Chapter – 9

WIRE ELECTRICAL DISCHARGE MACHINING (WEDM)

9.1 INTRODUCTION

Electrical Discharge Machining (EDM) is a well-established non-traditional machining process that can be applied to machine very hard conductive materials. Wire Electrical Discharge machining (wire-EDM) is one of the most important thermo-electrical advanced machining processes. In this process, a very thin metallic wire (electrode) generally made of brass, copper etc is fed into the workpiece, which is submerged in a dielectric fluid such as deionized water. In this process, there is no contact in between the workpiece and electrode. Therefore, there is no physical pressure imparted on the workpiece and also the process leaves no residual edge (burr) on the machined edges and therefore, this eliminates the need for subsequent secondary finishing operations. Wire-EDM process play a vital role in manufacturing processes for a wide range of industries, like electronic, biomedical, military, automobile and aerospace etc. and also essential for manufacturing precision parts for micro assemblies or micro systems. The common applications of this process are in making punches, tools and dies from difficult-to-machine materials that are very tough to cut by common conventional machining processes. The first wire-EDM machine became commercially available in the late 1960s for the purpose of making tools (dies) from hardened steel. As time progressed, manufacturers began to observe more and more benefits of this machining process. In 1976, first Computer Numerical Control (CNC) wire-EDM machine was developed. Today, this machine makes it possible to manufacture delicate, intricate and complex parts. In this process, electrically conductive material can be machined irrespective of the hardness of the material.

9.2 MATERIAL REMOVAL MECHANISM

Wire-EDM involves the complex erosion effect by rapid and repetitive (discrete) spark discharges between the wire tool and the job immersed in a liquid dielectric medium. A D.C. power supply is used to generate a very high frequency pulses. The wire electrode is threaded through a starting hole or pre-drilled hole in the workpiece mounted on the table. Generally, the job-blanks are hardened and annealed, and the starting hole is drilled before the heat treatment of the work-blank. The wire is unwounded from the feeding spool by a drive unit moving at constant speed to pass

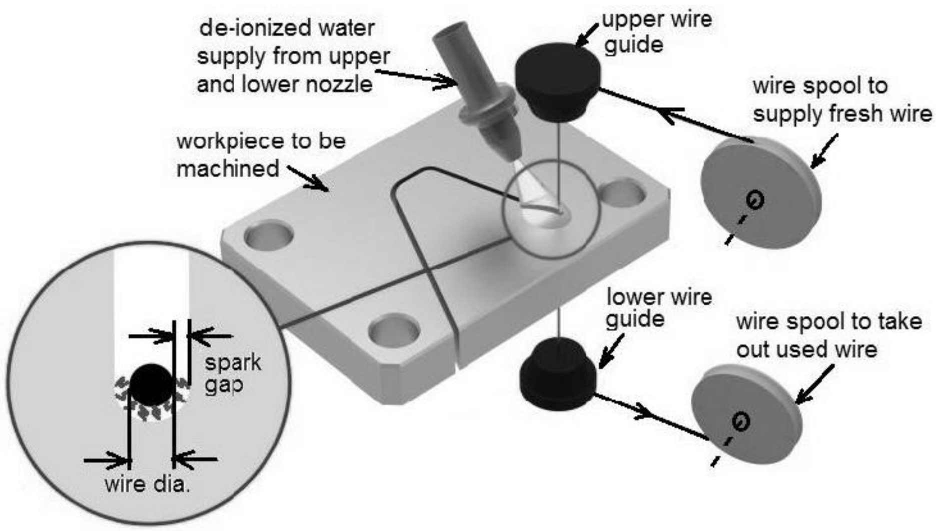

Figure 9.1 Schematic view of configuration of wire-EDM process

through a tension mechanism and then through the workpiece. The expanded wire is either rewound on a take up spool or chopped off in small pieces to be collected in a bin. However, a fresh electrode wire is continuously presented to the machining zone. A dielectric, usually de-ionized water, is continuously forced fed to the machining zone to flush away the eroded particles from the machining zone. De-ionized water is used as the dielectric medium because of the fact that it not only affords a better flushing and cooling but also creates an environment of low conductivity dielectric medium to provide a larger spark gap. The applied voltage across the workpiece and the wire tool creates an ionized channel in the spark gap. The resistance of the ionized channel gradually decreases until a spark discharge occurs with sparks of very short durations causing the temperature of the electrodes to be raised locally to more than the boiling of the workpiece material due to the transformation of the kinetic energy of electrons into heat. Thus, a very high energy density erodes a part of material from the workpiece and to some extent, also from the wire electrode by local heating, melting and vaporization. The schematic diagram of machining principle of wire EDM process is shown in Figure 9.1 with machining configurations.

9.3 WIRE-EDM SYSTEM DETAILS

The complete wire-EDM setup consists of three major units, (i) machine tool unit, (ii) dielectric supply unit and (iii) power supply unit. Each of these major units has several sub-units. Figure 9.2 shows the schematic representation of complete wire-EDM setup with its all sub-systems.

9.3.1 Machine tool unit

The details of various subsystems of a typical machine tool unit of wire-EDM setup are discussed hereunder.

(A) Worktable: The main worktable moves along X and Y axes, with minimum step of 1 μm (typically) by means of DC servo motors. The U and V axes, which are parallel to X and Y axes respectively are also driven by the same type of motors to drive the U-V table. The X-Y worktable is mounted on the base of machine. There

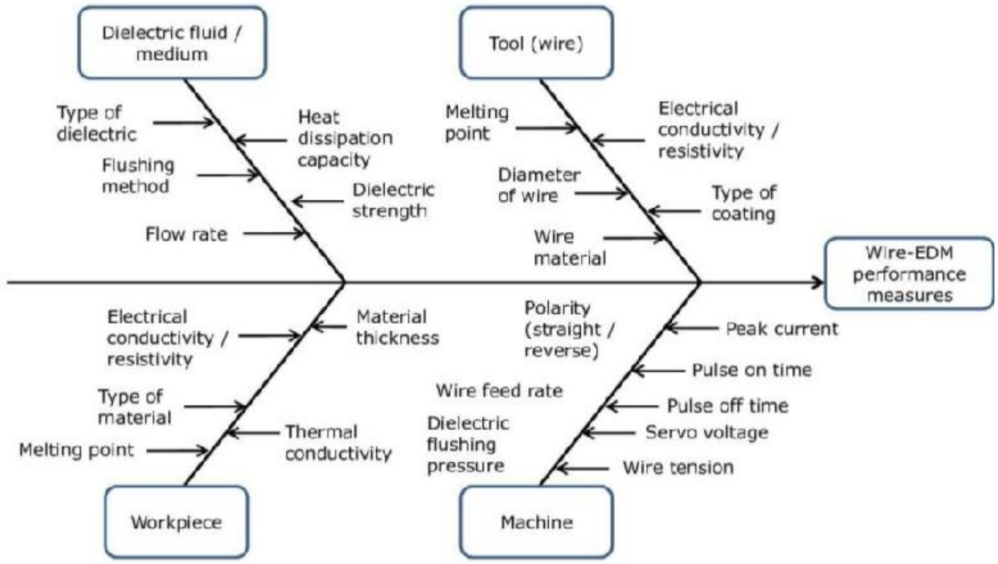

Figure 9.3 Fishbone diagram of process parameters of wire-EDM process

9.4 PROCESS PARAMETERS IN WIRE EDM

In wire-EDM process, there are a number of significant process parameters which have huge influences on dimensional accuracy as well as material removal rate. Figure 9.3 shows the fish-bone diagram of process parameters of wire-EDM process. Process parameters are divided into two main categories, (i) electrical parameters and (ii) nonelectrical parameters. The details of these process parameters are briefly explained in the following.

(A)Pulse-on-time and pulse-off-time: The duration of time for which the current is allowed to flow in each cycle is known as pulse-on-time. It is denoted by T_{on} and measured in micro seconds (μs). Similarly, the duration of time between two consecutive sparks is known as pulse-off-time. It is denoted by T_{off} and also expressed in micro seconds (μs). Voltage is applied only during the pulse-on-time (T_{on}) in between the electrode (wire) and the workpiece. So, the electric discharge is occurred only when the pulse duration is on.

(B) Peak current: It refers to the maximum amount of current that is passing through the electrodes for the given pulse. It is denoted by Ip and measured in amperes (A). During each pulse on time, the current increases until it reaches a pre-set value which is known as the peak current. Maximum amount of current is determined by the cutting surface area. Higher peak current leads to rough surface operation. Peak current has great influence on the material removal rate of the machining.

(C) Gap voltage: It provides the specific voltage for the actual gap between the workpiece and electrode (wire). This is also known as open circuit voltage. It is measured in volts (V). Greater the gap voltage, greater will be the electric discharge.

(D) Servo voltage: Servo voltage (SV) is used as the reference voltage for controlling the wire advances and retracts. The wire will advance or retracts during machining that depend on the variation of mean machining voltage. If the value of the mean machining voltage is greater than the level of the set servo voltage, the wire advances and if it is lower, the wire will retract. When a lower value of SV is set, gap between the workpiece and electrode also becomes narrower which leads to an increase in number of electric sparks and resulting in higher machining rate. However, if the state of machining at the gap becomes unstable then wire breakage will occur.

(E) Dielectric flow rate: It is the rate at which the dielectric fluid flows into the machining chamber to perform proper cooling and removal of debris. It is one of the most important process parameter for efficient machining. Typically, deionized water is used as dielectric fluid in WEDM process. Flushing helps to determine feed rates to be given for different thickness of material and it also produced pressure from both the top and bottom nozzles. Generally, the dielectric pressure is measured in bar.

(F) Wire feed: In WEDM, the wire is continuously fed from a spool to provide constant wire during machining. The wire feed is measured in meter per minute. With the increase of wire feed rate, the consumption of wire as well as machining cost will increase. Low wire speed will also cause wire breakage when cutting speed is high.

(G) Wire tension: It is the factor which controls the tightness of the wire. If it is high enough then the wire remains straight otherwise it drags behind. This helps to keep the wire free from vibration during machining. The higher tension decreases the vibration amplitude in the wire and as a result it decreases the cut width, thus the speed is higher for the same discharge energy. Due to improper wire tension, wire breakage may occur.

9.5 WIRE ELECTRODE

When Wire-EDM was introduced, copper wire was usually used due to its high electrical conductivity. But as the time progressed, the limitations of copper wire were discovered. Later on, a variety of wires are used in this process, like brass, molybdenum, tungsten etc. for different purpose. The materials of the electrode (wire) vary with the application requirements. Then coated wire is developed which has more advantages than plain wires. These are the wires that have had a very thin layer (2-3µm) of pure zinc applied to a brass or copper core. There are different types of coated wires are used for machining in wire cut EDM. They are (i) single layer coated wires, (ii) double layer coated wires, (iii) multi-layer coated wires and (iv) diffusion annealed coated wires.

(A) Single layer coated wires: Nowadays coated wires are available in a wide range due to its various applications and machine requirements. Zinc is coated with brass wire to increase the cutting speed over plain brass wire, with no loss in any of the other critical properties. Zinc is also coated with copper wire in order to combine the conductivity of a copper core as well as flushability of zinc. It has no current application because when sparks penetrate the thin zinc coating, the cutting rate slows to the sluggish pace of pure copper wire. When a wire electrode is coated with a metal or alloy having a low vaporization temperature like zinc, cadmium, tin, lead, antimony, bismuth etc., it protects the core of the wire against thermal shock.

(B) Double layer coated wires: A lot of patent inventions have been made in US to enhance the property of coated wires. Patent No. US4968867 discloses a wire electrode with a core of copper, silver, aluminum, or alloys, which has relatively high thermal conductivity. This electrode wire has a lower coating layer formed by a low boiling point material as well as an outermost brass layer of high mechanical strength. It has some effects like vibration dumping, heat transfer and breakage resistivity which ultimately results in increasing machine speed. Patent No. US4977303 also disclosed a method of forming an EDM wire electrode by coating a copper wire core with zinc. After coating, it is heated in an oxidizing atmosphere to provide a copper-zinc alloy layer over the copper core and a zinc oxide surface over the alloy layer simultaneously. As a result of this, the wire electrode permits greater current density and traction force to be employed, yielding a significantly higher machining speed in the EDM process than the speed which was achieved by using earlier electrode wires.

(C) Multi-layer coated wires: Patent number US4341939 has been invented to increase in machining speed by eliminating the short circuits which can decrease the machining efficiency, more precisely by rapidly changing the transformation of non-erosive short circuited electrical discharges into electro-erosive effective discharges. The wire electrode is coated with at least one thin layer of non-metallic material and the film has a sufficient thickness to provide a semi-conductive effect when the film is in contact with the electrode workpiece. When a few volts are applied between the electrode (wire) and workpiece, the film completely becomes a conductor by electrical and/or thermal breakdown resulting applied voltage rises from a few volts to about 100V. The metallic coating is generally made of zinc and then it is subjected to an oxidizing thermal or electrolytic treatment such that on the surface of the metallic layer a thin film of zinc oxide is formed.

(D) Diffusion annealed coated wires: If zinc has a great flush ability, one can assume that a pure zinc coating would produce the ultimate wire. In theory, this may be possible but not practically. Zinc has a low melting point, and it is only plated on the surface of the core wire. The intensity of the spark discharge has a tendency to blast the zinc off the wire core surface. Therefore, a coating with high zinc content and relatively high melting point will result in good adhesion to the core wire. All these effects can be achieved by heat-treating the zinc-coated wire and the process is known as diffusion annealing. Diffusion will occur under an elevated temperature and an inert gas environment. It is the process where atoms diffuse from higher concentration areas to lower concentration areas. The zinc atoms diffuse into the brass then the copper atoms from the brass diffuse into the zinc. This diffusion process changes the zinc coating into a high-zinc brass alloy which has a relatively high melting point and is also metallurgical bonded to the core material.

9.6 WIRE ELECTRODE FAILURE AND ITS PREVENTION

Wire rupture is one of the biggest problems in wire cut EDM application. This is occurred due to mainly high peak current and increases in spark frequency. The diameter of the wire and the tension applied on the wire are the other important factors for wire breakage. If the wire is too thin or the tension is too high then rupture will happen in spite of the gap condition. Wire breakage increases overall machining time and decreases the accuracy of workpiece. If the wire breaks during the machining then rethreading has to be done but it is very difficult to reset the wire where it ruptured. Though, various automatic wire-feed mechanisms (AWF) are available on sophisticated machines. It allows an automatic restart of the

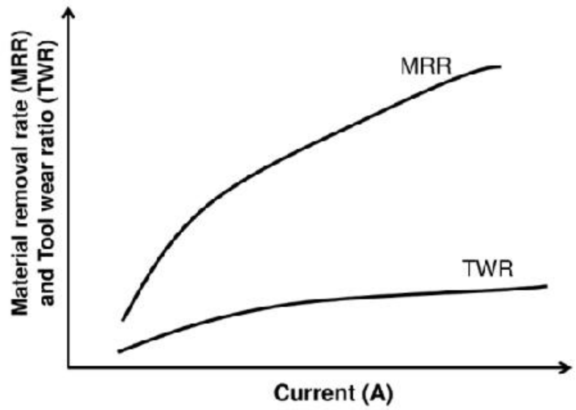

Figure 9.7 Influence of discharge current on material removal rate (MRR) and tool wear ratio (TWR)

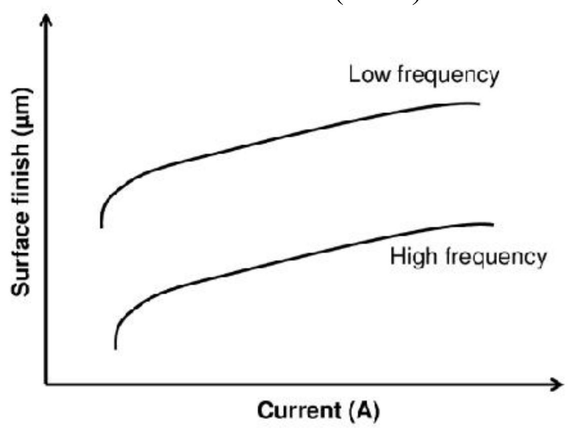

Figure 9.8 Influence of discharge current on surface finish

9.9 INFLUENCES OF PROCESS PARAMETERS ON PERFORMANCE CRITERIA

(A) Effect of discharge current: With increase in the value of discharge current, the value of material removal rate, surface roughness and wire wear ratio / tool wear ratio also increase. High discharge current is generally used for rough operations as well as for making cavities. It is also one of the major factors which affect the surface roughness during machining. Figure 9.7 show the effect of discharge current on material removal rate and tool wear ratio in wire-EDM process. In Figure 9.8, the effect of discharge current on surface finish is shown.

(B) Effect of gap voltage: As the gap voltage increases the peak current also increases which in turn can improve the cutting rate further. This also effects on material removal rate of the machining.

(C) Effect of pulse duration: As the value of pulse on time increases results into production of higher energy which will lead to the removal of more material. But, with higher values of Ton, surface roughness (Ra) will also be higher. There must be some optimal value of pulse on time otherwise breakage of wire will occur due to higher energy. Figure 9.9 shows the influence of pulse on time on machined surface

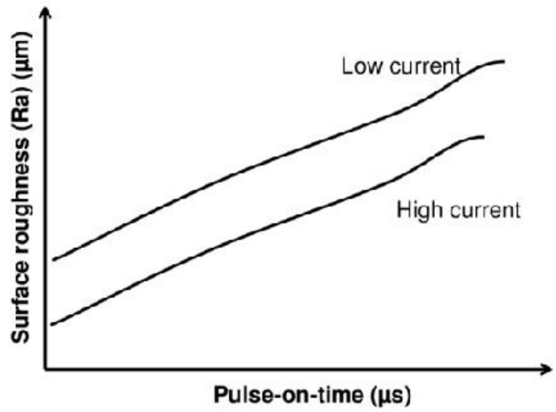

Figure 9.9 Influence of pulse on time on machined surface roughness (Ra)

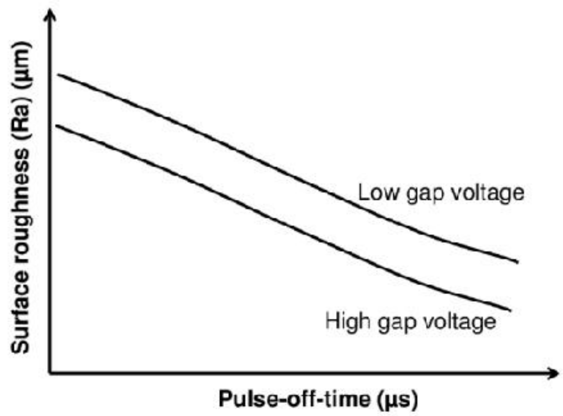

Figure 9.10 Influence of pulse off time on machined surface roughness (Ra)

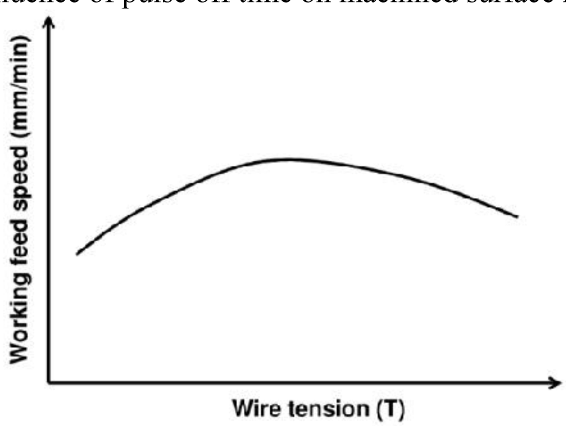

Figure 9.11 Influence of wire tension on cutting / wire feed speed

roughness (Ra). The influence of pulse off time on machined surface roughness is shown in Figure 9.10.

(D) Effect of wire tension: If the wire tension is high enough then the wire stays straight otherwise it drags behind. In Figure 9.11, the effects of wire tension on cutting speed / wire feed speed is shown. Within certain range, an increase in wire tension significantly increases the cutting speed and accuracy in the finished part. The higher tension decreases the wire vibration amplitude and hence decreases the cut width so that the speed is higher for the same discharge energy. However, if the applied tension exceeds the tensile strength of the wire, it leads to wire breakage.

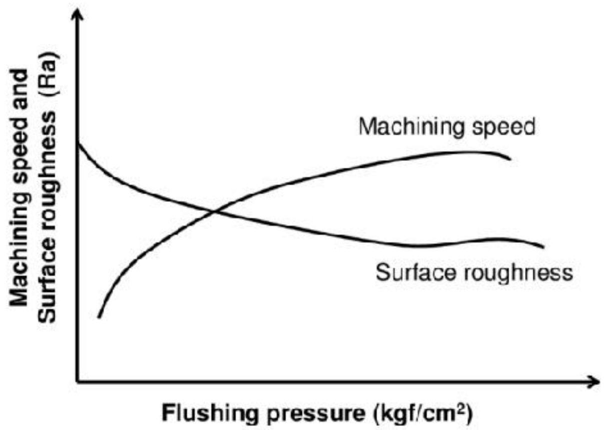

Figure 9.12 Influence of dielectric flushing pressure on machining speed and surface roughness (Ra)

(E) Effect of dielectric pressure: Dielectric flow rate significantly affects material removal rate and surface roughness especially for the workpiece with low thermal conductivity. Figure 9.12 shows the effect of dielectric flushing pressure on machining speed and surface roughness (Ra). The cutting performances during roughing cuts have been improved since the removed particles in the machining gap are evacuated more efficiently. It can be seen that when flushing pressure is less than certain pressure value, it is impossible to do any machining. Along with increased flushing pressure the machining speed also increases, but when it is over certain value, the increased trend slows down while the surface roughness improves gradually with increased flushing pressure; due to effective removal of debris.

(F) Effects of feed rate: With the increase of wire feed rate, the consumption of wire and cost of machining will increase. But low wire speed will also cause wire breakage in high cutting speed. So, there must be some optimum value for proper machining.

9.10 VIBRATION OF WIRE

The vibrational phenomena of the wire is very complicated in nature because the magnitudes and directions of various forces acting along or upon the wire are not always remain constant as the occurrence of sparks is highly stochastic in nature. The stochastic nature of the Wire EDM process is occurred due to combination of various factors like fluctuation in voltage and current, interaction of two successive discharges and presence of debris particles in machining zone, decomposition and distribution of dielectric etc. However, sparks still continue to occur in the extreme modal positions of the wire while the wire is in vibrational mode. It is almost impossible to determine forces quantitatively which are acting along or upon the wire. Though, the main forces are forces from the gas bubbles formed by the plasma of the erosion mechanism, hydraulic forces due to flushing, electrostatic force and electrodynamic force. Among these forces, electrodynamic force has little effect on the vibrational behavior of the wire. A high tension without wire rupture is always favorable to reduce the amplitude of wire-tool vibration.

9.11 WIRE LAG PHENOMENA

WEDM is very useful whenever there is a need to generate complex geometry with high accuracy. Geometrical inaccuracies are not acceptable in those conditions. So, wire lag should be as minimum as possible because it will produce geometrical inaccuracies. It is generally measured using profile projector by measuring the projection image. The effects of various process parameters on wire lag during rough cut like pulse on time, pulse off time and pulse peak current and during trim cutting like pulse peak voltage, wire tension, servo spark gap set voltage are the significant factors.

9.12 AUTOMATIC RELOADING OF BROKEN WIRE

Now-a-days automatic wire thread system is used for higher productivity as well as less time wastage for threading the wire. It provides approximately 100% reliability. This feature helps to cut die block, progressive dies and prototype workpiece automatically. Cutting and threading of the wire are controlled by coding program. During machining, if there is a wire breakage, the machine returns to the initial starting point, re-threads the wire and move through the program path to the wire break position then it powers up and continues cutting without hampering the accuracy.

9.13 ADVANTAGES AND LIMITATIONS OF WEDM

Advantages

The advantages of WEDM process are listed below.

(i) Wire-EDM is a non-contact type thermo-electric machining process, therefore, the process is irrespective of physical, mechanical and metallurgical properties of material.

(ii) The process is very well suited for making fragile parts, which cannot take the stress of machining.

(iii) This process is useful for cutting intricate mold cavities and difficult to machine parts.

(iv) The surface finish generated in this process is high, therefore, secondary finishing operations are not required.

Limitations

The disadvantages of WEDM process are listed below.

(i) Due to electrical discharges, material is removed from travelling wire and therefore, the wire is not re-usable.

(ii) Since the process needs to generate electrical discharge for machining, the workpiece should be electrically conductive.

(iii) For starting the cutting process, a pre-drilled hole is required.