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On the attraction force applied on metal pieces in a traveling wave conveyor

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ABSTRACT

The traveling wave conveyor (TWC) which is generally used for moving high-resistivity particles is employed in this paper to analyze a magnetic attraction force applied on nonferrous metal pieces. A planar three-phase conveyor, constituted of parallel electrodes supplied by high voltage amplifiers controlled by digital function generators, has been used for analyzing the attraction force applied on 15 mm × 15 mm square metal pieces made of copper, bronze and steel. The TWC is supplied by three high voltage amplifiers (2 kV, 20 mA) and fixed on a mechanical device allowing its manual inclination from 0° (horizontal; initial condition) up to an angle of 180°. The intensity of the force is then estimated by measuring the drop angle for which the metal piece detaches from the surface of the conveyor. The obtained results have shown the existence of an electromagnetic force that depends on the frequency and the amplitude of the applied voltage. Based on this force, two new separation techniques of mm-size metal/plastic granular mixtures were proposed and tested succefully.

1. Introduction

Traveling wave conveyors (TWC) are typically used to produce the movement of micronized insulating materials as result of the interaction between the polarized particles and a phase-shifted electric field. A TWC comprises parallel electrodes with 2, 3 or 4 phase shifted AC potentials.

When a non-uniform electric field *E* is applied to an insulating particle, an electric dipole moment *P* is induced and thus a non-zero resultant force, called the dielectrophoretic force, becomes applied on it [1]. Several applications using electric curtain, such as dust mitigation, have been reported [2,3]. Moreover, this technique was employed for moving an aerosol cloud [4], and for transporting blood cells in a liquid [5]. Later, it was used for the charged toner conveyer device to spread xerographic toner into a thin film [6–9]. Other applications have been proposed such as bubble and radioactive dust containment [10,11], liquid droplet transport [12,13], granulometric size classification [14], and separation of fine particles [15–18]. Furthermore, several studies for space applications, using electric curtain technology, have been also reported [19–21].

The objective of the work described in this paper is an experimental investigation of a phenomenon totally different from the one generally observed in the TWCs, namely the displacement of the insulating particles by the dielectrophoretic force. This new phenomenon is the attraction force exerted by these conveyors on nonferrous metal pieces and that keeps them "glued" to their surface. An analysis was conducted to study the influence of several factors on the intensity of this force, such as the amplitude and the frequency of the applied voltage.

2. Material and methods

Two experimental setups were developed and used in this study:

Setup 1: a three phase Planar conveyor (P-TWC) and a mechanical system that varies the inclination angle of the conveyor from 0° up to 180°. The TWC is made with a plate of Poly-Methyl-Meth-Acrylate (PMMA-plexiglas®) of dimensions 30 × 15 cm^2, on which were fixed identical parallel electrodes of copper wire of diameter 1 mm and length 15 cm, separated by an interval of 2 mm (Fig. 1). The plate is then covered by an insulating acrylic varnish layer to prevent breakdown between the electrodes.

The electrodes belonging to the same electrical phase are connected together as shown in Fig. 1. The electrodes are then supplied by three-phase square-shaped alternating voltages with 120° phase shift between them using, voltage amplifiers (TREK, Model 2220) that can deliver a variable voltage up to 2 kV with a current of 20 mA. The amplifiers are controlled by two function generators (Siglent SDG 1025).

An experimental device using a TWC with variable inclination was developed to analyze the intensity of the attraction force applied to the

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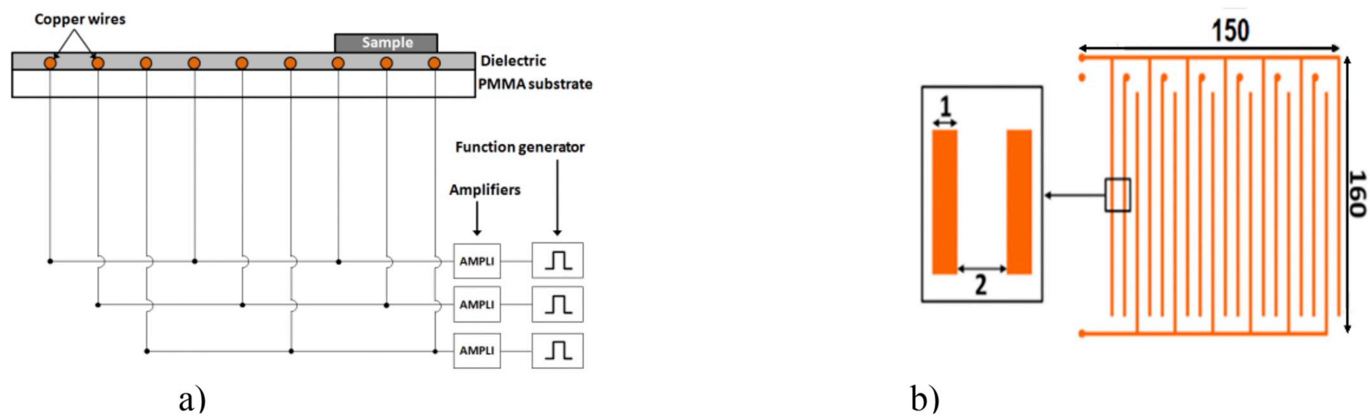


Fig. 1. The three-phase conveyor a) Schematic description b) Dimensions in mm.

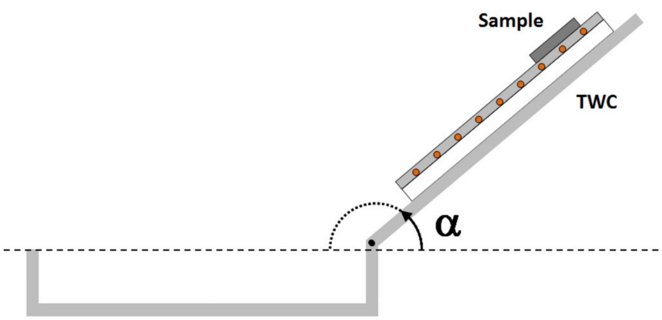
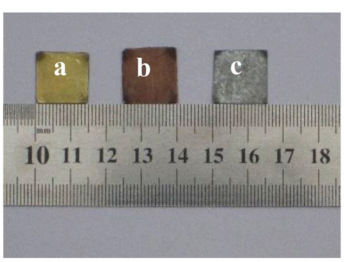


Fig. 2. Inclination system of the traveling wave conveyor.



(a) Copper; (b) Bronze; (c) Steel

Fig. 3. Metal pieces.

metal pieces. In order to measure the drop angle α which corresponds to the planar inclination at which the metal samples start to slide on the surface of the conveyor, the TWC was fixed on a mechanical device allowing its manual inclination from 0° (initial conditions, i.e. the horizontal plan) to an angle of 180° (Fig. 2).

The metal samples used in this study are 15 mm × 15 mm square-shaped pieces made of three different types of metal: copper, bronze and steel, with respective mass values 1.4 g, 1.6 g and 1.3 g (Fig. 3).

For each experiment, three identical pieces of the same metal were placed in a same defined area on the conveyor surface at the horizontal plan (α = 0°). Once the TWC was turned on, it was then slowly inclined until the pieces detached one after the other from the surface of the conveyor up to α = 180°. The drop angle considered for plotting is the mean value of the three identical samples. Furthermore, the experiments were carried out under two different humidity conditions (35% RH and 75% RH) in order to detect a possible effect which could affect their adhesion on the TWC.

Setup 2: The experimental device is shown in Fig. 4, it represent a new separation technique of particles using a cylindrical TWC. It comprises a Teflon (PTFE) cylinder of radius 12 cm and length 15 cm on the surface of which were glued identical parallel copper-wire segments of diameter 1 mm and same length 10 cm. The wire segments were coated with an insulating varnish layer to prevent sparks between adjacent electrodes, and supplied by two-phase square-shaped alternating voltage with 180° phase shift between them using two voltage amplifiers (TREK, Model 2220).

The experiments were carried out using a combination of copper and plastic particles, which are cylinders with average sizes of 1 mm diameter and 10 mm length (Fig. 5). The same mass m = 20 g was used for all the experiments, comprising 50% copper and 50% plastic.

3. Results and discussion

We have noticed a new electrical phenomenon produced by the TWC that consists of an attraction magnetic force applied on the metal pieces causing their "attachment" to the surface of the conveyor.

The metal pieces are pinned to the conveyor surface by the Laplace force expressed by:

$$F = \int I.\, dl \wedge B \tag{1}$$

where I is the Eddy current induced by the induction B, this latter being produced by the time-variable electric field, according to the Maxwell-Ampère equation:

$$Rot\ \vec{H} = \vec{J} + \varepsilon\frac{d\vec{E}}{dt} \tag{2}$$

With ε permittivity of air, $\vec{H}$ magnetic field and $\vec{J}$ current density.

Since the TWC comprises electrodes which are isolated from each other, the conducting current is then almost zero (J = 0). Therefore the magnetic field is produced by the variation of the electric field expressed by the term ($\varepsilon\frac{d\vec{E}}{dt}$). Thus, the variation of a high voltage (up to 2 kV in our case) generates a magnetic field high enough to produce an Eddy current in the piece followed by a magnetic attraction force.

3.1. Experiments with the planar TWC

The results plotted in Fig. 6 representing the variation of the drop angle as a function of the applied voltage for the three pieces, show that the force depends strongly on the value of the applied voltage; the higher the voltage is, the greater the electric field, and consequently the magnetic force becomes stronger.

Moreover, the steel piece "sticks" better to the surface of the TWC because of its smaller mass (1.3 g) compared to copper and bronze samples (1.4 g and 1.6 g respectively). However, we have observed no effect related to the ferromagnetic nature of the steel piece, as shown in Fig. 7 representing the variation of the drop angle for two steel pieces having the same surface but of different masses; the lighter the piece is