ELECTRIC DISCHARGE DEPOSITION EQUIPMENT

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ABSTRACT: The electric discharge deposition process (EDD) is a new machining process for metal fabrication. In this process, the high level of wear of the tool electrode is used to obtain the deposition of the metallic material. The equipment was modeled in Autodesk Inventor Professional 2022, and the simulation process was simulated in Comsol Multiphysics 5.5. In this paper, the coil was modeled to simulate the variation of the magnetic flux and how it affects the trajectory by changing the intensity.

KEYWORDS: deposition, electric discharge, equipment, simulation, trajectory

1. Introduction

The demand for micro-scale parts production has been increasing day by day. The deposition of thin layers on metals and semiconductors finds a great application in these fields. Electric discharge deposition (EDD) is one of the most important deposition techniques in the research community. The following are reported from the literature currently available.

The μ-EDD process is performed in normal atmosphere, and the tool electrode is connected to the positive terminal, where ions are emitted from its surface and have a path directed by the magnetic field to the surface of the part. (see Fig. 1). Because the ion pulse is higher, they lead to the deposition of the tool's material on the surface of the workpiece [1].

During the discharge process, a voltage is applied between two electrodes (the tool and the workpiece). When the electrodes are very close to each other, under the action of Joule heating and the force of the electric field, the surface of the cathode will emit a mass of electrons. Under the force of the electric field, the electrons are accelerated, going to the anode. High-speed electrons collide with the average electrical particles bringing a large portion of electropositive particles. This collision occurs continuously during the discharge process, so the electrical particles will grow, forming a plasma channel [2].

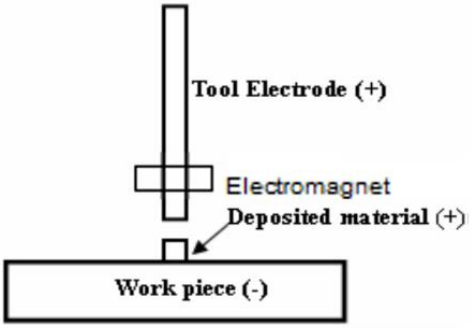


Fig. 1. Diagram of electric discharge [1]

2. Current stage of EDD

The electric discharge equipment is designed to be mounted on an EDM machine, which will change its polarity in order to deposit material on a part with electrical conductivity.

3. Strategic product marketing

3.1 Identifying market opportunities

a. Client's portfolio of needs

There were identified 4 needs numbered N1, N2, N3, N4.

N1: The need of depositioninf material at low costs.

N2: The need to adjust magnetic field strength and ion particle trajectories in EDD so as to increase material deposition rate and quality.

N3: The need to ensure an adequate working head feed rate for the purpose of deposition by electric discharge.

N4: The need to increase productivity and machining times through coordinated CNC movement.

b. Opportunities/ Products/ Customers

For each identified need, the following will be established

1) Market opportunities (causes of the need):

• For N1: Lack of such equipment on the market to achieve deposition of material by electrical discharge at low cost.

• For N2: Lack of an electromagnetic device on the market that directly influences the deposition process by electrical discharge.

• For N3: The non-existence on the Romanian market of a similar product for customers who have an electroerosion machine and and who want an extension into the EDD process

• For N4: Lack of electrical discharge deposition equipment on the market and CNC assisted using electroerosion equipment.

2) Products that satisfy the customer needs:

For need N1: P1. Electroerosion processing equipment

For N2 need: P2. Helmholtz coils

For need N3: P3. Working head for EDM

For need N4: P4. Equipment containing multi-axis travel systems

3) Customers for the sale of products

• Research and educational institutions (students, teachers, research laboratories)

• Enterprises performing non-conventional processing (workshops and production departments within the company)

3.2 Mission formulation

• Magnetic field assisted electrical discharge deposition using EDM equipment improves deposition quality and the molten material particles are directed and concentrated towards the electrode by adjusting the current density on the surface.

• By moving the workhead, it is possible to deposit a larger layer of material on the workpiece.

• The equipment has high productivity and good operating times thanks to the machine table's multi-axis travel ability.

3.3 Selecting potential customers

Customer selection involves identifying actual and potential customers who could benefit from CNC magnetic field assisted electrical discharge deposition equipment. EDD equipment is of interest to: micro-enterprises, small and medium-sized enterprises, large enterprises, research and educational institutions.

3.4 Data collected from potential customers.

Identifying a customer’s needs aims to create a base for the entire product development process. The accuracy and quality of the information gathered from customers will have a decisive influence on the final product. The method used to gather raw information about customer needs was the interview.
Ten people were interviewed and their statements were interpreted in such a way as to prioritise user requirements, Table 2 being significant in this respect.

4. Establishing specifications

4.1 Characteristics - demands matrix

The main characteristics and their classification for the product "Electrical discharge deposition equipment" are presented, and the equipment development stage is the establishment of objective product specifications, for which market success of the product is possible. These characteristics are shown in table 3 to facilitate the identification of the primary sizes and requirements.

Table 1. Interview

Costumer: *PÂRVU GABRIELA*		Interviewer: *Bîțoi Ion-Vlăduț-Valentin*
Question	Costumer statement	Question
Typical uses Do you need equipment to deposit metal material on a surface? If so, on what kind of surfaces?	Yes, in the laboratories of the faculty for laboratory work with students using this equipment for teaching purposes, projects or in research work. I would use this equipment for laying on flat or cylindrical surfaces.	Typical uses Do you need equipment to deposit metal material on a surface? If so, on what kind of surfaces?
If you used this filing procedure, what form and arrangement did you use?	I did not use similar equipment in practice, but from various research papers I noticed that layers of material were deposited in different shapes (circle, star, spiral, hexagon).	If you used this filing procedure, what form and arrangement did you use?
What applications did you use this procedure for?	We have not used similar equipment in practice, but it certainly has to be universal in terms of parts. The equipment should also be able to deposit on cylindrical, spherical, surfaces...	What applications did you use this procedure for?
If you used this procedure, what materials did you submit?	Because this equipment is not found in the laboratories of the faculty, we did not perform material deposition operations, but I know that they can be deposited on metal parts made of copper, tungsten, graphite filiform electrodes.	If you used this procedure, what materials did you submit?
Do you think it is a solid enough product?	The product must be as solid and precise as possible.	Do you think it is a solid enough product?
Why is this useful product?	Because it is a novelty in unconventional processes and I think it will have a positive impact in the coming years.	Why is this useful product?
What kind of parameters, functions or features of the product, do you consider necessary for this equipment?	Positioning accuracy, wire feed rate, intensity, pulse time, magnetic flux	What kind of parameters, functions or features of the product, do you consider necessary for this equipment?
User knowledge issues Do you have knowledge about this field?	Yes	User knowledge issues Do you have knowledge about this field?
Have you ever encountered such equipment?	Yes, I have come across such equipment in research laboratories.	Have you ever encountered such equipment?
Do you consider that you need training to use / adjust this equipment?	Yes, it is necessary to have the possibility to offer training sessions	Do you consider that you need training to use / adjust this equipment?
Pleasant aspects of the current product Is it easy to use?	Yes	Pleasant aspects of the current product Is it easy to use?
How do you maintain your current equipment?	With average ease	How do you maintain your current equipment?
What do you think of the product in terms of maneuverability?	Very good due to the small size	What do you think of the product in terms of maneuverability?
How detailed is the use, installation and maintenance manual?	Detailed, with explicit figures and tables	How detailed is the use, installation and maintenance manual?
What do you think about the cost of the product?	Be as small as possible compared to the competition	What do you think about the cost of the product?
Disadvantages of the current product There is a risk of injury during use.	Yes, if the staff is unskilled and inexperienced	**Disadvantages of the current product** There is a risk of injury during use.
How would this product bother you during processing?	It would bother me if it is not stable and safe in operation	How would this product bother you during processing?
Improvement proposals What is the degree of flexibility for this product?	Pretty big. I have encountered such subsystems in many areas.	**Improvement proposals** What is the degree of flexibility for this product?
You would like something specific from EDDE	Fixing the equipment is easy, with few fasteners, easy maintenance.	You would like something specific from EDDE

Table 2. User requirements and relative importance

No.	*Customer requirements*	*Relative importance*
1	EDDE is used in many areas.	4
2	EDDE allows the deposition of material in different forms and layouts.	5
3	EDDE allows deposition in the form of layers of different materials.	5
4	EDDE prezintă costuri reduse.	4
5	EDDE is low cost.	4
6	EDDE provides the desired processing characteristics.	5
7	EDDE allows the use of qualified persons.	2
8	EDDE makes maintenance easy.	3
9	EDDE provides detailed user manual.	3
10	EDDE offers safety in operation.	4

Table 3. Characteristics - demands matrix

Column #				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Direction of Improvement: Minimize (▼), Maximize (▲), or Target (o)																										
Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") \ Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	External dimensions of the equipment	Equipment weight	Magnetic field assist	Power consumed	Interstitial processing	Energy source	Pulse time	Magnetic flux	Current density on surface	Machine tool precision	Dimensions of the machine table	Diameter of tillform electrode	Maximum electrode weight	Thickness of the deposited layer	Maximum workpiece dimensions	Maximum workpiece weight	Current to be processed	Material deposition speed	Roughness of the deposited layer	Mean Time Between Failures	User safety	Design	Equipment price
9	10.3	4.0	EDDE has uses in many areas			⊙		▲		o	o	o	▲				o	o		o		⊙	⊙			
9	12.8	5.0	EDDE allows the deposition of material in different forms and depositions			⊙		⊙		▲												▲				
9	12.8	5.0	EDDE allows deposition as layers of different materials					⊙		⊙	⊙	⊙	o		o		▲			▲	▲	▲				
9	10.3	4.0	EDDE provides low costs	⊙	⊙	o	▲						⊙	o		o		▲					o		⊙	
9	10.3	4.0	EDDE provides manoeuvrability	⊙	⊙				▲					⊙	▲	▲			o						▲	
9	12.8	5.0	EDDE provides the desired processing characteristics			⊙						⊙	⊙	⊙	▲						⊙	⊙				
3	5.1	2.0	EDDE allows the use of qualified persons			o	o		o	▲	o	o			▲					▲		▲				
9	7.7	3.0	EDDE allows easy maintenance	o	o									▲									⊙		⊙	o
9	7.7	3.0	EDDE provides detailed user manual	⊙	▲	⊙			o			o		o	o	▲	o	o	o	o				⊙		▲
9	10.3	4.0	EDDE offers operational safety	o	o				o					o	▲	▲		o	o	▲			▲	⊙		

⊙ Strong Relationship | o Moderate Relationship | ▲ Weak Relationship

5. Conceptual design

5.1 General function and component functions

The general function of the EDD equipment, which is the subject of this paper, is to deposit material by electric discharge in the magnetic field.

The general function is subjected to an analysis process which will result in first the main functions and then the secondary ones. The main functions are properties of the product that determine the general function. Secondary functions result from the interaction between the main functions and are called internal interactions, and the interactions between the main functions and the environment are external interactions.

The functions of the EDD equipment are listed in Table 4.

Table 4. Functions of the EDD equipment

GF	***Layer deposition***
No.	*EDD functions*
1	Attaching the tool electrode *Secondary functions:* chuck opening; electrode insertion; screwing in the chuck key to tighten the electrode.
2	Adjusting the perpendicularity of the electrode-tool in relation to the surface of the workpiece *Secondary functions:* loosening the perpendicularity adjustment screws; changing the position of the electros-tool; maintaining the position with the openwork of the springs.
3	Workpiece holding *Secondary functions:* vise opening; the introduction of the piece; screwing in the chuck key to tighten the electrode
5	Providing an electromagnetic field: *Secondary functions:* power supply start; Supply of the subassembly of electromagnets with electricity from the source;
6	Ensuring the generation of magnetic flux; *Secondary functions:* pressing the buttons on the control panel, adjusting the voltage and current, in the drives, adjusting the current density on the surface; ensuring a direction of propagation.

7	Providing the working environment. *Secondary functions:* ensures a normal atmosphere; prevents objects from entering the work area.
8.	Secures to the rest of the machine. *Secondary functions:* vibration reduction; positioning on the surface, fixing on the surface, prevention of overturning, prevention of slipping
9.	Ensures the user's safety and health during machining *Secondary functions:* light signaling; audible signaling when the equipment is switched on. visualizing the status of the machine on the control panel

Among the main functions established above, a list of critical functions has been compiled (Table 5), which determines the commercial success of the product. These critical functions correspond to the sizes and requirements with the maximum relative importance.

Table 5. List of critical functions

Function number	***The critical function of the product***
1	Ensuring ion flow generation
2	Providing an electromagnetic field
3	Attaching the tool electrode
4	Workpiece holding

5.2 Internal research for new construction solutions

The need to identify technological and constructive solutions has determined a more intense participation of the creative component of thinking; for this reason, more attention has been paid to the study and use of methods to stimulate technical creativity (both of the group and of the individual).

- Concepts generated individually. For the design and determination of the optimal mechanism of EDD, we proposed the use of the diagram of ideas from table 6:

Table 6. Diagram of ideas

Equipment for material deposition by electric discharge			
A. Electrode shape in cross section	B. Power supply to the equipment	C. Ensuring the power supply in the machining area	D. User protection
A1. Circula	B1. Power from the socket	C1. Source circuit	D1. Protective equipment
A2. Tubular	B2. Power obtained by combustion	C2. Rechargeable battery circuit	
A3. Square	B3. Rechargeable battery power	C3. Battery circuit	
A4. Rectangular	B4. Power obtained by chemical reactions		

- Group-generated concepts. The functions of the product were analyzed and solutions were proposed for their proper accomplishment:

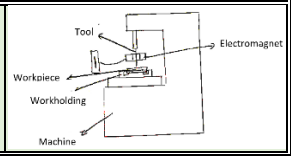
Table 7. Solution diagram

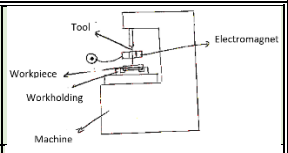
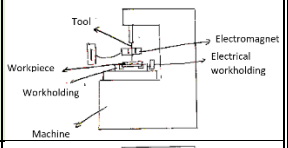
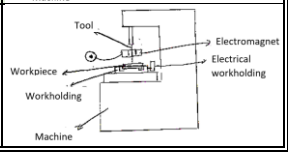
A. Workpiece holding	B. Utilizarea magneților	C. Asigurarea fluxului magnetic	E. Reglarea sculei la cotă	F. Asigurarea mediului de lucru
A1. Mechanical workholding	B1. Temporary	C1. Lever	E1. Preliminary test passes	F1. Normal atmospher
A2. Electrical workholding	B2. Permanent	C2. Button	E2. Adjustment by test pieces	F2. Dielectric fluid
A3. Hydraulic workholding;	-	C3. Switch	-	F3. Vacuum
A4. Pneumatic workholding;	-	C4.Potentiometer	-	-

5.3. Resulting concepts

Following the compilation of the database of known and new conceptual solutions for the main functions of the product, a number of technically possible solutions are established by combining the concepts. As, in general, the number of technically possible solutions is very large, taking into account the objective specifications established in the previous works, a number of conceptual solutions are excluded.

Table 8. Conceptual solutions

Concept		Draft
A	Electric discharge deposition machine with a mechanical part clamping device, a lever-operated electromagnetic field, and the tool adjustment at the dimension is done by preliminary test passes.	

B	Electric discharge deposition machine that has a device for mechanical fastening of the semi-finished part, the provision of an electromagnetic field actuated by a button, and the adjustment of the tool at the dimension is done by preliminary test passes.	
C	Electric discharge deposition machine that has a device for electrically gripping the semi-finished part, ensuring an electromagnetic field actuated by a lever, and adjusting the tool at the level is done by preliminary test passes.	
D	Electric discharge deposition machine that has a device for electrically gripping the semi-finished part, ensuring a button-operated electromagnetic field, and adjusting the tool at the dimension is done with the help of test pieces.	

The concept evaluation matrix is presented in Table 9.

Table 9. Concepts evaluation matrix

Selection criteria	***Weight [%]***	***Concept A***		***Concept B***		***Concept C***		***Concept D***	
		Assessment	*Score*	*Assessment*	*Score*	*Assessment*	*Score*	*Assessment*	*Score*
Ease of operating	20								
Ease of voltage programming	8	3	0.24	3	0.24	3	0.24	3	0.24
Ease of intensity programming	8	3	0.24	3	0.24	3	0.24	3	0.24
Ease of programming feeds	4	3	0.12	3	0.12	3	0.12	3	0.12
Ease of use	15								
Ease of electrode supply	5	3	0.15	3	0.15	3	0.15	3	0.15
Ease of assembly	5	3	0.15	3	0.15	2	0. 1	2	0.15
Ease of cleaning	5	3	0.15	3	0.15	3	0.15	3	0.15
Reliability	25								
Interchangeability of parts	20	3	0.6	3	0.6	3	0.6	1	0.2
Strength, durability of equipment	5	3	0.15	3	0.15	3	0.15	2	0.1
Design and ergonomics	10								
Pleasant design	3	3	0.09	3	0.09	3	0.09	3	0.09
Proportionality of shapes	2	3	0.06	3	0.06	3	0.06	3	0.06
Overall dimensions	3	3	0.09	3	0.09	3	0.09	3	0.09
Stability	2	3	0.06	3	0.06	3	0.06	3	0.06
Safety in exploitation	10								
Trained staff	4	3	0.12	2	0.08	3	0.12	4	0.16
Protective equipment	3	3	0.09	3	0.09	3	0.09	3	0.09
Acousting and light signaling	3	3	0.09	3	0.09	3	0.09	3	0.09
Ease of manufacturing	15								
Type of material	10	3	0.3	2	0.2	3	0.3	4	0.4
Machinability of materials	5	3	0.15	2	0.1	3	0.15	3	0.15
Cost	20								
Manufacturing cost	10	3	0.3	2	0.2	2	0.2	1	0.1
The cost of maintenance	5	3	0.15	3	0.15	3	0.15	2	0.1
Decommissioning cost	5	3	0.15	3	0.15	3	0.15	3	0.15
Total score			3.45		3.16		3.2		2.89
Rank		1		3		2		4	

The variant with the highest score, the concept A, is adopted.

6. Detailed design

Figure 2 shows the components of the magnetic field-assisted electric discharge equipment:

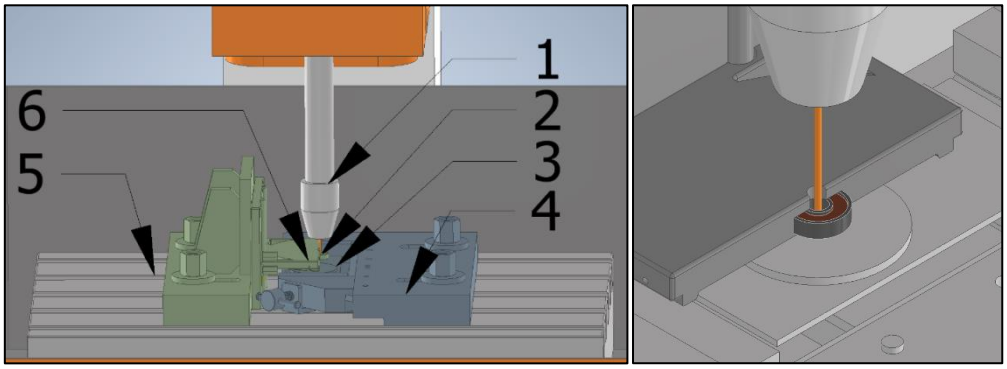


Fig. 2. Components of magnetic field electric discharge equipment which are:
1. Electrode holder; 2. Tool electrode; 3. Electrode-part; 4. Electrode-part clamping device;
5. Worktable; 6. Electromagnet clamping device;

7. Finite element analysis

The Inventor Autodesk 2022 software simulated a force of 0,1 N on the “Clamping device” and “Workhead” subassemblies to observe deformations and determine their safety factor, the results being shown in Figure 3.

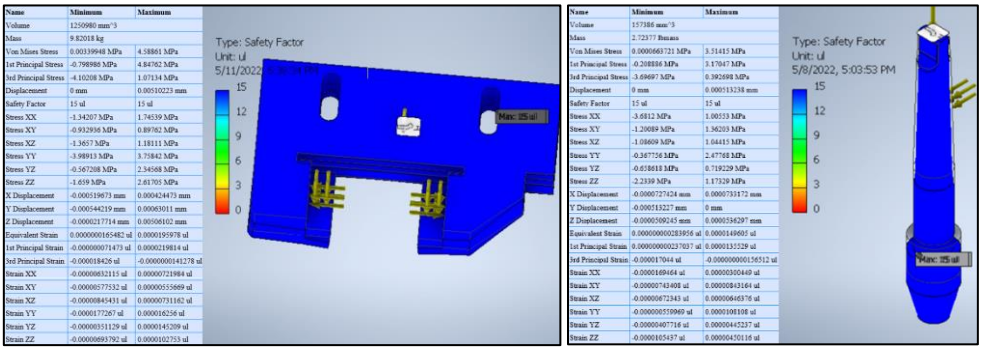


Fig. 3. FEA analysis for " Clamping device" and "Workhead" in Autodesk Inventor 2022

According to the data obtained from the finite element analysis, the "Clamping device" and "Workhead" subassemblies have a safety factor of 15.

Using Comsol Multiphysics 5.5 program, the magnetic flux created by the electromagnet and the particle’s trajectory from the electrode were modeled and simulated, the results of these simulations are shown in figure 4.

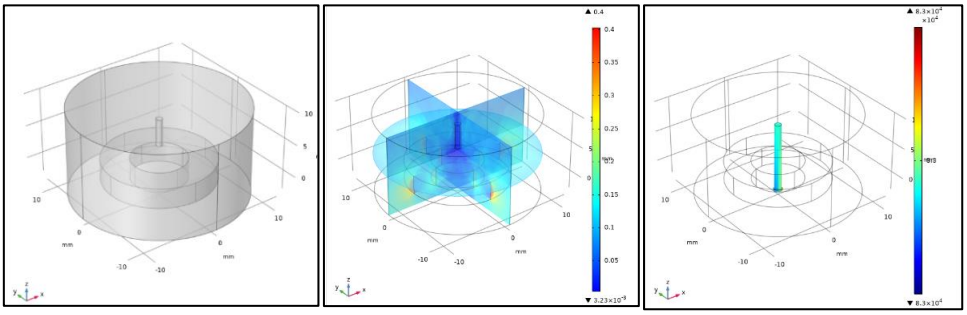


Fig. 4. Geometry modeling, magnetic flux simulation and particle trajectory in Comsol Multiphysics 5.5

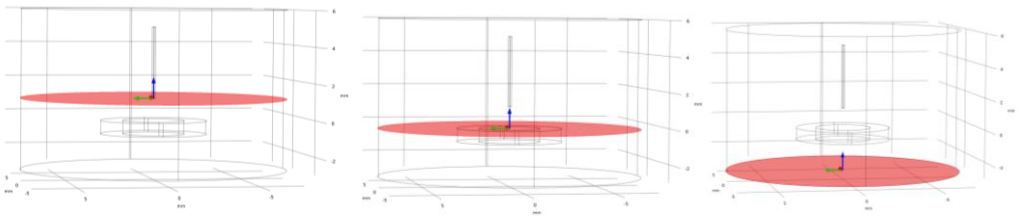


Fig. 5 Cutting planes at Z=1 mm; Z=-1,25 mm; Z=-3 mm;

In order to be able to see the deviation of the beam trajectory, the planes in figure 5 were used to highlight the position of the beam in red, black and blue respectively in the Poincaré graph in figure 6.

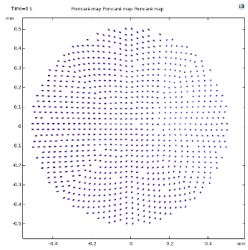


Fig. 6 Poincaré graph

8. Conclusions

The EDD process has a low cost and high precision, because it uses an EDM machine, with the polarity of the tool and the workpiece reversed. Using electrical discharge deposition, products can be manufactured at micro and nano scales.

From the literature it has been found that::

- The weight and height of the layer increases with increasing current, duty cycle, and pulse over time, but decrease with increasing voltage. Increasing the current, the operating cycle and the pulses in time and voltage leads to an increase in the deposited width.
- Important factors influencing this electrical discharge deposition process are current, duty cycle and pulse on time. Voltage has a smaller contribution to the deposition process..
- The multi-layer deposition process also shows the same trend as that followed by the single-layer deposition process.
- Increasing the pulse time increases the heat-affected area, but the deposition diameter is almost constant and the deposition height.

From numerical modelling and simulation of the EDD process we observed that the particle distribution on the part could be kept under control by ED parameters of discharge and magnetic flux. The material deposition dimensions are framed within a range of 0.2 - 0.3 mm if the tool has a similar diameter. If the surface current density increases, a larger and more irregular distribution over the sample results, with an optimal distribution at an average value of magnetic flux.

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