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"Study on Electro Discharge Machining (Edm)"

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---ABSTRACT---
The electrical discharge machining (EDM) is one of the most common and most accepted non traditional machining processes used. It is a electro-thermal process and is based on the eroding effect of an electric spark on both the electrode and workpiece. It is a thermal erosion process where metal removal takes place by a series of recurring electrical discharges between a cutting tool acting as an electrode and a conductive workpiece, in the presence of a dielectric fluid. This discharge occurs in a voltage gap between the electrode and workpiece. EDM technology is increasingly being used in tool, die and mould making industries, for machining of heat treated tool steels and advanced materials (super alloys, ceramics, and metal matrix composites) requiring high precision, complex shapes and high surface finish.

KEYWORDS: *EDM, Electronic Discharge Machining, Machining Process, Study of Machining Process EDM*

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I. INTRODUCTION

It was originally observed by Joseph Priestly in 1770, EDM Machining was very imprecise and riddled with failures. Commercially developed in the mid 1970s, wire EDM began to be a viable technique that helped to shape the metal working industry that we see today. In the mid 1980s.The EDM techniques were transferred to a machine tool. This migration made EDM more widely available and appealing over traditional machining processes.Electrical discharge machine (EDM) is commonly used in tool, die and mould making industries for machining heat-treated tool steel materials. The heat-treated tool steels material are difficult-to-cut material when using conventional machining process. One of the main problems in electrical discharge machine (EDM) is high rate of tool wear . The wear ratio defined as the volume of metal lost from the tool to the volume of metal removed from the work material. Wear ratio varies with the tool and work materials used. If the rate of tool wear is high then the material is easy to wear and not good for machining performance.Electro Discharge Machining (EDM) is a Process, where electrical energy is used to generate electrical spark and material isremoved mainly due to thermal energy of the spark. The Heat from the discharge vaporizes minute particles of workpiece material, which are then washed from the gap by the continuously flushing dielectric fluid.EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. EDM can be used to machine difficult geometries in small batches or even on job-shop basis. Work material to be machined by EDM has to be electrically conductive.

II. PRINCIPLE OF EDM

In this process the metal is removed from the work piece due to erosion cause by rapidly recurring spark discharge between the tool and work piece. The figure below shows 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 shown in figure. Both tool and work piece are submerged in a dielectric fluid .Kerosene/EDM oil/deionized water is very common type of liquid dielectric although gaseous dielectrics can also be used in certain Case.

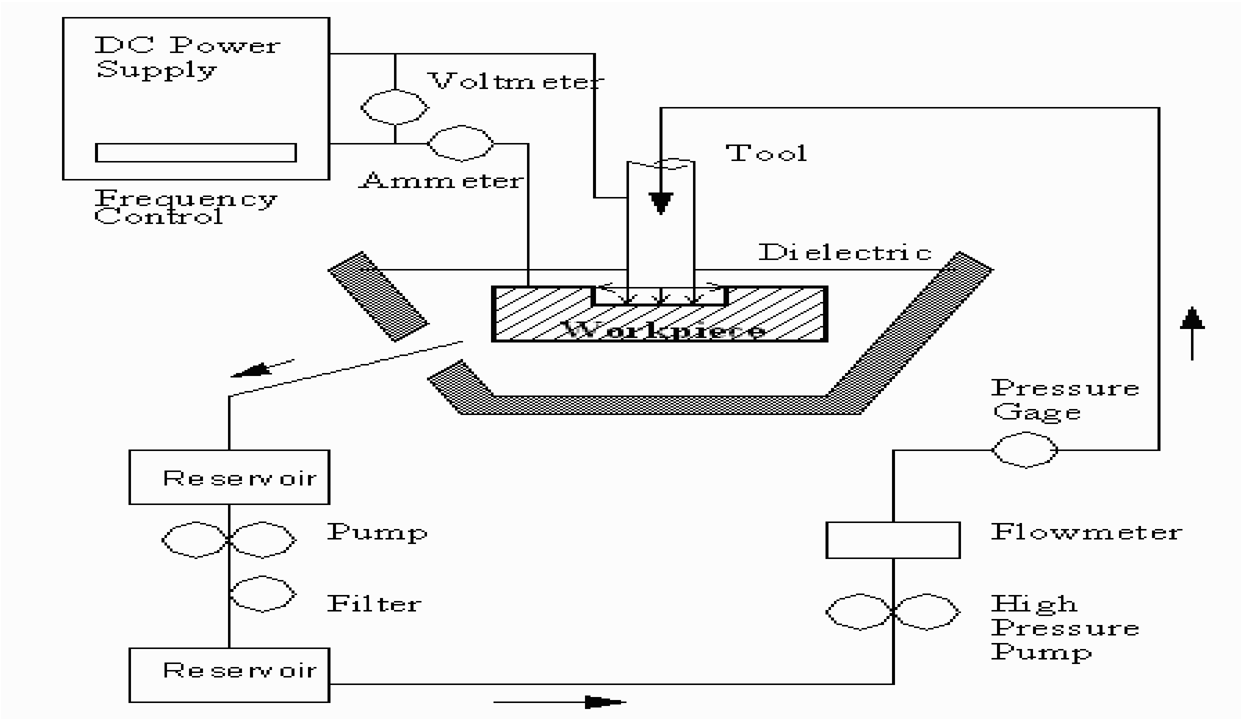

Figure1 : Diagram of the Principle of operation of EDM Process

The tool is made cathode and work piece as 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. The positive ions and electrons are accelerated due to the heat, 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 current density to reach very high values producing an increase of ionization and the creation of a powerful magnetic field. The moment spark occurs sufficiently pressure is developed between work and tool as a result of which a very high temperature is reached and at such high pressure and temperature some part of 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.

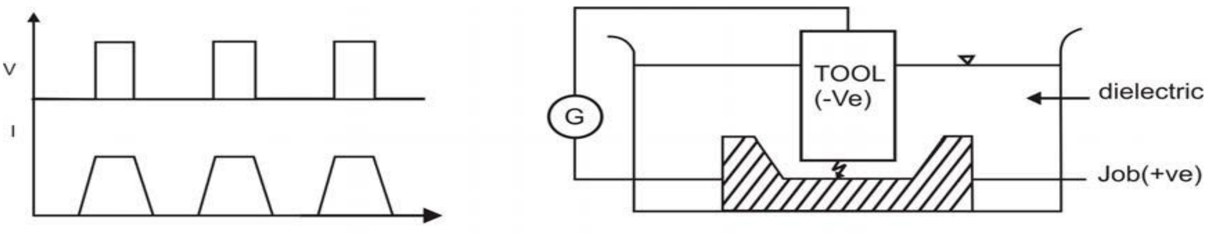

Figure2 : Figure to show the charge on tool and the workpiece

As the potential difference is withdrawn as shown in Fig., 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.

2.1 EDM: PRINCIPLES OF OPERATION

The basic components of an EDM system are illustrated in figure. The workpiece is mounted on the table of the machine tool and the electrode is attached to the ram of the machine. A DC servo unit or hydraulic cylinder moves the ram (and electrode) in a vertical motion and maintains proper position of the electrode in relation to the workpiece. The positioning is controlled automatically with extreme accuracy by the servo system and power supply.

During normal operation the electrode never touches the workpiece, but is separated by a small spark gap.During operation, the ram moves the electrode toward the workpiece until thespace between them is such that the voltage in the gap can ionize the dielectricfluid and allow an electrical discharge (spark) to pass from the electrode to theworkpiece. These spark discharges are pulsed on and off at a high frequencycycle and can repeat 250,000 times per second. The spark discharge (arc) always travels the shortest distance across the narrowest gap to the nearest or highest point on the workpiece. The amount of material removed from the workpiece with each pulse is directly proportional to its energy.

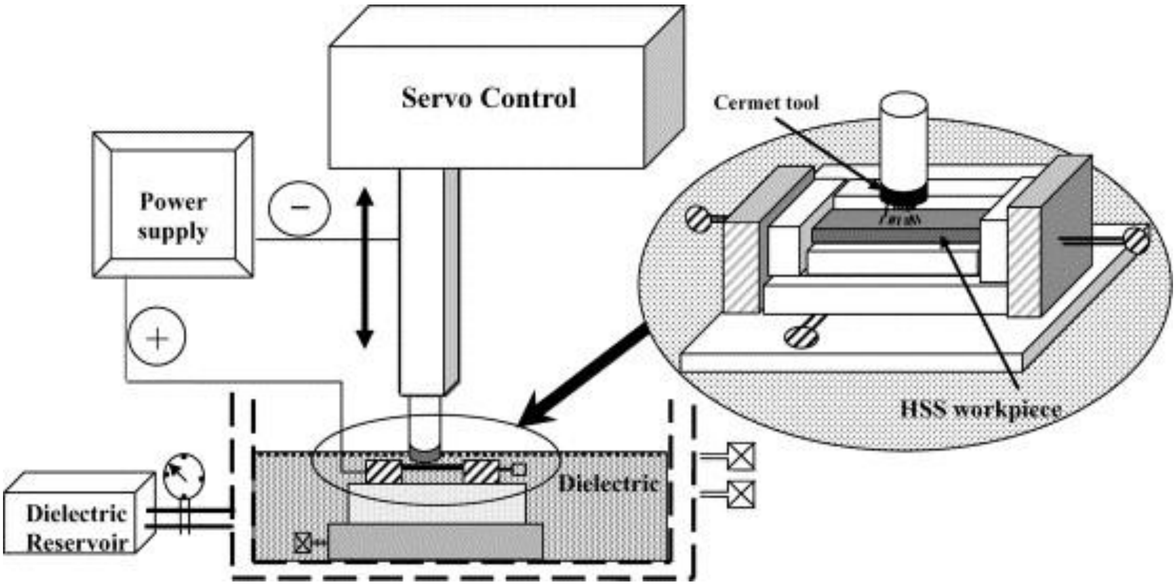

Figure3 : Servo control mechanism representation in EDM

Each discharge melts or vaporizes a small area of the workpiece surface. Thismolten metal is then cooled in the dielectric fluid and solidifies into a small spherical particle (swarf) which is then flushed away by pressure/motion of the dielectric. The impact of each pulse is confined to a very localized area, the location of which is determined by the form and position of the electrode.Both the workpiece and electrode are submerged in a dielectric fluid which actsas an electrical insulator to help control the spark discharges. In EDM, the dielectric fluid also performs the function of a coolant medium and reduces the extremely high temperatures in the arc gap. More importantly, the dielectric fluid is pumped through the arc gap to flush away the eroded particles between the workpiece and the electrode. Proper flushing is critical to high metal removal rates and good machining conditions.

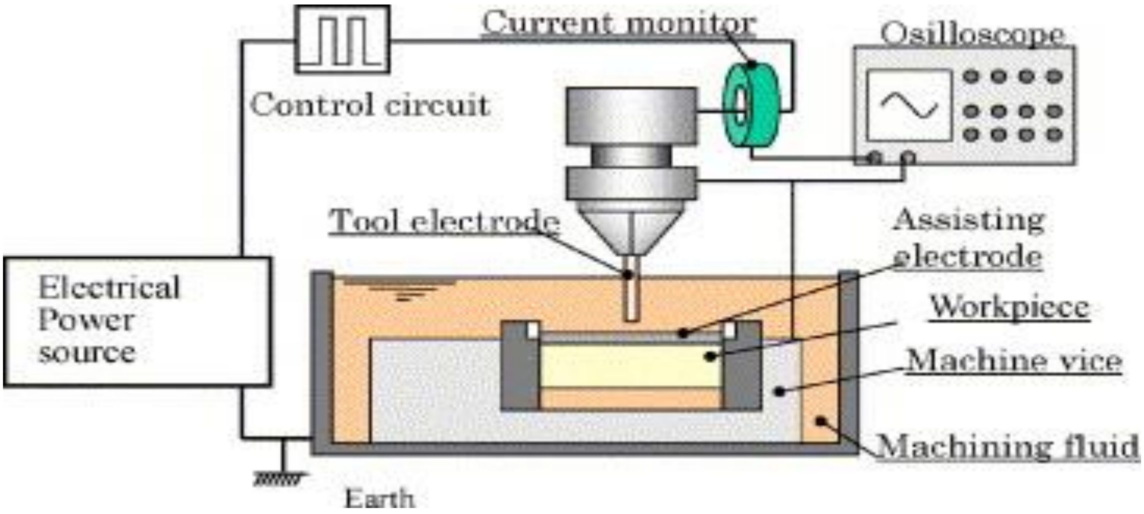

Figure4 : Complete EDM Process Representation

Because EDM erodes metal with electrical discharges and not with chip machining cutting tools, the hardness of the workpiece does not determine whether material can be machined by EDM or not .
It eliminates the risk of damage or distortion which could scrap an expensive workpiece during heat treating.

III. TYPES OFELECTRO DISCHARGE MACHINING (EDM)

There are following two types of Electro Discharge Machining process.

1. Die-Sinking Edm (The Ram Type)
2. Wirecut Edm

Each of them are used to produce very small and accurate parts as well as large items like automotive stamping dies and aircraft body components. The largest single use of EDM is in die making.

3.1. Die-sinking EDM

In the die - sinker EDM Machining process, two metal parts are submerged in an insulating liquid and are connected to a source of current which is switched on and off automatically depending on the parameters set on the controller. When the current is switched on, an electric tension is created between the two metal parts and if the two parts are brought together to within a fraction of an inch, the electrical tension is discharged and a spark jumps across. Where it strikes, the metal is heated up so much that it melts.

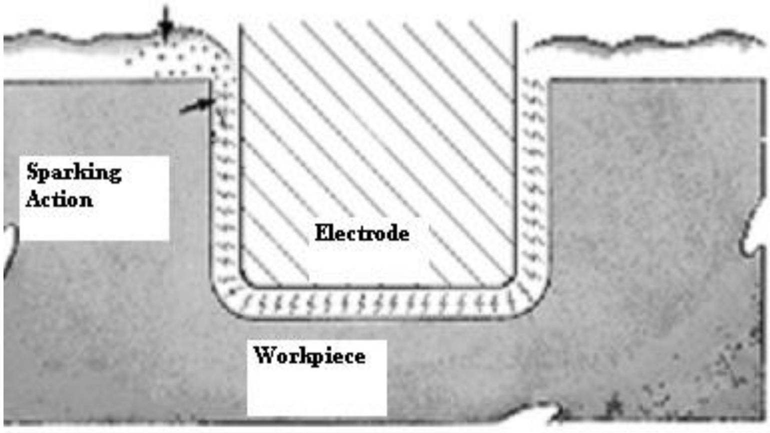

Figure5 : Conventional (RAM) EDM

Sinker EDM is also called cavity type EDM or volume EDM . It consists of an electrode and the workpiece submerged in an insulating liquid such as oil or other dielectric fluids. The electrode and workpiece are connected to a suitable power supply. 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. 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.

3.1.1.Important parameters of Die-Sinking EDM

(a) Spark On-time (pulse time or Ton): It isthe 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.

(b) Spark Off-time (pause time or Toff): 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.

(c) Arc gap (or 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 .

(d) Discharge current (current Ip): Current is measured in amp allowed per cycle. Discharge current is directly proportional to the Material removal rate.

(e)Duty cycle (τ): It is a percentage of the on-time relative to the total cycle time. This parameter is calculatedby dividing the on-time by the total cycle time (on-time pulse offtime).

$$T = Ton / Ton + Toff$$

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

(g)Over cut – It is a clearance per side between the electrode and the workpiece after the marching operation.

3.2. Wire-cut EDM

Wire EDM Machining is also known as Spark EDM. It is an electro thermal production process in which a thin single-strand metal wire (usually brass) in conjunction with de-ionized water which is used to conduct electricity allows the wire to cut through metal by the use of heat from electrical sparks. Wire-cut EDM is typically used to cut plates as thick as 300mm and to make punches, tools, and dies from hard metals that are difficult to machine with other methods Wire-cutting EDM is commonly used where low residual stresses are desired, because it does not require high cutting forces for removal of material. If the energy/power per pulse is relatively low (as in finishing operations), little change in the mechanical properties of a material is expected due to these low residual stresses, although material that hasn't been stress-relieved can distort in the machining process. Due to the inherent properties of the process, wire EDM can easily machine complex parts and precision components out of hard conductive materials.

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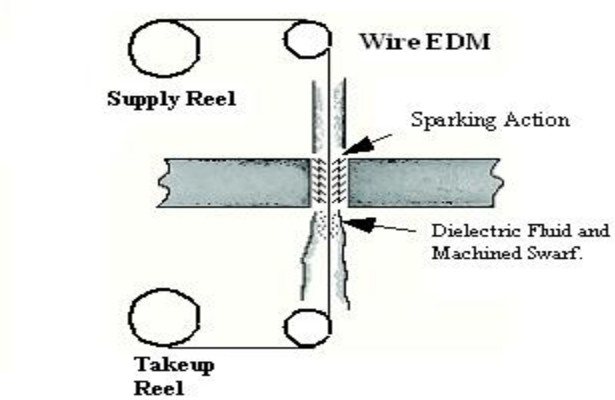

Figure 6: Traveling Wire EDM (TW EDM)

3.2.1. Major Components In Wire Cut Machine

A Wire EDM system is comprised of four major components.

(1) **Computerized Numerical Control** (CNC): This act as **"The Brains."**

(2) **Power Supply:** Provides energy to the spark.This act as **"The Muscle."**

(3) **Mechanical Section:**Worktable, workstand, taper unit, and wire drive mechanism.This is the actual machine tool.This act as **"The Body."**

(4) **Dielectric System:** The water reservoir where filtration, condition of the waterresistivity/conductivity and temperature of the water is provided and maintained. This act as **"The Nourishment".**

3.2.2. Principle Of Wire Electrical Discharge Machining

In wire EDM a series of electrical discharges (sparks) are produced between an accurately positioned moving wire (the electrode) and the workpiece for machining a material. Alternating or direct current High frequency pulsesare discharged from the wire to the workpiece with a very small spark gap through an insulateddielectric fluid (water).Many sparks can be observed at one time. The volume of metal removed depends on the desired cutting speed and the surface finish required.

The heat of each electrical spark is around 15,000° to 21,000° Fahrenheit, it erodes away a very small bit of material which is vaporized and melted from the workpiece and some of the wire material is also eroded away. These particles (chips) are flushed away from the cut with a stream of de-ionized water through the top and bottom flushing nozzles.

The water also acts as coolent to prevent heat build-up in the workpiece. If this cooling is not there then the thermal expansion of the part would affect size and positional accuracy
The material removal rate is given by the formula:

MRR (g/min) = WRR/T

Where MRR = material removal rate
WRR = the work piece removal rate
T=time

Higher isthe material removal rate in the EDM process, the better isthe machining performance. However, the smaller is the electrode wear ratio and
surface roughness in EDM process, the better is machining performance. Therefore, the material removal rate is higher-the-better performance characteristic is obtained and the lower the electrode wear ratio and the surface roughness better is the performance characteristic.

IV. MODELLING OF MATERIAL REMOVAL AND PRODUCT QUALITY

Material removal in EDM mainly occurs due to intense localised heating almost by point heat source for a rather small time frame. Such heating leads to melting and crater formation as shown in Fig. 3.

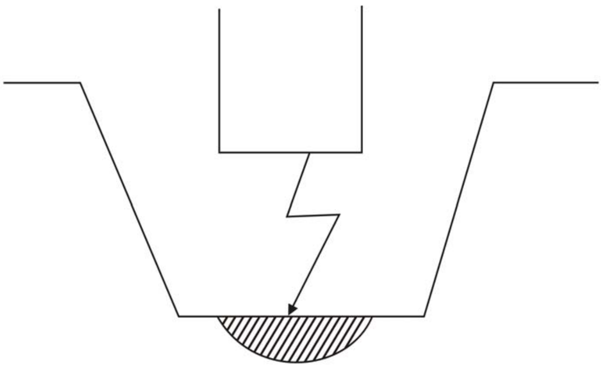

Figure7 Schematic representation of crater formation in EDM process

The molten crater can be assumed to be hemispherical in nature with a radius r which forms due to a single pulse or spark. Hence material removal in a single spark can be expressed as

$$\Gamma = 2/3 * (\pi*r*r*r)$$

The energy content of a single spark is given as

$$E_s = V*I*t_{on}$$

V= voltage supply
I= current supply
t (on)= time for which current is supplied

A part of this spark energy gets lost in heating the dielectric, and rest is distributed between the impinging electrons and ions. Thus the energy available as heat at the workpiece is given by

$$E_w = k*E_s$$

Now it can be logically assumed that material removal in a single spark would be proportional to the spark energy. Thus

$$\therefore \Gamma = g*E_s$$

Now material removal rate is the ratio of material removed in a single spark to cycle time.

Thus

MRR= Γs / tc = Γs / [t (on)+t (off)]

MRR = g* { VIt(on) / [t(on) + t(off)] }

MRR= g * VI / [1+(t (on) / t(off)]

V. SPECIFICATION ON EDM

Mechanism of process	Controlled erosion (melting and evaporation) through a series of electric spark
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 paraffin, silicon oil, deionized water etc.
Tool material	Copper, Brass, graphite, Ag-W alloys, Cu-W alloys.
MRR/TWR	0.1-10
Materials that can be machined	All conducting metals and alloys.
Shapes	Microholes, narrow slots, blind cavities
Limitations	High specific energy consumption, non conducting materials can't be machined.

VI. DIELECTRIC FLUID

In EDM removal of material mainly occurs due to thermal evaporation and melting. Thermal process is carried out in absence of oxygen so that the process can be controlled and oxidation can be avoided. Oxidation often results in poor surface conductivity (electrical) of the work piece which hinders further machining. Hence, dielectric fluid provides an oxygen free machining environment. It should have enough dielectric resistance so that it does not breakdown electrically easily but at the same time it should ionize when electrons collide with its molecule. Moreover, during sparking it should be thermally resistant as well.The dielectric fluid generally used are EDM oil, kerosene (paraffin oil) and de-ionized water. Tap water cannot be used as it ionizes too early and thus breakdown due to presence of salts as impurities occur. Dielectric medium is generally flushed around the spark zone. It is also applied through the tool to achieve efficient removal of molten material.

6.1. Functions Of Dielectric Fluid

(a) It serves as a conducting medium when ionized and conveys the spark. It concentrates the energy to a very narrow region.
(b) It helps in cooling the work, tool electrode and enables arcing to be prevented.
(c) It removes the eroded metal.
(d) It acts as a coolant in quenching the sparks.

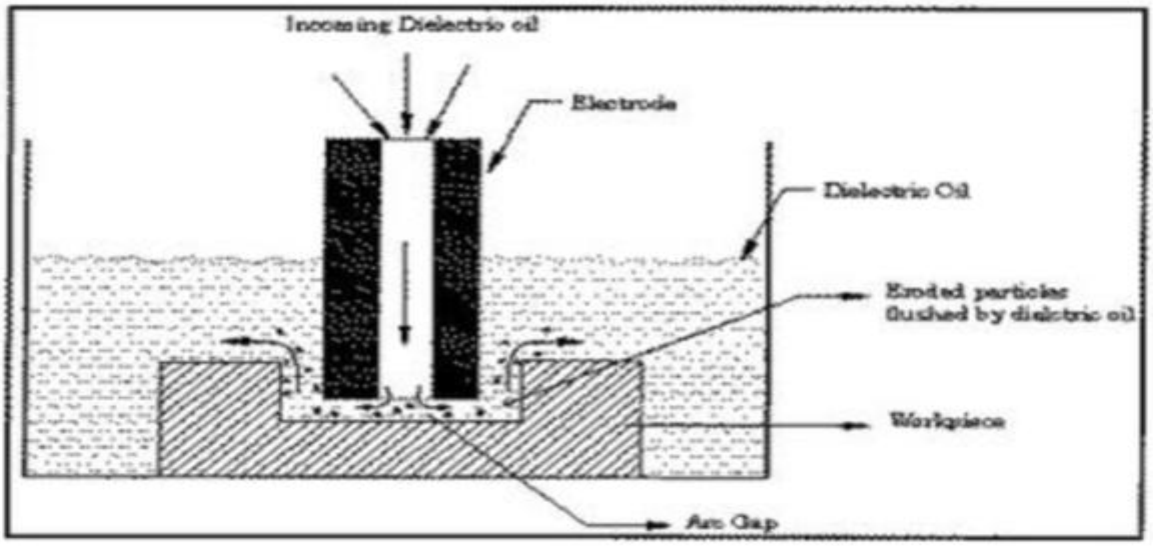

Figure 8 : Removal of material from workpiece

6.2Requirements of Dielectric Fluid

[1] The dielectic fluid should have sufficient stable dielectric strength to provide insulation between the tool and workpiece till the breakedown voltage is reached.
[2] After the spark Discharge has taken place fluid should de-ionise.
[3] It should have low viscosity and a good wetting capacity to provide effective cooling mechanism.
[4] It should flush out the particles produced during the spark out of the gap.This is the most important function of dielectric fluid . Inadequate flushing can result in decreasing the life of the electrode and increasing the machining time.
[5] It should be chemically neutral so as not to react with the electrode , the workpiece , the table or the tank.
[6] The flash point should be high so that there are no fire hazards.
[7] Niether emission of any toxic vapoursnor unpleasantodours are desireable.
[8] It should maintain these properties with temperature variation, contamination by working residuals and products of decomposition.
[9] It should be economical and easily available.

6.3 Properties of dielectric fluids that need to considered while selecting them for operation

Dielectric strength: The ability of the fluid to maintain high resistivity before spark discharge and in turn the ability to recover rapidly with a minimal amount of OFF time. Anoil with a high dielectric strength will offer a finer degree of control throughout the range of frequencies used.

Viscosity: The lower the viscosity of the fluid the better is the accuracy and finishes that can be obtained . In mirror finishing or close tolerance operations, spark gaps can be as small as 0.005 or less. With such tight, physical restrictions such as this, it is much easier to flush small spark gaps with lighter and thinner oil.

Specific gravity: is the "weight" of a substance measure by a hydrometer. The "lighter" the oil or lower its specific gravity, faster the heavier particles (chips) settle down. This reduces the gap contamination and possibilities of secondary discharge and/or arcing.

Color: All dielectric oils will eventually darken with use, but it seems only logical to start with a liquid that is as clear as possible to allow viewing of the submerged part. Clear or "water-white" should be your choice, because any fluid that is not clear when brand new certainly contains undesirable or dangerous contaminants.

Odour : the oils that have a strong odour give an indication for the presence of sulfur which is undesirable in the EDM process.

Polarity : In EDM, polarity describes which side of the spark gap is positive or negative. Polarity can effect speed, finish, wear, and machining stability. Spark erosion machines can use both positive and negative polarity, depending upon the particular application, but most operations are performed using a positive electrode. Positive polarity will remove material more slowly than negative polarity, but is most of the time to protect the electrode from excessive wear.Negative polarity is used for high-speed metal removal when using graphite electrodes, and should be used when machining carbides, titanium, and refractory metals using copper electrodes. Negative electrodes polarity is sometimes used with copper electrodes when no other method is as successful. With graphite electrodes, negative polarity is much faster than positive polarity by as much as 50% or more, but with as much as 30% to 40% electrode wear. Wire EDM machines generally run with negative polarity – that is the wire is negative and the work-piece is positive. In spark EDM applications, electrode wear is not a consideration as metal removal rates are higher using negative polarity. However, if the wire is burned deep enough, usually about 20% of its diameter, it can no longer withstand the tension and will break. Increasing the speed of the wire will reduce the severity of the wire erosion and help eliminate wire breakage, at the small expense of increased wire consumption.

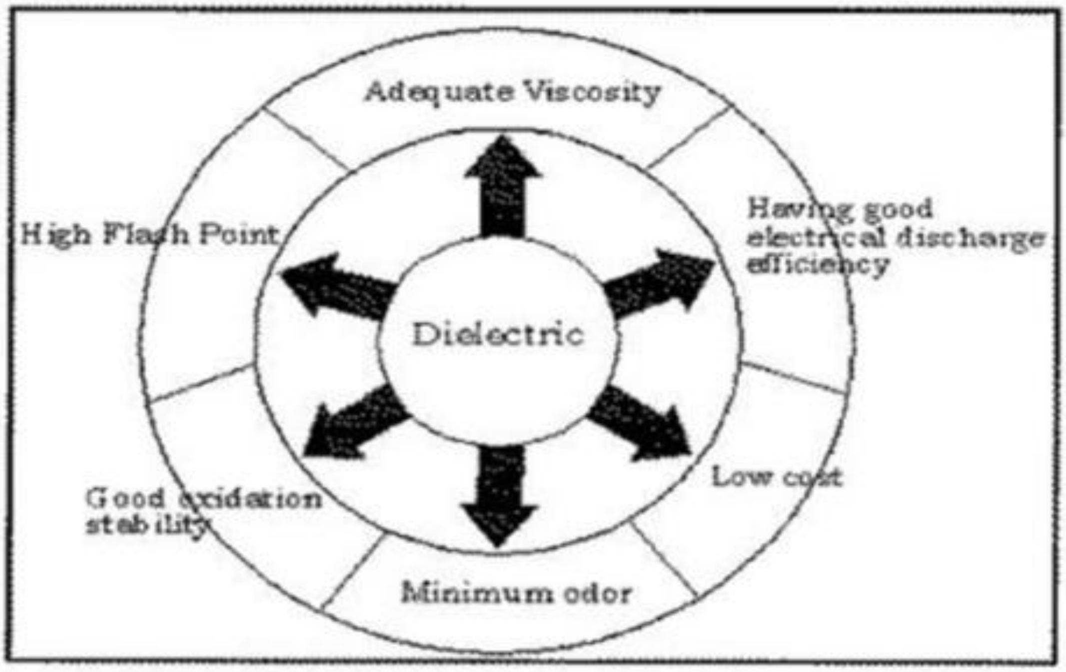

Figure 9 :figure representing the properties of Dielectric Fluid

Tool Material

Desired tool material should not undergo much tool wear when it is impinged by positive ions. Even when temperature increases, there would be less melting. Further the tool should be easily workable as complex shaped geometric features are machined in EDM.

Thus the basic characteristics of electrode materials are:

1. High electrical conductivity – electrons are cold emitted more easily and there is less bulk electrical heating.
2. High thermal conductivity – for the same heat load, the temperature rise would be less due to faster heat conducted to the bulk of the tool and thus less tool wear.
3. Higher density – for the same heat load and same tool wear by weight there would be less volume removal or tool wear and thus less dimensional loss or inaccuracy.

4. High melting point – high melting point leads to less tool wear due to less tool material melting for the same heat load.
5. Easy manufacturability.
6. Cost – cheap.

7.1 The followings are the different electrode materials which are used commonly in the Industry

1. Graphite
2. copper
3. Tellurium copper – 99% Cu + 0.5% tellurium
4. Brass

COMPARISON OF DIE-SINKER AND WIRE-CUT MACHINES

Both die-sinker and wire-cut EDM machines use sparks to removeelectrically conductive material. But while both types are electrical dischargemachines, there are differences in their use and operation. Someof these differences are listed in the following text.

***** Dielectric fluid:

1. **die-sinker** EDM machines use hydrocarbon oil and submerse theworkpiece and spark in the fluid.
2. **wire-cut** EDM machines generally use deionized water and containonly the sparking area in the fluid.

* Applications:

[1] **die-sinker** EDM machines are normally used for producing threedimensional Shapes. These shapes
[2] utilize either cavity-type machining or through-hole Machining.

[3] **wire-cut** EDM machines are always used for through-hole machining,since the electrode wire must
[4] pass throughthe workpiece being machined.

- Sparking:
  die-sinker machines produce sparks that occur between the electrodeend and the workpiece.

  wire-cut machines produce sparks that occur between the electrode-side surface and the workpiece.

[5] Both die-sinker and wire-cut machines use sparking to remove electricallyconductive material.
[6] However, they do not normally use the same kind of dielectric fluids or electrodes.

Flushing method

Flushing is the most important function in any electrical discharge machining operation. Flushing is the process of introducing clean filtered dielectric fluid into the spark gap. There are a number of flushing methods used to remove the metal particles efficiently.

Flushing method is consist four parts:

1. Normal Flow
2. Reversed flow
3. Jet Flushing
4. Immersion Flow

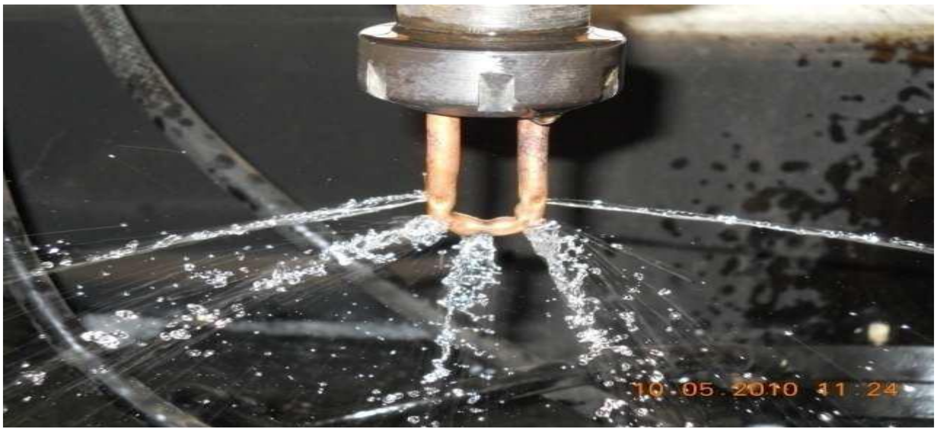

Figure 10 : Introduction of Dielectric Fluid in EDM process

Application Of EDM

[1] The EDM process is becoming a common method of making prototype and production parts, especially

[2] in the aerospace, automobile and electronics industries in which production quantities are relatively
[3] low.
[4] It is used to machine extremely hard materials that are difficult to machine like alloys, tool steels, tungsten carbides etc.
[5] It is used for forging, extrusion, wire drawing, thread cutting.
[6] It is used for drilling of curved holes.
[7] It is used for internal thread cutting and helical gear cutting.
[8] It is used for machining sharp edges and corners that cannot be machined effectively by other
[9] machiningprocesses.
[10] In EDM machining higher Tolerance limits can be obtained. Hence areas that require higher surface
[11] accuracy use the EDM machining process.
[12] Ceramic materials that are difficult to machine can be machined by the EDM machining process.
[13] Electric Discharge Machining has also made its presence felt in the new fields such as sports, medical a
[14] andsurgical, instruments, optical, including automotive R&D areas.
[15] It is a promising technique to meet increasing demands for smaller components usually highly
[16] complicated,multi-functional parts used in the field of micro-electronics.

Wire EDM Application

[1] Parts with complex geometry's
[2] Thin or delicate parts that are susceptible to tool pressure
[3] Progressive, blanking and trim dies
[4] Extrusion dies Precious metals
[5] Narrow slots and keyways
[6] Mold components
[7] Medical and dental instrumentation
[8] Aerospace, defense and electronic parts

Advantages of EDM

(a) Any material that is electrically conductive can be cut using the EDM process.
(b) Hardened workpieces can be machined and the deformation caused by heat treatment is eliminated.
(c) X, Y, and Z axes movements allow for the programming of complex profiles using simple electrode.
(d) Complex dies sections and molds can be produced accurately, faster, and at lower costs.
(e) Thin fragile sections such as webs or fins can be easily machined without deforming the part.

Limitation of EDM

(a) **The need for electrical conductivity –**the work piece has to be electrically conductive to be able to create discharges. Isolators like plastics, glass and most ceramics cannot be machined by EDM, althoughsome exception like for example diamond is known.Machining of partial conductors like Si semi-conductors, partially conductive ceramics and even glass is also possible.

(b) **Predictability of the gap -** The dimensions of the gap are not always easily predictable, especially with complex work piece geometry.

(c) **Low material removal rate -** The material removal of the EDM-process is low, especially in the case of die-sinking EDM where the total volume of a cavity has to be removed by melting and evaporating the metal. With wire-EDM only the outline of the desired work piece shape has to be machined. Due to the low material removal rate, EDM is principally limited to the production of small series although some specific mass production applications are known.

(d) **Optimization of the electrical parameters -** The choice of the electrical parameters of the EDM-process depends largely on the material combination of electrode and work piece and EDM manufactures only supply these parameters for a limited amount of material combinations. When machining special alloys, the user has to develop his own technology.
(e) Heat Affected Zone (HAZ) near cutting edges.

(f) Dielectric vapour can be dangerous.

Disadvantages Of EDM

a. The wear rate on the electrode is considerably higher . Sometimes it may be necessary to use more than one electrode to finish the job.

b. The workpiece should be electrically conductive to be machined using the EDM process.
c. The energy required for the operation is more than that of the conventional process and hence will be more expensive.

Following conclusion can be drawn for EDM

[1] EDM can be used effectively for machining of complex shapes.
[2] EDM machining process is independent of material's mechanical properties.
[3] EDM machining can result in high accuracy.
[4] EDM is widely being used as non traditional machining process in manufacturing process.