Movement of discrete materials under the influence of a pulsed electromagnetic field

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Abstract. The article considers the phenomenon of accelerated movement of small-sized objects in a pulsed electromagnetic field. For experimental studies capacitor-type pulsed current generators were used. The experiments were carried out on metal powders with a size of 50-200 microns and compact metal fragments with a weight of 1-50 g. The influence of mass, electrical conductivity and magnetic permeability of the particle material on the process of particle movement was established.

1. Introduction
The use of pulsed electromagnetic field (PEF) energy in technological processes has been known since the 70s. The most significant achievements were obtained by methods of magnetic-pulse welding and assembly of tubular thin-walled metal parts [1,2]. The method of magnetic-pulse processing of materials is used for punching holes in sheets and pipes [3], electromagnetic orientation of parts [4], deposition and removal of coatings [5]. Proposals for the use of the method to obtain one-piece compounds of powder parts are known [6,7]. The phenomenon of pulsed movement (IP) of metal objects in a pulsed electromagnetic field is described, for example, in [8].

A relatively new version of the technology that allows simultaneous additional alloying and rebuilding of the initial metal material array is pulsed processing methods [9,10], which, in combination with the use of pulsed accelerators of metal particles, provides technological opportunities for industrial use.

In [11,12], the possibility of using PEF for moving powder materials was shown. The studies were carried out on ferromagnetic dispersed materials, in particular with the aim to assess the possibility of transporting of iron powders by an electromagnetic field.

It was found out that in this case, the efficiency of the process (mass of powder to be lifted, maximum lifting height, productivity) depends on many factors - the amplitude, duration and shape of the curve of the electric current passing through the inductor at the time of discharge. This limits the practical application of this method, since the movement of each material requires taking into account the effects of the totality of factors. In this case, movement is possible only for ferromagnetic materials. This limitation is especially noticeable when moving a mixture of powders from various materials. In this case, delamination often occurs due to the difference in the electrical and magnetic properties of the components. Thus, it is necessary to develop a method that eliminates these problems.
2. Materials and Experimental Methods

Experimental studies were carried out using capacitor-type pulsed current generators (PCG) with an energy capacity of 0.3 to 2.0 KJ (figure 1). The main parameters of the PCG are the discharge current voltage \( U \) and the accumulated energy \( W \) (see Table 1).

![Figure 1](image1.png)

**Figure 1.** Pulse current generators MIC-500 with a cylindrical inductor (a) and MIC-300 with flat inductor (b).

| PCG    | Energy consumption, W, kJ | Operating voltage, U, kV | Amplitude of discharge current, I, kA | Storage device capacity, C, microfarad | The pulse repetition frequency, f, Hz |
|--------|---------------------------|--------------------------|--------------------------------------|---------------------------------------|-------------------------------------|
| MIC-500| 0.5                       | 0.9                      | 8                                    | 1200                                  | 0.5                                 |
| MIC-300| 0.3                       | 0.3                      | 1                                    | 100                                   | 30.0                                |

To measure the pulse currents, the Rogowski loop was used. A system to record and analyze experimental data was created. It included a digital storage oscilloscope of the GDS-810S type and a computer with a microphone-type sensor (figure 1a).

The movement of objects in the pulsed magnetic field was carried out directly by a pulsed electromagnetic field in a pipe placed in a cylindrical inductor (figure 1a), or on a pallet in the form of an aluminum disk using a flat multi-turn inductor (figure 1b).

At the output of the Rogowski loop, a voltage of 100 mV corresponds to 1 kA of discharge current in the inductor. The obtained oscillograms (figure 2) show that the maximum discharge current in the inductor winding is 6-12 kA.

Figure 3 shows an acoustic signal recording obtained using a microphone sensor. The time of flight of the object was estimated as a value equal to the difference between the values of the peaks of the pulses along the abscissa. With the pipe length \( S = 0.85 \) m, the average speed of the object was varied from 3 to 50 m/s.
3. Results and Discussion

Table 2 shows the data of the pulsed movement of objects from various metal materials.

| №  | Object name          | Object mass, g | Time of flight, s | Average speed, m/s | Size, mm                      | The magnetic permeability of the material, H/m |
|----|----------------------|----------------|-------------------|--------------------|-----------------------------|---------------------------------------------|
| 1  | Iron powder (Fe-98%) | 1.00           | 0.260             | 3.26               | The average particle size – 0.08 | 6.3·10⁻⁴                                  |
| 2  | Cast-iron shot       | 1.00           | 0.190             | 4.47               | The average particle size – 0.14 | 1.00·10⁻⁵                               |
| 3  | Steel fragment       | 0.45           | 0.070             | 12.14              | Diameter – 7.00 Thickness – 2.00 | 1.26·10⁻⁴                               |
| 4  | Aluminum disc No. 1  | 6.00           | 0.100             | 8.50               | Diameter – 100.00 Thickness – 0.40 | 1.25·10⁻⁶                               |
| 5  | Aluminum disc No. 2  | 17.00          | 0.060             | 14.17              | Diameter – 100.00 Thickness – 0.80 | 1.25·10⁻⁶                               |
| 6  | Aluminum disc No. 3  | 51.00          | 0.017             | 50.00              | Diameter – 100.00 Thickness – 2.50 | 1.25·10⁻⁶                               |

The analysis of the data shows that the presence of ferromagnetic properties of iron powder, steel and cast iron fragments provides their direct pulsed movement in an electromagnetic field. At the same time, the flight speed of a fragment of steel is higher than that of cast-iron shot and iron powder. It can be explained by the higher magnetic permeability of the steel fragment.

The movement in a pulsed magnetic field of non-magnetic aluminum disks with high electrical conductivity is of a different nature. In this case, a change in the magnetic flux in the inductor generates eddy currents in the electrically conductive object. It creates a magnetic flux counter to the main magnetic flux of the inductor. As a result of the interaction of magnetic fluxes, the aluminum disk moves in compliance with the law of inverse proportionality of speed and mass. Moreover, the greater the mass of the disk, the higher the speed of its movement.

Moving on an aluminum pallet allows you to accelerate various materials, regardless of their electrical conductivity and magnetic properties. Here, the main characteristic parameter is the mass of the object. In this case, to a certain value of the mass of the fragment, its speed increases, and then drops (figure 4).
Figure 4. Change in the speed of movement in a pulsed magnetic field of steel fragments placed on an aluminum pallet.

4. Conclusion
- The presence of ferromagnetic properties in iron powders, steel and cast iron fragments makes it possible to ensure their direct pulsed movement in an electromagnetic field.
- Moving fragments on a pallet of electrically conductive material allows them to be accelerated, regardless of their magnetic properties and shows the prospects of using this method for industrial purposes

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