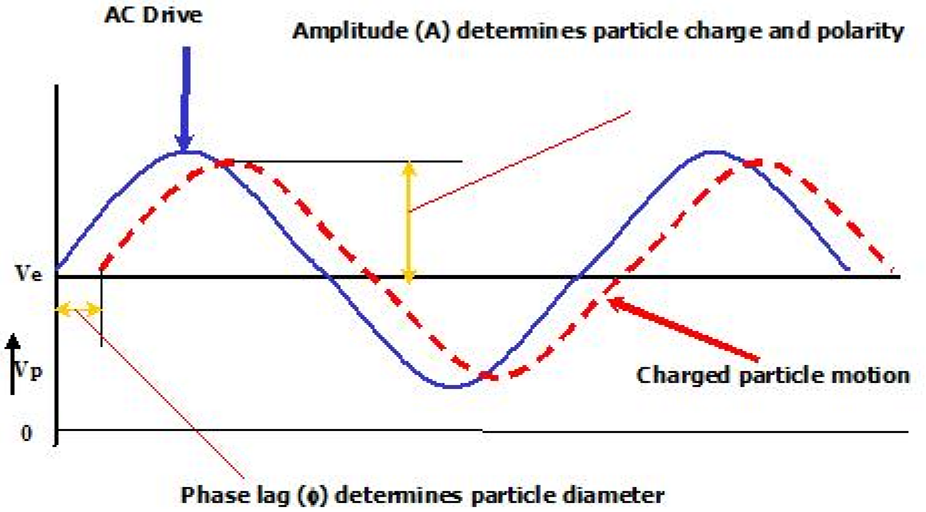

Fig. 2. The particle motion and the exciting signal are shown in this graphic. The particle motion is shown here with the exciting signal leading with a phase lag, φ.

The frequency of excitation will depend heavily on the particle size being characterized. To move the ESPART into the nanometer range, we will need to use a higher frequency exciting signal to achieve a greater phase lag between the particle motion and the excitation signal. This relationship is illustrated graphically through figure 3. We can see from this figure that a high frequency is important so that a greater phase lag can be achieved for the nanometer size range.

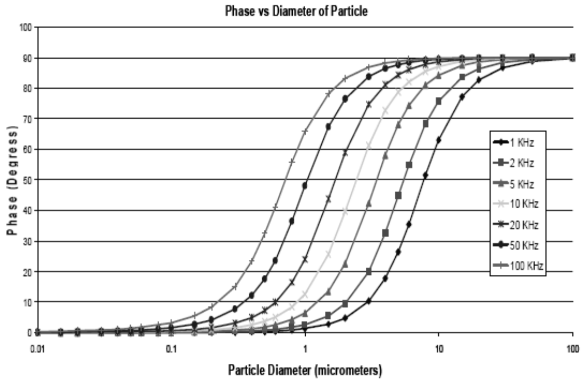

Fig. 3. The relation of exciting frequency to particle characterization is shown in this graph. A discernable phase lag is dependent on higher exciting frequency.

The phase lag from excited particles moving through the LDV sensing volume causes light to enter the PMT. This creates a Doppler burst which can then be demodulated using a personal computer. Data is entered into the computer using a LabView digitizing card, along with the exciting signal that was used. The information is processed with LabView software and then displayed in a graphical readout of particles sizes and charge, if AC electric field is used.

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