I.J. Engineering and Manufacturing, **2018, 5, 22-31**
Published Online September 2018 in MECS (http://www.mecs-press.net)
DOI: 10.5815/ijem.2018.05.03

Available online at http://www.mecs-press.net/ijem

Electromagnet Separator of Different Particles

Ayad Ahmed Nour El Islam [a*], Ayad Abdelghani [b], Boudjela Houari

[a] *Djillali Liabes University APPELEC Laboratory and Kasdi Merbah University, Ouargla 30000, Algeria*
[b] *Djilali liabesUniversity, ICEPS Laboratory Sidi Bel Abbes* 22000, *Algeria*

Received: 11 May 2018; Accepted: 13 June 2018; Published: 08 September 2018

Abstract

In this paper we simulate and realize an electromagnetic separator excited with an alternating current. And, we will to see the factors that influence the separation. This realization is used for the separation of the ferromagnetic and non ferromagnetic particles. The aim of this application is to recover the particles of non ferrous and ferrous from mixture by attractive magnetic force with big rate of separation. Experiments' results and simulation of this separator, finally the parameters of separation are optimized with prediction method is presented in this paper.

Index Terms: Magnetic separation, Electromagnet, Modeling, magnetic field, Small particles.

---

1. Introduction

Electromagnetic separation is an effective method of recovering the mixture particles. The magnetic separators are widely used by various waste recyclers for valuable material extraction and in such industries to improve product purity. The magnetic separation of various materials depends not only on magnetic deflection or attraction forces but other competing forces: gravitational and the centrifugal forces [1,2]. The idea of this paper is the application of a variable generator of magnetic field by the variation of excitation source. The applicability of electromagnet to produce variable magnitude of magnetic field, used to a sort out variety of small metals sizes [2,3]. This must allow having an intense magnetic effect according to the variation of the excitation voltage in order to make better separations [9].

In this work we will study a modeling and simulation of magnetic propriety of a separator (ferromagnetic core and coils) and various small ferrous and non ferrous particles with finite element method (FEM), where the magnetic propriety of the separator they will be represented.

* Corresponding author. Tel.: 213661244622; fax: 213591452
E-mail address: ayadnourislam@yahoo.fr

In the second part we will construct a prototype of variable magnetic field supplied by an adjustable power source for the generation so an important magnetic field, and improving the force of separation and make better separations of various sizes of particles with big rate of sorting. The parameters of separation are optimized with prediction method using Modde05 software. This technical is used because the cost of dispositive is also encouraged recycling of fine particles.

2. Description of the Electromagnet Separator

The electromagnet separator (ferromagnetic core and coils) of recycling particles is shown in Fig. 1 The system is composed of ferrite core with a U geometry form. The length is 7cm, width 2cm, thickness 2cm and the turns coil is 500 turns. The power supply voltage with potentiometer for adjusting current of coil and voltage excitation is generate by an electronic circuit characterized by a continuous voltage source of 30Volt, with a maximum current of 3 *Ampere*.

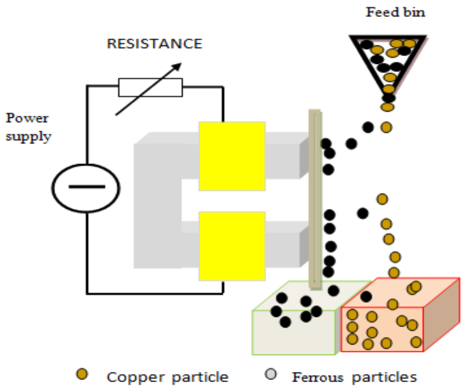


Fig.1. Electromagnet Devices

The circuit provides the necessary excitation current of the coils. There are two collectors: the closest to the first electromagnet which collects iron (C_I fe) and the second collector farther that recovers non-ferrous particles (C_{II} cu). The particle jet is at a horizontal distance of 5cm below the separator at a vertical distance of 12cm.

3. Numerical Model

The electromagnetic representation of magnetic field is solved by Maxwell's equations with boundary conditions. We can rewrite the Ampere's law as

$$\nabla \times \left(\mu_0^{-1} \nabla \times A \right) - \sigma v \times \left(\nabla \times A \right) = J \tag{1}$$

This equation can be described mathematically the problem by the partial differential equation in terms of the magnetic vector potential [4].

Where, A represents the magnetic vector potential, J^e the current density (A/mm^2), v the velocity, μ the permeability of the involved media (H/m) and σ the electrical conductivity (S/m). A numerical method is used to calculate the magnitude of the magnetic field in the structure presented in the fig.2. 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. The results obtained with 2D FEM solving allow evaluating distribution of magnetic field.[11] *Fm*

4. Expression of the Magnetic Force

The dipolar magnetic attraction force acting on a paramagnetic particle in a vacuum is given by:

$$\vec{F}m = \vec{\nabla}\int_V \vec{J}\vec{H}dV \tag{2}$$

$\vec{F}m$ Magnetic force, $\vec{H}$ The magnetic, V the particle volume and $\vec{J}$ represents the magnetic polarization [10]

$$\vec{J} = \frac{\chi}{1 + D\chi} + \mu_0\vec{H} \tag{3}$$

With D is the demagnetization coefficient of the particles.
The force on the dipole is then:

$$\vec{F}m = \left(\vec{M}\vec{\nabla}\right)\vec{H} \tag{4}$$

M: magnetic moment. After development the final formulation of the force is given by:

$$\vec{F}m = \frac{1}{2}\mu_0\chi V\vec{\nabla}\left(H^2\right) \tag{5}$$

5. Simulation of the Model

- Meshing the Area of Study

Fig.2 shows the refine mesh of the study across the core area and the end of the ferrite core to have better accuracy than possible [5,9]. The simulation results are represented in the fig. 3 for a core configuration.

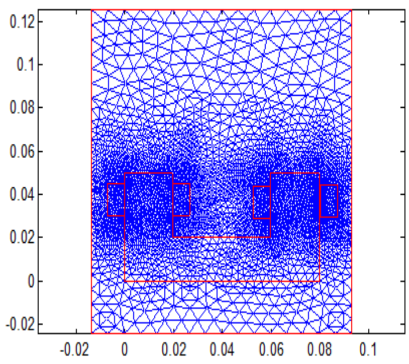


Fig.2. Presentation of the Device in Matlab Pdetool in 2D

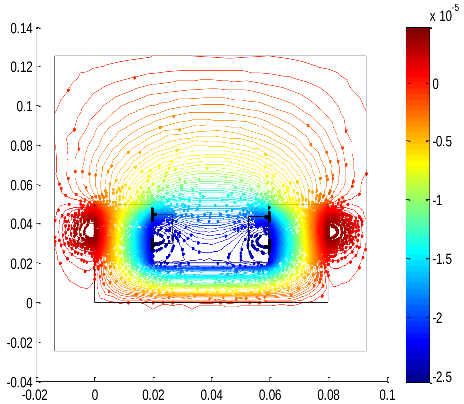
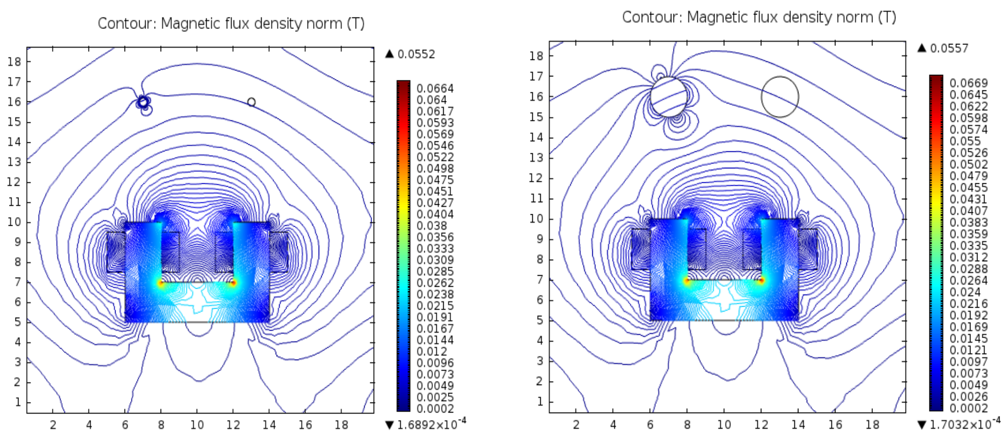


Fig.3. Magnetic Vector Potential A

Fig.3 represent the distribution of the magnetic vector potential A in the air. This map shows a high concentration in the core of the electromagnet, this distribution becomes small proportions moving away from the separator.

5.1. Electromagnet Separator with Particles

The presence of ferrous particles (iron) and non-ferrous (aluminum and copper) are around magnetic field lines resulting in a phenomenon of attraction between the induction separator and the ferrous particles. This attraction is owing to the nature of the iron in the presence of the magnetic field. This phenomenon can be explained by representing in a well-defined in the simulation results which are shown in the figure 4.



a- fine particles b-big particles

Fig.4. Distribution of the Magnetic Flux Density of Far Particles

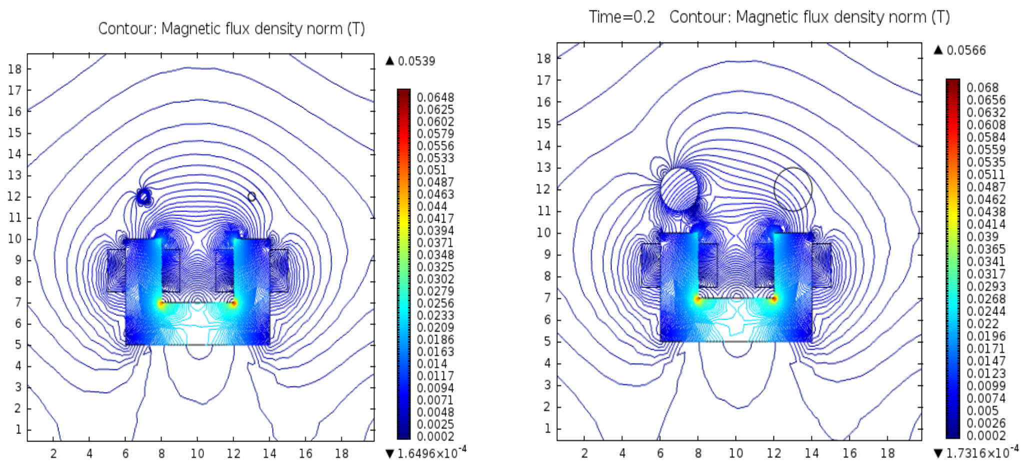
- Particles of Various Sizes far from the Separator

In this section we see a large distance between the particles and the separator of about 6 centimeters but we see clearly the field lines in the materials used in the separation. When the particles are thrown, they are far from separator, but the magnetic field is exerted and causes an attractive force on ferrous particles (ferromagnetic) and no force on non-ferrous (copper or aluminum) particles.

- Particles of Various Sizes near from the Separator

In this second simulation we chose a small distance between the particles and the separator of about 2 cm to visualize the field lines around the selected materials. The fine particles have a diameter of 4 millimeters, and big particles have diameter of 2 cm, see fig 5.

The simulation results are given in fig 5. It is clear that the ferrous particles are attracted to the magnetic separator and gives a good distribution of the magnetic flux with a very high density around the surface of the ferrous particle, which will be translated into reality with strength of big attraction [6].



a- fine particles b-big particles

Fig.5. Distribution of the Magnetic Flux Density of near Particles

Fig 6 show big variation of magnetic induction as a function of important current of excitation near and voltage of the separator

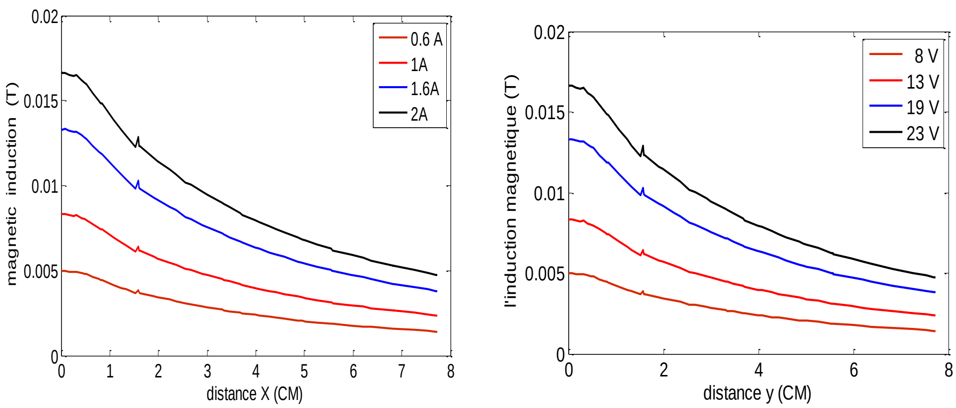
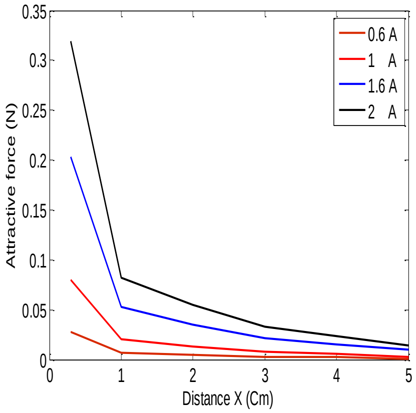
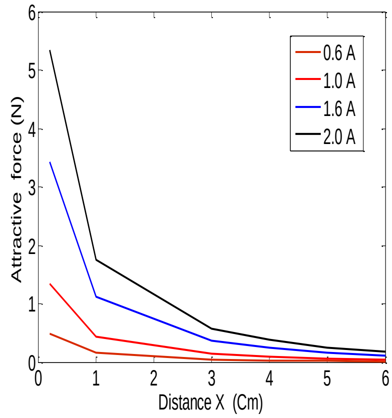


Fig.6. Variation of Magnetic Induction as a Function of Current of Excitation near and Voltage of the Separator



a- Fine particles



b- Big particles

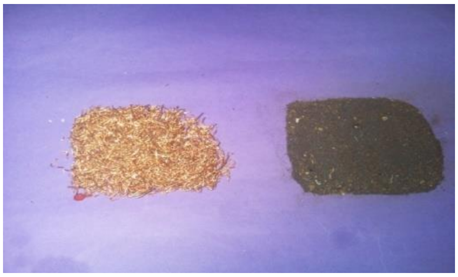
Fig.7. Attractive Force near from Separator

We can to saying when moving away from magnetic separator the induction decreases. In Fig 7, the force increase when the particles approach at the separator and current of excitation increase.

6. Realization of Magnetic Separator

In experimental work of the static separator with single core Fig8, we will vary the supply voltage and see the influence on the separation process of a mixture of ferrous and non-ferrous particles of 4 mm and 2Cm Fig 8. The quantities of mixture particles are equal to 10g of each material (iron and copper).

a- Electromagnet separator



b- Particles copper/iron of small size used in separation

c- Result of separation by voltage of 20 V

Fig.8. Realization of Magnetic Separator

7. Results and Discussion

The totals of separation with the particles mix are given in the table 1(fine particles). The variation of supply voltage was taken in consideration with the quantity of materials recovery. In each separation, were measured the weight of each materials by using a digital balance and we have compute the rate of separation between initial mass of ferrous particles and the recovered mass in the collector, SEE Fig 9.

The quantity of the iron was separated easily in spite of the variation of its rate of recovery. But the copper will go on its vertical way during the fall of mixture. This separation was easy and uncomplicated [7].

Table 1. Quantity of Separate Mixture as a Function of the Supply Voltage Variation of Fine Particles

Voltage (v)	30	25	20	15	10
Current (A)	3	2.3	1.8	1.3	0.9
C_I (fe g)	10	8.1	7	6.9	2.2
C_{II} (cu+fe g)	9.8	11.8	12.4	13.5	17.5
Mass tot (g)	20	20	20	20	20
Recovery (%)	100	81	70	69	22

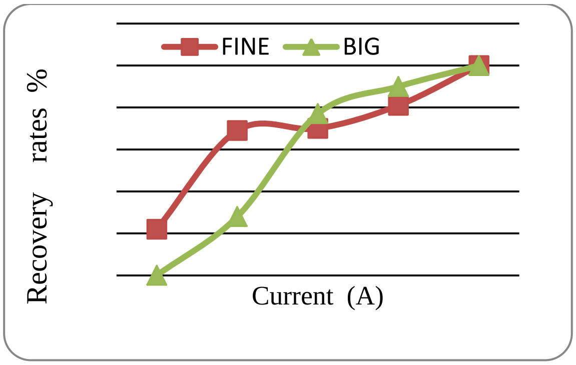


Fig.9. Recovery Rate of Iron as a Function the Current and Size

So, the separation of particles is better by increasing the voltage and current of excitation of the coil. The coil generates a significant flux in the ferrite core there will be a strong magnetic field and a high attraction force to sort particles. The quantity of the ferrous and non ferrous particles separated increases with high purity and big rate of recovery. [8]

From Table 1, we can say that iron masses separated are proportional with the magnitude of current and supply voltage. The separation of iron contains copper particles at weak voltage but at high voltage the separation of iron does not contain copper, it's purely separated.

8. Optimization of Separation with MODDE.05 Software

Figure 10 represents the prediction curves obtained with MODDE.05 of the rate of separation according to the applied voltage, the size of particles and the distance between electromagnet and particles.

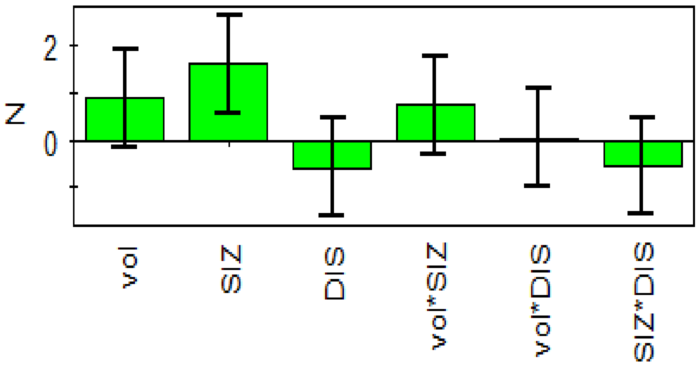


Fig.10. Plotted Coefficients of the Obtained Model for Magnetic Separation

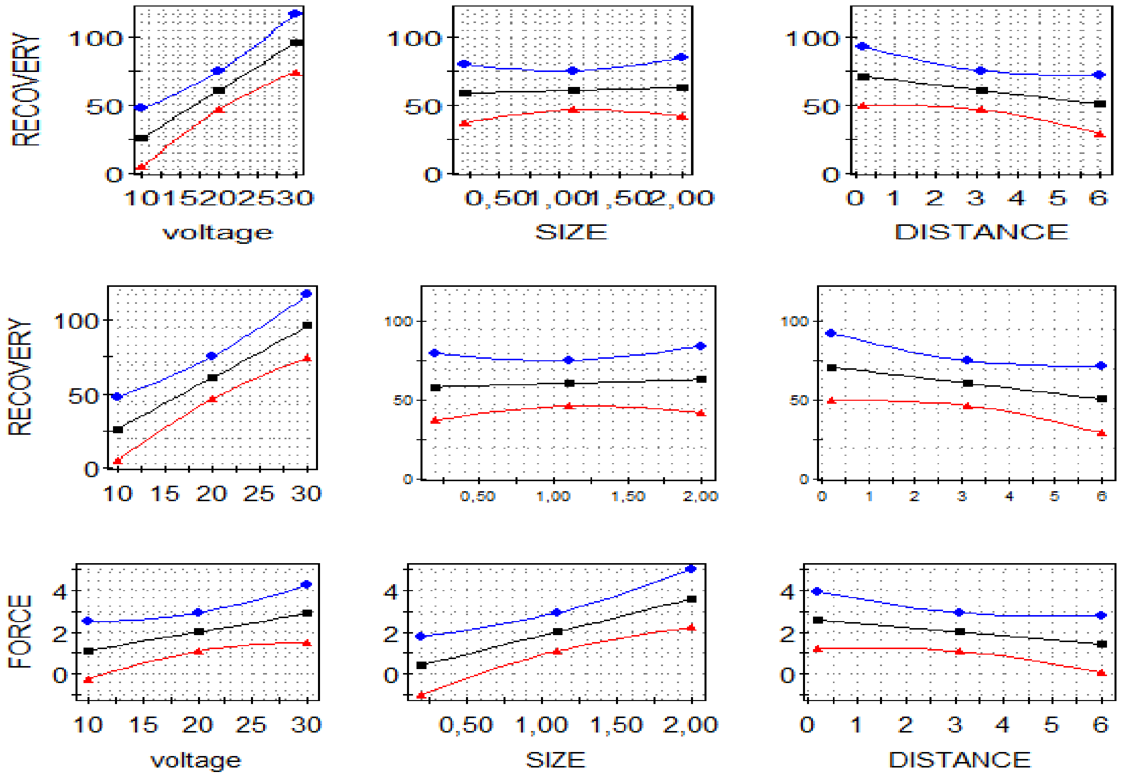


Fig.11. Prediction Curves of the Recovery Rate According to the a) Voltage; b) Size of Particle and c) Distance of Air Gap

MODDE.05 offers the possibility to identify the optimal values of the coefficients which should give the highest amount of rate of separation with optimal values of voltage and size, distance.

The software contains an optimization routine that is capable of simultaneously processing several responses, affected by different weighting coefficients. MODDE.05 has an optimizer tool which proposes the optimal values of factors by maximizing the rate of separation and minimizing the other factors (Fig.11, 12).

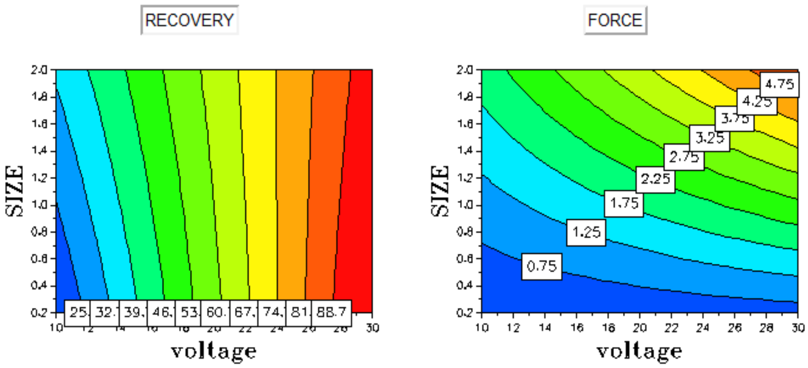


Fig.12. Response Contour Plots of a) Particles Recovery b) Magnetic Force

9. Conclusion

In this work, the objectives are to simulate the characteristics magnetic by FEM and to show the effect and distribution of lines of magnetic field around the particles ferrous and non ferrous near or far of the separator and also the computation of the attractive force of the separator of particles. But, the aim of experiment is to have a high recovery of particles. Improve the separation performance with high rate of recuperation by electromagnetic device when the excitation of coil is increase. The combination of the simulation results and the experiment explains the phenomenon of magnetic separation and the factors that influence the separation such as increasing voltage, a small distance between the particles and the separator and the important force of magnetic field. When these factors are realized, the separations give good results. There are many other factors affecting the separation which may be study in the future.

References

[1] Pol Grasland-Mongrain .Applications de la force de Lorentz en acoustique medical. Theses of Lyon university France 2013.

[2] Fletcher, D., R Gerber. The small particle limit for electromagnetic separation. IEEE Transactions on Magnetics, 1994. Vol. 30, n. 6, pp 4656-4658.

[3] Fletcher, D., R. Gerber, T. Moore. The electromagnetic separation of metals from insulators. IEEE Transactions on Magnetics, 1994. Vol. 30, n. 6, pp 4659-4661.

[4] A. Deug. Electromagnétique Equations locales Equations de Maxwell. online Support U.P.F. Tahiti 2001.

[5] M. Ito, F. Tajima, H. Kanazawa .Evaluation of force calculation methods. IEEE Transactions on magnetic, VOL. 26, NO. 2, March 1990.

[6] Pugh E.M., Pugh E. W., Principles of Electricity and Magnetism. Addison- Wesley Publishing Company, Inc. 1960.

[7] Gillet, G. Séparation magnétique haut gradient (SMHG) et haut champ. Techniques de l'ingénieur, Génie des procédés,., 2004. Vol papier JB3, J3222, Mars.

[8] Spencer, D.B. Schloemann, E., 1975. Recovery of nonferrous metals by means of permanent magnets. *Resource Recovery and Conservation*, 1 (2), 151- 165.

[9] J. Pedro A. Bastos. Electromagnetic modelling by finite element methods .Book Marcel Dekker, Inc, 2003 http://books.google.dz/.

[10] Ayad A.N.E.I, Ayad. A, Ramdani. Y, Yann .L, Guillaume.K, Dey. Z. Simulations and Experiments on

Electromagnetic Induction Separator by excitation variation. Australian Journal of Basic and Applied Sciences, 8(1) January 2014, Pages: 351-357.
[11] Ayad AN, Ayad A, Ramdani Y. Simulation of Eddy Current Separation of Gold Particles from Sands. ApplMechMater 2016; 6: 30-37.

Authors' Profiles

Ayad Ahmed Nour El Islam, was born in Algeria 1985. He received his master degree in electromagnetic compatibility from Djillali Liabbes University, Algeria in 2011. Currently, Ph.D in electrontechnics in Djillali Liabbes University. His major fields of interest are eddy current and magnetic separator process.

Ayad Abdelghani was born in Algeria in 1969. He received Ph.D. degree at the Sidi Bel Abbes University in 2009 in Electrical Engineering specializing in electromagnetic and CND control by eddy current. He is currently working at Sidi Bel Abbes University, Department of Electrical Engineering as an associate professor. The research interest is particularly about characterization of materials by eddy current.

Boudjela Houari was born in Algeria 1981. He received his master degree in electrical network from Djillali Liabbes University, Algeria in 2008. Currently, PHD student in electrical network in sciences and technologies of Oran - Mohamed-Boudiaf University. His major fields of interest are optimization and simulation of electrical network power flow and fact.

How to cite this paper: Ayad Ahmed Nour El Islam, Ayad Abdelghani, Boudjela Houari,"Electromagnet Separator of Different Particles", International Journal of Engineering and Manufacturing(IJEM), Vol.8, No.5, pp.22-31, 2018.DOI: 10.5815/ijem.2018.05.03