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Electrostatic sensors applied to the measurement of electric charge transfer in gas-solids pipelines

S R Woodhead[1], **J C Denham and D I Armour-Chelu**
School of Engineering, University of Greenwich at Medway, Chatham Maritime,
Kent ME4 4TB

E-mail:s.r.woodhead@gre.ac.uk

Abstract. This paper describes the development of a number of electric charge sensors. The sensors have been developed specifically to investigate triboelectric charge transfer which takes place between particles and the pipeline wall, when powdered materials are conveyed through a pipeline using air. A number of industrial applications exist for such gas-solids pipelines, including pneumatic conveyors, vacuum cleaners and dust extraction systems. The build-up of electric charge on pipelines and powdered materials can lead to electrostatic discharge and so is of interest from a safety viewpoint. The charging of powders can also adversely affect their mechanical handling characteristics and so is of interest to handling equipment engineers. The paper presents the design of the sensors, the design of the electric charge test rig and electric charge measurement test results.

1. Introduction

The accumulation of electric charge on granular and powdered materials during handling and transport is of interest to design engineers and plant managers for a number of reasons; the accumulation of charge can lead to significant changes in the handling properties of many materials; large accumulations of electric charge can lead to electrostatic discharge within plant, which has obvious safety implications. In particular, significant electric charge can accumulate on particulate materials during pneumatic transport [1].

A number of investigations of such charge accumulation have been reported [1-6], but none have attempted to sense and record the charge transfer throughout a pipeline system. By developing a number of electric charge sensors and incorporating these into a small gas-solid test rig, the work reported in this paper aims to gain a better understanding of electric charge accumulation in such systems.

Section two of the paper will detail the design of the sensors themselves, with section three providing an overview of the test rig. Section four will outline a test programme, along with the associated results. Sections five and six will discuss the outcomes of the work and draw some conclusions respectively.

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[1] To whom any correspondence should be addressed

2. Sensors

As particles are carried along the pipeline by the air stream, they will, at various times, come into contact with the pipeline wall. The frequency and nature of such contacts will be dependent on a number of factors, including the characteristics of the flow, the pipeline geometry, the nature of the particles and pipeline wall and the exact composition of the conveying gas. When these contacts take place, a triboelectric electric charge transfer can take place between the pipeline wall and the particle. The sensors reported in this paper have been designed to measure this electric charge transfer in six positions within the pipeline system.

Figure 1 shows the general mechanical arrangement of a sensor. The sensing head is an electrically isolated pipeline section, separated from the main pipeline by nylon spacers and fixed in place using flanges and nylon bolts. Four straight sensors are incorporated into the pipeline. Two sensor heads are made form pipeline bends. All of the sensor heads and the main pipeline were manufactured from stainless steel. An aluminium shield is incorporated into each sensor, to reduce noise from stray electric fields. The shields were manufactured from 0.8mm aluminium sheet and are electrically connected to the main pipeline at the end of each sensor.

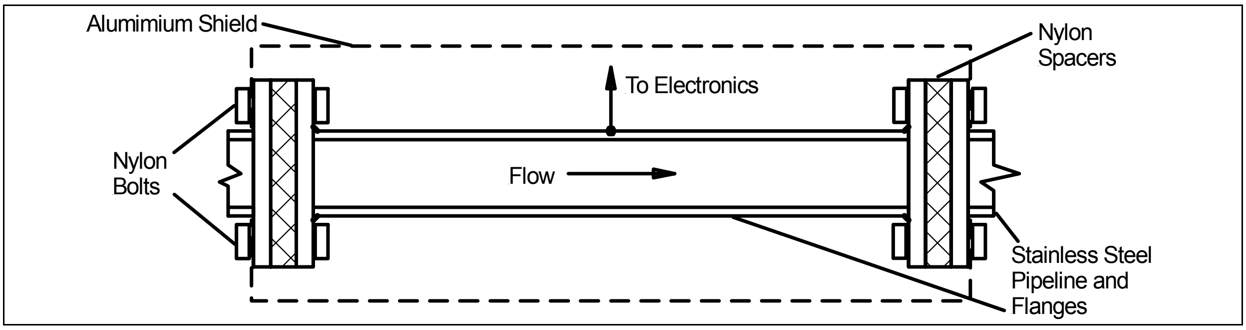

Figure 1. Sensor mechanical arrangement

Figure 2 shows the circuit for the sensor head electronics. The isolated pipeline section is connected to ground (which is designated as the main pipeline) through a 1MΩ resistor. The terminals of the resistor are connected to the input terminals of an instrumentation amplifier, which has a specified input impedance >10GΩ. The inherent stray capacitance between the isolated pipeline section and the main pipeline forms a capacitor in parallel with the 1MΩ resistor. The voltage gain of the instrumentation amplifier is set to unity. The amplifier output is taken to a PC based data acquisition system.

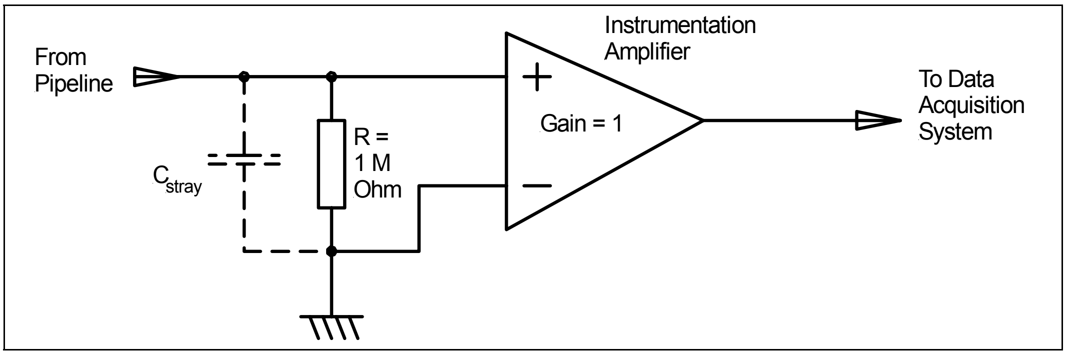

Figure 2. Sensor electronic circuit

When a triboelectric transfer takes place within the sensor head section, this will result in a small charge (positive or negative) being deposited on the upper plate of the capacitor. A small voltage will therefore be present between the capacitor plates according to equation 1. This voltage will be sensed by the instrumentation amplifier and logged by the data acquisition system. The capacitor will then discharge through R, according to equations 2 and 3. For the sensing heads used, C_{stray} is of the order of 80pF and so the time constant of discharge, τ, is of the order of 80μs. Assuming no further triboelectric interaction, the sensor voltage will therefore discharge through R to within approximately 5% of zero, within 240μs of the initial contact. Each triboelectric interaction therefore causes a step increase in the sensing head voltage, followed by an exponential reduction in voltage of time constant τ.

$$V = \frac{Q}{C_{stray}} \tag{1}$$

$$V_t = V_0 e^{\frac{-t}{\tau}} \tag{2}$$

$$\tau = C_{stray} R \tag{3}$$

3. Test rig

The general layout of the test rig is shown in figure 3. Compressed air, from the laboratory air supply, is fed into the particle feeder and then flows through a short section of straight pipeline before reaching sensor one. The solids laden air then passes through sensors two through six, and then enters a particle filter, where the solid phase is disengaged. The air then passes to atmosphere via an orifice-type air flow meter.

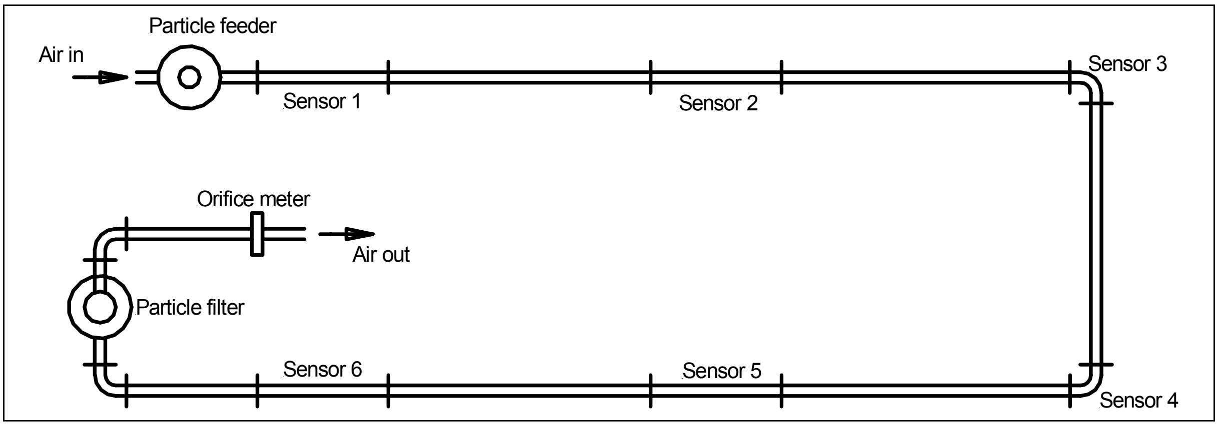

Figure 3. Gas-solids pipeline test rig and sensors

Each of the straight sensors has a length of 0.5m, with a straight pipeline section of 1m separating each of the sensors. The two bend sensors have a radius of 25mm, with the pipeline having a bore of 22mm throughout. Since relative humidity (RH) is known to affect triboelectrification [7], the RH of the exhausting air is monitored throughout each test. The rig has the ability to convey particles within the air velocity range 16 to approximately 36m/s. The sampling rate used by the data acquisition system for each of the sensors was 66.7k samples per second (one sample every 15μs).

4. Test methodology and results

The particulate material used for the tests reported in this paper was olivine sand, having a particle size range from 425 to 500μm. The following methodology is adopted for each test: 1) A 150g of particulate material is loaded into the particle feeder; 2) The air flow is initiated at the required velocity; 3) Simultaneously, the particle feeder is started and the data acquisition system triggered; 4) After six seconds, the data acquisition system is stopped and the air flow stopped also. Figure 4 shows a typical sensor output for such a test.

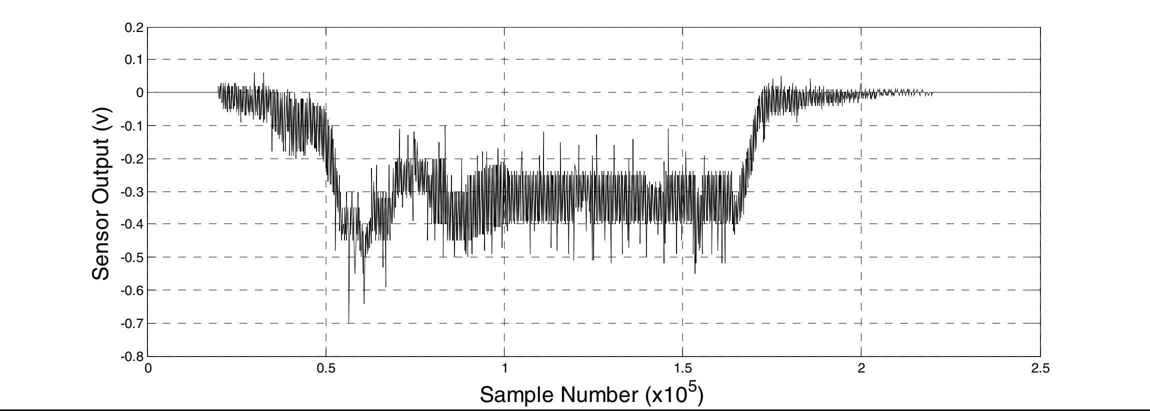

Figure 4. Typical sensor signal output

Initially, the flow of particles in the pipeline causes a significant transient, which settles to a relatively steady-state signal after approximately 90k samples. This steady-state signal is sustained, until the supply of particles is exhausted after approximately 165k samples. Since the sensor output is principally negative, this would indicate that the vast majority of the electric charge transfer activity is unipolar.

In order to make comparisons between the output from the various sensors, and between different flow conditions, the RMS value of the signal voltage in the steady state output condition was calculated. This is plotted in figure 5 for all six sensors and two air flow velocities. The data points at 0.25 and 1.75m indicate the charge transfer activity in the first two straight pipeline sensors (sensors one and two). The values at 3.1 and 4.2m correspond to the first and second bends respectively (sensors three and four), whilst those at 5.5 and 7m correspond to sensors five and six respectively. Each data point represents the average value obtained from three independent tests under similar conditions, whilst the range bars illustrate the maximum and minimum values obtained.

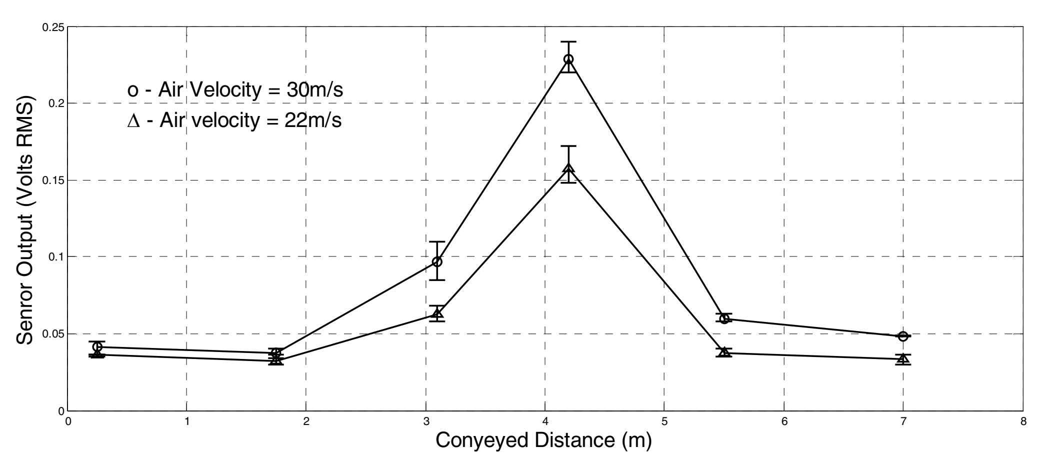

Figure 5. The effect of air velocity on charge transfer levels

5. Discussion

It maybe observed from figure 5 that the charge transfer activity measured in the straight sensors is modest, compared to that measured in the bend sensors; this was expected, as significantly more particle-wall interactions are likely to occur in the bend sensors. The charge transfer activity in bend two (sensor four) is significantly greater than that in bend one (sensor three); this was not initially expected and is the subject of further investigation by the authors. The charging activity at 30m/s is consistently greater than that at 22m/s; this was expected and is consistent with other published works in this area [2,3,6,7]. The reproducibility of the measurements reported in this paper is generally favourable in comparison with these other published works.

6. Conclusions

The development of the sensors reported in this paper has allowed the electric charge transfer activity to be measured directly in a number of positions throughout a gas-solids pipeline. In particular, it has been possible to directly measure the charge transfer activity taking place in gas-solids pipeline bends; to the authors' knowledge, this is the first time such direct measurements have been reported. The experimental test work has already produced some unexpected results and has contributed to a better understanding of charge transfer activity in such environments. The authors will be extending the reported work to include other particulate materials and a wider range of flow conditions.

7. References

[1] Singh S 1982 A study of electrostatic activity in a full scale pneumatic conveying system *Proc. Intl. Conf. on Pneumatic Conveying Tech., Stratford-upon-Avon UK*
[2] Gajewski J B 1994 *J. Electrostat.* **32** 297-303
[3] Gajewski J B and Szaynok A 1981 *J. Electrostat.* **10** 229-34
[4] Yan Y 1996 *Meas. Sci. Tech.* **6** 1687-1706
[5] Cole B N, Baum M R and Mobbs F R 1970 *ProcIMechE.* 3C **184** 77-82
[6] Armour-Chelu D I and Woodhead S R 2002 *J. Electrostat.* **56** 87-101
[7] Woodhead S R and Armour-Chelu D I 2003 *J. Electrostat.* **58** 171-83