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# Simulations and Experiments on Electromagnetic Induction Separator by excitation variation

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**ABSTRACT**

Magnetic separators have been used for many years to recover ferrous metal from scrap. However in the process of recovery, a mixture of nonferrous metallic and nonmetallic material remains. The separation technique is the best known for this purpose, and was mostly confined to the recovery of metals. In this work the separator is characterized by a coil excited with an alternating current and a magnetic circuit. Two applications are used: the first is a simple magnetic circuit and the second is with two magnetic circuits (Model with an air-gap). This conception is used for the separation of the ferromagnetic and the non ferromagnetic particles. Various excited voltages were used. Experiments' results and application of this separator is presented in this paper.



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## INTRODUCTION

In the human life the metals are essential, reusable resources. The reusable nature of metal contributes to the sustainability of its use through recycling, which will reduce landfill disposal and encourage recovery of valuable materials and reuse of components. Legislation and high cost of disposal also are encouraged recycling.

Electromagnetic separation is an effective way of recovering non-ferrous metals from streams of industrial (Fletcher, D., 1993; Fletcher, D., 1994; Fletcher, D., &Al., 1994; Mehasni, R., 2006). This separation has been used increasingly in the recycling industry since it is possible to recover metals of high value with high selectivity. However, selective separation of various materials by induction separation depends not only on magnetic deflecting forces but also on competing forces like the gravitational force and the centrifugal force. In this paper the applicability of a novel concept in separation to various nonferrous metals is presented. The previous applications involved the use of permanent magnets or a ramp embedded with permanent magnets for the generation of electromagnetic field. These methods are limited in the magnetic power (Spencer, D.B., 1975). On the other hand this new electromagnetic separation uses an AC current for this purpose, meaning more freedom in generating an electromagnetic field, and is thus applicable to a wide variety of metals and sizes.

In this work we will focus on the realization of a separator with electromagnetic induction. The idea is to design an electric circuit exciting two serially connected coils with a ferromagnetic core. This must allow having an intense magnetic effect according to the variation of the excitation voltage in order to make better separations (Sadiku,M.N., 2003). The implementation of this approach on a system of separation has permitted to evaluate its performances, and the numeric computing results with COMSOL software was realized where the electromagnetic field was described, and in the end experiments had been achieved.

### *II. Description of the Model:*

In our study we will use an electromagnet (magnetic circuit) shown in Fig. 1 for a one core configuration. It is this electromagnetic device which is used to separate the ferromagnetic materials.

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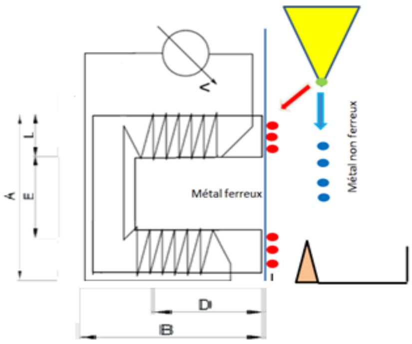



**Fig. 1:** Representation of the electromagnetic induction separator

The device consists in two serially connected coils each one of 1000 turns, with a ferrite ferromagnetic core of suitable geometry. The design parameters of the ferrite core are defined as follows:

A=7cm, E=3.2cm, L=1.9cm, D=4.5cm, and B=6.4cm.

The voltage excitation is generated by an electronic circuit. Thus many excitations were used.

a- Electronic circuit

Our circuit is described by the fig2. It is characterized by a continuous voltage source of 20V, an adjustable voltage source of type LM723, two power transistors and two potentiometers. The circuit provides the excitation current of the coils.

This circuit has the possibility to product a necessary current from the excitation of the coil.

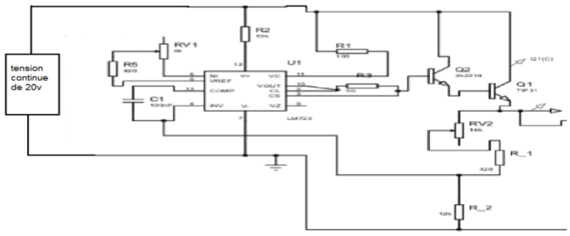



**Fig. 2:** schema of electronic circuit

The output voltage can be varied in an interval from 5 to 30 *V*, with a maximum current of 5 *A*.

### *III. Numerical Model:*

A numerical method is used to calculate the variation of the magnetic field in the structure presented in the fig 1.

This electromagnetic problem is governed by the Maxwell's equations. Maxwell's equations are a set of equations, written in differential or integral form.

The solution of these equations is obtained by finite element method (FEM). The FEM approaches provide a solution by minimizing the variation of a functional, taking into the problem description and the boundary conditions (Sadiku,M.N., 2003).

The problem can be described mathematically by the following partial differential equation in terms of the magnetic vector potential.

$$\nabla \times (\mu^{-1}\nabla \times A) - \sigma \mathrm{v} \times (\nabla \times A) = J^e \tag{1}$$

Where, $A$ (Tm) represents the magnetic vector potential, $v$ the velocity (m/s), $J^e$ the current density (A/mm$^2$), $\mu$ the permeability of the involved media (H/m) and $\sigma$ the electrical conductivity (S/m).

The results obtained with 2D and 3D FEM solving allow to evalutate the distribution of magnetic field.

### *IV. Simulation Results:*

The simulation results are represented in the fig. 4 for a one core configuration and 6 for a two cores configuration.

***1 Simulation using one ferrite core:***

This device is presented in the fig.3.

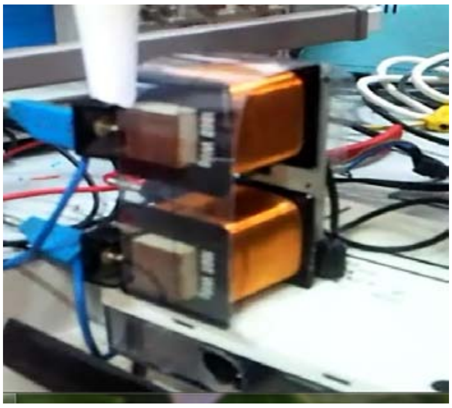
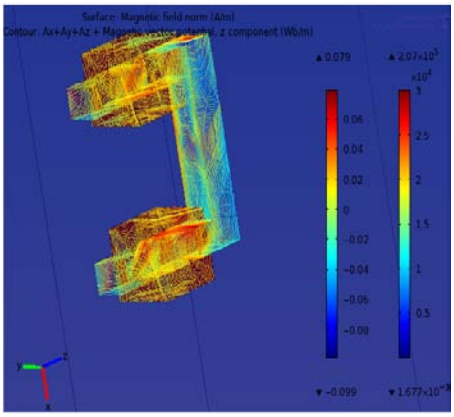
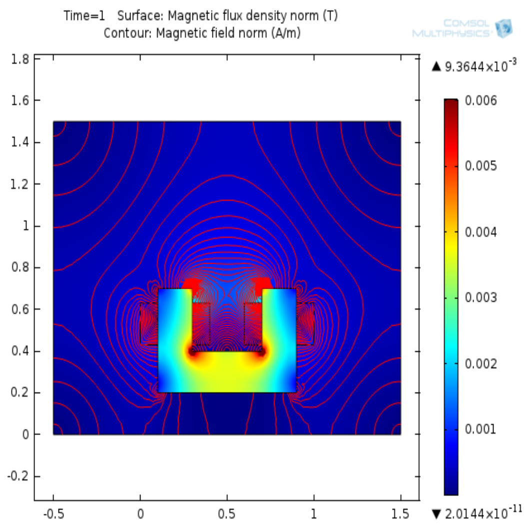


**Fig. 3:** View of one ferrite core



a- Model results in 3D




b- model results in 2D

**Fig. 4:** Simulation and distribution of magnetic field of an electromagnet

***Simulation Using Two Ferrite Cores With An Air Gap:***

The corresponding device is presented in the fig 5. The results of simulation show the lines of fields and the magnetic flux density in both cores ferromagnetic on the contrary with the first case of simulation Fig. 6.

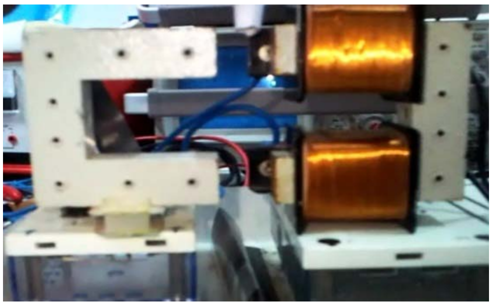


**Fig. 5:** Model with an air-gap

In this map the lines of magnetic field are canalized by the presence of a ferromagnetic core. This effect will have an influence on the separation

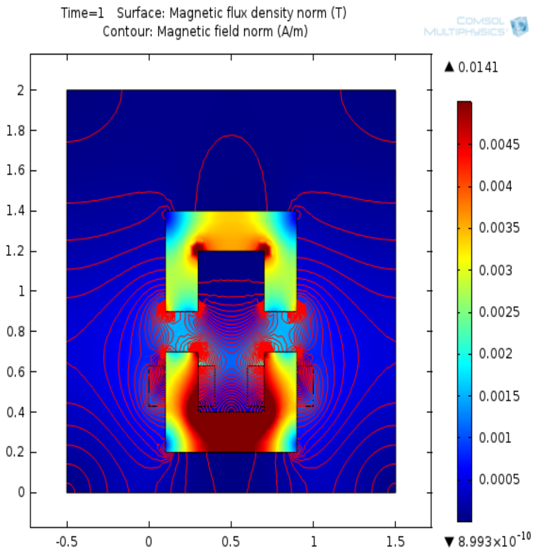



**Fig. 6:** Distribution of magnetic field and magnetic flux density for the Electromagnet with air gap.

***V. Experiments Results:***

An experiment was performed to verify the validity of the separation method.

Fig 7 shows the experimental elements used for separating ferrous and nonferrous metals.

In fig 7 we shows the metallic elements used in this study. Known quantities of the materials: 10g of each material (copper and iron) for the powder and 20g of each material (copper and iron) for the bolts (length: 2 cm) were placed into the separator.

In this work we will have two types of separation through varying the supply voltage:

- The first is with one ferrite core;
- The second is with two ferrite cores with an air gap.

**Fig.7:** Particles used in the separation

***Experiments Using One Ferrite Core:***

The totals of separation with the powder mix are given in the table 1, where the variation of voltage was taken in consideration. The maps indicate the variation of the supply voltage with the quantity of materials recuperate in elctromagnet circuit.

After each separation, the collected products were measured using a digital balance and recovery rate was defined as ratio of the mass of the material in the product and the mass of that same material in the supply (Mihai, L., 2009).

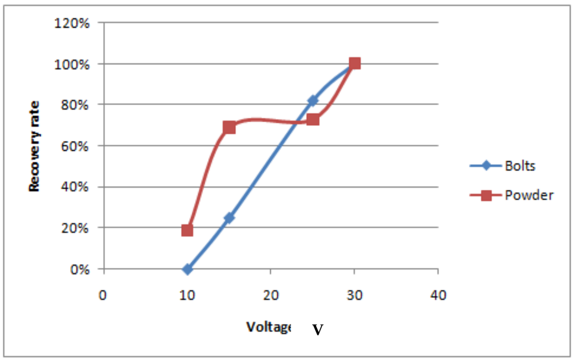



**Fig. 8:** Recovery rate of iron according to the supply voltage

**Table 1:** Quantity of powder mixture separated and the recovery rate according to variation from supply voltage.

| Voltage (V) | 30 | 25 | 15 | 10 |
|---|---|---|---|---|
| M $_{collector, Fe}$ (g) | 10 | 7.3 | 6.9 | 1.9 |
| M $_{collector, Cu}$ (g) | 8.8 | 7.5 | 7.1 | 5.5 |
| Ratio of recovered Iron | 100% | 73% | 69% | 19% |

In the table .2 there given the results of bolts mixture separation.

**Table 2:** Quantity of bolts mixture separated according to variation from supply voltage.

| Voltage (V) | 30 | 25 | 15 | 10 |
|---|---|---|---|---|
| M $_{collector, Fe}$ (g) | 20 | 16.4 | 5 | 0 |
| M $_{collector,Cu}$ (g) | 20 | 23.6 | 35 | 40 |
| Ratio of recovered Iron | 100% | 82% | 25% | 0% |

***Discussion:***

The separation with this device was easy and clear, the quantity of the iron was separated easily in spite of the variation of its rate of recovery**.** Thus copper goes on its vertical way during the fall of mixture.

So, if we increase the voltage there will be a strong magnetic field and a high attraction force. The difference of iron masses separated was connected with the voltage variation.

From Tables 1-2, we can summarize the difference between these types of mixture in the fig. 8.

It was found that the best separation is with a powder mixture due to its high efficiency relative to the bolt while taking into account the time factor and the cleanliness of separate iron, that is to say it contains no copper particle then, is that the best separation performance despite bolt that can change while playing on the power that is in real life in factories working with power with a very high interest rate fall faster the speed of our test.

***Experiments Using the Two Ferrite Cores with an Air Gap:***

In this part the results obtained by testing the efficiency of various combinations of experimental setups with the two ferrite cores and the voltage excitation.

The experimental results for this case show a significant improvement in the rate of recuperation of the ferrous particles due to the presence of a magnetic core which is useful as drain of the field lines and decreases the losses of magnetic field in the air (see fig 6).

In this part two experiments were realized the first with an air gap equal to 2cm and the second with 5cm.

***a-With an Air Gap of 2 Cm:***

In this test the separation was difficult because the size of the particles (Gillet, G., 2004). The iron particles are attracted to the ferrite core and block the path to the copper particles and prevent them to go except the first ones. The separation of iron was then not correct; it contains copper particles (Mehasni, R., 2004; Pugh, E.M., 1960).

### *a-1-Mixture of Powder:*

The following table summarizes the change in separated particles with a quantity of mixture equal to 20g (10g of iron and 10g of copper) and the rate of iron recovery according to the supply voltage with e=2cm.

**Table 3:** Quantity separate of powder mixture and the recovery rate of iron according to the variation from supply voltage.

| Voltage (V) | 30 | 25 | 15 | 10 |
|---|---|---|---|---|
| $M_{collector,\ Fe}$ (g) | 10 | 7.3 | 5.9 | 1.9 |
| $M_{collector,\ Cu}$(g) | 9.8 | 11.5 | 11.9 | 15.5 |
| Ratio of recovered Iron | 100% | 73% | 59% | 19% |

### *a-2- Mixture with Bolts:*

The table 4 summarizes the change in separated particles (bolts) with a quantity of mixture equal to 40g (20g of iron and 20g of copper) and the rate of iron recovery according to the supply voltage.

**Table 4:** Separated quantity of bolts mixture and the recovery rate of iron according to the supply voltage.

| Voltage en (volt) | 30 | 25 | 15 | 10 |
|---|---|---|---|---|
| $M_{collector,\ Fe}$ (g) | 20 | 17.2 | 15 | 14.4 |
| $M_{collector,\ Cu}$(g) | 20 | 19.5 | 20.5 | 20.8 |
| Ratio of recovered Iron | 100% | 86% | 75% | 72% |

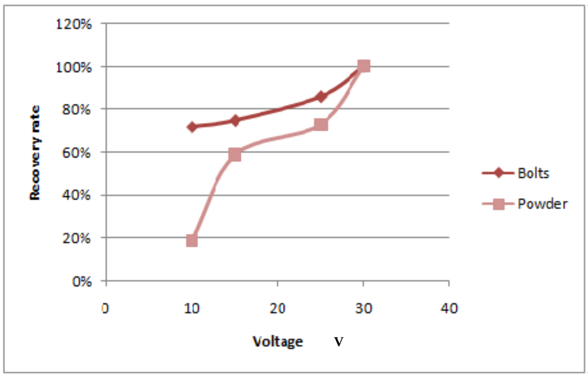



**Fig. 9:** Recovery rate of iron according to the supply voltage with e=2cm

The separation was easy, no space thanks to the size of the bolts and nuts which do not prevent the copper particles to penetrate and follow their paths, the separation is clear and clean (fig 9).

### *Discussion:*

The separation test of iron bolts is easy and does not take much time. There will be a separation of 100% despite using a small voltage. The separated iron does not contain copper. By comparison, considering the powder, the irons contain copper particles due to congestion.

The separation efficiency of the bolts is higher than the powder, then the best separation under these conditions is that the bolts that over 70% to win time with these volumes.

### *b-With an Air Gap of 5 Cm:*

In this test the separation was not easy and takes a lot of time due to the distance of the gap.

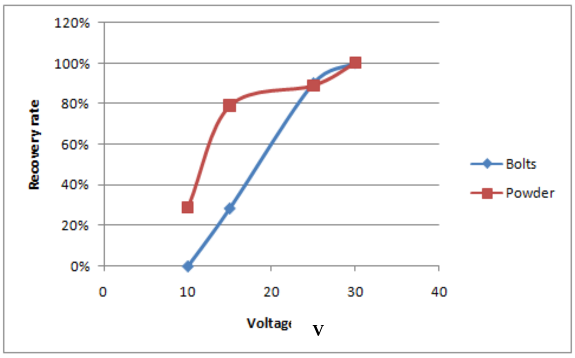



**Fig. 10:** Recovery rate of iron according to the supply voltage with e= 5cm

***b-1-Mixture with Powder:***

The same work than in a-1 will be done using the same amount of mixtures. The results are given in the table 5.

By varying the voltage and measure the amounts of separated iron / copper mixture and we can calculate the rate of recovery and traced the fig. 10.

**Table 5:** Quantity separate of mixture and the rate of iron recovery according to the variation in supply voltage.

| | | | | |
|---|---|---|---|---|
| Tension en (volt) | 30 | 25 | 15 | 10 |
| $M_{collector, Fe}$ (g) | 10 | 8.9 | 7.9 | 2.9 |
| $M_{collector, Cu}$(g) | 9.9 | 10.7 | 11 | 15.5 |
| Ratio of recovered Iron | 100% | 89% | 79% | 29% |

***b-2- Mixture with Bolts:***

In this part the same work than in a-2 will be done and the results were given by the table 6.

**Table 6:** Quantity separate of mixture (bolts) and the rate of iron recovery according to the variation in supply voltage.

| | | | | |
|---|---|---|---|---|
| Tension en (volt) | 30 | 25 | 15 | 10 |
| $M_{collector, Fe}$ (g) | 20 | 18 | 5.7 | 0 |
| $M_{collector, Cu}$(g) | 20 | 22 | 34.3 | 40 |
| Ratio of recovered Iron | 100% | 90% | 28.5% | 0% |

***Discussion:***

The separation was easy because of the size of the gap. The separation of iron is easy and does not take much time with a good voltage study there will be a separation of 100% despite using a small voltage is separate iron net, it does not contain copper. Thus the recovery rate is higher with a low voltage; this efficiency is due to the distance of air gap.

***Conclusion:***

In this work, the objectives of the experimental studies were to study the effect of the alternating magnetic field from the ferrite core with and without air gap to generate high recovery of ferrous particles or bolts from a mixture with nonferrous. The results of simulation show the physical phenomenon of the magnetic distribution of the magnetic field created by the electromagnet.

The conditions of good separation were based on the following parameters: choose the voltage between (5-30V); the particle size and the air gap for having a good separation.

When there is a very significant electromagnetic field, the separations give good results.

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