Electrostatic Sensor in Circular and Rectangular Shape Electrode for Solid Dry Pneumatic Conveyor System

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Abstract—The electrostatic sensor was used in industrial process because of less expensive and robust design. The particles movement in pneumatic conveying system can generate the electrostatic charges. The charges can be detected by using the sensing devices such as electrodes or plates. The electrodynamics transducer or associated electronics circuit on the sensing device was used to convert the charge to the voltage. 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 sensitivity of the sensor.

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

1. Introduction

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].

The principle of measurement techniques based on electrostatic phenomena in pneumatics pipelines is contains information of velocity and mass flow rate of particles. The information of particle is depend on large particle will carry higher charge on its surface than a smaller one [1]. This charge level will be detected by using electrostatic sensing and convert it to voltage signal. The charge level can be represented by:

\[ V(t) = \alpha \sum q(t) \]  

where,
q = is amount of electronic charge carried on each particle
\( \alpha \) = is constant depend the design of the charge amplifier circuit.
V (t) = is the resulting voltage signal

The fiction and collisions of particle in pipeline are entirely random [2]. So, the value of V(t) is the result voltage of un deterministic signal that capture by electrostatic transducer and change it to other forms such as discrete times sequence, V(n) at suitable sampling frequency which \( n = 0, 1, 2 \) and so on. In electrostatic sensor design, the different term was used such as electrostatic sensing technology, tri bioelectric, and electrodynamics and electrostatic.

There is two importance characteristics in electrostatic sensing is electrode sensitivity and the spatial filtering effect of the sensor. 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.

2. Theory

2.1. Circular Electrode

Consider a particle p, carrying a charge q, traveling at a uniform velocity V, constrained to pass a conducting circular electrode along a path which is perpendicular to the vertical axis of the electrode as shown in Figure 1.

\[ E = \frac{q}{4\pi \varepsilon_0 (PQ)} \]  
(2)

From this electric field, induce charge are produced, calculating for current signal using equation (3) and further find value of voltage.

\[ i' = \frac{dq'}{dt} \]  
(3)

Where,
q’=induced charged
i’=current signal

2.2. Rectangular Electrode

Consider a particle p, carrying a charge q, traveling at a uniform velocity V, constrained to pass a conducting rectangular electrode figure below along a path which is perpendicular to the vertical axis of the electrode as shown in Figure 2.
The electric field, $E$, due to charged particle at a distance $PQ$ was stated in equation (2) and From this electric field, induce charge are produced, calculating for current signal using equation (3) and further find value of voltage.

### 2.3. Electrodynamic Transducer

The electrostatic sensor consists of several parts such as an electrode, a noninverting voltage follower, a precision rectifier, and a low pass filter. Figure 2.15 illustrates the block diagram of an electrostatic sensor. The transducer consists of two basic elements, the electrode and associated electronics [10]. The electrode is a metal conductor which is electrically insulated from the metallic conveyor, and forms a capacitance to earth [9]. A capacitor is connected between input and earth so that measurements are made with a similar capacitance, which has a value of 5.5 to 5.7 pF. Charge $Q$ is induced in the electrode due to the passage of charging particles [3].

The charged particles in the pipe flow past the electrode inducing charge into it in the process. The flow of current through the resistor due to this induced charge results in a varying voltage. This voltage is buffered by a unity gain non inverting amplifier whose output provides a driven guard for the input circuitry and is amplified and conditioned by further circuitry as shown in Figure 3.

### 3. 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.

#### 3.1. 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 4 shows that the arrangement of difference diameter size of circular electrode shapes with ranging from 2mm to 9mm.

![Figure 4 Arrangement of circular electrodes for sensitivity measurement](image)

Figure 4 Arrangement of circular electrodes for sensitivity measurement

Figure 5 shows the arrangement of different lengths and fix 10mm wide for rectangular electrode shape with ranging from 20mm to 300mm.

![Figure 5 Arrangement of rectangular electrodes for sensitivity measurement](image)

Figure 5 Arrangement of rectangular electrodes for sensitivity measurement

### 4. Result and Discussion

The sensitivity can be determined by using different size of sensor. The solid dry particle flows passing each of the circular and rectangular electrodes. The level of charge on the flowing particle is very difficult to quantify, however since the sensors are evaluated at the same time their outputs may be compared directly. The small diameter electrode at each end of the array checks that the flowing particle does not change its characteristics as it traverses the section. A linear regression line is fitted from measured values of average voltage from electrodynamics transducer versus flow rate of conveying system.

#### 4.1. Circular

Results for the sensor sensitivity (2 mm to 9 mm) diameter electrode were shown in Figure 6 and Figure 7. A linear regression line is fitted to the measured values. The gradient of this line provides the overall sensitivity of the sensor (V/gm/s) and summarized in Table 1 and Figure 8.
In the step to observe the relationship of sensor sensitivity and sizes electrode, the transducer sensitivity of each size electrodes need to divide by the gain of each electronic amplifier is 150. The Table 1 show the calculation of electrode sensitivity and the results are summarized in Figure 8.

**TABLE I. ELECTRODE SENSITIVITY OF ELECTROSTATIC SENSOR (CIRCULAR SHAPE)**

<table>
<thead>
<tr>
<th>Electrode diameter (mm)</th>
<th>Electrode area (mm$^2$)</th>
<th>Transducer sensitivity (mV/g/s)</th>
<th>Electronic gain</th>
<th>Electrode sensitivity (mV/g/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3.14</td>
<td>0.631</td>
<td>150</td>
<td>$4.21 \times 10^{-3}$</td>
</tr>
<tr>
<td>3</td>
<td>7.07</td>
<td>0.504</td>
<td>150</td>
<td>$3.36 \times 10^{-3}$</td>
</tr>
<tr>
<td>4</td>
<td>12.57</td>
<td>0.775</td>
<td>150</td>
<td>$5.17 \times 10^{-3}$</td>
</tr>
<tr>
<td>5</td>
<td>19.64</td>
<td>1.384</td>
<td>150</td>
<td>$9.22 \times 10^{-3}$</td>
</tr>
<tr>
<td>6</td>
<td>28.28</td>
<td>1.512</td>
<td>150</td>
<td>$1.01 \times 10^{-2}$</td>
</tr>
<tr>
<td>7</td>
<td>38.49</td>
<td>2.050</td>
<td>150</td>
<td>$1.37 \times 10^{-2}$</td>
</tr>
<tr>
<td>8</td>
<td>50.27</td>
<td>2.325</td>
<td>150</td>
<td>$1.55 \times 10^{-2}$</td>
</tr>
<tr>
<td>9</td>
<td>63.62</td>
<td>2.941</td>
<td>150</td>
<td>$1.96 \times 10^{-2}$</td>
</tr>
</tbody>
</table>

The results show the linear relation between electrode sensitivity and area of circular electrodes. By increasing the diameter or size of electrode, the sensitivity of the sensor will be increased. The diameter 2 mm and 3 mm show the best fit or coefficient line less than 90 percent. That means measurement of small diameter isn’t stable and less sensitivity for circular electrode.
4.2. Rectangular

A series of different particle flow rates was applied to the rectangular electrodes and the output was determined. Results for the sensor sensitivity of rectangular electrode were collected and the result of several electrode area shown in Figure 9 and Figure 10. A linear regression line is fitted to the measured values. The gradient of this line provides the overall sensitivity of the sensor (V/gm/s) and summarized in Table 2 and Figure 11.

![Figure 9 Average voltages versus mass flow rate of 100 mm length](image1)

![Figure 10 Average voltages versus mass flow rate of 300 mm length](image2)

<table>
<thead>
<tr>
<th>Length electrode (mm)</th>
<th>Area electrode (mm$^2$)</th>
<th>Transducer sensitivity (mV/g/s)</th>
<th>Electronic gain</th>
<th>Electrode sensitivity (mV/g/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>200</td>
<td>0.98</td>
<td>150</td>
<td>0.0065</td>
</tr>
<tr>
<td>40</td>
<td>400</td>
<td>1.65</td>
<td>150</td>
<td>0.0110</td>
</tr>
<tr>
<td>60</td>
<td>600</td>
<td>1.74</td>
<td>150</td>
<td>0.0116</td>
</tr>
<tr>
<td>80</td>
<td>800</td>
<td>2.33</td>
<td>150</td>
<td>0.0155</td>
</tr>
<tr>
<td>100</td>
<td>1000</td>
<td>3.32</td>
<td>150</td>
<td>0.0221</td>
</tr>
<tr>
<td>150</td>
<td>1500</td>
<td>3.96</td>
<td>150</td>
<td>0.0264</td>
</tr>
<tr>
<td>200</td>
<td>2000</td>
<td>4.44</td>
<td>150</td>
<td>0.0296</td>
</tr>
<tr>
<td>250</td>
<td>2500</td>
<td>4.61</td>
<td>150</td>
<td>0.0307</td>
</tr>
<tr>
<td>300</td>
<td>3000</td>
<td>4.74</td>
<td>150</td>
<td>0.0316</td>
</tr>
</tbody>
</table>

In order to observe the relationship of sensor sensitivity and sizes electrode of rectangular electrodes, the transducer sensitivity of each size electrodes need to divide by the gain of each electronic amplifier is 150. The results are summarized in Table 2 and Figure 11 show the relationship for rectangular electrode shapes.

![Figure 11 Sensitivity versus electrode area for rectangular electrode](image3)
Figure 11 shows the non-linear relation between electrode sensitivity and area of rectangular electrodes. The best fit or coefficient line is 95.97 percent and the result show for the length of rectangular electrode, sensitivity is asymptotically increases to 0.03179 mV/g/s. so, the increasing of lengths rectangular electrode have certain limit with the sensor sensitivity. In this case of width 10 mm the highest length for higher sensitivity is about 250 mm to 300 mm, more than that will produced same sensitivity at 0.03179 mV/g/s.

5. Conclusion

The experiment shows that, the different shape of electrode will produced different sensitivity. The diameter size of circular shape sensor can be increased for better sensitivity and better measurement because of linear relationship between sensitivity and electrode area. But, the sensitivity of rectangular sensor is asymptotically increased with the area of electrode.

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7. References