Proceedings of EnCon2011
4th Engineering Conference
Kuching, Sarawak, Malaysia

Spatial Filtering Effect on Circular and Rectangular Electrode in Electrodynamic Sensor

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***Abstract*—This paper is focus on spatial filtering effect or frequency bandwidths characteristics in circular and rectangular electrode. This spatial filtering effect is the relationship between sensor size and the frequency bandwidth of transducer determine from frequency response obtained during which corresponds to a detectable particle. The sensing device was built from conductor and insulator materials that have the different size and shape. Three types of electrodes that commonly used were pin, quarter ring and ring shapes. This paper focuses on pin shape with variation of size for circular and rectangular shapes. Non-intrusive method was designed and applied to the both shapes to investigate the spatial filtering effect of the sensor.**

***Keywords*— particle, electrostatic, sensing devices, non-intrusive.**

I. INTRODUCTION

The movement of particle in pipeline of pneumatic conveying system generates an electrostatic charge and that electrostatic charge can be detected using electrodes or plates called sensing device and converted into voltage by the electrodynamics transducer or called associated electronics.

Particles in pneumatic pipelines carry a certain amount of net electrostatic charge. The electrification of the particles in pneumatic conveying can be attributed mainly to collisions between particles, impacts between particles and pipe wall and friction between particles and air stream [4]. The charge carried on the particles can be detected by suitable sensors, which derive their signals from the fluctuations in electric field caused by the passage of the flowing particles. To examine the fundamental interactions between the charged particles and the sensor and to quantify the sensing characteristics, physical and mathematical modeling of the sensor is necessary [4].

There is two importance characteristics in electrostatic sensing is electrode sensitivity and the spatial filtering effect of the sensor [1]. The electrode sensitivity is the changing in output of the transducer due to a change in the mass flow rate and the unit sensitivity is volts/gram/second. For the spatial filtering effect is the relationship between sensor size and the frequency bandwidth of transducer determine from frequency response obtained during which corresponds to a detectable particle.

II. THEORY

The Spatial filtering effect can be define as the relationship between sensor size and the frequency bandwidth of transducer determine from frequency response obtained during which corresponds to a detectable particle [9].

A. Circular Electrode

Assume that a charge in the form of pulse $\rho(t)$ of the conveyed component (termed a concentration pulse) passes the electrode, of length d with velocity υ as shown in Figure 1.

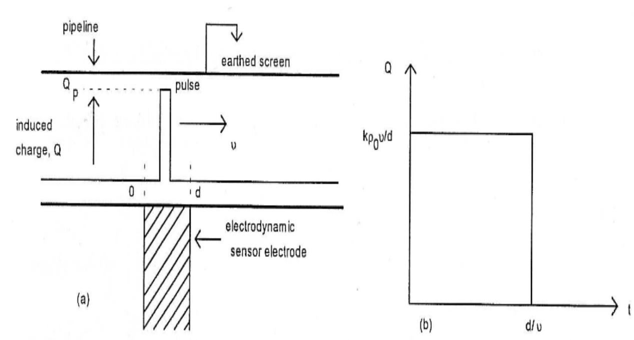

Figure 1 Time history of concentration pulse

If the electrostatic field between the sensor and screen are homogeneous and non fringing, the charge pulse will create a change induce in the sensor which can be describe by a rectangular pulse of duration $\frac{d}{\upsilon}$. The amplitude of the charge pulse can be determine from

$$\Delta Q_p = k\frac{\upsilon}{d}\int_0^{\infty} \rho_p(t)dt \qquad (1)$$

Where k is a constant of proportionality with appropriate of dimensions. If the pulse of concentration is short compared $\frac{d}{\upsilon}$ it can be regarded as direct pulse:

$$\rho_p(t) = \rho_0 \delta(t) \tag{2}$$

Where $\int_0^{\infty} \delta(t)dt = 1$ and ρ_0 is the amplitude of the concentration pulse.

The corresponding amplitude of the change in charge is

$$\Delta Q_p = k\frac{\rho_0 \upsilon}{d} \tag{3}$$

And the charge response may be described by the following equation

$$\Delta Q_p = \left(k\frac{\rho_0 \upsilon}{d}\right).\left(1-\exp\left(-\frac{ds}{\upsilon}\right)\right) \tag{4}$$

Where s is the Laplace variable $= \sigma + j\omega$. Hence the electrode transfer function is

$$h(s) = \left(\frac{1}{\rho_0}\right).\Delta Q_p(s) = \left(\frac{k\upsilon}{ds}\right).\left(1-\exp\left(-\frac{ds}{\upsilon}\right)\right) \tag{5}$$

This may be transformed into the frequency domain by replacing s with $j\omega$. Hence

$$h(j\omega) = \left(\frac{k\upsilon}{dj\omega}\right).\left(1-\exp\left(-\frac{dj\omega}{\upsilon}\right)\right) \tag{6}$$

Equation (6) may be written:

$$h(j\omega) = \frac{k\upsilon}{d}\left[\sin\left(\frac{\omega d}{\upsilon}\right) - j\left(1-\cos\left(\frac{\omega d}{\upsilon}\right)\right)\right] \tag{7}$$

and the amplitude frequency response for the transfer function between ρ_0 and ΔQ_p is

$$|h(jw)| = \left|\frac{\Delta Q_p}{\rho_0}\right| = k\left|\frac{\sin\left(\frac{wd}{2v}\right)}{\frac{wd}{2v}}\right| \tag{8}$$

This transfer function is plotted in Figure 2. Equation 8 enables the transfer function between conveyed component concentration and electrode sensor to be measured by recording the response generated by traveling pulse of concentration passing between electrodes provided that the pulse length is short compared to the electrode length.

The transfer function minima occur when $\sin\left(\frac{\omega d}{2\upsilon}\right) = 0$.

Therefore $\frac{\omega d}{2\upsilon} = \pi, 2\pi, 3\pi, ...$ and minima when $\frac{\upsilon}{d} = \frac{\omega}{2\pi}, \frac{\omega}{4\pi}, \frac{\omega}{6\pi}, ...$

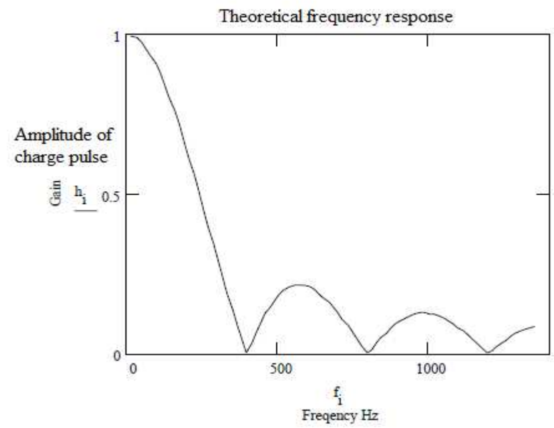

Figure 2 Theoretical transfer function for d=0.005 mm, υ=2.0 m/s

B. Rectangular Electrode

The rectangular electrode are much longer than the circular electrode ones and recordings of the voltage from the sensor, taken when investigating the spatial filtering effect, are slightly different from those from the circular electrodes. The analyses of above require modifying in order to determine the spatial filtering characteristic of long rectangular sensors [10].

In the experimental verification of this analysis, the long electrodes are curved to approximately the same radius as the charged bead moves along to ensure the bead electrode gap remains constant as it passes. In this case the charged bead is passing the electrode for a longer period than for the circular sensor. The charge and discharge currents are noticeably spaced in time, as are the corresponding rectified voltages as shown in Figure 3. The spatial filtering effect for this system is calculated by considering the system as consisting of two impulses with a time delay separating them. If the pulse duration's are short compared with a/v they may be regarded as two Dirac pulses.

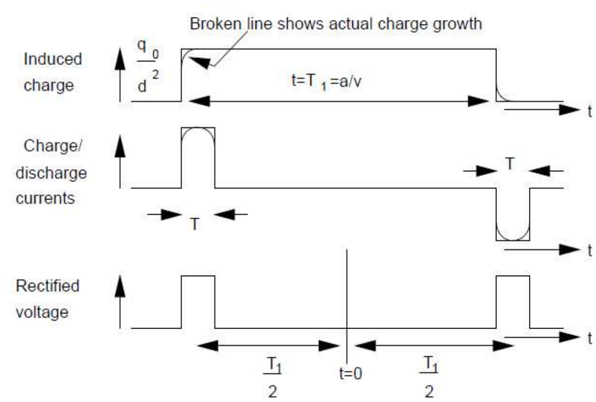

Figure 3 Idealised induced charge and corresponding voltages for the rectangular electrode.

Then the transducer response may be written

$$v_i(\omega)=\int_{-\frac{T_1}{2}-\frac{T}{2}}^{-\frac{T_1}{2}+\frac{T}{2}} k\frac{q_0}{d^2}e^{j\omega t}dt+\int_{\frac{T_1}{2}-\frac{T}{2}}^{\frac{T_1}{2}+\frac{T}{2}} k\frac{q_0}{d^2}e^{j\omega t}dt\,. \qquad (9)$$

Where T is the time taken to charge and discharge the electrode. After integration and expansion equation (9) gives

$$\frac{V_i}{q_0}=\frac{4k}{d^2\omega}\cos\frac{\omega T_1}{2}\sin\frac{\omega T}{2} \qquad (10)$$

This may be written in the frequency domain.
The modulus of Equation 10 is given by,

$$\left|\frac{V_i}{q_0}\right|=\frac{2k}{d^2}\left|\cos\frac{\omega a}{2v}\right|\left|\frac{\sin\left(\frac{\omega T}{2}\right)}{\frac{\omega}{2}}\right| \qquad (11)$$

and the effect of a and v on the modulus shown the 'sinc' function and the graphically in Figure 4.

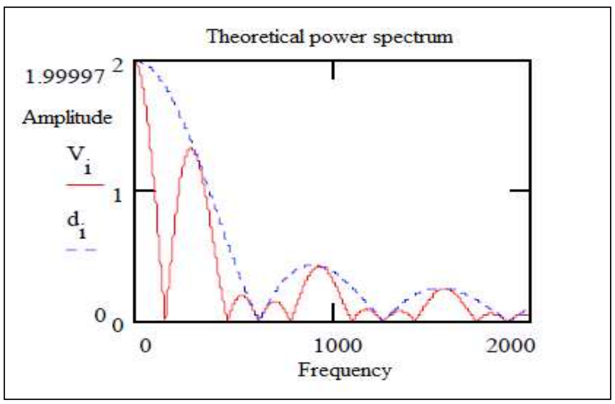

Figure 4 Predicted spatial frequency response for the rectangular electrode

III. METHODOLOGY

The process measurement of static charge using electrostatic sensor is consist of design the electrode or sensing device in circular and rectangular shape with various of sizing to be implement or assemble to pneumatic conveying plant of plastic bead. The electrical charge detected from electrode will convert to voltage by electrodynamics transducer or associated electronic, The calibration curve for gravity flow rig are important calibration of pneumatic conveying plant to measure mass flow rate for plastic beads at solid loading of flow indicator and then further process can be proceed after find the flow rate.

A. Sensor Design

The important part in designing the sensing device or electrode is to make capacitive [3] condition between pipe and the electrode. The design also must be non-intrusive electrode that not disturbs the flow of material. There is many type of electrode are applicable in static charge measurement such as ring, quarter ring and pin type. In this project will concentrate on pin type of electrode with several sizes on circular and rectangular shapes and investigate their characteristics on sensitivity and spatial filtering effect. Figure 5 shows that the arrangement of difference diameter size of circular electrode shapes with ranging from 2mm to 9mm.

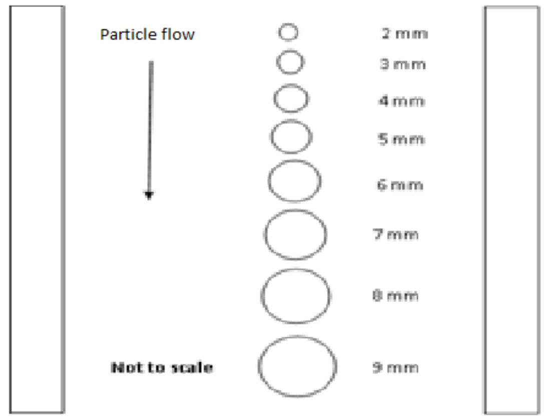

Figure 5 Arrangement of circular electrodes for sensitivity measurement

Figure 6 shows the arrangement of different lengths and fix 10mm wide for rectangular electrode shape with ranging from 20mm to 300mm.

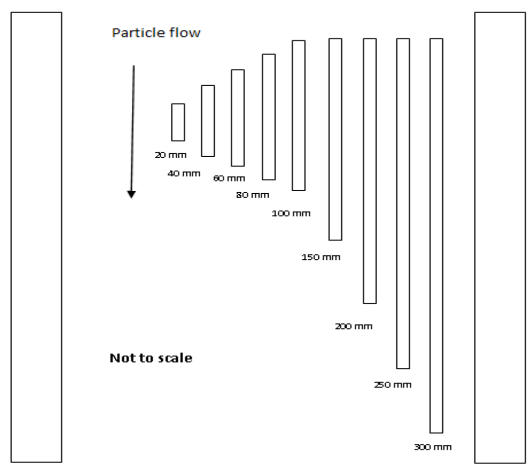

Figure 6 Arrangement of rectangular electrodes for sensitivity measurement

IV. Result and Discussion

A. Circular

For spatial filtering effect analysis, rectified voltage signal measured by electrodynamics transducer will be inversed and converted into frequency domain using Fourier transform analysis. The result for circular electrode on the frequency spectrum is 'sinc' function that follows the theory calculated. The frequency spectrum can be observed in term of cut off frequency. The result of frequency spectrum for circular electrodes with diameter ranging from 2 mm to 9 mm was shown in figure. 7 until 9 with mass flow rate is 45.85 g/s. At the right of the figure show the signal on time domain which is non-inverting voltage and rectified voltage signal. The left signal is frequency domain signal which is frequency spectrum of rectified voltage.

The result of frequency spectrum for circular electrode diameter 2 mm to 9 mm collected and result of several size electrode shown in fiigure. 7 to figure. 9.

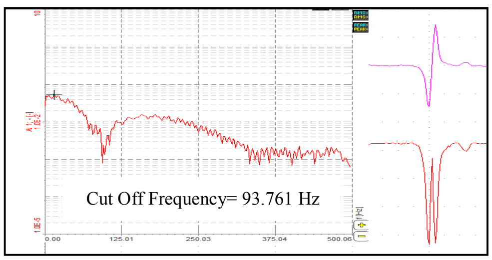

Figure 7. Rectified voltages in time and frequency domain for diameter 2 mm.

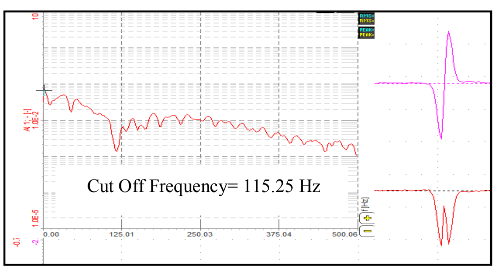

Figure 8. Rectified voltage in time and frequency domain for diameter 4 mm.

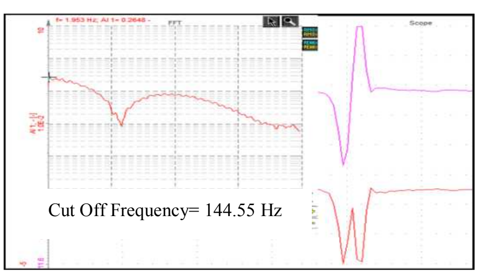

Figure 9. Rectified voltage in time and frequency domain for diameter 9 mm.

The result of frequency response show that, for all frequency spectrum are in same curve that gives from 'sinc' function in Equation 8 in the different in cut off frequency. The characteristic of spatial filtering effect will continue with the relationship between cut off frequency and electrode length of electrodes and the result shown in figure 10. From this observation, increasing of diameter circular electrode will increase the cut off frequency in linear properties of gradient 6.674 Hz/mm.

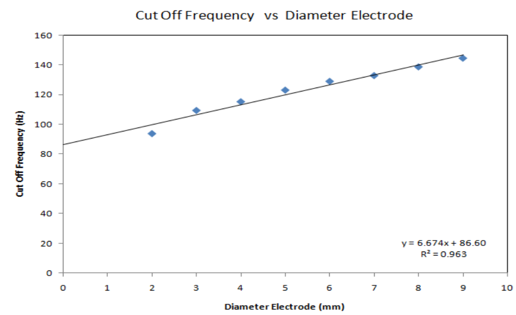

Figure 10. Relation between cut off frequency with diameter for circular electrodes.

B. Rectangular

For spatial filtering effect analysis of rectangular electrode shape, rectified voltage signal measured by electrodynamics transducer will be inversed and converted into frequency domain using Fourier transform analysis. The result for rectangular electrode on the frequency spectrum is combination of 'sinc' and 'cos' function that follows the theory calculated on (Equation 11). The frequency spectrum can be observed in term of cut off frequency [6]. The result of frequency spectrum for rectangular electrodes with different area was shown in Figure 11 until 13 with mass flow rate is fix to 45.85 g/s. At the right of the figure show the signal on time domain which is non-inverting voltage and rectified voltage signal. The left signal is frequency domain signal which is frequency spectrum of rectified voltage.

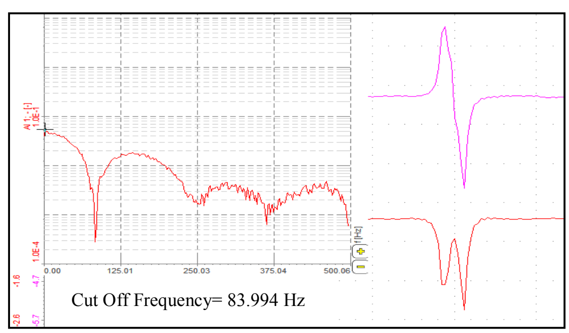

Figure 11**.** Rectified voltage on time and frequency domain for length 20 mm.

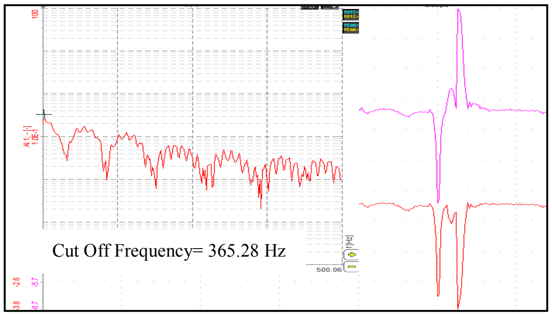

Figure 12**.** Rectified voltage on time and frequency domain for length 100 mm.

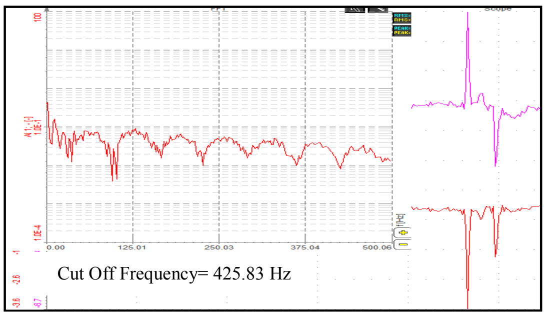

Figure 13 Rectified voltage on time and frequency domain for length 300 mm.

The result for rectangular electrode on frequency spectrum shows the combination of 'sinc' and 'cos' function that follows the theory. This frequency spectrum can be observed in term of cut off frequency acquired. The sensor characteristic of spatial filtering effect will continue with the relationship between cut off frequency and electrode area of rectangular electrodes and the result shown in Figure 14. From observation, increasing of length rectangular electrode will asymptotically increase the cut off frequency to 428.8 Hz.

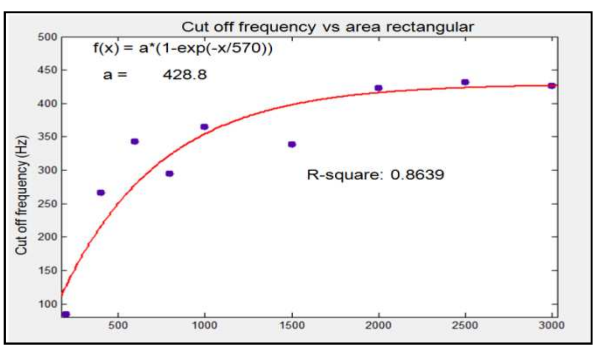

Figure 14. Relation of rectangular electrode on cut off frequency and electrode area.

V. CONCLUSION

The experiment shows that, the different shape of electrode will produced different spatial filtering effect. For spatial filtering effect investigation, the frequency response characteristics for circular size electrode give a sinc function response and produce linear relationship between cut off frequency and circular size electrodes For a rectangular size electrode give a combination of sinc and cos function response and produce the asymptotic relationship between cut off frequency and rectangular size length electrodes. Both sensor sizes are suitable to be applied in process tomography and solid particle sizing investigation

ACKNOWLEDGMENT

The authors wish to thank for the support given to this research by Universiti Teknologi Malaysia (UTM), which made this collaborative work possible.

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