A Review on Electric Discharge Machining and Its Parameters

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ABSTRACT

Electric discharge machining (EDM) is a thermal erosion process which is used to machine extremely hard materials that are difficult to machine like alloys, tool steels, tungsten carbide etc. The efficiency of traditional cutting process is limited by the mechanical properties and complexities of the workpiece material. In recent years EDM researchers have work to improve the EDM process parameters such as Electrical parameters, Non-Electrical parameters, Tool electrode base parameters and Powder base parameters. This paper reviews the electric discharge machining process and its parameters.

KEYWORDS

EDM, Dry EDM, WEDM, Die Sinking EDM, MRR, TWR

1. Introduction

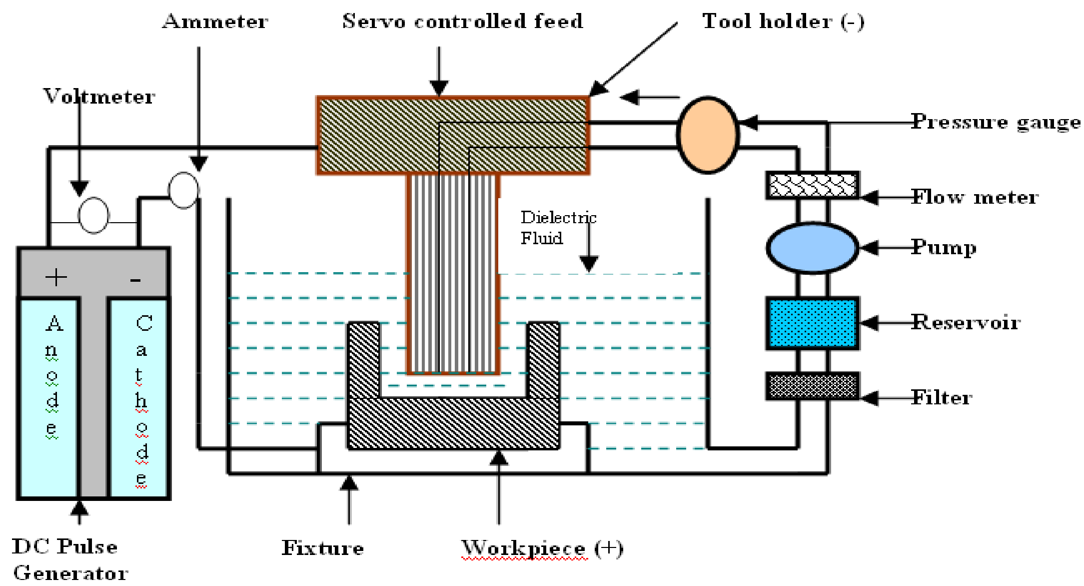
Electrical discharge machining is basically a non-conventional material removal process. This process is widely used to produce dies, punches and moulds, finishing parts for aerospace and automotive industry and surgical components. This process can be successfully employed to machine electrically conductive workpieces irrespective of their hardness, shape and toughness. During EDM process, the electrode shape is mirrored in the workpiece. Higher gap is required for higher removal rate but also higher gap results in poor surface quality [1]. EDM is a thermal process with a complex metal-removal mechanism, involving the formation of a plasma channel between the tool and workpiece. For several decades, EDM has been an important manufacturing process for the tool and die industry [2]. This process consists of three phases. Initially ignition breaks down the high voltage to low around 30 V. Peak current increases the high energy and remove the material from the work piece. Finally plasma channel collapses and the removed particles are flushed away by flushing [3].
The basis of EDM can be traced as far back as 1770, when English chemist Joseph Priestly discovered the erosive effect of electrical discharges or sparks. However, it was only in 1943 at the Moscow University where Lazarenko and Lazarenk exploited the destructive properties of electrical discharges for constructive use. They developed a controlled process of machining difficult-to-machine metals by vapourising material from the surface of metal. The Lazarenko EDM system used resistance–capacitance type of power supply, which was widely used at the EDM machine in the 1950s and later served as the model for successive development in EDM [4].

1.1 EDM Working Principle

EDM is thermal erosion process where controlled electric spark discharge takes place between tool and work-piece to have the eroding effect on work-piece to form a replica of tool on work-piece. As there is no mechanical contact between both electrodes during whole process and erosion is produced by electrical discharge. Electrical conductivity of electrode and work-piece is the basic requirement of this process. So, electrical resistivity of both electrodes must lie between 100 and 300Ω cm. This electric sparking process is carried out in a dielectric liquid or in gas. Dielectric mush have low-viscosity, high dielectric strength, quick recovery after breakdown, effective quenching/cooling and flushing ability. Flushing methods are classified into four main categories: immersion flushing, jet flushing, normal flow and reverse flow [5].

In this process the metal is removing from the work piece due to erosion case by rapidly recurring spark discharge taking place between the tool and work piece. Show the mechanical set up and electrical set up and electrical circuit for electro discharge machining. A thin gap about 0.025mm is maintained between the tool and work piece by a servo system. Both tool and workpiece are submerged in a dielectric fluid .Kerosene/EDM oil/deionized water is very common type of liquid dielectric although gaseous dielectrics are also used in certain cases [6].

Fig. 1 Schematic of EDM process [Choudhary & Jadoun (2014)]



The tool is made up of cathode and work piece is of anode. When the voltage across the gap becomes sufficiently high it discharges through the gap in the form of the spark in interval of from 10 of micro seconds. And positive ions and electrons are accelerated, producing a discharge channel that becomes conductive. It is just at this point when the spark jumps causing collisions between ions and electrons and creating a channel of plasma. A sudden drop of the electric resistance of the previous channel allows that current density reaches very high values producing an increase of ionization and the creation of a powerful magnetic field. The moment spark occurs sufficiently pressure developed between work and tool as a result of which a very high temperature is reached and at such high pressure and temperature that some metal is melted and eroded. Such localized extreme rise in temperature leads to material removal. Material removal occurs due to instant vaporization of the material as well as due to melting. The molten metal is not removed completely but only partially. As the potential difference is withdrawn, the plasma channel is no longer sustained. As the plasma channel collapse, it generates pressure or shock waves, which evacuates the molten material forming a crater of removed material around the site of the spark [6].

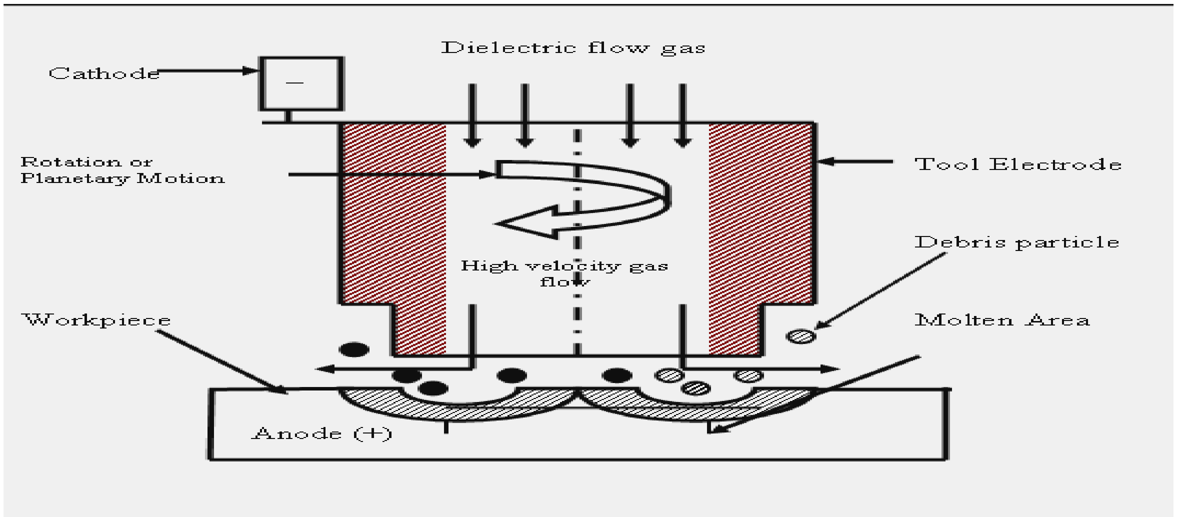
2. Types of EDM

There are basically four types of EDM. These are:

2.1 Dry EDM

Dry EDM, which applies high flow rate gaseous dielectric fluid, tends to alleviate the environmental problem resulted from the liquid and powder mixed dielectrics and also enhance the machining performance. Using inert gas to drill small holes (NASA, 1985) is the first dry EDM attempt. As a dielectric the gas at high pressure is used. In dry EDM, tool electrode is formed to be thin walled pipe. The flow of high velocity gas into the gap facilitates removal of debris and prevents excessive heating of the tool and work piece at the discharge spots. Tool rotation during machining not only facilitates flushing but also improves the process stability by reducing arcing between the electrodes The technique was developed to decrease the pollution caused by the use of liquid dielectric which leads to production of vapor during machining and the cost to manage the waste. Dry EDM method with the shortest machining time compare to oil die sinking EDM, & lowest electrode wear ratio. Work removal rate also get enhanced by dry EDM [7].

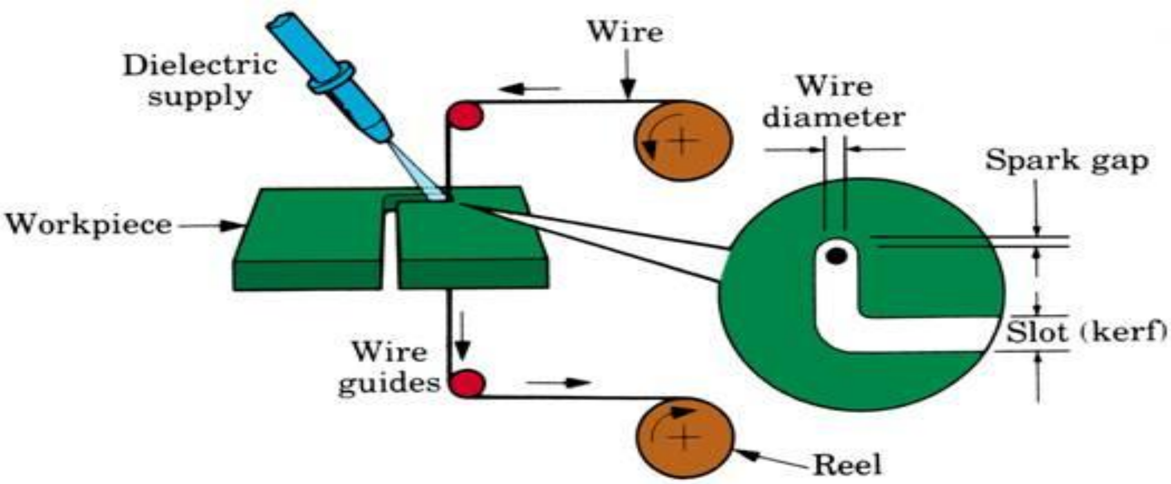
Fig.2 Principle of Dry Electrical Discharge Machining (DEDM) [Choudhary & Jadoun (2014)]



2.2 Wire EDM

Wire EDM machines are used to cut conductive metals of any hardness or that are difficult or impossible to cut with traditional methods. The consistent quality of parts being machined in wire electrical discharge machining is difficult because the process parameters cannot be controlled effectively. These are the biggest challenges for the researchers and practicing engineers. Keeping in view the applications of material titanium alloys, it has been selected and has been machined on wire-cut EDM. Wire cut electrical discharge machining (WEDM) or Electrical discharge wire cutting is a spark erosion process used to produce two and three dimensional complex shapes through electrically conductive workpieces. In WEDM process, a small diameter wire ranging from 0.05 to 0.25 mm is applied as the tool electrode A DC power supply delivers high-frequency pulses of electricity to the wire and the workpiece. The gap between the wire and workpiece is flooded with deionized water, which acts as the dielectric [8].

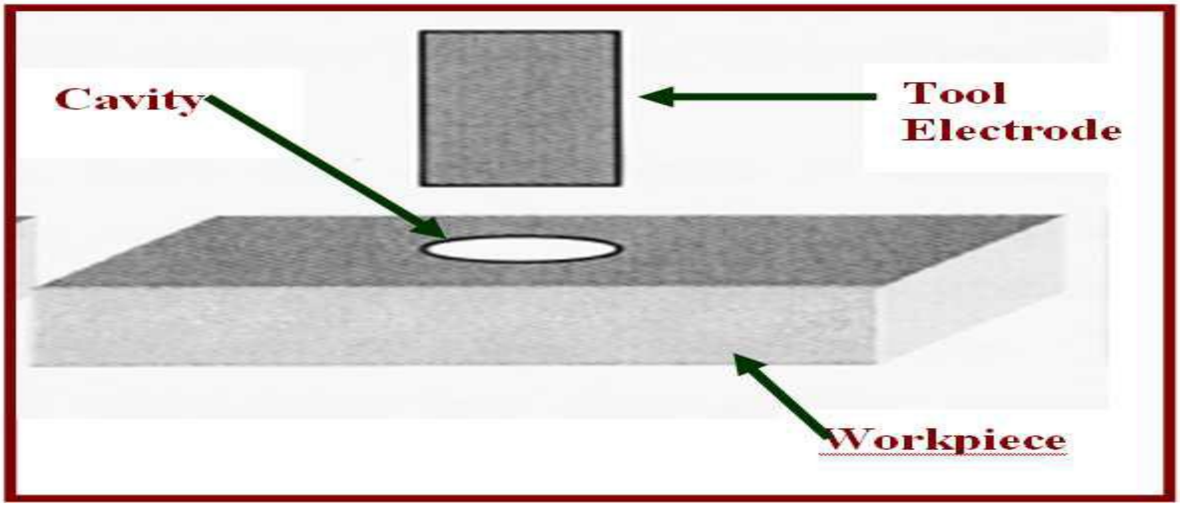
Fig 3 Schematic diagram of WEDM Process



2.3 Die Sinking EDM

Die Sinker EDM, also called cavity type EDM or volume EDM consists of an electrode and workpiece submerged in an insulating fluid such as, more typically, oil or, other dielectric fluids. The electrode and workpiece are connected to a suitable power supply.

Fig.4 Die Sinking EDM



The power supply generates an electrical potential between the two parts. As the electrode approaches the workpiece, dielectric breakdown occurs in the fluid, forming a plasma channel, and a small spark jumps.These sparks usually strike one at a time because it is very unlikely that different locations in the inter-electrode space have the identical local electrical characteristics which would enable a spark to occur simultaneously in all such locations. These sparks happen in huge numbers at seemingly random locations between the electrode and the workpiece. As the base metal is eroded, and the spark gap subsequently increased, the electrode is lowered automatically by the machine so that the process can continue uninterrupted. Several hundred thousand sparks occur per second, with the actual duty cycle carefully controlled by the setup parameters [9].
The characteristics necessary for die-sinker EDM are given below in the table-

Table 1 Process Parameters of Die-Sinker EDM Process [10]

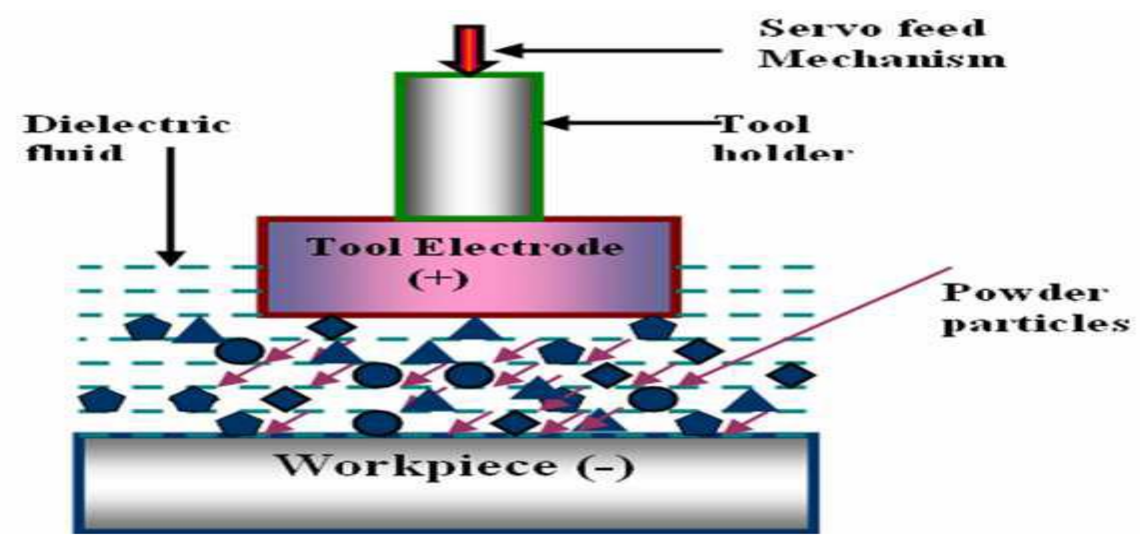
Mechanism of Processes	Controlled erosion (melting and evaporation)
Spark gap	0.010 – 0.500 mm
Spark frequency	200 – 500 KHz
Peak voltage across the gap	30 – 250 V
Metal removal rate (max.)	5000 mm3/min
Specific power consumption	2 – 10 W/mm3/min
Dielectric fluid	EDM oil, Kerosene liquid, Silicon oil, Deionised water etc.
Tool material	Copper, Brass, Graphite, AgW alloy, Cu-W alloy
Machine-able materials	All conducting metals and alloys
Shapes that can be produced	Micro holes, Narrow slots
Limitations	High energy consumption, can't machined nonconducting materials

2.4 Powder Mixed EDM

Powder mixed electric discharge machining (PMEDM) improves the quality of the electric discharge machined surface and reduces the surface defects. The effect of impurities like copper, aluminium, iron, and carbon in dielectric fluid was first studied by Erden and Bilgin (1980). Increase in material removal rate (MRR) was reported due to the addition of certain concentrations of powders to dielectric fluid. Further research revealed that the electrically conductive powder suspended in the dielectric fluid reduces the insulating strength of the dielectric and increases the spark gap between the tool and workpiece. As a result, the process becomes more stable thereby improving MRR and surface finish [2].

When voltage is applied the powder particles become energized and behave in a zigzag fashion. These charged particles are accelerated due to the electric field and act as conductors promoting breakdown in the gap. This increases the spark gap between tool and the work piece. Under the sparking area, these particles come close to each other and arrange themselves in the form of chain like structures. The interlocking between the powder particles occurs in the direction of flow of current. The chain formation helps in bridging the discharge gap between the electrodes. Because of bridging effect, the insulating strength of the dielectric fluid decreases resulting in easy short circuit. This causes early explosion in the gap and series discharge' starts under the electrode area. The faster sparking within a discharge causes faster erosion from the work piece surface and hence the material removal rate increases [11].

Fig.5 Working principle of PMEDM



3. Components of EDM

1. Work-piece-all the conductive material can be worked by EDM

2. Tool Electrode-The EDM electrode is the tool that determines the shape of the cavity to be produce.

3. Dielectric fluid-The EDM setup consists of tank in which the dielectric fluid is filled. Electrode & wokpiece submersed into the dielectric fluid.

4. Servo system-The servo system is commanded by signals from gap voltage sensor system in the power supply and control the feed of electrode & workpiece to precisely match the rate of material removal.

5. Power supply-The power supply is an important part of any EDM system. It transform the alternating current from the main utility supply into the pulse direct current (DC) required to produce the spark discharge at the machining gap.

6. ***The DC pulse generator*** is responsible for supplying pulses at a certain voltage and current for specific amount of time [9].

4. Major Parameters of EDM

EDM Parameters mainly classified into two categories.

4.1 Process Parameters

On-time or pulse time: It is the duration of time (μs) for which the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time.

Off-time Or Pause time: It is the duration of time between the sparks. This time allows the molten material to solidify and to be wash out of the arc gap.

Arc Gap: It is the distance between the electrode and the work piece during the process of EDM. It may be called as the spark gap.

Duty Cycle: It is the percentage of on-time relative to total cycle time. This parameter is calculated by dividing the on-time by the total cycle time (on-time plus off-time). The result is multiplied by 100 for the percentage of efficiency or the so called duty cycle.

Intensity: It points out the different levels of power that can be supplied by the generator of the EDM machine.

Voltage (V): It is a potential that can be measure by volt it is also effect to the material removal rate and allowed to per cycle [6].

4.2 Performance Parameters

Material Removal Rate (MRR) MRR is a performance measure for the erosion rate of the workpiece and is typically used to quantify the speed at which machining is carried out. It is expressed as the volumetric amount of workpiece material removed per unit time.

Tool Wear Rate (TWR) TWR is a performance measure for the erosion rate of the tool electrode and is a factor commonly taken into account when considering the geometrical accuracy of the machined feature. It is expressed as the volumetric amount of tool electrode material removed per unit time.

Wear Ratio (WR) WR is the ratio of TWR/MRR and is used as a performance measure for quantifying tool workpiece material combination pairs since different material combinations gives rise to different TWR and MRR values. A material combination pair with the lowest WR indicates that the tool-workpiece material combination gives the optimal TWR and MRR condition.
Surface Quality (SQ) Surface quality is a broad performance measure used to describe the condition of the machined surface. It comprises components such as surface roughness (SR), extent of heat affected zone (HAZ), recast layer thickness and micro-crack density.

Surface Roughness (SR) SR is a classification of surface parameter used to describe an amplitude feature, which translates to roughness of the surface finish. Of the many parameters available to quantify SR, the most commonly used in EDM are arithmetical mean surface roughness (*Ra*), maximum peak-to-valley surface roughness (*Rmax*) and root mean square surface roughness (*Rq*).

Heat Affected Zone (HAZ) HAZ refers to the region of a workpiece that did not melt during electrical discharge but has experienced a phase transformation, similar to that of heat treatment processes, after being subjected to the high temperatures of electrical discharge.

Recast Layer Thickness (RLT) The recast layer refers to the region of resolidified molten material occurring as the topmost layer of the machined surface. The recast layer is usually located above the heat affected zone [9].

5. Methods of Improving MRR

Material removal rate is an important performance measure. It can be improved by:

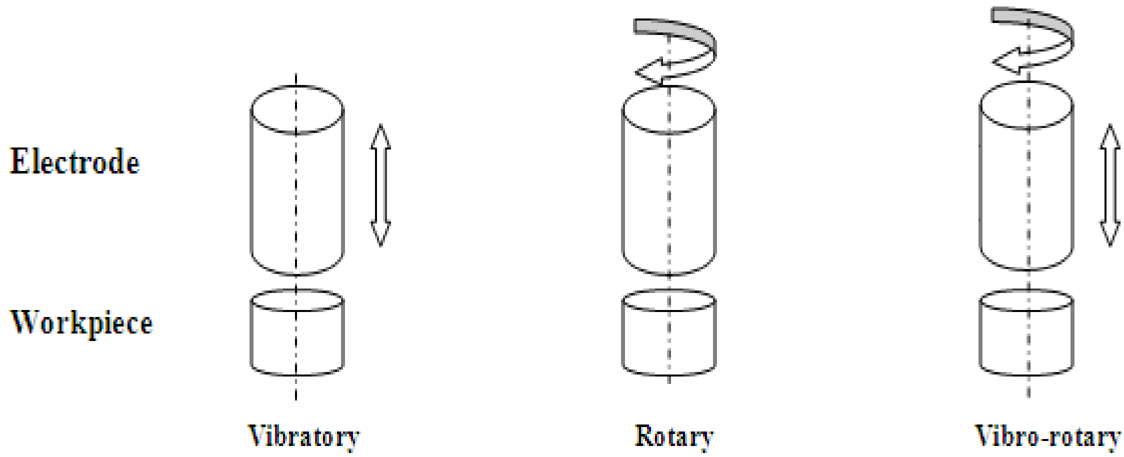
5.1. By Controlling Process Parameters

The material removal rate can be controlled and improved by controlling process parameters. The first parameter affecting the MRR is discharge voltage. This parameter is basically related to spark gap and dielectric strength. Higher voltage setting results in higher spark gap. Due to higher spark gap, flushing conditions improves resulting in higher MRR and rough surface [12].

5.2. By EDM variations (Vibratory, Rotary & Vibro-Rotary electrode)

Introduction of ultrasonic vibration to the tool is one of the methods applied to expand the application of EDM and to improve the machining performance on difficult to machine materials. The higher efficiency gained by
the employment of ultrasonic vibration is mainly due to improvement in dielectric circulation. Better dielectric circulation facilitates the debris removal and the creation of a large pressure change between the electrode and the workpiece, as an enhancement of molten metal ejection from the surface of the workpiece [12].

Fig 6: Vibratory, rotary and vibro-rotary electrode



Ghoreishi and Atkinson [14] compared the effects of high and low frequency forced axial vibration of the electrode, rotation of the electrode and combinations of the methods (vibro-rotary) in respect of MRR, tool wear ratio (TWR) and surface quality (SQ) in EDM die sinking and found that vibro-rotary increases MRR by up to 35% compared with vibration EDM and by up to 100% compared with rotary EDM in semi finishing.

5.3 Dry EDM & EDM with water

Machining in distilled water resulted in a higher material removal rate and a lower wear ratio than in kerosene for high pulse energy range. Jilani and Pandey [15] have investigated water as dielectric using distilled water, tap water and a mixture of tap and distilled water in 25% and 75% ratio. The best machining rates was obtained with tap water. It was found that erosion process in water-based medium possesses higher thermal stability and much higher power input can be achieved especially under critical conditions, resulting in much greater increases in the removal rate.

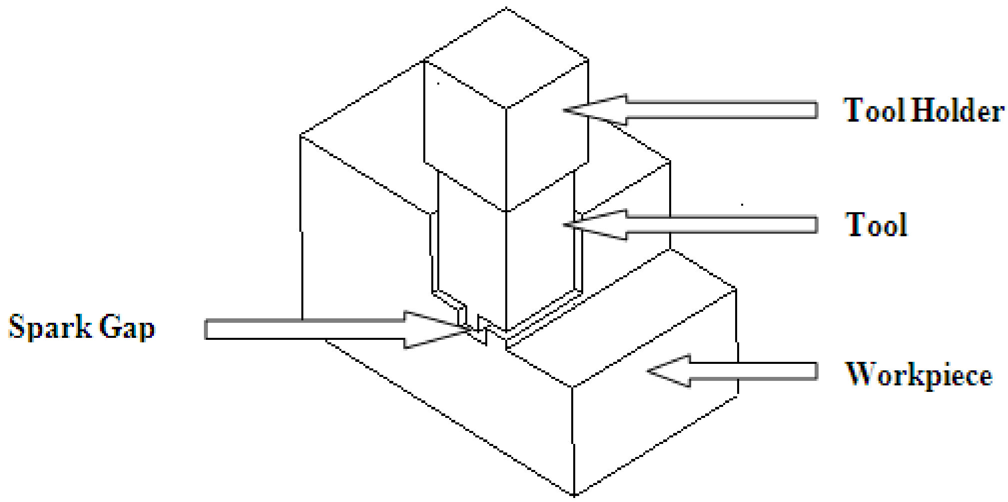
5.4 By Electrode Design

Several electrode geometries have also been tried to find improvement in material removal rate. Researchers have found that hollow tube electrodes and electrodes with eccentric drilling results in better material removal rate. This improvement takes place due to improved flushing condition arrangement for such designs. Research on 3D form tool with different geometries revealed that best tool shape for higher MRR and lower TWR is circular in shape, followed by triangular, rectangular, and square cross sections. Limitation of frame type and
plate type tool is that these tools are applicable only for basic (spheres, conics and simple 2 D sweeps) and intermediate (complex 2D sweeps, ruled surfaces, and fillets) shapes [12].

5.4.1. Different Aspects of Electrode Design

The prime role of EDM tool is to convey the electrical pulse to allow erosion of work piece with little or no tool wear rate. A lot of effort has gone into the EDM tooling problem regarding inexpensive tool materials, ease of manufacture, rapid work piece erosion, coupled with low tool erosion etc. To improve machining efficiency, roughing, finishing and semi-finishing electrodes are used in EDM process [16,17].

Fig 7: Electrode and the Workpiece



5.5. By Powder Mix Dielectrics

In this process, a suitable material in fine powder is properly mixed into the dielectric fluid. The added powder improves the breakdown characteristics of the dielectric fluid. The insulating strength of the dielectric fluid decreases and as a result, the spark gap distance between the electrode and workpiece increases. Enlarged spark gap distance makes the flushing of debris uniform. This results in much stable process thereby improving material removal rate and surface finish [12]. EDM process becomes more stable and improves machining efficiency, MRR and surface quality. However; most studies were conducted to evaluate the surface finish since the process can provide mirror surface finish which is a challenging issue in EDM. The characteristics of the powder such as the size, type and concentration influence the dielectric performance [13].

6. Conclusion

The EDM is an unconventional material removal process and flexible enough to meet the machining requirements posed by the demand in the global metal cutting industries. There are several types of EDM which have different advantages and applications in industries. Dry EDM is eco friendly machining. Wire EDM is commonly applied for the machining & micromachining of parts with intricate shape. In Die Sinking EDM the various mechanism like vibration, rotary & vibro-rotary used to improve MRR & surface finish. A powder mixed EDM enhances the capability of electric discharge machining. The different process parameters electrical & non-electrical affect the performance parameters (TWR, MRR, WR, SQ, SR, and HAZ) of electric discharge machine or whatever its types like (WEDM, Die Sinking EDM, PMEDM, Dry EDM).

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