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P Effect of Different Tool Geometries on Performance Measure in EDM Process: A Review

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Abstract-Electrical discharge machining is one of the earliest non-traditional machining processes. It is based on thermoelectric energy between the workpiece and a tool electrode. A pulse discharge occurs in a small gap between the workpiece and the tool electrode and it removes the unwanted material from the base metal through melting and evaporating. To generate the spark the workpiece and electrode the must have electrical conductivity. There are various type of product which can be produced using EDM such as dies and moulds. Parts of automobile industry, surgical components and aerospace can be finished by EDM. This paper reviews the recent research trends in EDM on effects of different tool geometry on performance measure in EDM and different electrode material. The final part of the paper discusses these developments and outlines the trends for future research work.

Keywords-EDM, Electrode Geometry, Manufacturing, MMR, Workpiece

I. INTRODUCTION

Electro discharge machining (EDM) is a process whereby metal removal is achieved by thermal discharges between a tool and workpiece, while both are submerged in liquid dielectric. Any complex 3D shape, which can be cut into tool, can be produced in workpiece. This process is widely used to punches, dies and moulds, finishing parts for aerospace and automotive industry and medical surgical component [1]. This process can be successfully employed to machine electrically conductive workpiece irrespective of their hardness, shape and toughness [2]. This technique developed in 1940s [3].Where the process based on removal of material from by means of a repeated electric discharge between tool called electrode and workpiece with the presence of dielectric fluid[4].The material removed by with erosive action of electric discharge from tool and workpiece[5]. EDM does not make direct contact between tool and workpiece where it can eliminate the mechanical stresses, vibration during machining [6]. Material of any hardness can be cut as long as the material can conduct electricity [7]. EDM techniques have developed in many areas. The trends on activity carried out by researcher depend on the interest of and the availability of technology. This is achieving by the development of different types of spark generation and optimizing production parameter. Although due to a great number of variable and a variety of products, an optimal machining process performance is very difficult to achieved [8].

However the review presented in this paper is on different technique proposed and investigated by researcher by resulting in improvement in material removal rate (MRR) in EDM. MRR improvement has always been major area of focus for researchers and scrutiny of the published research work emphasized the need for such review paper reporting all the available literature and suggesting the future direction for research. The end of the paper identifies the major EDM academics research areas and suggest future direction for the EDM research as novel contribution to the archival literature.

II. WORKING PRINCIPAL OF EDM

Figure 1.Explains the working principle of EDM [9]. The machine consists of a power supply, a dielectric system. A control system with a servo-mechanism is to control the rate of feed of the quill where the tool holder is attached. The work piece is clamped on the machine table. The Spark is produced between the workpiece and tool electrode. The duration of spark is measured in micro second. In the spark area temperature is very high due to which there is partly melting and vaporizing of work piece and tool electrode and results in removal of material in form of craters. The System moves in different axes and the movement is controlled manually or by a computer numerical controlled system [10]. The transistor pulse generator power supply is now commonly employed in EDM as Power supplier [11].

It changes the AC supply from the mains and provides a rectangular voltage wave. The amount of material removed from the surface of work piece depends on the magnitude of the electrical discharge voltage, current, pulse interval and pulse duration [12]. Pulse duration is the time interval between switching the generator on and off, while the pulse interval is time between switching the generator off and on for the next cycle. The ignition delay time is defined as the time during which the voltage remains at the value of the ignition voltage while the current stays at zero [13]. Discharge voltage is defined as the mean value voltage value from ignition to power-off [14]. The mean value of the current from ignition phase to power-off phase is known as discharge current [15].Duty cycle measures the amount of time the energy is on during each pulse.

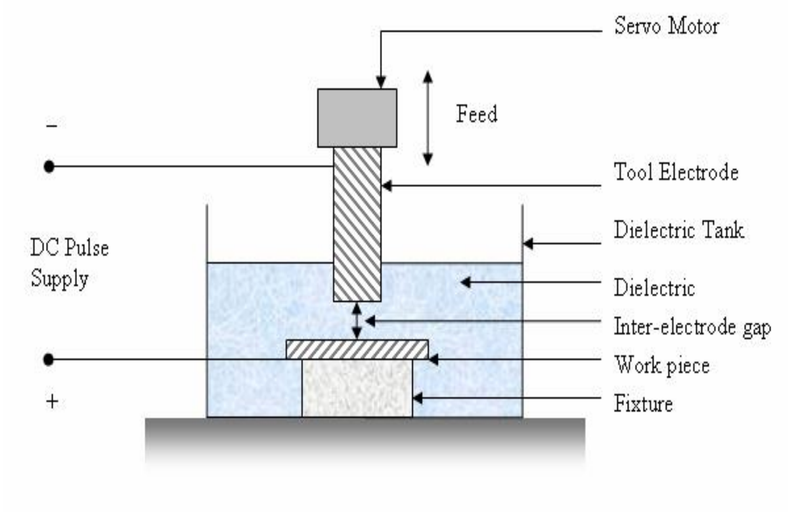


Figure 1. Schematic of an Electric Discharge Machining tool

III. VARIOUS PROCESS PARAMETER IN EDM

1. **Spark On-time /Pulse Time (Ton):** It is the duration of time the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is controlled by the peak current and the length of the on-time.
2. **Spark Off-time / Pause Time (T off):** The duration of time (μs) between the sparks. This time allows the molten material to solidify and to be wash out of the arc gap. This parameter is to

affect the speed and the stability of the cut. Thus if the off-time is too short, it will cause sparks to be unstable.

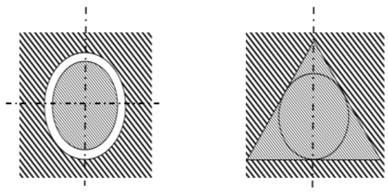
3. **Arc Gap (gap):** The Arc gap is distance between the electrode and workpiece during the process of EDM. It may be called as spark gap. Spark gap can be maintained by servo system.
4. **Discharge current (current Ip):** Current is measured in amp allowed per cycle. Discharge current is directly proportional to the Material removal rate.
5. **Duty cycle (τ):** It is a percentage of the on-time relative to the total cycle time. The parameter is calculated by dividing the on-time by the total cycle time (on-time pulse off time). T = Ton /Ton + Toff
6. **Voltage (V):** It is a potential that can be measured by volt, it is also affect to the material removal rate.
7. **Over Cut:** It is a clearance per side between the electrode and the workpiece after the machining operation.

IV. DETAILS OF WORK PIECE AND TOOL MATERIAL

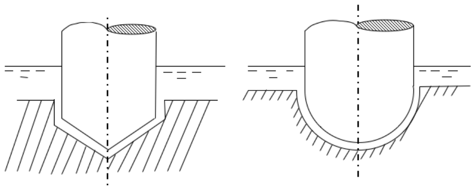
The prime function of EDM tool is to convey the electrical pulse to allow erosion of workpiece with little/ no tool wear. The selection of the most appropriate electrode material is a key decision in the process plan for any sinking EDM job. The important variables to be considered for selection of electrode material are material removal rate, tool wear rate, surface roughness, machinability and materials and their influence on EDM performance as well as on fabrication of electrodes have been summarized in EDM Handbooks [16, 17]. Electrode material should have the basic properties like electrical and thermal conductivity, a high, low wear rate, melting temperature and resistance offered to deformation during machining. Since electric current is cutting tool, in EDM, higher conductivity (or conversely, lower resistivity) promotes more efficient cutting. Drozda [18] explained that the tool electrode is responsible to transport the electrical current to the workpiece. Therefore, any material to be used as a tool electrode is required to conduct electricity. Since EDM is a thermal process, it would be assume to logical that the higher the melting point of the material of electrode, the better the wear ratio will be between electrode and workpiece. The mechanical properties of electrode materials most often considered for electrode materials are

- Tensile strength
- Transverse Rupture Strength
- Grain Size
- Hardness

These mechanical properties affect the ease in fabrication of the electrode [19]. The above mentioned desirable properties may provide general guidelines for electrode material selection but due to highly stochastic nature of EDM process, the basis for selection of particular work-tool interface is empirical rather than theoretical. Empirical results regarding performance of different work- tool interface is summarized in Table 1 [20].



EDM tools with flat buttends



EDM tools with flat butt ends and with 3-D shapes

Figure 2. Classification of EDM electrodes [21]

Therefore, it is important that we expend considerable effort to understand electrodes have a greater rate of metal removal in relation to its wear. In the spark gap graphite does not melt. Rather, at approximately 6062 °F (3350 °C), it changes from a solid to a gas. Because of graphite‘s relatively high resistance to heat in the properties and application. Studies reveal that graphite (compared to copper), for most jobs it is a more efficient electrode material. Graphite has certain properties quite different than metal based electrode materials.

In fact, there is a vast range of materials used for manufacturing electrodes like brass, tungsten carbides, electrolytic copper, tungsten- copper alloys, silver-tungsten alloy, tellurium-copper alloys, copper-graphite alloys, graphite etc. The five commonly used electrodes are copper, brass, tungsten, zinc, and graphite. In addition, some electrode materials are combined with other metals in order to cut more efficiently. Tungsten has a melting point similar to graphite, but tungsten is highly difficult to machine. Metallic electrodes usually work best for machining materials which have low melting points as aluminum, copper, and brass. As for steel and its alloys, graphite is preferred. The general rule is metallic electrodes should be applied for low temperature alloys and graphite electrodes should be applied for high temperature alloys. However, exceptions also exist. For example, despite higher melting points for cobalt, tungsten, and molybdenum, metallic electrodes like

Copper are recommended due to the higher frequencies needed to EDM these materials. The copper electrode can then be reused for a finishing cut or used to produce another part. Vartanian&Rosenholm [22] have pointed out that for many years there have been discussions about the relative merits of the different EDM electrode materials. The major debates are about copper versus graphite. The EDM users in different parts of the world have been using different electrode materials for doing exactly the same jobs. Normally, copper is mainly used in Europe or Asia for historical reasons. Graphite is the chosen material by the majority of EDM users from the USA. Most EDM jobs that can be done with copper can also be executed with graphite. The end result might be the same, but the cost to accomplish the job can be vastly different. In practical terms the choice of the electrode material will depend mainly on the tool size, the workpiece requirements, type of EDM machine and methods of making the electrodes.

Table1. Performance of work-tool interface in EDM [20]

Sr. No.	Material of Electrode	Work-piece Material	Available Form	Performance		Machina-bility	Best Application	Limitations and Undesirable uses
				Relaxation Type	Pulse Time			
1	Graphite	Steels	Blocks, Rods	Poor	Excellent	Excellent	Press tooling dies	Carbides
2	Brass	All Metals	Brass Tube , Wire	Fair	Excellent	Good	Hole size	Deep slots
3	Copper-Tungsten	All Metals	Short Bar, Flats, Shims, Tubes	Excellent	Excellent	Fair	Machining of carbides, slots, micro machining	Large areas
4	Cooper	All Metals	Bars, Wire, Tube	Excellent	Good	Good	Holes	Deep Slots with close Tolerance
5	Tungsten	All Metals and Refractory Metals	Wire , Rods	Good	Good	Poor	Small Slots and holes	Irregular holes
6	Tungsten Carbide	All Metals and Refractor	Sintered Rods	Good	Good	Poor	Small slots and holes	Irregular holes
7	Steel	Non-Ferrous Materials	Rods, Ingots, Forgings	Poor	Good	Good	Through holes	Carbides
8	Zink	Steel Only	Cast Shapes	Poor	Fair	Good	Forging Die Cavities	Through holes
9	Aluminium	Steel Only	Cast Shapes Extruded Bars	Poor	Fair	Good	Forging Cavities	Through holes

V. DIFFERENT 3-D FORM TOOL DESIGNS

Generally 3-D form tools are employed in EDM process which are found costly, take more time for their manufacturing and associated with high wear rate particularly when subjected to cutting of complex shapes [1, 23,]. Research on 3D solid form tool with different geometries revealed that best tool shape for higher MRR and lower TWR is circular in shape, followed by rectangular, square and triangular cross sections [24]. Yan and Wang [25] compared the performance of solid electrode and tube electrode. They observed that both the MRR and TWR considerably increase for tube type electrode in comparison to solid type electrodes. The same researchers compared the performance of a stationary electrode and rotational electrode in terms of machining characteristics [26]. Higher

MRR and tool wear rate (TWR) were reported for rotational electrode. This was possibly attributable to the superior debris disposal effect.

3D tools when applied for complex shapes together with high penetration depths was found to introduce flushing difficulties. This in turn restricts the removal of debris causing abnormal discharge so that only 60% useful machining time is obtained [27]. Flushing conditions may be improved by increasing the electrode gap but it results in lower metal removal rates [28]. Bayramoglu and Duffill [29] investigated the machining characteristics of 3D form and cylindrical tools.They reported that CNC EDM machine have the capability for developing 3D shapes using part programs to generate servo-controlled tool movements on four axises. CNC EDM can facilitate more sophisticated tool motions and the ability to generate complex shapes with simply shaped electrodes.

VI. PLATE, FRAME AND BALL ENDED CYLINDRICAL TOOL DESIGN

Four types of tooling methods have been reported by researchers for producing 3D shape cavities in workpiece as shown in Figure 3 [29-31].Plate type tools can only be applied with basic shapes (spheres, conics and simple 2D sweeps) and intermediate shapes (complex 2D sweeps, ruled surfaces and fillets). When applied for complex shaped deep cavities, plate tools results in poor dielectric flow causing the debris to accumulate and be suspended in the gap. With simple plate tooling, however, good flushing conditions can be achieved even in the most difficult circumstances [30]. The application of plate type tools results in high MRR, high relative electrode wear, good dimensional accuracy and better surface finish.

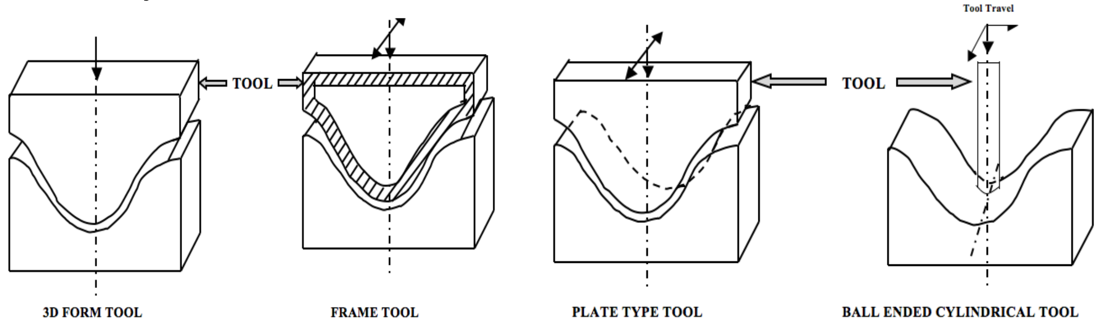


Figure 3. Design difference between 3D form tool, frame tool, plate type tool and ball ended cylindrical type tool.

Application of frame type tool in EDM is a novel technique for generation of linear, circular and curved contours without using any complex shaped electrodes. Bayramoglu and Duffill [31] have discussed the brief advantages of using frame type tools. Compared to form type tools, frame type tools are easy to produce and inexpensive. With application of frame type tool, the machining time reduces considerably. In EDM process surface finish depends upon generator setting and tool surface area [32].Smaller machining surface results in better surface finish. The total machining area of frame type tool is smaller than for 3 D form tool. Therefore application of frame type tool results in better surface finish. Also, catering for dimensional changes in frame type tools could be carried out under NC control rather than employing different tools for rough, semi finish and finish operations as in case of 3D form tool. Therefore, frame type tools are less expansive. Like plate type tools, frame type tools are only suitable for basic shapes (spheres,conics and simple 2D sweeps) and intermediate shapes like complex 2D, sweeps, ruled surfaces and fillets

VII. REMARK AND FUTURE TRENDS

The objective of the review article has been aimed to report the work carried out by various researchers in the field of EDM electrode and to bridge the gap between the untouched areas. After an elaborate scrutiny of the published work, the following remarks emerge from the existing published work.

- Most of the published work on EDM tool design relates to parametric optimization, improving performance measures and selection of suitable work-tool interface. There is not much published work on EDM electrode design.
- In addition, published works in tool design include a few materials like copper and its alloys, graphite etc. Use of new materials like cermets which has low tool wear rate, high corrosion resistance and reasonably good conductivity has not been sufficiently investigated.
- Generally, tool makers use thumb rule or trial and error method for EDM tool design. Therefore, scientific investigation of design of circular as well as non-circular electrodes is identified as an important area of research. Results of investigations may be extended for fabrication of tools with complex cavities.
- Most of research work in EDM relates to use of 3D form tool. Alternate types of tools like frame type and plate type are yet to be tried for work-tool interfaces.
- Application of plate, frame and ball ended cylindrical tool design seems to have a lot of potential for commercial applications. Their applications depend upon exploitation of CNC EDM capabilities allowing servo controlled tool movement along four axes. However, market survey shows that these capabilities are not fully being exploited by toolmakers. The reason for the same needs to be explored and thoroughly investigated.
- Even in 3D form tools, not much published work is available corresponding to use of different tool cross-sectional geometries like rectangular, triangular etc. on performance measure like MRR, TWR etc. Therefore, effect of different tool geometries on MRR, TWR, surface roughness (SR) needs to be investigated.
- In case of non circular electrode design, effects of profile parameters of a particular profile (like inscribed angle in case of triangular electrode) on performance measures of EDM process are yet to be investigated sufficiently.
- Hollow tube and eccentric drilled holes type electrodes are reported to have a positive impact on MRR due to improved flushing conditions. For more work material such designs need thorough investigations to evaluate their case to case effects.
- There is scant published work available on comparative study of different tool geometry with same /different work material so there is lot of scope for future research work in this field.

VIII. CONCLUSION

EDM has brought many improvements in machining process in recent years. The capability of machining complex and convoluted, contours and hard material has made EDM as one of the most popular machining processes. EDM is independent on the mechanical properties of workpiece. Design and manufacturing of electrode play an important role in EDM technology. The present review paper reports research and development work carried out by various researchers in the same field. The effect of different type tool geometries with constant area of cross section yet not investigated and influence of these on performance measure in EDM. There is a very scant work is done in this area by researcher and there is a large scope for future investigation.

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