23rdABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

MAGNETIC FILTER FOR AN ELECTRICAL DISCHARGE MACHINE

Cândido da Silva Junior
Pontifical Catholic University of Minas Gerais, Unit Coração Eucaristico, Avenue Dom José Gaspar, nº500 Coração Eucarístico, CEP 30535-901 - Belo Horizonte, MG - Brazil
candidosj@outlook.com

Izabella Gomes de Souza
Pontifical Catholic University of Minas Gerais, Unit Coração Eucaristico, Avenue Dom José Gaspar, nº500 Coração Eucarístico, CEP 30535-901 - Belo Horizonte, MG - Brazil
izabellags@outlook.com

Tiago Gabriel Caetano de Jesus
Pontifical Catholic University of Minas Gerais, Unit Coração Eucaristico, Avenue Dom José Gaspar, nº500 Coração Eucarístico, CEP 30535-901 - Belo Horizonte, MG - Brazil
caetano.tiago@outlook.com

Henrique Resende Martins
Federal University of Minas Gerais, Avenue Presidente Antônio Carlos, nº 6627 Pampulha, CEP 31270-901 - Belo Horizonte – MG - Brazil
henrique.martins@sempratec.com.br

Nilson Figueiredo Filho
Pontifical Catholic University of Minas Gerais, Unit Coração Eucaristico, Avenue Dom José Gaspar, nº500 Coração Eucarístico, CEP 30535-901 - Belo Horizonte, MG - Brazil
nilson@pucminas.br

Abstract.*The proposal of this work is to replace available EDM machine' filter, at VIASEF COMPANY, by a magnetic system. It is expected that the magnetic system becomes faster, more efficient and more durable if compared to the Cotton Linter Filter, currently used by the company. The prototype was built using proportionate dimensions close to the EDM machine filter to allow its use in the machine. Tests have been performed to determine the behavior and efficiency of the magnetic filter. These tests have indicated that the magnetic filter can operate continuously without maintenance and remove the magnetic particles more quickly when compared to the Cotton Linter Filter.*

Keywords: *Filtration system. Linter filter. Magnetic filter.*

1. INTRODUCTION

Machining by lightning or EDM (Electrical Discharge Machining) is a procedure to produce complex shapes in lectrical conductive materials, especially those of high hardness that can't be produced by traditional processes such as drilling, milling, grinding, among others. Its main applications are the manufacture of stamping dies, forging, drawing dies, extrusion, plastic mold, in general, for the tooling industry (Cruz et al., 1999). This process stands out in the manufacturing of metal parts without contact between tool and workpiece that are submerged in a dielectric fluid, during cutting. (McGeough, 1988).

The major components of an EDM machine are: the power tool, the power generator and the filter system. The power tool is responsible for controlling the exact position of the material to be exposed to the EDM, the generator provides the electrical power for current arc generation and, the filtration system that is responsible for maintaining the dielectric liquid the EDM machine.

The filtration system is one of the main components in the recycling process, ensuring that dielectric fluid can be used in more than one electro erosion process. The liquid is used to isolate part of the electrode, to provide the necessary conditions for ionization and deionization and cooling the removed material and particles from the spark location. The filtration function consists of retaining all machined material, which would break up from excess material accumulated in the filter element if exchange is not done. Thus, the entire operating system of the machine, including workpiece will be contaminated.

In general, there is a different kind of filter for each type of machine. For example, in the wire electroerosion machines, the filtering system comprises pleated cellulose paper pieces while in the penetration machines, filters can be cotton linters (sponges) or overlaid plates pleated cellulose paper.

In order to develop a filtering system that can retain all the machined material and at the same time prevent ruptures and contamination of the materials in sufficiently fast and efficient way, this paper proposes the development of a magnetic filter to optimize the filtering process of fluid machines EDM, available in VIASEF COMPANY - Solutions tooling.

2. ELECTRICAL DISCHARGE MACHINING PROCESS

The process of electro machining (EDM) is the erosion mechanism of materials made by the use of electricity that are modified internally with thermal energy and a series of discrete electrical discharges between the tool and the workpiece, immersed in a dielectric fluid (SANTOS , 2007).

In EDM, material is removed by heat produced by the flow of electricity between electrodes, tool and workpiece. The material in the closest points of the surface of the electrodes, where the spark starts and ends, heats about to vaporize. Thus, a quantity of material is stripped away from the surface and dragged out to the work front by dielectric liquid, which is responsible for cooling the system and then act as a conductor to achieve a tension that will provide machining.

The work gap is the lower electric resistance region where the electrical discharges occur, thus forming the so-called sparks, which promote the removal of material through erosion (SILVA, 2007). The tool-piece electrodes erode, removing less positive electrode material, which is usually the tool electrode. The tool electrodes and the piece electrodes can't get in touch together, otherwise a short circuit will not allow the operation of the system (JAMESON, 2001).

2.1 Eletroerosion machine

According to Silva (2006), an EDM machine for penetration has three systems Fig 1:

- Mechanical: System responsible for the relative movement between the tool and the piece, consists of three elements, which are, the first working table to position the workpiece relative to the X and Y axes; second the servo feed mechanism and positioning tool electrode; and third the machine structure.
- Electric: System composed of static pulse generator, control systems of tool electrode movement and power cables.
- Dielectric: System consists of the reservoir, working tank and pump motor (responsible for feeding the dielectric fluid in the process) and filters (responsible for cleaning the fluid).

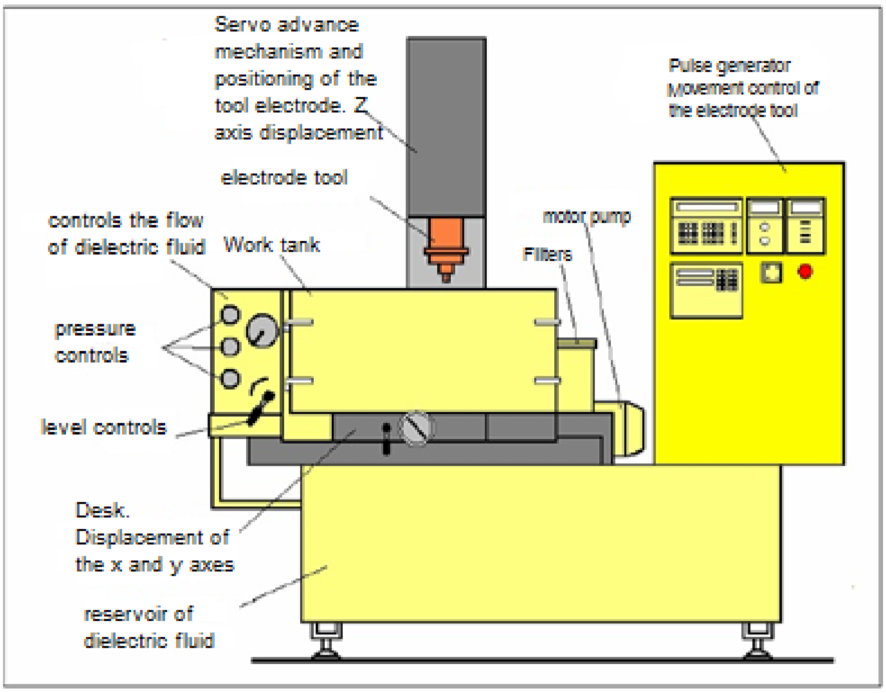

Figure 1. Eletroerosion machine by penetration

3. MAGNETIC SEPARATION

Magnetic separation is an environmentally friendly technique and can be used in both dry and wet conditions, enabling its utility in arid or where water is available. The dry method is generally used for thick grain size and the wet for fine particles.

Currently, several magnetic separators proposals have been introduced and probably the most practical and logical is the classification of these methods as dry or humid. Still, it should be noted that the separators can operate with magnetic fields of high or low intensity or high or low gradients (LIGHT, 2004).

The way equipments perform separation job has significant influence on the classification of the separators. Thus they are named drum separators, induced rolls, cross braces, carousel etc. Choosing the separator class to be used depends on several considerations, the most important are the particle size distribution, the magnetic distribution of the product to be processed and also the capacity of the equipment (SVOBODA, 2003).

3.1 Wet low intensity separator

The low intensity wet magnetic separator mostly used are the drums. They are used in the recovery of magnetite and ferrosilicon, which are used in the formation of dense-means. The principle of operation of such separators is based on permanent magnets, which can be oriented radially or axially to the drum. In the radial configuration, shown in Fig. 2A, the polarity of the magnets is alternated along the drum axis, while in axial configuration, as shown in Fig. 2B, the poles are alternated over the circumference of the drum. The radial configuration is commonly applied where the recovery of highly magnetic materials is important and the axial system is used when the aim is a high concentrate. The movement and agitation of the particles on the magnets with alternating polarities facilitate the removal of the embedded non-magnetic particles, generating high concentrate content (Svoboda 2003).

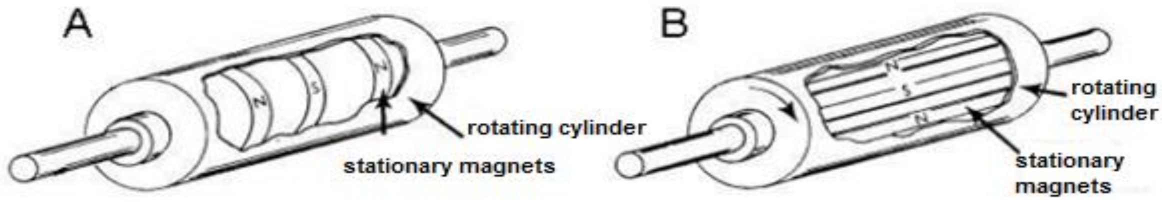

Figure 2. Configuration of the magnetic poles inside a magnetic roll.

3.1.1 Magnetic flux density and magnetic field strength

From the physical point of view, atoms can be considered magnets. Electrons have a proper rotational movement (spin) and also revolve around the nucleus, forming small magnetic dipoles. Different materials may have different magnetic behaviors due to interaction of these elementary dipoles with the magnetic field and with neighboring dipoles. Ferromagnetism, Paramagnetism and Diamagnetism are most common magnetic behavior which materials may present (SVOBODA, 2003).

Mineral or ferromagnetic materials match those that are strongly attracted by the common magnet. The best known example is magnetite. Paramagnetic are poorly drawn and the classic example is hematite. Diamagnetic minerals have negative magnetic susceptibility and therefore are repelled when subjected to a magnetic field, among others are: quartz, magnesite, fluorite, etc. (LUZ, 2004).

A magnetic field can be described as having the following quantities: the magnetic flux density (B) and the field strength, H. The density B is given by the number of induction lines that pass through a material. The intensity H is the magnetizing force which induces the induction lines passing through the material. According to Gussow (2009) the two quantities can be represented by the Eq. (1):

$$B = \mu H \tag{1}$$

Here μ is the magnetic permeability of the environment.

When a poor magnetic material is placed on an H space field, the magnetic flux B is the magnetic induction plus the material (ψ) such that: $\mu * = BH + \psi$ .The action of creating magnetic induction lines or substance in a magnetic field in space called J, which relates to the magnetic induction via the Eq. (2):

$$\psi = 4\ \mu J \tag{2}$$

Rewriting the Eq. (1),

$$B = \mu H + 4\ \mu J \quad (3)$$

The ratio between J and H is called the magnetic susceptibility k:

$$K = J/H \quad (4)$$

For paramagnetic materials, k is a positive constant and has a low value, usually not higher than the order of 10^{-3}. For diamagnetic materials, k is a negative constant, usually less (in magnitude) than 10^{-5}. The magnetic susceptibility of a ferromagnetic material is variable depending on the magnetization field, the nature and sample handling (LIGHT, 2004; Sradling, 1993).

3.1.2 Particles subjected to magnetic field

According Slovoba and Fujita (2003) when a magnetized particle is subjected to a not homogeneous magnetic field, it suffers the action of the magnetic field given by the Eq. (5):

$$\mathrm{Fm} = \frac{\mathrm{k}}{\mu_0} VB\nabla B \quad (5)$$

Where K, μ0 and V represent the volume magnetic susceptibility of the particle, the magnetic permeability in vacuum and the volume of the particle, respectively. ∇B and B represent the external magnetic field and the magnetic field gradient.

In a homogeneous magnetic field ($\nabla B = 0$), the force on the particle is also zero. When a uniform magnetic field is applied to a particle, the forces acting on two poles table are equal and opposite, thus the resultant of these forces is zero. If the applied field at both ends differ in intensity, it results in force acting on the particle. This fact shows that the applied field has a special variation that is a function of the magnetized material dimensions. This field gradient variation also results in force acting on the material, causing the attraction or repulsion of the same (LUZ, 2004).

In modern equipment, both the field and the gradient are responsible for separation process. Recalling that the field strength refers to the number of flux lines passing through a given area, while the gradient field describes the convergence or divergence of the flow lines. Fig. 3 illustrates this fact very well: in A a uniform field, and B, a converging course. The resultant force on the particle is zero. B has a converging field lines shows the flow of a field gradient. In this case, there is a force acting on the particle (LUZ, 2004).

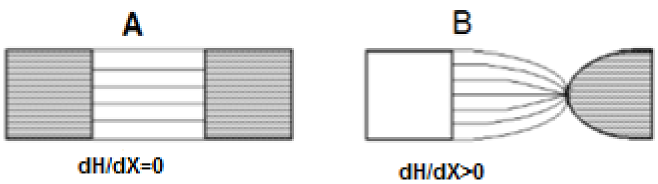

Figure 3. Uniform magnetic field (A) and convergent (B), introducing the Field gradient.

4. METHODOLOGY

The magnetic filter designed Fig. 4 was developed to replace the existing filter in the EDM machine VIASEF Company - Solutions tooling.

Figure 4. Linter filter at VIASEF COMPANY

Figure 5. Magnetic filter: (A) Reservoir 1; (B) Reservoir 2; (C) Reservoir 3; (D) Scraper; (E) Tap to feed the filter; (F) Magnetic Roll; (G) Motor – Reducer; (H) Bushing

4.1 Magnetic filter operation process

The process of the magnetic filter starts from the moment that the working vessel of the electroerosion machine receives the dielectric fluid reservoir in the EDM machine. This fluid cools the piece while it is being machined on the machine work tank, allowing not propagate the flame and improving surface finish.

At the end of the machining electroerosion process a regulator that is installed in the tank opens, which leads the dielectric fluid to the magnetic filter. The direction of fluid to the filter occurs through a faucet installed at the bottom of the reservoir 1 Fig. 5E.

After the fluid is directed to the magnetic filter, it is retained in the tank filter, which is subjected to the process of withdrawal of ferromagnetic particles (eroded), left in the fluid during the machining of the pieces. In the interior of the filter vessel is fixed a magnetic roller partially submerged within the fluid retained Fig. 5F. This roll is rotating clockwise, holding on its external surface eroded fluid particles to be removed by the scraper set off the filter bowl Fig. 5d.

The ferromagnetic particles removed from the scraper are directed to the disposal tank Fig. 5c, leaving in the filtering tube, the dielectric fluid clean. This clean fluid is directed to the reservoir 2 Fig. 5B fixed to the lower part of the filter structure. When the reservoir 2 in Fig. 5B became full, the sensor actuates the pump installed inside it, and starts pumping the fluid to the reservoir 1 Fig. 5A, which in turn starts the entire process again.

4.2 Magnetic filter construction

In order to replace the filter on existing VIASEF company we choose to use SAE 1020 for building the structure of the prototype. We dimensioned the size and thickness of the structure, considering the volumetric capacity (10 liters), and from the dimensions of the magnetic roller and the external components coupled to the frame (engine, gearbox, bearings, etc.). The minimum thickness of the frame was sized by calculating flexed prismatic beams.

For the construction of the magnetic roll were initially made three tests alternating N35 grid neodymium rings with rings of other material, according to Tab 1. The first two tests were united N35 grid rings interleaved with three steel rings SAE 1020. This set of magnets were sink in a pot with dielectric liquid mixed with ferromagnetic particles, after one minute we take down the set of magnets and were observed a large concentration of ferromagnetic particles trapped in the rings. They were repeated twice the same test but changing the type of material of the rings which interleave N35 grid rings Fig. 6.

After the three tests were finished we observed that the best set of rings used to hold the ferromagnetic particles are the N35 rings interspersed by SAE 1020 rings Tab 1, thus justifying the choice of rings for the prototype built in this work.

Figure 6. Magnetic rings interspersed with SAE 1020 rings.

From the results of the three tests Tab 1, we realize that is not necessary to use higher grades (cost-benefit).

Table 1. Results from the tests for the construction for the magnetic roll.

TESTS	MAGNETIC RINGS GRID	RING INTERLEAVING	RESULTS
1	N35	SAE 1020	High particle retention
2	N35	NAYLON	Average particle retention
3	N35	PLASTIC	No particle retention

After selecting the grid of the magnetic rings and merge rings (SAE 1020), we dimensioned the diameter of the magnets building upon on the structure height without the support feet. To support the magnetic rings was used a SAE 1020 shaft with a length of 230 mm and 20 mm diameter, where the neodymium and SAE 1020 rings were placed interchangeably, allowing the shaft passing through the inner diameter of the rings and installed in bearings fixed on the sides of the filter structure.

Furthermore, to that neodymium and SAE 1020 rings do not slip in relation to the support shaft they were connected face to face, allowing that the outer rings are stuck on two discs fixed by screws. The fasteners disks were screwed on the shaft.

After building the magnetic roll, he was coated by a stainless steel plate in order to protect it from of corrosion and abrasion of ferromagnetic particles present in the fluid Fig. 7.

Figure 7. Magnetic roll

The scraper which is responsible for removing ferromagnetic particles from the magnetic roller was made from rubber since its mechanical strength is lower when compared to the roller material making it easier to replace than the roller in case of excessive wear.

Finally we dimensioned the external frame components, such as bearing for supporting the magnetic roller; the motor and the gear unit for moving the roller. And finally we developed an electronic system for controlling the rotational speed of the magnetic roller.

Table 2. Prototype dimensions

	Material	Lenght	Hight	Thickness	Diameter
Rings	Neodymium - N35	-	-	5 mm	32x20 mm
	SAE 1020	-	-	5 mm	32x20 mm
Roller shaft	SAE 1020	310 mm	-	-	20 mm
Coating	Steel Inox	210 mm	-	0,4 mm	33 mm
Estructure	SAE 1020	235 mm	160 mm	2 mm	-
Feet (bracket)	SAE 1020	-	200 mm	3 mm	-
Scraper	Rubber	194 mm	103 mm	2 mm	-
Bushing	SAE 1020	85 mm	85 mm	7 mm	17 mm
Motor and the reductor	**Voltage**	**Current**	**Reduction**	**Torque**	**Rotation**
	24V	0,38A	1:23		51rpm

4.3 Tests

To determine the efficiency of the magnetic filter tests we measured quantity of magnetic material removed by the scraper. First we mixed 5,4kg of clean fluid with 600g of ferromagnetic material. After mixing the ferromagnetic material in the clean fluid it was placed in the vessel 1, Fig. 5. This reservoir has the function of feeding the magnetic filter through a tap at the bottom of it.

To the first test we turn on the magnetic filter with a 24V supply, measuring the rotation of the engine. We vary the motor voltage until we achieve the maximum rotation 51rpm, Tab 3.

The second test was to determine filter efficiency, to that we let the filter connected for 5 minutes, leaving the constant feed rate. After 5 minutes we turn off the source of 24V and weighed ferromagnetic particles concentrated in the scraper also weigh the concentration of fluid mixed with the magnetic material retained in the reservoir 3, Fig 5. This test was repeated for times of 10, 15, 30 and 60 minutes, Tab 4.

We conducted a final test, repeating the second test but varying the flow that feeds the filter. We realize that increasing the feed rate also increases the fluid mixed with the magnetic particles accumulated in the reservoir 3, Fig. 5, it is not possible to remove all the magnetic particles by the scraper. Because the particles do not accumulate on it in a visible manner as it was in the second test, this happens because the fluid has swept the magnetic particles retained in the scraper to the reservoir 3, Fig. 5.

Table 3. First Test - Motor-reducer rotation

Voltage (V)	ROTATION (RPM)
24v	51 rpm
20,5v	45 rpm
16,5v	34 rpm
12,7v	24 rpm

Table 4. Second Test - Magnetic Filter Efficiency

Time (minutes)	Sludge removed from scraper (Kg)	Mixed fluid to the magnetic particles - Retained in the reservoir 3
5 min	0,016 g	0,400 Kg
10 min	0,018 g	1,000 Kg
15 min	0,020 g	1,100 Kg
30 min	0,016 g	2,100 Kg
60 min	0,07 g	4,500 Kg

4.4 Result Analysis

When we analyze the three tests and the results obtained Tab. 4, we can see that the first filtration had a high concentration of magnetic iron particles in a shorter filter operation, when compared with other tests. We also realize that during the removal of the magnetic particles by the scraper, we have a high concentration of fluid mixed with magnetic material, trapped in the reservoir 3 Fig. 5.

To have a real confirmation of magnetic filter efficiency for VIASEF company, it is necessary that this prototype magnetic filter, work approximately 30 days, in order to have a concentration of ferromagnetic materials without fluid, to compare with the amount retained by Linter filter used today in the company.

5. CONCLUSION

We conclude that it is feasible to construct a magnetic filter in actual size for the VIASEF company but it needs some modifications, such as:

- Exchange the magnetic grid of magnets for a greater one in order to get a higher magnetic field, resulting in higher material removal and reduced machine operating time
- Replacement of rubber scraper for magnetic scraper so there is a greater retention of magnetic material.
- Design a motor with a rotation that allows to be varied to follow variations of the filter feed rate, without losing the scraper efficiency.

These modifications are necessary because the magnetic prototype filter has a low removal rate of magnetic material, living at a high working time to obtain a substantial removal of magnetic material.

6. ACKNOWLEDGEMENTS

We would like to thank the VIASEF COMPANY - Tooling Solutions- for the available space and help to build the magnetic filter prototype.

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