Manuscript refereed by Dr Christophe Martin, INP Grenoble

Conveying of Ferromagnetic Powder Materials by Pulsed Electromagnetic Field

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ABSTRACT

Use of pulse electromagnetic field for conveying of ferrous and steels ferromagnetic powders is shown. A basic model for material conveying electromagnetic field is proposed. A relationship between powder chemical composition and conveying efficiency, as well as a distance factor influencing on conveying process are evaluated. An experimental device for ferromagnetic powders conveying is proposed.

Keywords: pulse electromagnetic field, ferromagnetic material, conveying, transportation of materials.

INTRODUCTION

Conveying of ferromagnetic powder materials is extremely important to vast variety of technological processes. The most common operations where conveying of powdered materials is taking place are: vertical, horizontal and inclined transportation, dosage, loading to and unloading from containers [1,2,3] (Fig. 1).

Today, the main conveying systems for powder metallurgy are bucket elevators, vibratory and belt conveyors [4]. Use of chain tubular conveyors (Fig. 2) offers a transportation of powdered materials in closed tubes [5].

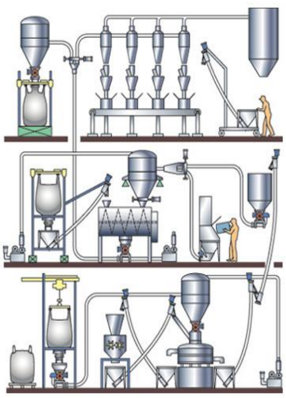


Fig. 1. Various routes of powder transportation (*source: Flexicon Corporation UK*)

Fig. 2. Tube chain conveyor for powder material transportation (*source: Schrage Rohrkettensystem GmbH,*)

These devices are simple, efficient, and allow moving powder materials in different directions. Their major disadvantages are: large wear of the pipes and paddles, as well as a large energy losses due to friction [6]. Several companies are working in pneumatic transportation of powder and bulk materials, offering feasible solutions especially for chemical industry [7,8].

At the Latvian enterprises centralised system of pneumatic transport has been used, yet this approach proved ineffective because of frequent product swap, different raw materials, and other factors [9].
In current paper, use of electromagnetic pulsed fields for conveying of ferromagnetic powders is proposed.

1. CONVEYING OF POWDER MATERIALS BY IMPULSE ELECTROMAGNETIC FIELD.

Taking into account good magnetic properties of ferrous powders, and rapid development of electromagnetic equipment, offer great prospect for research of conveying processes by pulsed electromagnetic field. The behaviour of ferromagnetic materials in magnetic fields is well-known and is used in a variety of applications [10]. At Riga Technical University (Latvia) a research of pulsed electromagnetic fields on ferrous and non-ferrous materials has begun more that 30 years ago and mainly was tied to metallic and non-metallic powder pressing and treatment of powder compacts by pulsed electromagnetic fields [11]. Due to the increased interest of PM sector and manufacturers to automatic powder conveying, the laboratory of powder metallurgy (at Riga Technical University, Latvia) has started a search for new techniques of powder conveying. [12-14]. As a research result, an experimental equipment for powder conveying by pulsed electromagnetic field in closed pipe has been developed [15].

2. EXPERIMENTAL STUDIES OF THE POWDER CONVEYING PROCESS

Model of device for the electromagnetic powder conveying (EPC) contains: a generator of pulsed current (PEMFG), a pipe for powder transport, and inductor (electromagnetic coil) which creates a directed electromagnetic field. Schematic of the device is shown in Fig.3.

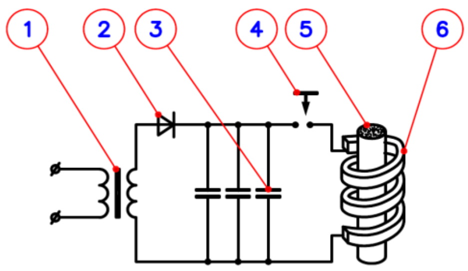


Fig. 3. Schematic of powder conveying by pulsed electromagnetic field.
1 – transformer; 2 – rectifier; 3 – battery of capacitors; 4 – discharger; 5 – ferromagnetic powder; 6 – coil

Powder conveying process can be expressed mathematically as a movement of the determined centre of mass under the influence of pulse pressure. The electromagnetic force F_m on the powder can be determined by the following equation (1):

$$F_m = \mu_0 \mu k \left(\frac{i(t)}{n}\right)\frac{r}{z} \qquad (1)$$

where:
μ_0 - permeability of vacuum, μ - permeability of powder, k – factor coil-powder, $i(t)$ - coil impulse current, n – a number of coil turns, r - mean radius of winding, z – a gap between winding and a powder.

In this case, coil is primary circuit, which is inductively connected to a lifted body (a ferrous powder), which acts as a secondary circuit. Discharging of a capacitor to the coil inductor current flowing in the primary circuit, excites the eddy currents in the secondary circuit. The coil and the lifted body induce a magnetic fields in two opposite directions. This leads to rapid rising of ponderomotive forces, due to a lifted body acquires an initial velocity. So the energy of the capacitor is converted into the energy of magnetic field inducer, and then into mechanical energy of projectile thrown from the coil's electromagnetic coupling zone, and partially into heat.

Schematic of lifting process by pulsed electromagnetic field is shown on Fig. 4.

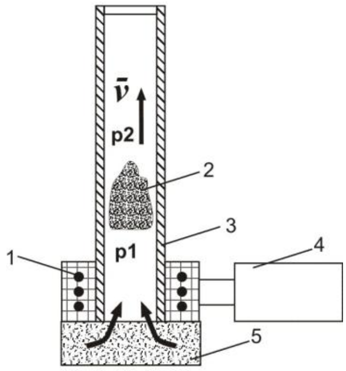


Fig. 4. Schematic of experimental equipment for electromagnetic conveying. 1 – coil, 2 – conveyed material, 3 – duct (material: organic glass), 4 – pulsed electromagnetic field (PEMF) generator, 5 – reservoir with conveyed material.

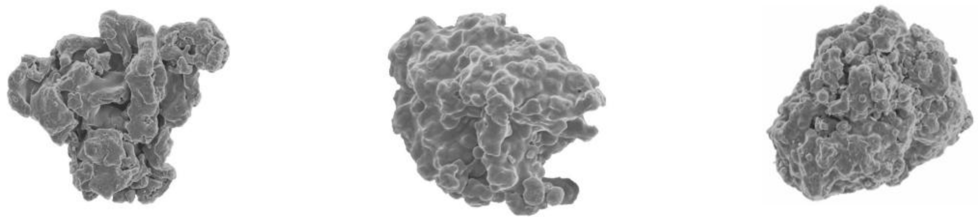
Experimental studies were carried out using the equipment designed at Riga Technical University (Fig. 5). The powder was placed in the cavity of pipe in alignment with the inductor (Fig. 6). Height of transportation varied between 1 and 2 meters. For weight estimation of conveyed powder a special dumping bin was used (Fig. 7). A control of lifting process was achieved by changing the inductor operating voltage and pulsed discharge current.

Fig. 5. PEMF generator. (U = 380 V, W = 0,4 кJ)

Fig. 6. Cylindrical coil (internal diameter: 50 mm) connected to PEMF generator.

Fig. 7. Dumping bin for powder and metallic parts

The ability of different ferrous powders to be conveyed to the height of 1 m by impulse electromagnetic field have been investigated [16]. For experimental trials several powders with moderate magnetic permeability were selected. Experimental part was carried out for the following powders NC100.24, ASC100.29, Distaloy AE (Fig. 8. and Table 1.).



NC100.24 ASC100.29 Distaloy AE.

Fig. 8. Particles of powder materials used in electromagnetic conveying tests.

Table 1. Properties of ferrous powders used in experimental trials.

Type of powder	NC100.24	ASC100.29	Distaloy AE
Apparent density, g/cm^3	2.45	2.98	3.05
Elemental composition, %			
C	<0.01	<0.01	<0.01
O (total)		0.08	0.1
Cu			1.50
Ni			4.00
Mo			0.50
H_2	0.14		

Preliminary studies have shown that powder properties have significant influence on conveying by electromagnetic pulsed fields. The presence of alloying elements in powder type Distaloy AE reduces the efficiency of the electromagnetic elevator (Fig 9) .

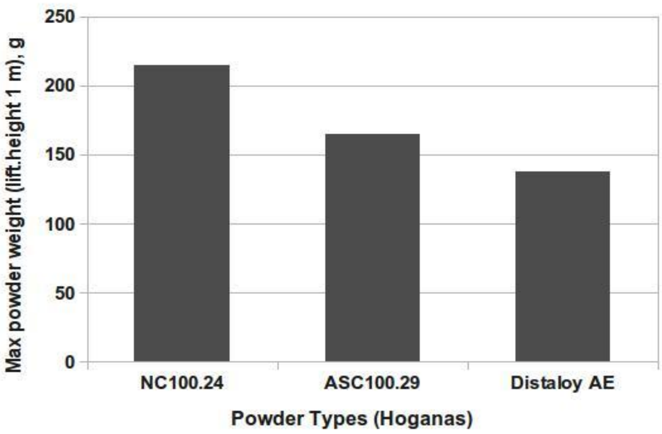


Fig. 9. Maximum weight of ferrous powders lifted to the height of 1 m.

The following test trials of different ferromagnetic materials have shown a strong dependence between maximum lifting height and a distance between electromagnetic coil and surface of ferromagnetic powder. It was established, that small changes of distance may lead to very significant change of maximum lifting weight. As we focused on ferrous powder lifting, the following figure represents a relationship between maximum lifting height and the gap between electromagnetic coil and filling surface of ferromagnetic powder (Fig. 10)

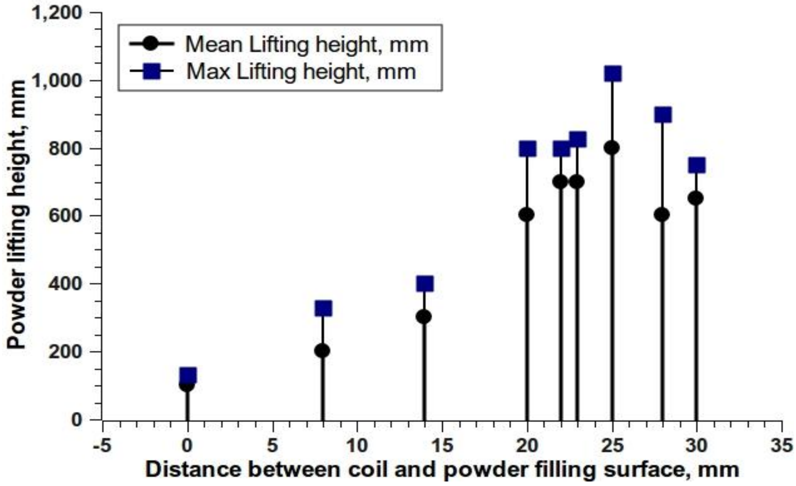


Fig. 10. Mean and maximum lifting height values in dependence on the distance between coil and powder filling surface (powder ASC100.29, U=380 V).

3. CONCLUSIONS AND PROSPECTS FOR FURTHER WORK

1. Studies have confirmed the previously expressed possibility of ferromagnetic powders conveying by pulsed electromagnetic field. This approach opens new opportunities for the transportation of iron and steel powders, and other ferromagnetic materials.
2. It was established experimentally, that there are optimum conditions for efficient ferromagnetic powders conveying.
3. For efficient powder conveying, it is necessary to take into account composition and properties of conveyed powder, as well as the conditions when maximum powder weight can be conveyed.
4. There is a strong need for further investigation of mathematical model, which may describe adequately a wide range of processes, including pulsed magnetic acceleration of ferromagnetic powders for trajectory of motion conveyed powders control.

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