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# Electrical Discharge Machining: Vital to Manufacturing Industries

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***Abstract*: This paper presents an insight of state of art of electrical discharge machining process. In this process, material gets eroded from the workpiece because of chain of speedily repeating current discharges amidst twin electrodes, which are parted by dielectric fluid and made prone to a potential difference. This process offers various advantages over conventional process and finds wide applications in various industries. The information provided in this study will be very useful for the beginners to understand the basic fundamentals of unconventional EDM process.**

***Keywords* : Advanced machining process, electrical discharge machining, non-conventional machining.**

## I. AN OVERVIEW OF NON-CONVENTIONAL MACHINING

Since genesis of the mankind, people started developing tools and sources of energy to power these tools in order to make life comfortable and satisfying. During the early phase, stone was used for making tools. With the invention of iron, more advantageous metals and trailblazing products can be developed. By twentieth century, products were made from the more enduring and consequently, difficult to machine materials. In order to machine such materials, tools of various materials (like alloy steel, carbide, diamond, ceramic etc.) have been evolved. Alike development has taken place with the approach to operate the tools. Early, tools were operated by either humans or animals. However, with the advent of electricity, human being became able to develop new machines having better accuracy and machining efficiency, thus expanded manufacturing proficiency. Every time fresh tool design, material or energy sources are employed, the efficiency and proficiency of manufacturers are further increased. The manufacturing revolution can be said to be focused upon the use of advanced tool designs and power sources. This has resulted to initiation of advanced type manufacturing procedures employed for evacuation, forming and joining of the material. Conventional machining technique involves cutting and abrasion of the workpiece for material removal. These processes are usually centered on expulsion of material by utilizing electrical power and tools made up of material harder than that of workpiece. Conventional machining processes failure to machine advanced materials having greatly improved mechanical, thermal and chemical properties of materials. Along with the new engineering materials, complicated contours, low rigidity assembly and micro-machined parts with close permissible limits and high quality surface topograph are commonly required to be produced. Similarly, material joining is conventionally carried out by means of thermal energy sources such as electric arc or burning gases. Conventional machining methods are unsuccessful in coping up with these challenges. To fulfill these requirements, a novel method known as non conventional machining have been evolved.

In contradistinction, unconventional processes utilizes sources of energy which are considered to be non conventional. Process of material expulsion can take place by means of electrochemical reaction, high temperature plasma and colossal velocity jets of abrasives and fluids. Materials which were considered to be difficult to machine in past, can now worked by employing magnetic fields, electric sparks and action of chemicals. Material joining capabilities have been enhanced by utilizing electron beams, acoustic waves and LASER. In non conventional machining process, also known as advanced manufacturing method, excess material is evacuated utilizing different techniques involving mechanical, chemical, electrochemical or amalgamation of these energies. These processes are reliant on chemical properties of the material, mechanical disintegration, melting and vapor formation of the material and electrolytic expulsion of ions or their combination. These processes do not require pointed cutting tool made up of hard material as needed in conventional machining methods. Further, in such processes, tool and workpiece don't have any straight contact between them. Unconventional machining methods are employed where conventional methods are unachievable, inacceptable or cost ineffective. It is difficult to work on extremely hard and brittle materials like carbides, stainless steel, nitralloy, waspalloy etc. by means of conventional methods. When such materials are machined using conventional techniques, either tool will undergo extreme wear or the workpiece may get damaged. Numerous non conventional techniques have been developed to achieve special machining conditions. When such machining methods are engaged appropriately, they provide several benefits over conventional methods. High strength alloys can be machined easily, complex shapes and difficult geometries with close tolerances and fine surface topograph can be developed using non conventional processes. Further, complete automation of the process is possible.

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Such machining processes find wide applicability in aircraft, automotive, electronics, die and mould making industries. Non-conventional machining processes offer some disadvantages which include higher cost, requirement of high skilled operator and complicated setup. [1-3]

## II. CATEGORIZATION OF NON-CONVENTIOANL MACHINING PROCESS

These processes can be categorized as follows:

### A. Single-action non-conventional machining

In this type of process, a single machining action is engaged for removal of the material. Such processes are grouped on the basis of energy source employed to perform machining action.

1. Mechanical machining
   In the mechanical machining processes, erosion of the workpiece occurs due to colossal velocity of abrasives or fluids (or twosome). Examples are abrasive jet machining, water jet machining etc.
2. Chemical Machining
   In such process, selective removal of the stock from the work sample take place by using chemicals, while other portions of the work sample are shielded by suitable covering. Examples are chemical machining and photochemical machining.
3. Electrochemical Machining
   Such a machining process involves the material removal of electrically conductive material ultilizing electrochemical dissolution of anodic workpiece with the help of cathodic tool and suitable electrolyte. Examples are electrochemical machining and electro jet drilling.
4. Thermal Machining
   In this category of machining process, thermal energy is used on a small part of the workpiece, resulting in removal of that segment by fusion or vaporization of the material (or both). Examples are electric discharge machining, electron beam machining, LASER beam machining, Ion beam machining etc.

### B. Hybrid Machining

In these processes, amalgamation of different machining actions is used to achieve desired material removal. [3]

Unconventional processes have their own distinct characteristics, benefits and limitations. Specific process found acceptable under given condition may not be equally suitable under other condition. Hence, the choice of appropriate manufacturing process for a given application needs a prudent evaluation of several aspects including the physical variables, characteristics of workpiece material, shape to be produced, dimensional accuracy required, process proficiency, cost effectiveness. [2]

## III. ELECTRICAL DISCHARGE MACHINING

This unconventional machining method is popular from more than seven decades [4]. Other names for this type of machining are spark machining and spark eroding. Process of EDM has gained popularity worldwide and substituted conventional machining operations. In this method, stock is eroded from the sample because of chain of speedily repeating current discharges amidst twin electrodes, which are parted employing dielectric fluid and made prone to a potential difference [5]. One of the electrodes is tool while the other is work-piece. The shape of the material removed is controlled to develop an object with required geometry and surface finish. This process is employed to machine hard metals like titanium and pre-hardened steel and materials which can't be easily machined using traditional process.

## IV. GENESIS OF EDM

Foundation of spark eroding was placed in 1770 by Joseph Priestly, an English chemist by discovering the erosion impact of electrical discharges [6]. The impact of electrode material and current on the dimensions of cavity were further explored [7]. Spark machining process was concocted by Russian scientists, B.R. Lazarenko and N.I. Lazarenko in 1943. The Soviet government solicited them for exploring the cause of wear originated by sparkling amidst tungsten electrical contacts, a problem which was severe for automobile engines in the Second World War. They observed that when the electrodes were put in oil, the spark becomes more consistent and foreseeable compared to air. Further, they inverted the process and utilized controlled sparking as an erosion technique [8]. Lazarenko developed at the time of the war is the earliest electric discharge machine, which was very purposeful in eroding hard metals like W and WC [9].

During 1950's, advancements were built on comprehension of the erosion phenomenon [9-12]. During this period, industries made the primary electrical discharge machine. However, on account of the inferior characteristics of electronic segments, EDM performance was not upto the mark. During 1960's, the blooming sector of semi-conductor enabled significant progress in spark machining. Die-sinking machines came to be reliable and produced surfaces having precise features, while wire-cutting machines were in the infancy stage. Launching of numerical position control by late 1960's and in the beginning 1970's made maneuvering of electrodes to be significantly more definite. This crucial refinement promoted development of wire-cutting machines. With advent of Computer Numerical Controlled (CNC) systems in the middle of 1970's, the performance of electric discharge machine further improved [6]. During the next decades, attempts were basically actualized in automation, robotization, generator configuration and servo system [13]. Utilization in micro-machining became area of activity during 1980's [14]. It is also from this phase that the International market of electric discharge machine started to grow dynamically and pragmatic research on this machining process took over foundational research [15].

Finally, a novel process of EDM started in early 1990's by utilizing fuzzy control and neural networks [13].

## V. WORKING PRINCIPLE OF EDM

It is a controlled material removal process which employed for removing material from the part through recurring sparks between tool and workpiece immerged in a reservoir of dielectric fluid [16]. Figure 1 illustrates basic operational principle of EDM.

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Tool and workpiece are attached with different electrodes and are parted by a gap in which the dielectric fluid flows [17]. Servo system retains the working gap for continual operation [16, 18].

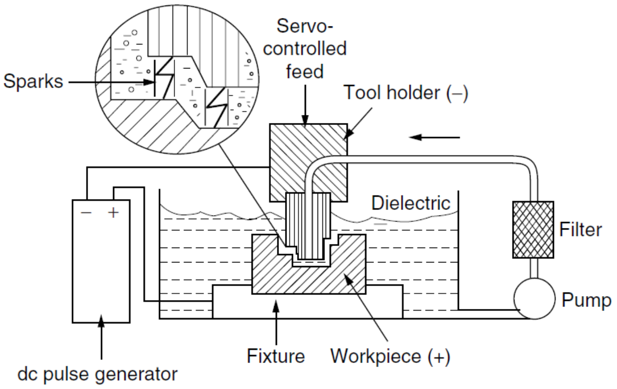


**Figure 1. Basic operational principle of EDM [3]**

Tool has a shape of desired profile to be made on the workpiece [18]. High value of voltage is applied across the gap. When potential difference turns out to be enough high, it releases through the gap in the form of the spark in interim of µs. The positive ions and electrons are quickened because of the heat, producing discharge channel which turns conductive. It is basically as of now when the spark bounces inflicting collisions amidst ions and electrons and making a channel of plasma. A sharp drop of the electrical resistance of the previous channel permits current density to achieve extremely high values producing a rise of ionization and therefore, setting up a strong magnetic field. The instant spark happens sufficient pressure is developed between workpiece and tool as a consequence a very high value of temperature is attained. At such high pressure and temperature, melting and erosion of some part of material takes place. Such localized high shoot up of temperature prompts material evacuation. Material evacuation happens in view of instantaneous vaporization of the material along with melting. This melted material is not expelled fully yet just mostly [19-21].

Electrical Discharge Machines are provided with a servo control system which automatically keeps a fixed gap amidst tool and the work sample. It is essential to note that tool and work sample don't have immediate contact otherwise arcing could be harmful for the workpiece. The servo-mechanism progresses the tool towards the workpiece as the operation proceeds, senses the workpiece-tool gap and maintains proper gap which is necessary for successfully performing machining operation.

If the gap is sizeable, the dielectric fluid amidst tool and work sample will not ionized, a spark cannot be conducted and therefore machining will not occur. If the gap is pint-sized, the tool can touch the workpiece, causing tool to short [22].

Electrical discharge machines can mainly be classified into two types.

a) Die-sinking EDM
b) Wire-cut EDM

## VI. PROCESS PARAMETERS

Important process parameters are discussed below.

1. Pulse on-time ($T_{on}$): It is the time period (in µs) in which the current is permitted to stream in every cycle. [18, 23].
2. Pulse off-time ($T_{off}$): It is the time period (in µs) in between the two successive sparks (pulse on-time). This time enables the molten material to set and to be washed away through flushing process.
3. Spark gap or Arc gap: It is the distance amid the tool and workpiece in which the spark is generated for crumbling the material out of the workpiece [24].
4. Discharge Current ($I_p$): It is the current (in A) permitted per cycle [23].
5. Duty cycle (τ): It is a percentage of the pulse on-time relative to the total cycle time [22].
6. Voltage (V): It is a potential difference applied by the power supply in a constrained manner. Material removal rate is greatly affected by voltage [24].

## VII. MACHINING PARAMETERS

Main performance parameters are discussed below.

1. Material Removal Rate (MRR): It is the volume of material expelled from the work sample in unit time. [18, 25].
2. Tool Wear Rate (TWR): During the machining operation, the tool electrode gets eroded due to the spark generated [26].
3. Wear Ratio (WR): It is defined as the proportion of tool wear rate to material removal rate (TWR/MRR) [25, 27].
4. Surface roughness (SR): It is an important parameter of EDM specifying machined surface [25, 26].

## VIII. DIELECTRIC FLUID

Dielectric fluid is extremely necessary requirement for EDM process and performs significant function related to the quality of the machined components. The selection of proper dielectric fluid is important for machining processes since various dielectrics are having different compositions and rate of cooling. Dielectric fluid must be cautiously selected in order to obtain best performance and command over electrical spark. Filtration system for the dielectric liquid should also be given due importance, as it is helpful in maintaining steady gap and dielectric immaculacy. The main purposes of dielectric fluid include insulation, ionization, cooling and waste material disposition. Various types of dielectric fluid are employed in electric discharge machining [28]. Commonly employed dielectric fluids are kerosene, de-ionised water etc. Faucet water is not preferred since it ionizes quickly and disintegrate because of impurities present in it [29].

The main requirements for dielectric fluids are:

1. It needs to have required and fixed dielectric strength to act as insulation amidst tool and workpiece until attainment of breakdown voltage.

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2. It must de-ionize speedily following discharge of spark.
3. Viscosity of dielectric fluid should be low and wetting capacity should be good to support effectual cooling and removal of fine chips from the gap.
4. It should be capable of flushing out the debris from the machined area to avoid arcing.
5. It should be chemically inactive to prevent attack on tool, work or tank materials.
6. It should be able to retain the above mentioned qualities during change in temperature and contamination. [30]

Flushing refers to the method in which the dielectric fluid is made to flow amid electrode and work sample. To a greater extent, machining efficiency depends on the effectiveness of the flushing method. The wear debris present in the spark gap should be removed as quickly as possible. With poor flushing, there is a possibility of build-up of the machined particles in the gap resulting in the sort circuiting and lower material removal rates [30].

## IX. TOOL MATERIAL

The profile of the tool (electrode) is impressed on the work sample in its complimentary form and as such the shape and accuracy of the electrode performs a major role in the final accuracy of the work sample. Tool material ought to have the subsequent characteristics to function as a good tool.

1. It must be able to conduct electricity and heat.
2. It should removal material from the workpiece efficiently.
3. It should be able to withstand deformation during the erosion process.
4. It must be easily workable to any configuration at acceptable cost.
5. It needs to have low wear rates.
6. It should have high melting temperature.

Commonly used material for tool in electric discharge machining process include Cu, brass, graphite, Cu-graphite, Cu-W, Ag-W, Zn alloys, Cu-Te (99% Cu + 0.5% Te) etc. [30]. Tool geometry also has a good influence on EWR and is associated with the tool profile and also aspect ratio (length:diameter) [31].

## X. INDUSTRIAL APPLICATIONS OF EDM

Ability of EDM process to function solitarily for hours or days enhance its utility. Through this process, it becomes easy to work on hard and difficult to machine materials [15]. Components having complicated, specific and inconsistent dimensions and complex inner configuration can be easily manufactured by using this machining process. Tiny aperture in hardened steel of carbide can be produced by specially designed Cu-W electrodes, employing a micro machining attachment [24]. Composites and ceramics, which are otherwise hard to work, conceivably machined using EDM method. EDM can be used for producing gear and internal threads cutting [32]. It finds extensive applications in mould and die making industries [33]. It has also made its presence felt in aerospace, automotive, telecommunication and biotechnology industries [34]. Its applications can also be found in the electronics, healthcare, optics, sports, jewellery making and toys manufacturing [35]. Parts manufactured by using EDM process are shown in Fig 1(a) and (b).

**Fig. 1(a). Parts manufactured by EDM [36]**

**Fig. 1(b). Parts manufactured by EDM [37]**

## XI. CHARACTERISTICS OF EDM

Characteristics of electrical discharge machining are presented in Table I.

**Table- I: Characteristics of electric discharge machining [23]**

| Characteristics | Range |
|---|---|
| Mechanism of operation | Controlled erosion (melting and evaporation) through a series of electric spark. |
| Spark gap | 0.010-0.500 μm |
| Spark frequency | 200-500 kHz |
| Peak voltage across the gap | 30-250 V |
| Maximum material removal rate | 5000 $mm^3$/min |
| Specific power consumption | 2-10 W/$mm^3$/min |
| Dielectric fluid | EDM oil, kerosene, silicon based oil, de-ionized water, hydrocarbon fluids etc. |

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| | |
|---|---|
| Electrode material | Cu, brass, graphite, Cu-graphite, Cu-W, Zn, Ag-W etc. |
| Tool wear rate | 0.1-10 µm |
| Materials | Electrically conductive metals and alloys. |
| Shape | Micro holes, thin slots, complicated shapes and blind craters. |

## XII. ADVANTAGES OF EDM

It offers multiple advantages over conventional machining methods.

1. Material removal in spark erosion process is predominantly dependent upon thermal characteristics of the workpiece material instead of mechanical properties [29].
2. Forces developed during machining operation are negligible.
3. Difficult-to-machine materials can easily be machined [14].
4. Complicated cutting profile, pointed and briery angles and internal junctions can be easily developed.
5. Machining of hardened material could be carried out without any distortion attributable to heat treatment.
6. Burrs do not develops on machined surface. [38]

## XIII. LIMITATIONS OF EDM

EDM operation offers following limitations

1. This process is able to machine only electrically conductive materials. The tool used should necessarily be electrically conductive too.
2. Sometimes the wear rate of tool is greater due to which more than one tool may be needed to complete the required operation.
3. Optimal settings of the machining operation to a great extent are affected by the tool-workpiece combination. [24]
4. Metal erosion rate in as case of EDM is relatively low. Also, Overall machining operation is slower in comparison to conventional process [35].

## XIV. CONCLUSIONS

In this paper, a brief introduction of unconventional machining process has been made. EDM process is a subtractive type of machining which utilizes electrical current for removal of stock from work sample. An overview have presented on how EDM process works, when it should be used and what considerations must be made. Other important aspects of EDM process have also been discussed. This paper will be of great help for beginners to understand basics of EDM in a simple and lucid language.

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