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New technique to measure particle size using electrostatic sensor

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ABSTRACT

A new technique is proposed to measure the particle mean size using an electrostatic sensor in frequency domain. This paper starts with a finite-element modeling simulator to model the induced electric charge of a ring electrode and to find the electrode sensitivity. The mathematical modeling was used to extract particle size information from the simulated signal in frequency domain. The method is applied in an experimental test where a low-noise signal conditioning was designed with a ring electrode as the electrostatic sensor. The method can be used to establish a cost effective size measurement system using electrostatic sensor.

1. Introduction

One of the interesting areas to develop a reliable and cost effective instrumentation in particle and powder industries have been designing the measurement systems by using electrostatic sensor, which led to a lot of research and development on it. Particle movement in a pipeline or a conveyor can produce a small amount of electric charge on the particle surface due to particle to particle and particle to pipe wall friction and collision. The electric charge on the particle's surface can be detected using electrostatic sensor. Analysis of the sensor's output signal can provide information about the flow parameters. For instance, the velocity of the moving particle can be measured using the cross-correlation technique [1] or spatial filtering method [2]. Particles' mass flow rate measurement in direct method [3], concentration and charge distribution profile-map by utilizing process tomography method [4,5] and particle mean-size measurement [6,7] are some other studies that used the electrostatic sensor capabilities.

Particle size measurement using electrostatic sensor is studied by Zhang and Yan [7] to measure the mean size of particles in a mass flow in the conveyor. A direct method is used in which the magnitude of the output signal is directly related to the mean size of the particles in the conveyor. It is proposed that, from the statistical perspective the larger particle carries more charge than smaller one, and that has been the fundamental basis for the proposed method. However, It dependents on the conditions, e.g., under a constant mass flow rate, based on this theory, signal level should decrease [8].

The mean size measurement of a single particle is challengeable using the direct method. At the first, hardly two particles with the same size, material type and density can get an equal amount of electric charge on their surface. As a result, they induce a different level of electrostatic noise to the sensor, so the measurement system produces different results for the two the same size particles. Second, if two different size particles have an equivalent amount of electric charge on their surface, the measurement system will show identical results for the two particles with different sizes.

Based on the above, the purpose of this study is to measure the mean size of a single particle by applying a magnitude independent method in frequency domain using the electrostatic sensor. The solution involves the simulation results and mathematical modeling, where a logical relation was established between particle size and the frequency at the peak of the frequency spectrum (PFS) of the detected electrostatic noise. In the end, the experiments were conducted, and the experimental results were compared to that obtained from the simulation.

The rest of the article has four parts: a brief background of the electrostatic sensor and detail explanation of the charge induction process to the electrode with its related simulation results, the methodology using the simulation results and mathematical modeling, electrostatic sensor design with a test rig and in the end, the discussion on results.

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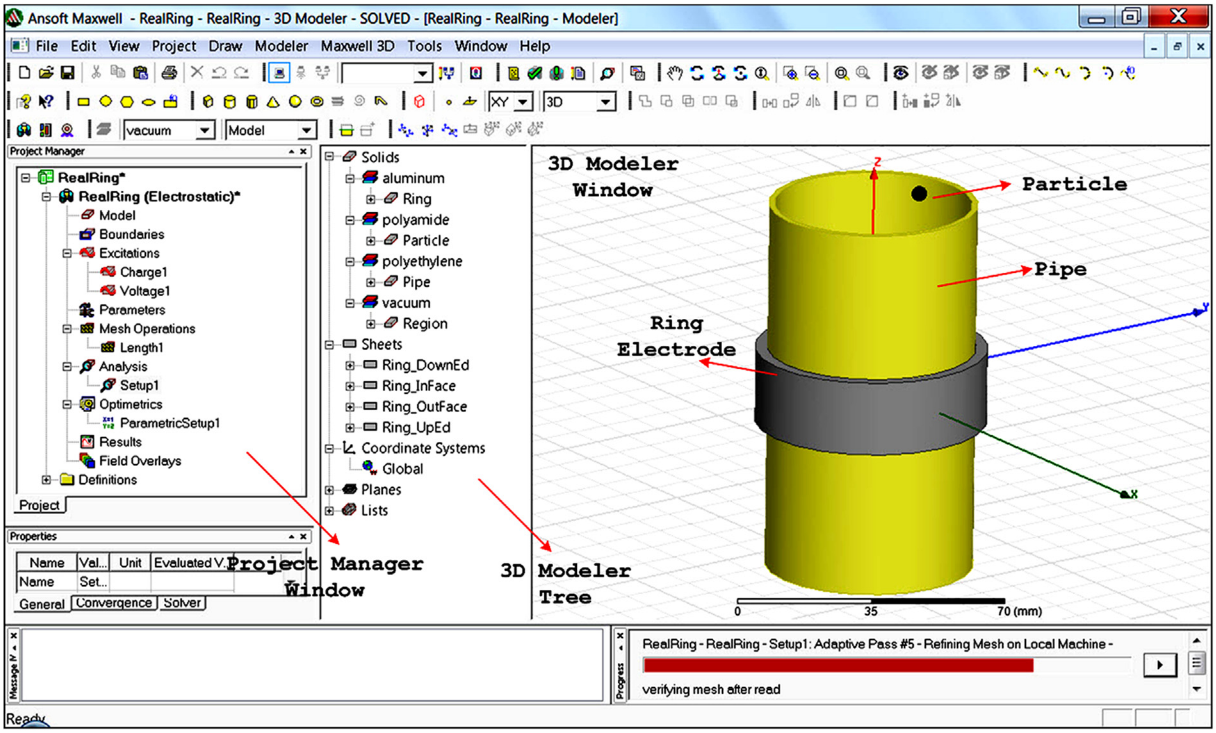

RealRing - RealRing - Setup1: Adaptive Pass #5 - Refining Mesh on Local Machine -

verifying mesh after read

Fig. 1. Maxwell Ansoft interface and the schematic representation of the ring electrode.

2. Electrostatic sensor

Electrostatic sensor consists of two main parts, sensor electrode and signal conditioning circuit. A signal conditioning circuit collects the induced charge to the electrode and amplifies it to a desired level. In the signal conditioning circuit, the electric charge on the electrode either can be collected as the original shape of electrostatic noise using a capacitor [9], or it can be collected as voltage or current using a resistor [10].

The electrode is the main part of the sensor, and its physical properties affect the sensitivity and the frequency bandwidth of the sensor. Depend on the application, the electrode can get different shapes such as ring electrode, pin electrode and plate electrode. The spatial filtering effect or spatial filtering property of the electrode is a terminology that refers to the relation between frequency properties of the sensor's output signal and geometrical size and shape of the electrode. Hammer and Green [11] discussed that the cutoff frequency of a capacitance sensor, which is functionally similar to the electrostatic sensor, depends on the length of the ring shape electrode. Later, the method is used by Gajewski [12] and Yan et al. [1] to model the frequency response of the electrostatic sensor. Zhang in his thesis [13] and Zhang and Coulthard [10] have modeled spatial sensitivity of the electrode by utilizing the FEM analysis; the method later followed by C. Xu et al. [14,15]. To design any measurement system based on electrostatic sensor, the electrode modeling comes as its first importance.

2.1. Charge detection

An electrostatic sensor can detect electrostatic flow noise from a moving particle passing through electrode detection area. Amount of induced charge depends on flux density passing through the electrode and electrode surface area. In this study, a ring electrode as shown in Fig. 1 was used to detect the electrostatic noise from a single particle passing inside a pipe. To find the induced charge to the electrode, an analytical solution is started by Gauss's law. According to Gauss's law, the charge enclosed at any surface is equal to the flux passing to that closed surface [16,17].

$$q = \int_s \vec{D}\,\mathrm{d}s \tag{1}$$

In Equation (1), $\vec{D}$ is electric flux and q is the charge in the electrode surface. The electric flux is proportional to electric field and subsequently to electric potential as given in Equations (2) and (3).

$$\vec{D} = \varepsilon_0 \cdot \varepsilon_r \cdot \vec{E} \tag{2}$$

$$\vec{E} = -\nabla\phi \tag{3}$$

Where $\vec{E}$ is the electric field; $\vec{\nabla} = \hat{i}\partial/\partial x + \hat{j}\partial/\partial y + \hat{k}\partial/\partial z$ is called Del operator; $\phi(x,y,z)$ is the electric potential at any point and $\varepsilon_r(x,y,z)$ is relative permittivity, and can be a function of position; $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m is vacuum permittivity. According to Poisson's equation, divergence from the vector field of the electric potential gradient $\nabla\phi$ produces a value in scalar field, which is proportional to the total volume charge density $\rho_v(x,y,z)$ as given in Equation (4).

$$\vec{\nabla} \cdot (\varepsilon_r \cdot \varepsilon_0 \vec{\nabla}\,\phi) = -\rho_v \tag{4}$$

If the volume charge density on the electrode is known, the Equation (4) can be solved for electric potential and after that the electric field, electric flux and charge on the electrode surface can be measured respectively. Equation (4) is a second-order differential equation where in complex geometries such as a sensor electrode, it is difficult to be solved. A numerical method called finite-element analysis can be hired to solve this problem. In finite