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Virtual instrument for statistic control of powder tribo-charging processes

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Abstract

The paper demonstrates that statistic process control (SPC) techniques could be of great use for monitoring the tribo-charging of pulverulent materials in compressed-air transportation systems or in electrostatic deposition devices. A virtual instrument was developed using LabView® in order to process the data acquired by an electrometer connected to a modified Faraday pail. By sampling the charge of the powder collected in the pail, it was possible to build up SPC charts that appropriately reflect the tribo-charging phenomena related to the processing of finely divided materials.

Keywords: Tribo-charging; Powders; Statistic process control

1. Introduction

The tribo-charge accumulated by powders and granular materials during transportation through ducts is a well-documented source of electrostatic hazard [1,2]. The efficiency of the electrostatic methods of powder deposition technologies,

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as well as that of tribo-electrostatic separation processes, is intimately related to the charge/mass ratio ensured by tribo-charging [3–6].

Statistical process control (SPC) techniques are widely used in manufacturing industries for monitoring repetitive processes to determine whether they are operating properly [7]. Variability of the response is the key-concept of these techniques. Thus, the common cause of variation is the naturally occurring oscillations of system response around a long-term average value, due to inherent fluctuations of system parameters. The special-cause variations are typically generated by some problem in the system, and can be quickly detected with SPC techniques.

In the case of electrostatic processes considered in this paper, the system response is the charge Q acquired by the powders transferred at constant feed-rate through a tribo-charging device. The first step of standard SPC consists in monitoring this response for a reasonably long period of time. The measured data serve to compute the standard deviation σ. It is then possible to evaluate the upper-control-limit (UCL) and the lower-control-limit (LCL) for the $\overline{X}$ and σ control charts [8]. A point on the $\overline{X}$ chart is the average value of n items of a sample taken at a given time; represented on the σ chart is the standard deviation of the same sample. A point situated outside the control limits on either of the two charts is the most easily detectable out-of-control condition.

The aim of this paper is to present a modified Faraday pail and a virtual instrument that were designed in view of performing the charge measurements needed for the implementation of such techniques for monitoring industrial tribo-charging process.

2. Experimental procedure

The experimental set-up consists of a tribo-charging device [9] provided with means to control the charge by adjusting the air pressure in different circuits (Fig. 1). The injection pressure p_{inj} determines the particle speed through the tribo-gun and the energy of particle–wall impacts; the dilution pressure p_{dil} is used to modify the concentration of powder in the transported air, hence the number of particle–wall contacts; the vortex pressure p_{vor} controls the turbulence of the motion.

The charged powder (starch, characteristic size: 0.02 mm) was collected in a modified Faraday pail (Fig. 2), connected to an electrometer (model 6514, Keithley Instruments). The charge measurement data acquired during 2–4 min of steady-state operation of the tribo-gun were processed by a virtual instrument (VI) developed in the LabView environment [10]. The VI commanded the grounding of the electrometer input every 5 s. In this way, it displayed the charge accumulated in the modified Faraday pail within 5 s intervals. These data were then employed for the statistical control of the powder tribo-charging process.

A first experiment (30 measurements, carried out at 5 s intervals, during $2\frac{1}{2}$ min of steady-state operation), was aimed at establishing the upper and lower control limits

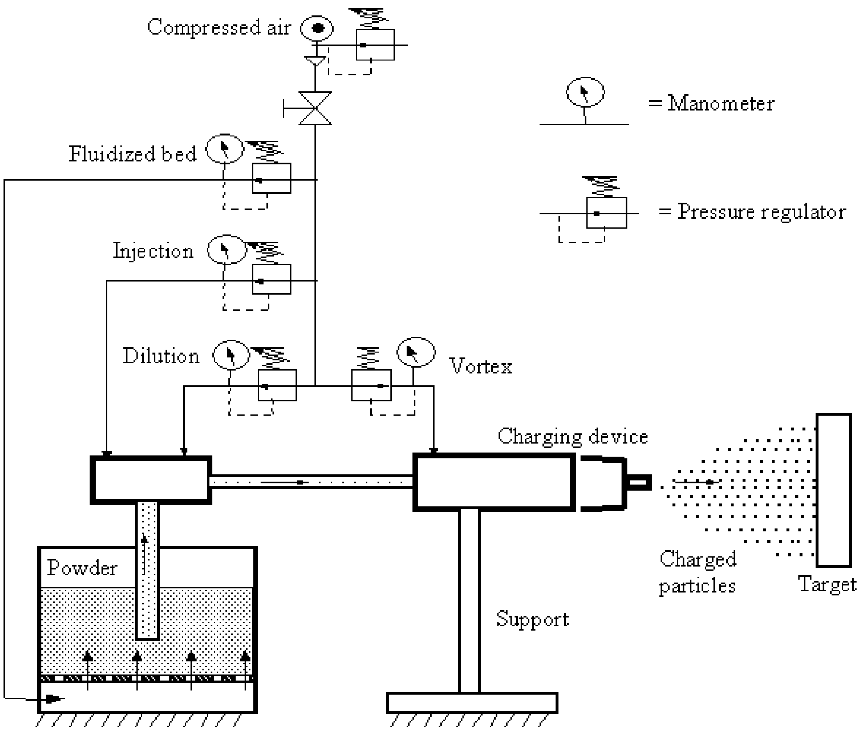

Fig. 1. Schematic representation of a powder tribo-charging installation.

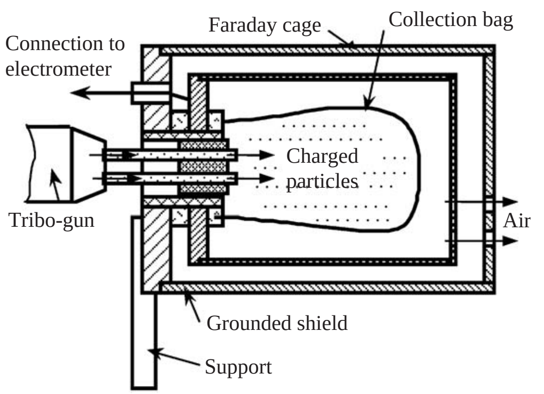

Fig. 2. Schematic representation of a custom-designed Faraday pail for powder charge measurement.

for the SPC charts, at rigorously controlled operating conditions ($p_{inj} = 1.4$ bar, $p_{dil} = 1.1$ bar, $p_{vor} = 0.8$ bar; ambient temperature 20.2 °C, relative humidity of ambient air 49.7%).

The second and third experiments simulated the occurrence of two special causes of response variability: (i) a 5% diminution of the air pressure in the installation that supplied the experimental installation; (ii) a transient obstruction of the duct that ensures the powder transfer from the fluidized bed to the tribo-gun. The air temperature (19.8–21.3 °C) and relative humidity (48.5–50.4%) were similar to those in which the first set of experiments were conducted.

3. Results and discussion

A typical charge measurement chart displayed by the VI is shown in Fig. 3. The measured charge has a peak at about 10 s from the moment when the air pressure is turned on, and then it slightly decays to attain a steady-state condition. At equilibrium, the charge acquired by the powder in friction with the Teflon walls of the tribo-gun should be equal to that conveyed from the metallic screen connected to the ground. After about 2 min of steady-state operation, the value of the charge diminishes, as the powder obstruates the pores of the collecting bag and increases the pressure drop at the output of the tribo-gun, hence modifying the conditions of particle charging (particle speed through the device).

Based on the results of the first experiment (measurements #12 to #41 in Fig. 3), $\sigma = 0.15\,\mu C$, with the target set at $9.6\,\mu C$, the upper and lower limits were established

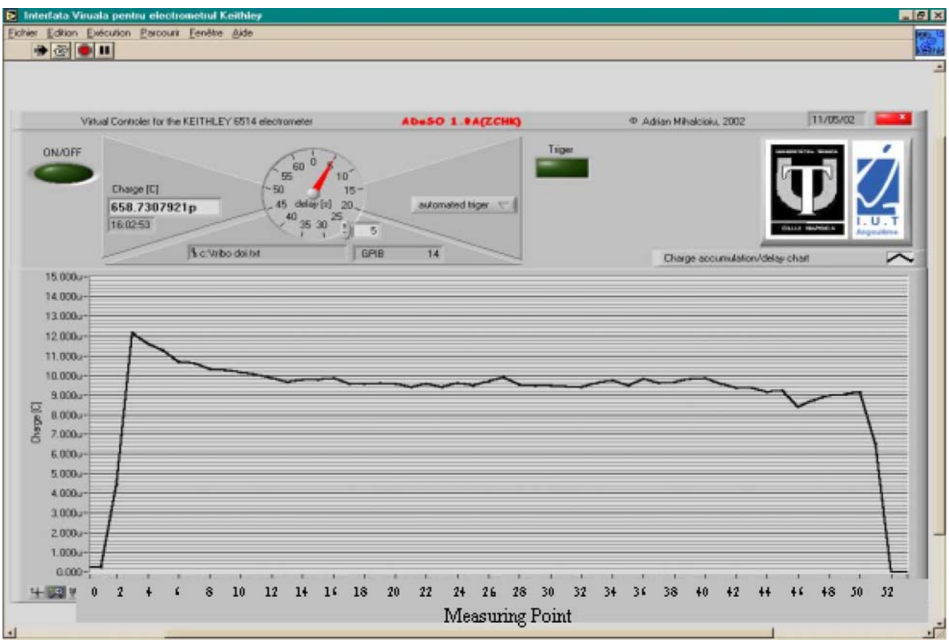

Fig. 3. Charge measurement chart displayed by the custom-designed VI, for the first experiment.

for the two charts at

$$\text{Target} \pm \sigma = 9.6 \pm 0.949 \times 0.15 \cong 9.6 \pm 0.15\,\mu\text{C}, \tag{1}$$

$$B_6\sigma = 1.669 \times 0.15 \cong 0.25\,\mu\text{C} \quad \text{and} \quad B_5\sigma = 0.277 \times 0.15 \cong 0.04\,\mu\text{C} \tag{2}$$

the values for A, B_5, and B_6 being those given in [8, p. 184] for $n = 10$.

In most applications, the interval of tolerance (IT) represents about 10% of the target; in such a case, the capability of the device, defined as the ratio between IT and the dispersion of the response

$$Cp = IT/6\sigma = 0.1 \times 9.6/(6 \times 0.15) \cong 1.066 \tag{3}$$

is rather poor. This could be explained by the slightly defiant airtightness of the tribo-gun, and the difficulty to ensure a uniform powder transfer from the fluidized bed to the charging device.

The results of the second experiment (Table 1) contain 7 consecutive points below the target. The response of the system came back to normal as soon as the air pressure was established at its rated value. As expected, the simulated diminution of air pressure is a cause of variability that could be easily detected using the $\overline{X}$ chart, but not with the σ chart.

The values contained in the $\overline{X}$ and σ charts of the third experiment are given in Table 2. One point on the σ chart is out of the control limits; it corresponds to the experiment where a transient obstruction of the duct that connects the fluidized bed and the tribo-gun disturbed the normal operation of the installation. This event could not be detected with the $\overline{X}$ chart.

Table 1
Results of the second experiment (5% lower air pressure in the system)

Sample no.	1	2	3	4	5	6	7
$\overline{X}$	9.52	9.48	9.55	9.46	9.47	9.5	9.48
σ	0.17	0.12	0.14	0.2	0.19	0.11	0.09

All $\overline{X}$ values are higher than the lower control limit 9.45 μC, but below the target 9.6 μC.

Table 2
Results of the third experiment (transient obstruction of powder duct)

Sample no.	1	2	3	4	5
$\overline{X}$	9.66	9.68	9.48	9.54	9.63
σ	0.13	0.16	0.32	0.12	0.11

One σ value is higher than the upper control limit 0.25 μC.

4. Conclusion

The experiments prove that the VI developed for monitoring the powder tribo-charge is an effective SPC tool. By sampling, at well-established time intervals, the charge of the powder collected in a modified Faraday pail, it is possible to build up SPC charts that appropriately reflect the output of the respective processes.

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