Simulating a coaxial induction probe for measuring the charge, size and distance of a passing object

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***Abstract*—A new kind of probe for measuring the charge, size and distance of a passing object has been simulated, built and calibrated previously** [1]**. The probe consisted of a circular inner sensor, surrounded by an insulator, and an outer ring. In this geometry, two different current signals were induced to the sensors as a charged object passed by. By integrating the signals over time, the induced charge could be obtained. The charge, size and distance of the object were calculated from the amplitudes and widths of Gaussian curves fitted to the data. However, calibrating the new probe with charged spheres pointed out some weaknesses. Unlike in the simulations made with Comsol Multiphysics, the speed of the object could not be calculated since the Gaussian peak width data proved to be poor. Moreover, all the simulations and testing were done with objects passing the axis of the probe. If the object passed the probe asymmetrically, the calculations gave false results. According to the new simulations, the poor Gaussian width ratio, which is required for more reliable calculation, can be improved by using a larger outer ring. The displacement problem can be solved if the outer ring is split vertically into two adjacent parts. This way the outer probe tells how much the object is aside from the center. We present simulation results obtained by varying the probe geometry.**

I. INTRODUCTION

Electrostatic charging is very important in such industrial processes where large amounts of powder are handled. For example, in pharmaceutical industry the charging of pharmaceutical powders can cause detrimental problems during manufacture. Traditionally, the charge of an object or a powder sample is measured using a Faraday cup. A Faraday cup consists of two cups, one inside the other, which are separated by an insulator. The outer cup is grounded, and the inner cup is connected to an electrometer. When a charged object is placed in the inner cup, an equal but opposite charge will be induced on the wall of the cup [2]. This charge can be measured with the electrometer. Even though the Faraday cup is simple and reliable, it is not suitable for on-line measurements with fluidized beds, but is mostly used for off-line laboratory measurements. Also, the system only measures the net charge, not the amount of negative and positive charge on the object. Sampling may furthermore cause additional charge and thus give false results [3].

Fluidized beds are used in various technical processes, such as granulation in pharmaceutical industry. In a fluidized bed, the gravitational force of a powder is counterbalanced with the upward moving gas. Since there are many particle-particle and particle-wall collisions in the system, charge is accumulated on the insulating powder [4]. Charging may remarkably increase the adhesion of the particles on the walls and therefore adversely affect the performance of a fluidized bed reactor. Electrostatic adhesion causes "sheeting" on the walls [5], process breaks and great financial losses. Therefore, the charge density of the powder is an important parameter in powder industry.

On-line measurements of a charge in fluidized beds are most commonly done using electrostatic probes. In these probes, signals arise from collisions between particles and the probe and also from variations in surrounding charge density. In this research, an opposite charge is induced on the probe as an air bubble within the powder passes the probe. Charged object induces a charge of opposite sign to the probe. From the probes point of view, it is indifferent whether the object is a charged particle travelling in the air or an air bubble in the charged powder. By measuring the current signal when the bubble passes by, the charge density of the powder can be calculated. The signal obtained is a function of object's charge, speed, size and shape, and distance from the probe.

Moreover, bubble size and rising velocity are other important properties of the hydrodynamics of the system [6]. At the moment, there are no sensors which could give all these parameters accurately. Thus, the lack of a proper measurement system is the main motivation for this research. If the distance between the bubble and the probe is unknown, a single probe gives no information about the size of the bubble.

II. Methods

A. Previous simulations and calibrations

An electrostatic probe for measuring powder properties in a bubbling fluidized bed system was previously presented [1]. According to the computer simulations done previously with Comsol Multiphysics, the charge, speed, distance from the probe, and size of the passing object, could be determined by using two different probes. In the simulations, a charged sphere was set to vertically pass the probe in a steel pipe at 1 mm steps. The charge, distance and size of the object were varied, and the induced charge was determined by integrating the surface charge density over the sensor surfaces. In this geometry, the probe consisted of a circular inner sensor (radius 1 mm) surrounded by a 1 mm thick ring shaped outer sensor (radius 3 mm). They were separated from each other by an insulator. The outer ring was also surrounded by a 1 mm thick insulator. A schematic picture of the coaxial probe is presented in Fig. 1. The probe was connected to a grounded fluidized bed container made of steel (inner diameter 35 mm), and its surface was built so that it was in the same surface as the pipe wall.

The coaxial probe was built and previously calibrated with frictionally charged spheres and induction charged water droplets. The charge of a sphere was determined with a Faraday cup which was placed under the probe. The induced currents were collected with a virtual instrument written in LabVIEW. Since two different sensors were used, two different current signals were induced. The current data were integrated over time, Gaussian curves were fitted, and amplitudes (A_o and A_i for outer and inner probe respectively), widths (W_o and W_i) and ratios (A_o/A_i and W_o/W_i) of the fitted curves were collected. Since uniform charging of the spheres was difficult, the measurements were repeated several times for better statistics.

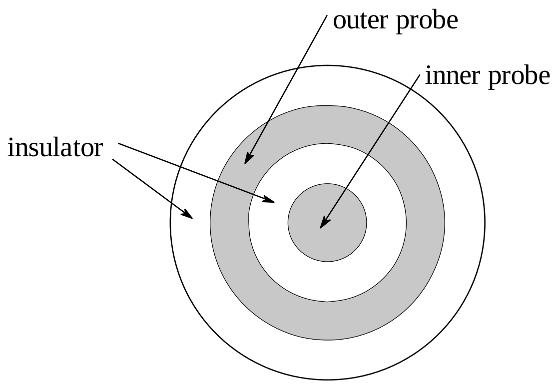

Fig. 1. A schematic picture of the coaxial probe. The inner and the outer probe are separated with an insulator. The outer probe is also separated with an insulator from the wall of the fluidized bed container.

Both simulations and experiments showed that the amplitude ratio increased exponentially with increasing distance from the probe. Exponential curves were fitted and the fitting parameters were plotted as a function of the radius of the sphere. The widths of the curves increased almost linearly as a function of the distance. Linear curves were fitted to the data and the slopes were collected. Next, an average of the slopes was calculated, new fits were made with this slope and the intercepts were plotted as a function of the radius. Amplitude ratio, widths and width ratio remained constant as the charge was varied. However, the signal amplitudes increased linearly as a function of the charge. A linear curve, intercept at zero, was fitted to the data. As the sphere size was increased, the slope decreased exponentially. Again, exponential fits were made and the fitting parameters were plotted as a function of the radius. From these, calibration equations for $A_o/A_i(r, d)$, $W_o(r, d)$ and $A_o(q, r, d)$ were formed.

B. Weaknesses

Calibrating the probe pointed out some weaknesses. First of all, the Gaussian width ratio data was poor and therefore it could not be used in calculations, and the speed of the object could not be calculated. Also, the simulations and all the calibration measurements were made so that the object passed the axis of the sensor. If the object passed the probe asymmetrically, the calculations gave false results. This is illustrated in Fig. 2

where the simulated amplitude and width ratios are plotted as a function of the perpendicular distance from the probe and the displacement from the probe axis. The amplitude ratio increases in case of displacement, especially in the vicinity of the probe, since relatively less electric field lines couple with inner probe as an object passes the probe off-axis, thus decreasing the inner amplitude more than the outer amplitude.

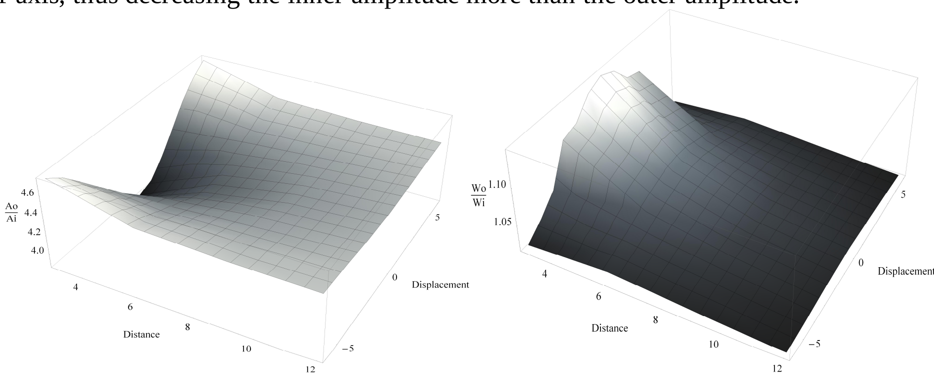

Fig. 2. The simulated amplitude ratio A_o/A_i (left figure) and width ratio W_o/W_i (right figure) as a function of the perpendicular distance from the probe and the displacement from the probe axis. The radius of the passing object was set to 3 mm.

III. Results and discussion

As shown in Fig. 3, increasing the radius and therefore the surface area of the outer ring increases the Gaussian amplitude ratio at distances larger than 6.5 mm, since relatively more electric field lines couple with the outer ring. As expected, the width ratio also increases with increasing the outer probe. Importantly, these ratios change more as a function of the objects distance from the probe as the outer ring radius is increased. Also, bigger changes in the amplitude and width ratios would make the probe more sensitive to changes in the size, distance and charge of the object, which enables more accurate calculations. This makes it possible that the experimental width ratio data would improve, and therefore the speed of the object could possibly be determined.

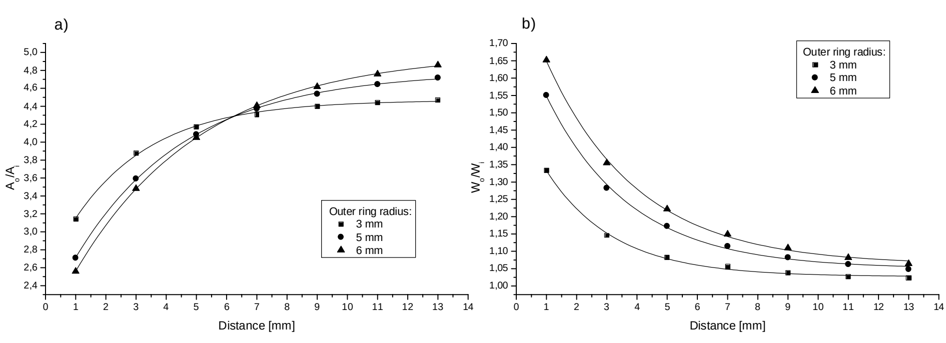

Fig. 3. a) Simulated amplitude ratio (A_o/A_i) and b) width ratio (W_o/W_i) as a function of distance for different sized outer rings. Exponential function was fitted to the data. The radius of the passing object was set to 3 mm and the charge to 1 nC.

Simulations also show that objects passing the probe asymmetrically are not a problem if the outer ring is split vertically into two adjacent parts. A schematic figure is presented in Fig. 4 (left). By doing this, two different current signals are induced to the outer probe so that the outer amplitude ratio A_o^{left}/A_o^{right} changes asymmetrically. If the object passes the ring from the left, more electric field lines couple with the left part than with the right part. This is illustrated in Fig. 4 (right) where A_o^{left}/A_o^{right} is plotted as a function of the distance and the displacement from the axis. Dividing the sum of these signals with the inner sensor amplitude gives again the same graph as in Fig. 2. Therefore, the real position of the object from the probe axis can be solved combining these data.

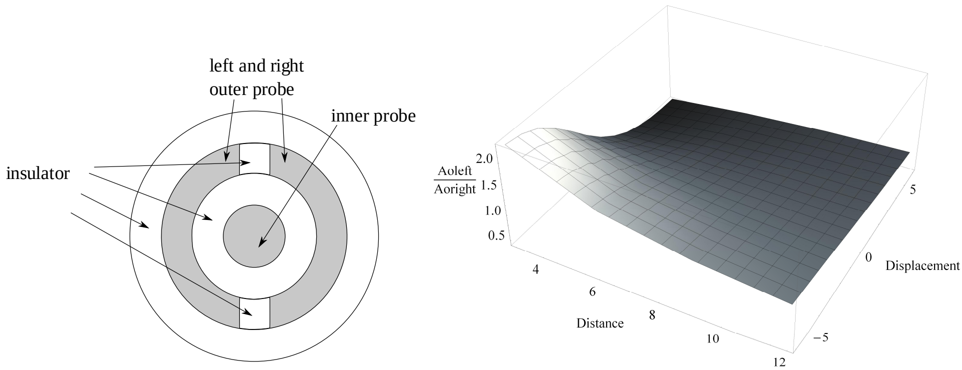

Fig. 4. By splitting the outer ring into two parts (left figure), the real position of the passing object could be determined from the different current signals induced into the left and right part of the probe (right figure).

IV. Conclusion

A new kind of coaxial probe for measuring the charge, size and distance of an object was previously presented. The probe suffered from poor Gaussian width ratio data. Moreover, objects passing the probe off-axis gave false results. The new study shows, that, according to simulations, these problems could be solved with a larger outer ring made of two adjacent parts.

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