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Original Research

Design and Fabrication of Magnetic Field System for Improving EDM Process

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Abstract: Electric discharge machining is one of the non-traditional machining methods. In this process, many of the limitations of traditional machining methods have been removed, which is why the use of EDM in the manufacture of industrial parts and molds has greatly increased today. However, electric discharge machining has low efficiency and high energy consumption, and the quality of the machined surface in this method is low. For this reason, researchers have always been trying to find a way to increase the efficiency and quality of the surface. One of the most effective methods is the application of external magnetic field in electric discharge machining. Applying a magnetic field around the machining range in EDM leads to increased machining efficiency, reduced tool corrosion, increased chipping rate, reduced surface roughness and improved surface integrity. Previous research has shown positive results from magnetic field applications, but so far, no mention has been made of how to design a magnetic field application system. Undoubtedly, building an efficient system to apply the magnetic field in EDM is a challenges of using this method. In this article, using previous research, experiences gained and scientific foundations of a method to build this system will be presented.

Keywords: EDM; MF-EDM; Magnetic field system; Design and construction; Optimization.

Introduction

With the increasing need for advanced materials and their creation, new methods for making work-pieces are needed [1]. Mechanical methods such as ultrasonic assisted machining, chemical methods, biological methods, and so on are some of these process [2, 3]. These methods increase dimensional accuracy, and reduce heat and energy loss and surface roughness of the work-piece [4]. Electrical discharge machining (EDM) is a thermophysical-based material removal process that has excellent ability for noncontact machining of brittle and hard materials with accurate 3-D complex shapes. Improvements in machining characteristics, including the material removal rate (MRR), surface integrity, electrode wear rate (EWR), energy consumption, and negative environmental impact, are significant for further developing the performance of the EDM process.

Recently, magnetic field assisted method has shown great potential and superiority for enhancing the machining process and its performance due to the ease of contactless forces [5]. Accordingly, various research works have been conducted on the subject of electric discharge machining with the help of magnetic field in recent years.

In this research work, magnetic field machining has been done alone or in combination with different methods. For example, Ablyaz et al. [6] investigated the effect of magnetic field application on the performance of electric discharge machining on AL-SIC metal matrix composites. They concluded that under the same parametric conditions, the MRR with the help of the magnetic field was 118% higher than the state without the help of the magnetic field. Also in the presence of graphite powder the surface smoothness and surface integrity has been significantly improved with the help of magnetic field. Anthuvan et al. [7] investigated the electrical discharge of micro-holes in Ti-6Al-4V using a magnetic field. They added some activated carbon to the dielectric. The results showed that in electric discharge machining with the help of magnetic field and dielectric fluid containing activated carbon, the amount of MRR and TWR increased and the dimensional accuracy (diameter) in this case decreased compared to normal machining. Sivaprakasam et al. [8] conducted research on the micro-machining of electric discharge using a magnetic field on the Inconel 718 alloy. In this experiment, tungsten was used as the electrode. Experimental results show that the addition of an external magnetic field increases the MRR by about 22%. Rouniyar et al. [9] carried out an experimental study on the Recast layer and the surface roughness of 6061 aluminum work-piece in electric discharge machining using a magnetic field and a mixture of aluminum powder. In this experiment, oil was selected as the dielectric fluid and aluminum powder was added to it. They concluded that by increasing the powder concentration and the amount of magnetic field, smaller openings and cavities are formed on the surface, the surface roughness decreases and the density of cracks on the surface decreases. Renjith et al. [10] investigated the properties of electromagnetic discharge micro-machining. In this experiment, ionized water was used as the dielectric and tungsten copper was used for the instrument. According to the results, the magnetic field leads to an increase in MRR and a decrease in TWR. The magnetic field pushes chips and debris out of the machining gap, reducing arcs and short circuits and increasing machining efficiency. The amount of corrosion of the tool is reduced due to the reduction of machining time in the presence of a magnetic field. Rouniyar et al. [11] investigated the improvement of machining level in the process of electric discharge machining in the presence of magnetic field and on 6061 aluminum work-piece. In this experiment, aluminum powder was mixed with oil and used as a dielectric. They found that by increasing the concentration of aluminum powder along with increasing the magnetic field, the surface roughness could be reduced and a surface with fewer cracks and smaller cavities could be achieved. Sivaprakasam et al. [12] investigated the increase in material removal rate in magnetic field-assisted micro-machining of electrical discharges on AMCs. In this experiment, tungsten was used as a tool, and a thin sheet of aluminum matrix composite (A413-9% B4C) was used as a work-piece. In this experiment, it was found that by applying an external magnetic field in the Micro EDM process, the MRR rate increases by about 20%. Ming et al. [13] conducted a comparative study of energy efficiency and the effect of the environment on electric discharge machining with the help of a magnetic field. They found that applying a magnetic field to electric discharge machining could improve energy efficiency by 15.2%, tool corrosion by 22.6%, and material removal rate by 21.9%. They also found that CO_2 emissions were significantly reduced with the help of a magnetic field. Gholipoor et al. [14] investigated the effect of magnetic field on the performance of almost dry electric discharge machining. In this study, they used a rotating external magnetic field around the machining gap. They found that with the help of the magnetic field, the amount of material removal is greater and the surface roughness is lower, but the tool wear rate is slightly higher. Also, the optical micrographs of the machined surfaces showed better surface integrity.

In research on MF-EDM, no research has been done on how to build a magnetic field application system, while the most important part of using this method is to build an efficient magnetic field application system. In this research, based on previous research, scientific principles and experiments, a solution for the optimal design of a magnetic field generator set for use in EDM will be investigated. Different parameters must be considered in the design. Including coil housing design, selection of coil housing material, selection of wire diameter, number of windings, calculation of magnetic field and electrical circuits used in the system.

EDM Process

EDM machining method is one of the most widely used non-traditional machining methods. In this method, there is no contact between the tool and the work-piece, and the chip removal operation is performed by creating a spark. When sparking, the tool and the work-piece are a short distance apart. This distance is called chat. The gap is filled by a dielectric. Whenever the voltage rises as much as the dielectric breakdown voltage, it sparks between the tool and the work-piece and a plasma channel is formed. The plasma channel is an ionized column. In the plasma channel, electrons are attracted to the positive pole and positive ions to the negative pole. Bombing of the tool surface and work-piece by positive electrons and ions increases the temperature. As the temperature rises, the surface of the work-piece and tool melts and evaporates, leading to chipping. Many of the vaporized particles return to the surface and weld to the surface. This increases the surface roughness and reduces the surface integrity, as well as reducing machining efficiency. On the other hand, if the chips are not removed from the machining gap, they cause inactive pulses and reduced machining efficiency [15].

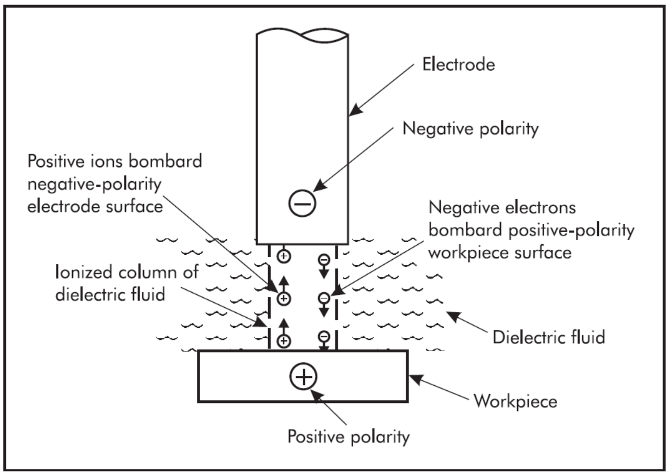

Figure 1: Electron and Positive-ion bombardment in EDM process [15].

MF-EDM Process

The use of an external magnetic field causes the plasma channel to condense and the spark energy to increase. It also allows chips to come out of the machining gap more and faster. The removal of chip particles from the machining gap increases the surface quality and reduces inactive pulses [16].

In general, the application of magnetic field in EDM machining increases material removal rate and efficiency, improves surface roughness and surface integrity, and reduces tool wear [17].

Materials and Methods

In order to use the magnetic field in EDM machining, we need to build a system that can apply the magnetic field seamlessly in the machining space, the amount of magnetic field is adjustable, takes up little space, has a long life and the environment has the least impact Have on its performance. This system includes different parts that in this section, how to design and build it will be discussed.

Coil Housing Design

The first step in making a coil is to design its enclosure. After determining the dimensions of the work-piece and the electrode, the coil housing should be designed to fit them. The coil housing should be designed to cover the entire machining area, also because the coil heats up during operation, it is better to use aluminum to build the housing. Aluminum is paramagnetic, so it does not affect the magnetic field and does not change the direction of the field. Aluminum is also one of the best options for making coil chambers due to its relatively high heat transfer coefficient in metals and low price. To make the coil, it is better to use a cylindrical coil. According to magnetic theories, the magnetic field at the inside diameter and the center range of the cylinder is approximately parallel to the height of the cylinder, thus not causing the plasma channel to deflect in the EDM. In this research, and considering the dimensions of the work-piece and the electrode, we have considered the height of the coil housing to be 4 cm and its inner diameter to be 6 cm.

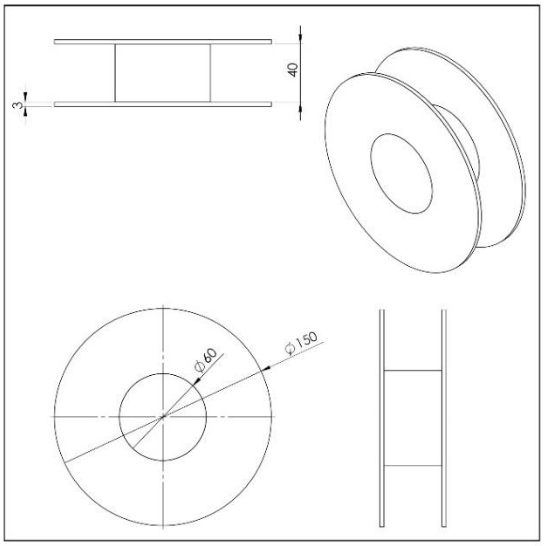

Figure 2: 2D design of the coil housing.

Magnetic Theories

The next step in designing a coil is its mathematical calculations, for which we use eq. (1).

$$B = \mu_0 \frac{NI}{L} \quad (1)$$

Where *B* is the magnetic field in tesla, μ_0 is the vacuum permeability and equal to $4\pi \times 10^{-7}$, *I* is the current in ampere, *N* is the number of turn and *L* is the height of the coil [18].

According to the height designed for the coil housing, the choice of 1000 rpm for *N*, and the maximum current of 6 amps, the amount of magnetic field using eq. (1) is obtained as eq. (2).

$$B = 4\pi \times 10^{-7} \frac{1000 \times 6}{0.04} = 0.1884\,T \tag{2}$$

Another issue in the design and construction of a coil is the choice of wire diameter. Wire manufacturers publish tables that show the maximum allowable current through the wire at a specified length. According to the number of rounds calculated for the coil and the maximum current required for the coil, we select the wire diameter from these tables. In this study, copper wire with a diameter of 0.7 mm was used. In selecting the wire diameter, the minimum wire diameter must be selected from the table, the larger diameter leads to an increase in electrical resistance, the coil heat increases during operation, and the magnetic field generated by the coil decreases due to voltage drop.

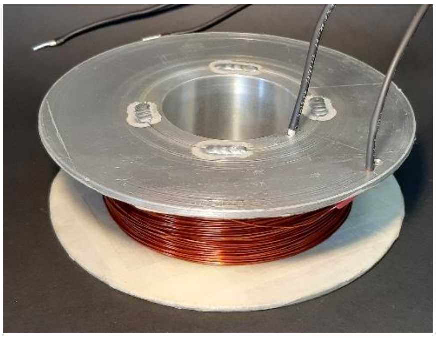

Figure 3: Fabricated coil image.

Power Supply

We need an adjustable voltage source to supply the required voltage and current to the coil. In this research, a 5kw variac has been used. When connecting the coil to the power supply, the direction of current should be such that the direction of the system magnetic field is parallel to the direction of the EDM plasma channel magnetic field, otherwise the application of an external magnetic field will weaken the plasma channel and reduce machining efficiency. By changing the connection of the input wires, the direction of the magnetic field in the coil can be changed. To determine the direction of the magnetic field, the law of the right hand can be used, so that whenever the direction of the four fingers is parallel to the direction of the input current, the direction of the thumb will be equal to the direction of the magnetic field.

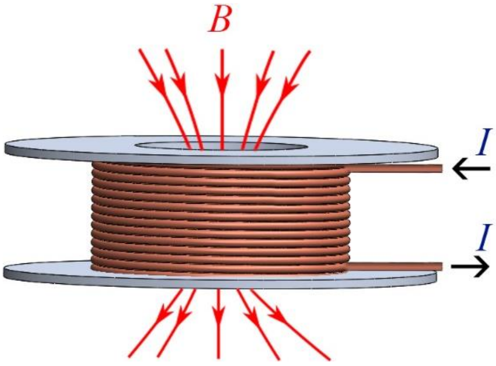

Figure 4: The direction of the magnetic field in the coil.

Electrical Circuits

In previous research, the magnetic field has been used in EDM in three modes: variable, fixed and fixed pulsating [17]. The difference in the type of magnetic field is related to the difference in the input current to the coil. If the input current is AC, the magnetic field is variable, if the input current is DC, the magnetic field is constant, and if the input current is DC half-wave, the constant magnetic field will be pulsating. The meaning of a pulsating constant magnetic field is that the value of the magnetic field, due to the type of input current to the coil, over time, constantly reaches the maximum positive value from zero and becomes zero again, as in Figure 5.

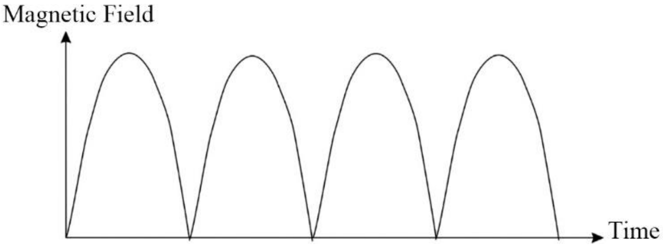

Figure 5: The chart of pulsating constant magnetic field.

If the selected power supply has only AC voltage output, we need a diode bridge circuit to achieve DC voltage. Figure 6 shows the electric circuit of a constant magnetic field and Figure 7 shows the electrical circuit of a constant magnetic field with pulsating [19].

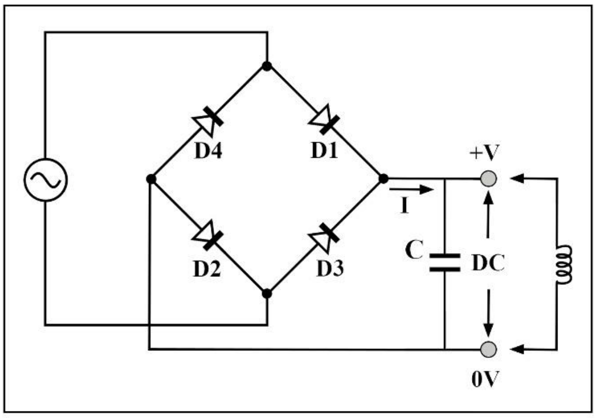

Figure 6: Constant magnetic field generator electrical circuit.

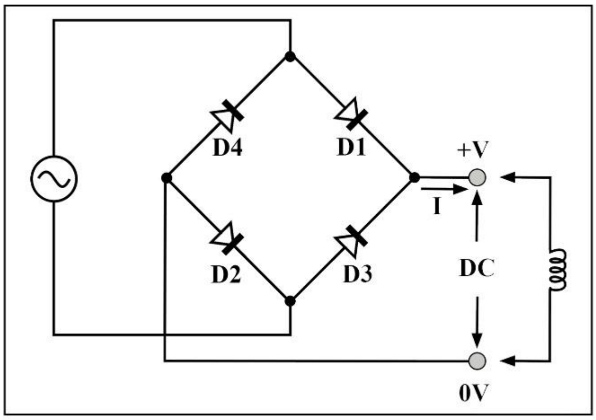

Figure 7: Pulsating constant magnetic field generator electrical circuit.

The characteristics of diodes and capacitors should be selected based on the maximum current and output voltage of the power supply.

Fixture

Fixers are commonly used to hold the work-piece for machining. In the MF-EDM process, the fixture must be designed to reduce the effects of the environment on the magnetic field in addition to holding the work-piece in place. In this research, Teflon has been used to make fixtures. Teflon fixture is installed on the machine table. The positive pole is also connected to the work-piece by a tightening screw and a wire attached to the machine table.

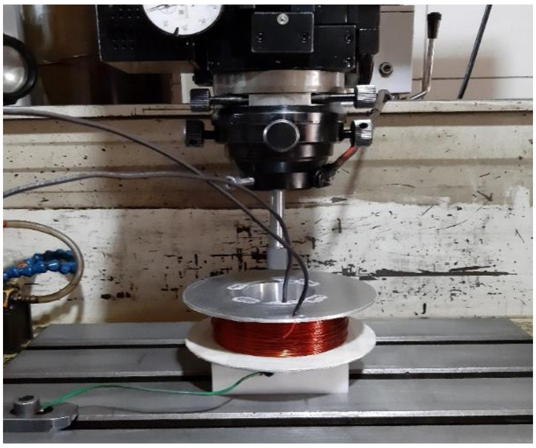

Figure 8: Image of coils and fixtures installed in the EDM machine.

Experimental Details

The performance of the designed system (Figure 9), in terms of the amount of magnetic field and how it is distributed in the coil, has been tested by Teslameter with a resolution of 0.01 mT in the laboratory.

Figure 9: Image of the coil performance checking in laboratory.

Results and Discussion

Tables 1 and 2 show the results of the magnetic field obtained from the coil at different voltages. According to the studies, the maximum amount of magnetic field was recorded in the center of the coil, and the closer the probe was to the inside diameter, the lower the amount of magnetic field.

The distribution of the magnetic field at the top and bottom of the coil was exactly the same. It is better to insulate the part of the input and output wires of the coil that is outside the housing with a polymer coating so that the connection to the body does not occur due to the wear of the wire cover. To increase machining efficiency (Figure 10), the optimal amount of magnetic field should be selected by changing the power supply voltage.

Table 1: Magnetic field values at different AC voltages.

V(V)	25	50	75	100	125	150	175	200
I(A)	0.9	1.5	2.2	3	3.6	4.3	5	5.5
B(mT)	10	10	16	22	26	30	36	42

Table 2: Magnetic field values at different DC voltages.

V(V)	4	7	15	20	22	50	75	100
I(A)	0.2	0.3	0.7	0.9	1	2.3	3.4	4.5
B(mT)	4	6	11	15	16	38	58	77

Figure 10: Image of EDM Machining with the assisted of magnetic field system designed.

Conclusion

In this paper, the design and fabrication of a magnetic field application system in EDM machining was investigated. According to research, the application of magnetic fields in EDM machining leads to increased machining efficiency, improved surface integrity, increased material removal, reduced tool erosion and reduced surface roughness. The results obtained from the design and testing of the EDM magnetic field generator system showed that the maximum amount of magnetic field is obtained in DC current mode and in the center of the coil. This amount decreases with distance from the center. As the coil height decreases, the number of wire turns increases, and the coil input current increases, the amount of magnetic field increases. Also at an equal voltage, the amount of magnetic field at the DC voltage is almost twice that of the AC voltage. When selecting the coil wire diameter from the table, it is better to select the minimum allowable diameter. Choosing a larger diameter increases the electrical resistance, increases the heat of the coil during operation, and reduces the magnetic field generated in the coil due to voltage drop. The values of the magnetic field obtained in the coil test in the laboratory are less than the values calculated by the mathematical equations. This field reduction is due to wire resistance and voltage drop. It is possible to install the coil on the EDM machine without insulation and the dielectric fluid acts as an insulation between the coil and the metal body of the Machine. It is better to use aluminum in the construction of the coil housing. Aluminum is cheap, has a high heat transfer coefficient, and the heat generated in the coil does not deform it. Aluminum is also paramagnetic and has the least impact on the magnetic field created by the coil. The work-piece fixture should be made of materials that have the least impact on the magnetic field, as well as reduce the potential effects on the magnetic field by the machine table.

Disclosure Statement

The author(s) did not report any potential conflict of interest.

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