Chapter – 8

ELECTRICAL DISCHARGE MACHINING (EDM)

8.1 Introduction

Electrical Discharge Machining (EDM) is a well-established nontraditional machining process. It is widely used for machining complicated contours in hard materials. Thus, it is a well-accepted practice in die and mold-making industries for quite a few decades. EDM is a machining method primarily used for hard metals or those would be impossible to machine with conventional techniques. find a wide range of applications for production of complicated shapes, micro holes with high accuracy in various electrically conductive materials and high strength temperature resistant (HSTR) alloys. The tool (electrode) and the workpiece are separated by a small gap and submerged in a dielectric fluid. The metal is removed by means of series of discrete but controlled electrical sparks between the workpiece and electrode immersed in a dielectric fluid and consequently melting and vaporizing of material from the workpiece. In this process, there is no physical contact between the tool and the work piece; the process is not restricted by physical and metallurgical properties of the work materials.

8.2 MATERIAL REMOVAL MECHANISM IN EDM

Electro-Discharge Machining is a thermo-erosive process that utilizes the precisely controlled pulsed discharge energy to erode any electrically conductive materials irrespective of their mechanical, thermo-physical and chemical properties. The controlled sparks are produced between the shaped tool electrode and the workpiece submerged in a dielectric fluid namely kerosene, EDM oil, de-ionized water and paraffin oil etc. The schematic of basic EDM process is shown in Figure 8.1. The location of discharge is determined by the narrowest gap between the tool and the workpiece. The duration of each spark is very short i.e. entire cycle time lasts usually for few micro-seconds (μs). The frequency of sparking may be as high as few tens of thousands per seconds. Thus, the machining process consists in successively removing very small volumes (of the order of 10-6 to10-4 mm^3 per spark) of work material, partly molten and partly vaporized during a discharge when the localized temperature at the discharge spot goes as high as 12,000ºC. Figure 8.2 illustrates the sequence of events occurring during single discharge of an EDM process. When a DC pulsed voltage is applied to the electrode and workpiece, an electrical field is

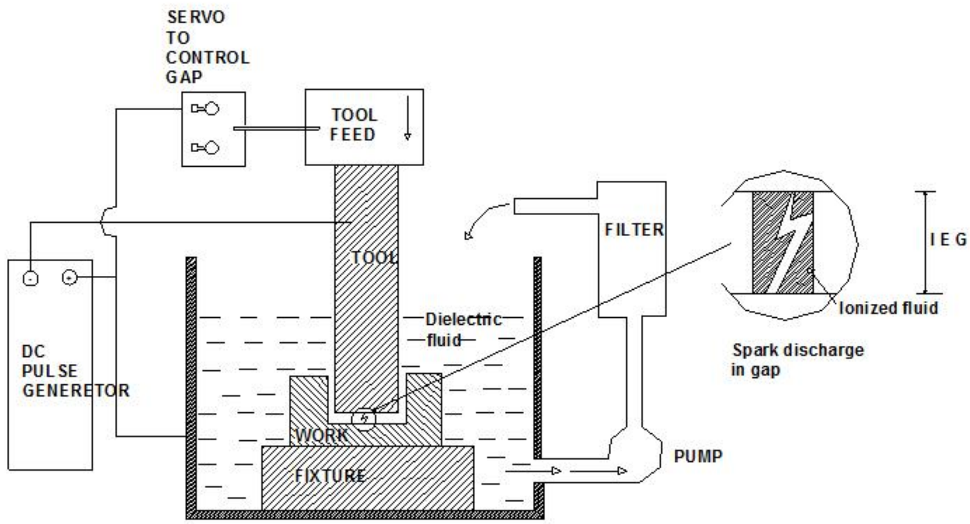

Figure 8.1 Schematic of electrical discharge machining (EDM) process

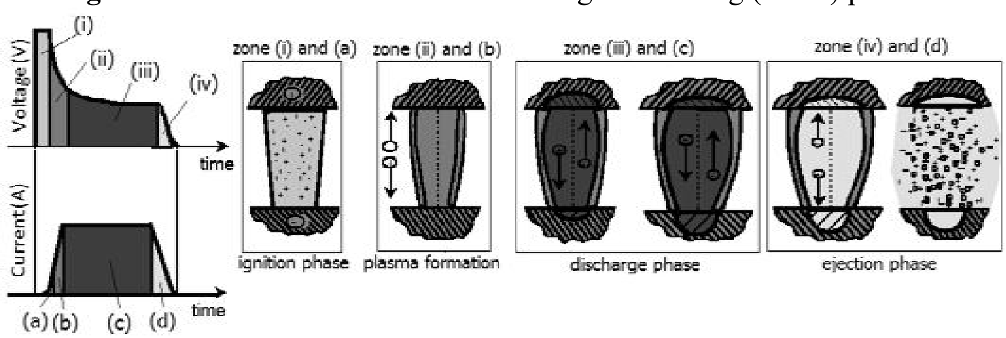

Figure 8.2 Representation of typical voltage and current trends with sequential phenomena occurring due to single discharge

created at the point where narrowest gap is provided by surface micro-irregularities. As a result of this electromagnetic field, the microscopic contaminants suspended in the dielectric fluid begin to migrate and align at the strongest point of the field. These contaminants along with other particles form the conductive bridge across the gap, typical spark gap distance varies from 10 to 100 μm. As voltage between the electrode and workpiece increases at the beginning of the pulse, the temperature of materials increases. A small portion of the dielectric fluid and charge particles of the conductive bridge vaporizes and ionizes thereby forming a plasma channel. When the potential difference across the spark gap sharply falls, voltage breakdown occurs, and the channel starts to conduct current whose magnitudes rises instantaneously. The abrupt increase in current results in instantaneous increase in localizes temperature and pressure in the plasma channel. The extremely high temperature of the discharge melts and vaporizes a small amount of material from the surfaces of both the electrode and workpiece at the points of discharge. The vaporization of both the electrodes and dielectric fluid results in formation of gaseous bubbles in the plasma channel, which rapidly expands in a radially outward direction from the point of its origin.

At the end of the discharge, the supply of electrical pulse is terminated. This sudden termination of the pulsed power results in collapse of plasma channel and

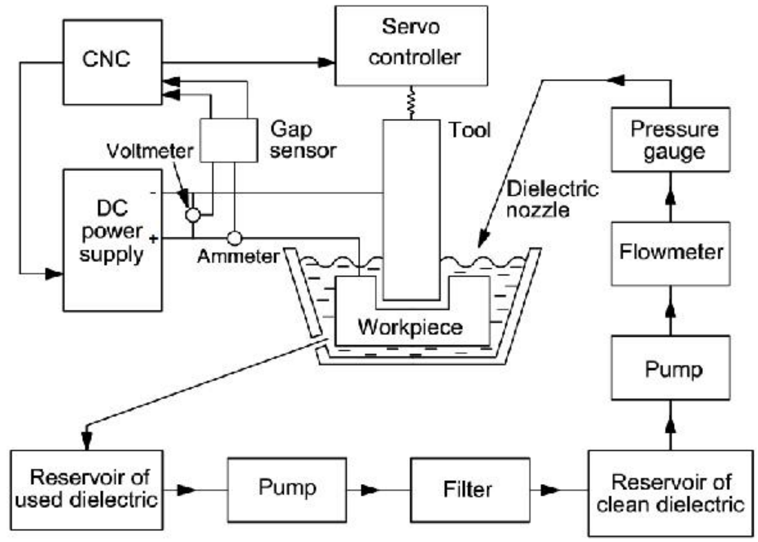

Figure 8.3 Schematic view of EDM system with various sub-units

consequently the vapour bubble under the influence of pressure imposed by dielectric fluid from surrounding. The violent in rush of relatively cool dielectric fluid results in an explosive expulsion of molten materials both from the tool electrode and the workpiece surfaces, resulting in the formation of small crater, typically 1-500 μm in diameter depending on the current density, in both the surfaces. The molten materials are expelled from the electrodes are resolidified due to rapid cooling as fresh dielectric fluid covers the site of explosion.

The dielectric fluid plays a vital role during the whole cycle of the process. It cools down the electrodes, ensures high plasma pressure and therefore high removing force on the molten materials when the plasma channel collapses, solidifies the molten metal into tiny globular form, and flushes away the carbonized dirt particles from the gap as well as from the machining zone. The post-discharge period is as important as pulsed discharge period because during this off-time, spark gap and the surfaces of the workpiece and tool are get cleaned for the next discharge, otherwise these dirt particles help to enhance the electrical conductivity of the dielectric fluid resulting in arcing and poor control of the process causing unstable machining. For flushing of machining by-products, the dielectric is made to flow through the gap. In addition, the tool is vibrated or reciprocated at an amplitude of about 4μm typically once in every second. This vibratory movement of tool helps in creating turbulence at the machining zone and enhances the flushing of carbon particles thereby ensuring the efficient and stable machining.

8.3 ELECTRICAL DISCHARGE MACHINING (EDM) SYSTEM DETAILS

A typical EDM setup has various subunits. The schematic view of complete EDM setup is shown in Figure 8.3. The brief discussions on these sub-units are given below.

(A) Pulse generator: In EDM setup. Power supply is a major component. It is assembled with some sun-components with electrical power distribution, DC power

8.4 TOOL ELECTRODE

Since the machined cavity depends on the tool electrode shape and size, the type (composition) and thermo-electrical properties play important role in achieving desired machining rate, dimensional accuracy and surface finish. The tool electrode should possess some essential desirable properties as follows:

(i) The thermal conductivity of tool material should be high so that dissipation of generated heat can be effectively done and cool down the tool electrode to prevent thermal wear of tool material.

(ii) The electrical conductivity of tool material should be high for efficient conduction of current through inter electrode gap (IEG).

(iii) The melting point of tool material should be high so that tool wear can be avoided as much as possible.

(iv) Tool material should be easily machinable.

(v) It should not be expensive.

Some of the metallic materials which are used as tool material in EDM are copper, chromium copper, tungsten, copper tungsten, brass, aluminium alloy, silver tungsten. Beside these, some non-metallic materials are also used to fabricate electrode for EDM process. These are graphite, copper graphite, etc. Brief discussion on these tool electrode materials are given hereunder.

(a) Copper: Amongst various materials, copper and brass are mostly used tool electrode material for EDM. They are inexpensive and easily available. In spite of high wear rate, copper is popular due to its availability and cost. In EDM process, the spark has a temperature of 3800ºC; while copper melts at around 1800ºC. This limitation along with high wear rate made the use of copper unacceptable. However, in micro-EDM, the amount of discharge energy involved is far less than that employed in EDM, thus copper electrode is commonly used because of higher thermal conductivity.

(b) Graphite: This electrode material is commonly used in electro-discharge machining. It is basically a metalloid having a high sublimation temperature of 3350ºC, good electrical and thermal properties along with excellent machinability. This is the material which does not melt; therefore it shows less wear than copper and suffers less thermal damage compared to copper and brass. Graphite is classified according to the particle size. The nature of the EDM process is greatly influenced by the grain size. When a larger grain size electrode is used, the rate of machining is very slow as the large particles clog the gap and flushing becomes ineffective. The particles size also has an effect on the surface finish that can be obtained. Also, graphite has superior fabrication capabilities.

(c) Brass: After copper and graphite, brass is another best-known material for its high electric and thermal conductivity, availability, consistent in quality and low cost. However, due to low melting point of this material, it suffers from rapid electrode wear. The other problems of brass material include difficulties in fabrication and low material removal rate during EDM operation.

(d) Tungsten: Theoretically tungsten is the best metal used as the tool electrode. It has high strength, hardness and melting point in the range of 3400ºC. But there are two main problems associated with the use of tungsten. This material is expensive and difficult to machine to give proper shape. Therefore, it is combined with ductile materials like copper to improve its machinability and usages. The resulting material is machinable, conductive, strong and wear resistant. Tungsten composites like silver tungsten and tungsten carbide can also be used as tool material.

(e) **Copper-Tungsten:** This electrode material is used for fabricating small drilled hole using tubular shaped tool. This material is highly expensive and used when application of other electrodes shows impractical. Cu-W has high rigidity and flexural strength.

(f) **Silver-Tungsten:** Due to high percentage of tungsten, this silver-tungsten material is very expensive and used as EDM tool rarely. However, due to low wear of sharp corner of complicated tool electrode, complex profiles with accurate finished corners can be achieved using this electrode.

8.5 DIELECTRIC FLUID

Dielectric fluids are in general electrically non-conductive though it behaves as a conducting medium under a particular potential difference applied at two different points in the medium. Common dielectric fluids used in EDM process are hydrocarbon oil (kerosene), distilled water, parafins, white spirits, transformer oil, mineral oil, etc. kerosene is the common dielectric used with certain additives that prevent gas bubbles and de-odouring. Silicon fluids and mixture of these fluids with petroleum oils give excellent results. The dielectric fluid serves as a spark conductor, concentrating the spark energy to an extremely narrow region. Once the total spark energy is discharged, again the dielectric fluid regains its dielectric strength due to the supplying of fresh dielectric fluid in the narrow gap. The maximum potential difference that a unit thickness of a dielectric medium can withstand is known as dielectric strength.

The main functions of the dielectric fluid are as follows:

(i) To provide insulation in the gap between the tool electrode and the workpiece.

(ii) To make the ionization possible i.e. the building of discharging channel.

(iii) To carry the conductive particles into the ionised channel forming a bridge, over which sparks will jump and current flows.

(iv) To flush away the eroded particles (debris) from machining zone produced during machining, from the discharge gap i.e. work–tool gap retaining only the small number of conductive particles.

(v) To build up a new electric field in the discharge channel with help of conductive particles.

(vi) To cool the section of tool electrode and workpiece, which are heated by the discharge machining

(vii) To extinguish the sparks after the discharge is completed.

The choice of the dielectric has been dictated by many practical considerations, complying with the following essential requirements:

(i) It should have sufficient dielectric strength to meet the process requirement.

(ii) It should be chemically non-reactive so that it does not react both at room and elevated temperatures with tool, work material, dielectric tank material etc.

(iii) It should have desirable viscosity in order to maintain and regain the dielectric strength once the discharge is over.

(iv) The flash point of the dielectric fluid must be sufficiently high enough to avoid any fire hazards.

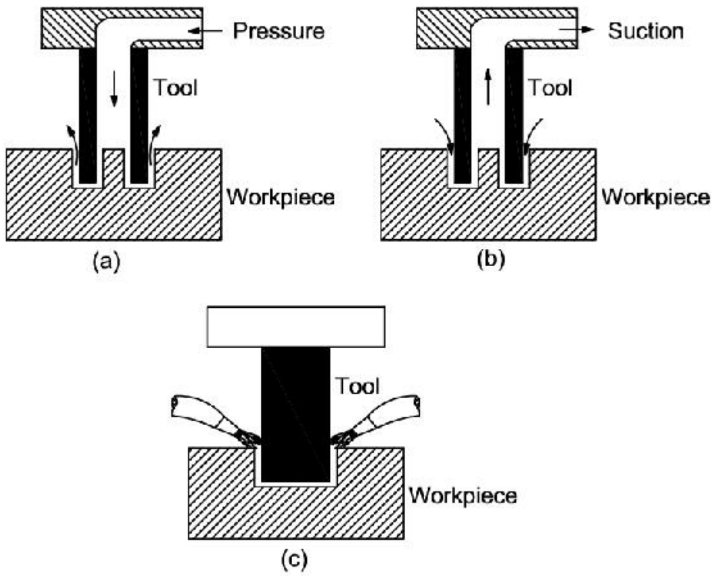

Figure 8.6 Schematic view of (a) pressure flushing, (b) suction flushing and (c) jet flushing

(v) It should not have any unpleasant odours and also should not produce any toxic vapour while machining which may otherwise cause health hazards to the operators.

(vi) It should have stable thermal, physical and chemical properties with the variation of temperature during machining, contamination caused by machining debris particles and decomposition products.

(vii) It should be readily available in the market at reasonable price.

Kerosene perfectly matches the desirable requirements of a dielectric fluid and therefore, it is widely used as dielectric fluid in die-sinking EDM. The other most commonly used dielectric fluid is de-ionized water. However, due to large tool wear ratio, deionized water is not preferred in conventional EDM but it can be used in micromachining in EDM as it does not produce carbon as byproduct of machining and cleaning of machining zone during micromachining becomes easier.

8.6 FLUSHING OF DIELECTRIC FLUID

The circulation of dielectric medium in the gap of the tool electrode and workpiece is called flushing in EDM. When hydrocarbon-based dielectric is employed, the removal of debris particles is very difficult due to the accumulation of carbon particles at the bottom of the cavity generated. These eroded debris particles are usually get trapped between the tool electrode and workpiece which reduces the dielectric strength and results in low MRR and higher tool wear. Hence, a very good and effective dielectric flushing system is required in order to machine the work material effectively. In addition, machining performances and efficiency are highly dependent on the correct layout and adjustment of the flushing system. In die-sinking EDM system, mainly three types of dielectric flushing are employed such as (i) pressure flushing (ii) suction flushing (iii) jet flushing. However, based on the requirement of job and applications, the type of dielectric flushing is selected. The schematic views of these dielectric flushing are shown in Figure 8.6.

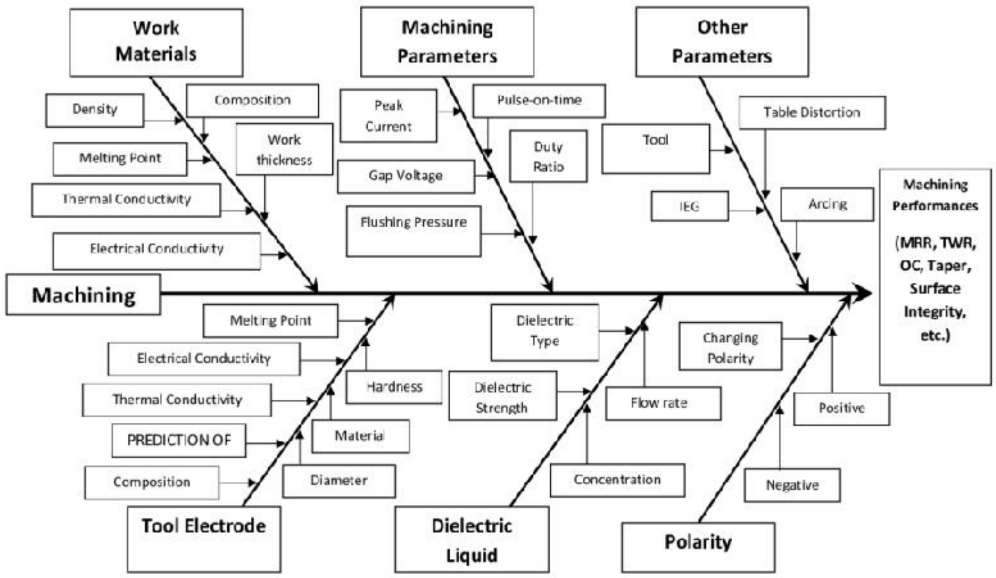

Figure 8.7 Fishbone diagram for EDM process parameters and performance measures

8.7 PROCESS PARAMETERS IN EDM

In EDM, the process parameter has direct effect on the machining performances as the discharge energy created between the tool electrode and workpiece depends on the parametric combination of various process parameters. In Figure 8.7, the fish-bone diagram of EDM process parameters is shown. The description of some of these process parameters are given hereunder.

(a) Gap voltage: It is the voltage between the tool electrode and workpiece during EDM. Higher voltage setting produces rough EDMed surface although higher value of gap voltage improves flushing ability and assists in stabilizing the machining operation. In addition, MRR is improved at high gap voltage although it causes higher tool wear.

(b) Peak current: It is defined as the highest level of current that flows through the tool electrode and workpiece during EDM. Peak current provides necessary energy to break down the dielectric fluid in inter electrode gap (IEG) and sufficient heat is produced for removing the materials from workpiece. In pulse-on-time duration, the current increases until to a preset value (peak current). Higher value of peak current produces higher MRR but at the same time, rough surface is obtained and more wear of tool occurs.

(c) Pulse duration: This is the duration when peak current is flowing through the tool electrode and workpiece. In this duration, the dielectric breakdown and removal of material from workpiece occurs. The amount of material removal from the workpiece is directly depends on the value of pulse duration. Higher pulse duration results in broader and deeper crater formation due to longer duration of current passing through the electrodes. Thus, rough machined surface is obtained. Smaller value of pulse duration results in smooth surface finish but the material removal rate is comparatively less.

several types of tool wear of EDM tool electrode such as (i) end wear, (ii) corner wear, (iii) volumetric wear and (iv) side wear. In Figure 8.10, the schematic view of various tool wear is shown. Out of these wear types, corner radius wear is the most important wear since this determines the accuracy and final shape of machined feature. This wear severely affects the total machining process as the sharp corner wears off rapidly due to the concentration of large heat flux. If the electrode is resistant to wear at the most sensitive portions, this results in increase in tool life and machining efficiency.

The various tool wears can be estimated in the following ways:

(i) End wear = Initial length of the tool – final length of the tool
(ii) Corner wear = Apparent corner wear + End wear
(iii) Side wear = Initial diameter of tool at tool end - Initial diameter of tool at tool end
(iv) Volumetric wear = Volume of material removed / Volume of Electrode lost or eroded.

The tool wear can be minimized by selecting proper combination of electrode and workpiece material. The polarity plays another dominant role on wear. Thus, the tool wear can be compensated by adopting uniform wear method, refeeding and providing extra length to the electrode. The proper selection of process parameters further minimizes the tool wear.

8.12 INFLUENCES OF PROCESS PARAMETERS ON MACHINING CHARACTERISTICS

In EDM, there are several performance measures which determine the productivity as well as degree of accuracy of machining. Descriptions of these performance characteristics are briefly discussed.

(a) Material removal rate (MRR): The amount of material removal per unit time of machining is known as material removal rate (MRR) and is expressed in mm^3/min or mg/min. MRR is evaluated for various process parametric combinations to exactly investigate the actual nature of influence of various controllable process parameter. The difference in weight obtained by measuring the weight of workpiece before and after machining when divided by the actual machining time will give the material removal rate (MRR). Higher value of process parameters such as peak current, pulse duration, duty cycle, discharge voltage and lower value of pulse interval results in higher material removal rate.

(b) Tool wear rate (TWR): During machining, the tool also gets eroded and this erosion of tool material is known on tool wear, which affects the geometry of the machined features or cavity. The tool wear per unit time of machining is known as tool wear rate. This is also measured and calculated in the similar fashion as mentioned for MRR. Lower value of TWR is always expected as it represents more stable and economic machining during EDM. The higher values of gap voltage, capacitance, peak current and pulse duration increase the tool wear.

(c) Overcut (OC): The dimensions of the machined cavity are always larger than the dimensions of the tool electrode used due to secondary sparking occurs between tool electrode surface and cavity side wall. The dimensional difference between these dimensions is called as overcut (OC). The overcut for hole machined in EDM is the difference between diameter of hole generated and the diameter of tool electrode. For

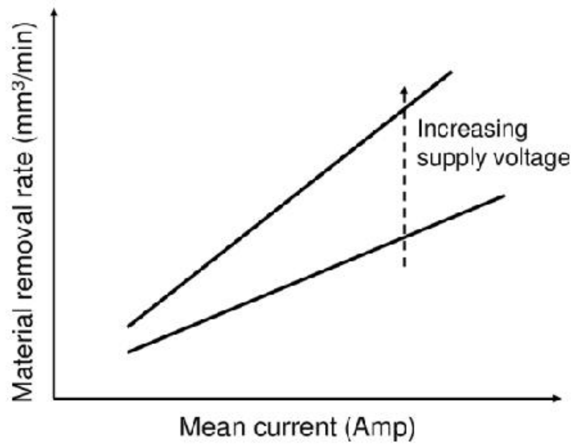

Figure 8.11 Effect of mean current on material removal rate

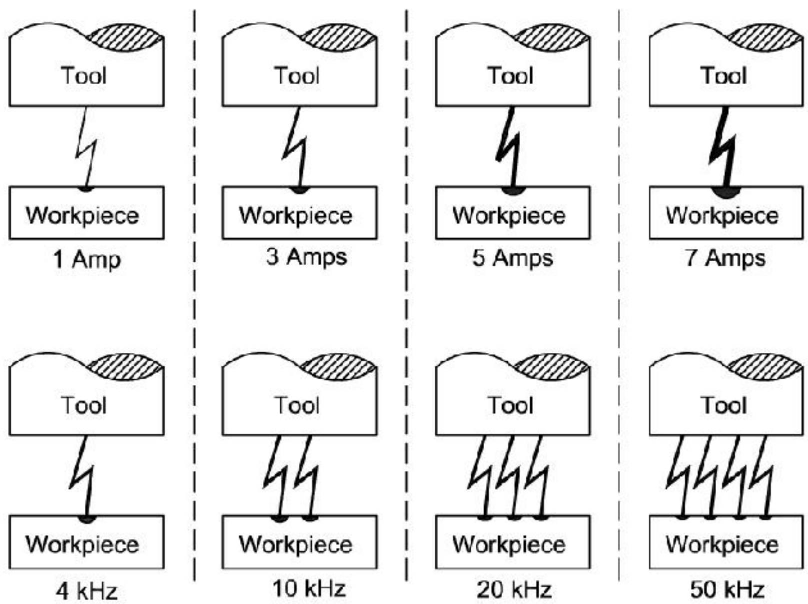

Figure 8.12 Effect of increasing current and spark frequency on crater depth

achieving desired dimensional cavity, the overcut should be accounted while designing the tool electrode.

(d) Surface roughness: In EDM, for generating a desired cavity, the machining process is carried out in two parts, i.e. roughing and finishing. In these two stages of operation, initially, the values of process parameters are kept at higher values so that most of the materials are removed very faster. However, in later stage, the values of process parameters are set at low level to machine at low rate and hence, high level of surface finish is achieved. The surface roughness increases with the increase of gap voltage, capacitance, peak current and pulse duration. The surface roughness increases with the increase of discharge energy. At higher settings of discharge energy, the crater sizes become coarser, which results in higher values of surface roughness.

In Figure 8.11, the effect of increasing the mean current on material removal rate is shown graphically at various supply voltage settings. It is observed from this plot that the material removal rate sharply increases with current due to more energy per

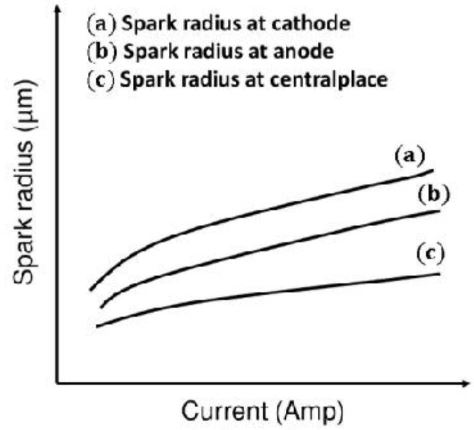

Figure 8.13 Effect of discharge current on generated spark radius

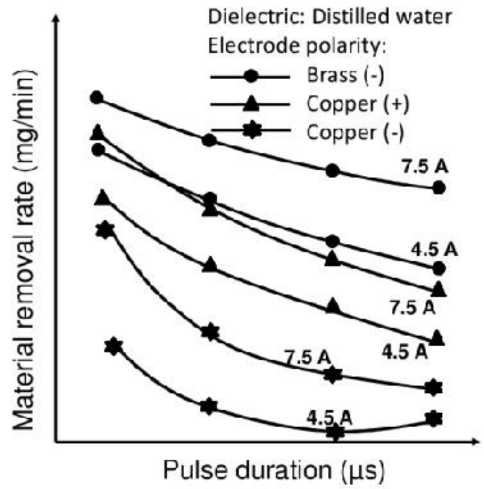

Figure 8.14 Effect of pulse duration on material removal rate for various tool electrode polarity and current

spark and consequently higher volume of crater per discharge. In addition, it is also seen that increasing the supply voltage, the rate of material removal increases and this is also due to higher value of spark energy created between the electrodes. Although, material removal rate largely improved with higher current setting, the surface finish of machined cavity decreases drastically.

In Figure 8.12, the schematic representation shows the effect of increasing the current and spark frequency on crater depth. It is observed that with increasing the current, the crater depth correspondingly increases due to higher energy of spark. However, with increasing the spark frequency, it is seen that the depth of crater per discharge is reduced due to the fact that the energy available for creating crater depth is shared by number of sparks between the electrodes and consequently, depth of crater reduces. Therefore, good surface finish of the machined cavity is obtained. Depending on the current supplied between the electrodes, the spark radius also varies at various location of the inter electrode gap as shown in Figure 8.13. The plot shows that the spark radius at the tool surface (cathode) is larger than spark radius at the workpiece surface (anode). Due to this characteristic of spark profile, the energy of spark is concentrated onto the work surface and material is removed by generating a crater depth on the workpiece.

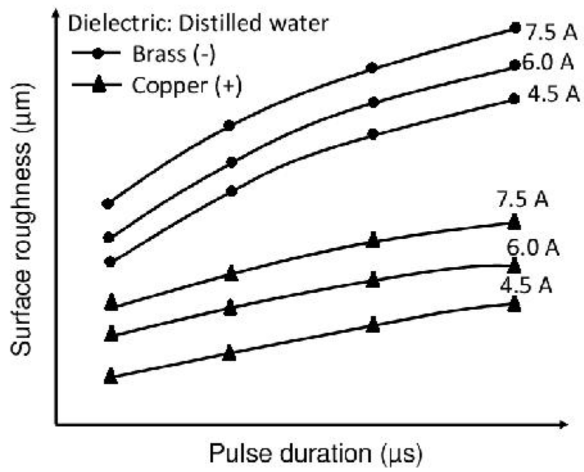

Figure 8.15 Effect of pulse duration on surface roughness for various tool and polarity at different current settings

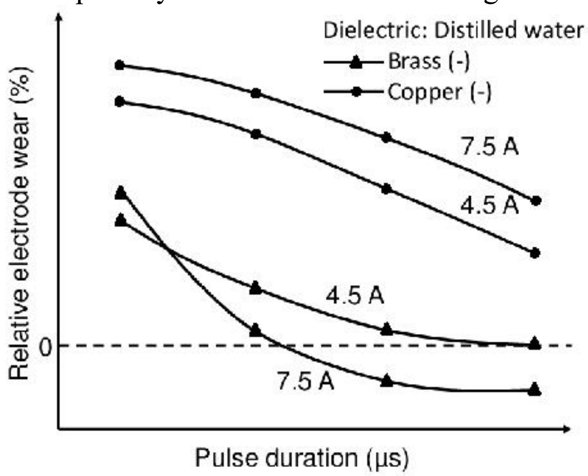

Figure 8.16 Effect of pulse duration on relative electrode wear using different tool electrodes

The effect of pulse duration on material removal rate for various tool electrode polarity is represented graphically in Figure 8.14. It is obvious from this plot that with increase in pulse duration, the material removal rate reduces for all tool electrode materials and current settings. Comparing various graphs, it is observed that using copper electrode, positive polarity setting results in higher value of material removal rate compared to negative polarity setting at same current setting. Moreover, for tool electrode at negative polarity setting, brass material results in higher material removal rate compared to using copper material for the same combination of the process parameters.

In Figure 8.15, the graphical plot shows the effect of pulse duration on surface roughness for brass (negative polarity) and copper (positive polarity) tool materials at different current settings. It is obvious from this plot that with increase in pulse duration, the roughness of machined surface increases and this is due to the prolonged discharge occurred between tool electrode and workpiece.

The relative electrode wear is defined as the ratio of volume of eroded material due to electrode wear to the volume of eroded material due to workpiece wear. In Figure

8.16, the graphical plot shows the effect of pulse duration on relative electrode wear using distilled water as dielectric and brass and copper materials as tool electrode at negative tool polarity. It is seen that the copper tool material shows higher relative electrode wear than using brass tool material for same parametric combination. With increasing of pulse duration, the relative electrode wear decreases at all current settings. It is also observed that at 7.5 A current and using brass electrode (negative polarity), the relative electrode wear is negative and this may be due to material deposition onto the tool surface during discharge.

8.13 ADVANTAGES AND LIMITATIONS OF EDM

Advantages

The advantages of EDM process are listed below.

- (i) The process is applicable to machine any hard-to-machine material i.e. Material removal is irrespective of hardness of material.
- (ii) The process is capable of machining thin fragile sections such as webs or fins without deforming the part or component.
- (iii) In EDM, complex dies sections and molds are generated accurately, faster and at lower price.
- (iv) The process is burr-free.
- (v) Since EDM is contactless material removal process, delicate sections and work material can be machined easily without any distortion. Moreover, no mechanical stress is developed in the machined workpiece.
- (vi) EDM has the ability to machine complex shapes which are difficult to manufacture by the conventional machine tools/processes.
- (vii) The process can produce tapered holes.
- (viii) The process provides good surface finish and repeatability for manufacturing tools and dies.

Limitations

The disadvantages of EDM process are listed below.

- (i) The EDM process can only be applied to machine electrically conductive materials.
- (ii) Since the material removal in EDM process is by melting and vaporization of work material, the machined surface may have surface damages or micro-cracks which may reduce the durability of the component.
- (iii) Tool electrode wear is high and overcut of machined cavity cannot be overcome.
- (iv) Production of sharp corners of cavity cannot be produced in EDM.
- (v) Since EDM is thermos-electric type machining process, the heat affected zone (HAZ), recast layer and conversion layer exist around the machined profile.
- (vi) Straight through hole is difficult to obtain.
- (vii) Cost of the EDM setup is high. Moreover, to run EDM machine, skilled operator is required.