# MACHINING

# Level - III

# Learning Guide 6

**Unit of Competence: Perform EDM Plunger and Wire Operations**

**Module Title: Performing EDM Plunger and Wire Operations**

**LG Code: <u>IND MAC3 06 0217</u>**

| Instruction Sheet | Learning Guide #1 |
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This learning guide is developed to provide you the necessary information regarding the following **content coverage** and topics:

- Determine work requirements
- Prepare EDM machining operations
- Perform electro-discharge machining (EDM)
- Check components for conformance to specification

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, **upon completion of this Learning Guide, you will be able to**:

- Drawings are interpreted, and sequence of operations is determined with accordance to standard
- Electrode surface area is calculated and process parameters are set to give safe, accurate and efficient operation
- Machine and work piece is aligned to specified datum points in accordance with worksite standard procedures
- Components are checked using appropriate techniques, tools and equipment with conformance to specification

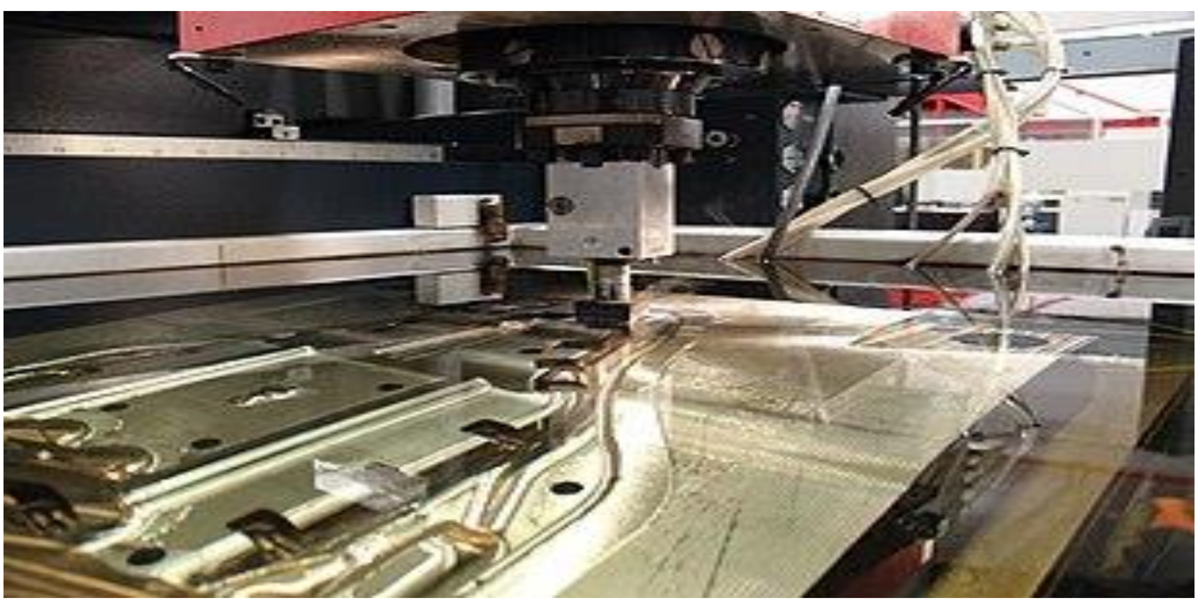
**Learning Instructions:**

1. Read the specific objectives of this Learning Guide.
2. Follow the instructions described below 3 to 20.
3. Read the information written in the information "Sheet.
4. Accomplish the "Self-check test.
5. Do the "LAP test".

# *Determine work requirements*

Electrical discharge machining (EDM), also known as spark machining, spark eroding, die sinking, wire burning or wire erosion, is a metal fabrication process whereby a desired shape is obtained by using electrical discharges (sparks).[1] Material is removed from the work piece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the tool or electrode, while the other is called the workpiece-electrode, or work piece. The process depends upon the tool and work piece not making physical contact.

When the voltage between the two electrodes is increased, the intensity of the electric field in the volume between the electrodes becomes greater, causing dielectric break down of the liquid, and produces an electric arc. As a result, material is removed from the electrodes. Once the current stops (or is stopped, depending on the type of generator), new liquid dielectric is conveyed into the inter-electrode volume, enabling the solid particles (debris) to be carried away and the insulating properties of the dielectric to be restored. Adding new liquid dielectric in the inter-electrode volume is commonly referred to as flushing. After a current flow, the voltage between the electrodes is restored to what it was before the breakdown, so that a new liquid dielectric breakdown can occur to repeat the cycle.



## Introduction

In recent years, the rapidly rising demand for materials with special characteristics in such advanced industrial applications as aerospace and surgical instruments, has led to the development of new materials. However, these materials are mostly difficult-to-cut using more conventional manufacturing processes and this pushes manufacturers to explore new machining processes which maintain or even improve precision but at reasonable cost.

***Stainless steel*** is one of the widely used difficult-to-cut materials because of its superior properties which combine good corrosion and chemical reaction resistance, with the ability to be easily cleaned, polished and sterilized. New stainless-steel compositions are developed to meet the need for higher corrosion resistance, increased strength and elevated temperature resistance.

As mentioned in Reference about 150 separate and distinct compositions of stainless steels already exist. These compositions include grades #304, #305 and #316, each of which was developed to meet a specific end-use and each of which—in common with most stainless steels—contain common alloying ingredients, such as chromium, nickel or molybdenum.

Electric discharge machining (EDM) is one of the most advanced and successful manufacturing methods used to machine materials that are difficult-to-cut.

EDM is being used in modern industries to facilitate complex machining processes and achieve highly accurate machining.

EDM is utilized to remove material from a conductive workpiece by repetitively applying sparks between the EDM electrode tool or wire and the workpiece. In this process, no mechanical cutting forces are applied because no contact exists between the electrode tool and the workpiece. The fundamental principles of the EDM process are applied in many processes, including: die-sinking EDM, wire EDM, micro-EDM, powder-mixed EDM and dry EDM. These variants make the process suitable for machining components from the relatively large to the micro-scale. The EDM process has advantages over other machining processes. EDM can machine complex shapes and extremely hard materials as described in a number of publications. The EDM can be used to machine very small, delicate and fragile products without damage because no cutting forces are applied and hence there are no mechanical induced residual stresses. However, EDM has its own limitations with regards to the workpiece material and shape. At present EDM can only be applied on electrically conductive materials. The process has low material removal rate and high electrical power consumption. Furthermore, additional cost is incurred preparing the electrode tool in case of the die-sinking EDM. Finally, sharp corners are difficult to produce using EDM because of electrode tool wear.

While many studies have reviewed EDM, wire EDM and other EDM processes, no study has reviewed and reported on the use of EDM for machining of stainless steel specifically, though there are many reviews available on other materials machined by EDM. This study aims to provide an overview of the significant contributions of EDM to the machining of various stainless-steel variants. This paper reviews the research studies that used different EDM variants for machining different types of steel materials. The paper starts with a brief introduction of EDM and its development, then it provides the working principles of this machining method. EDM process parameters and performance measures are then discussed. Next, the paper presents the various types of EDM processes. This study also provides a review of the major areas of research into the application of EDM to different grades of steel. The conclusions drawn by and the trend of, the reviewed research are presented and discussed. Figure 1shows the EDM processes and their main input (process) parameters and output (performance) measures.

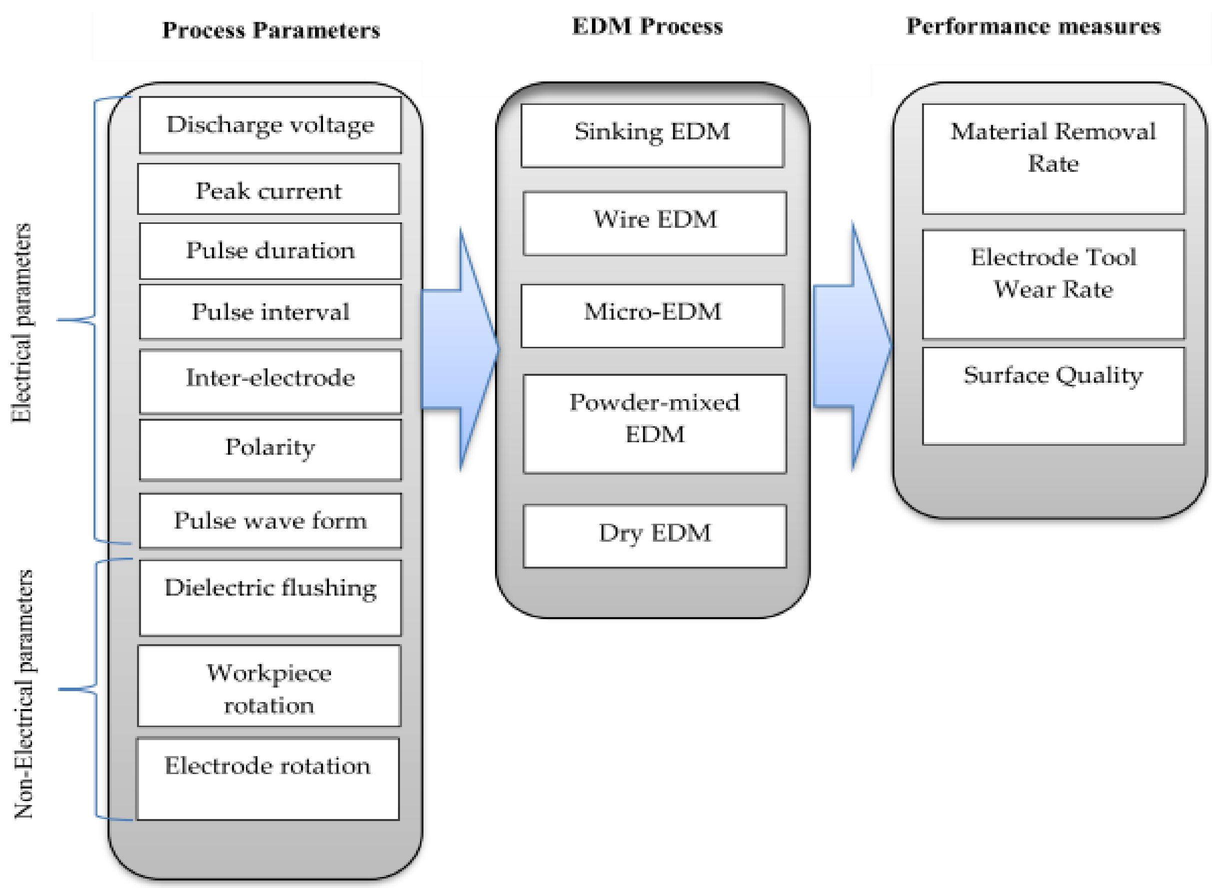



**Figure 1.** Electric discharge machining (EDM) processes, process parameters and performance measures.

## General View of the EDM Method

## EDM Principles

The EDM manufacturing process was invented in the 1940's. The principle of the EDM technique is to use thermoelectric energy to erode a workpiece by automatic spark repetition. The rapidly recurring electrical discharges (sparks) between a non-contact electrode tool and the workpiece allow erosion caused by sparks generated between electrode tool and the workpiece surface. In this process, both the workpiece and the electrode tool are submerged in an insulating dielectric fluid. The gap between the electrode tool and the workpiece is carefully selected so that the voltage across the gap has a value that can ionize the dielectric fluid in the gap due to electrical breakdown. Discrete electric discharges between the electrode tool and workpiece are produced which in turn generates a high temperature plasma channel, where instant thermal dissipation occurs. The local high temperature melts both workpiece and tool. Then, the eroded material solidifies in the form of debris. Flushing the dielectric fluid during the machining process carries away debris (separated solid particles) and restores the sparking condition in the gap and avoids short circuiting. No cutting forces exist between the electrode tool and the workpiece because there is no contact between them. This minimizes the vibration and stress problems that can occur during machining.

A principle of EDM is shown in Figure 2

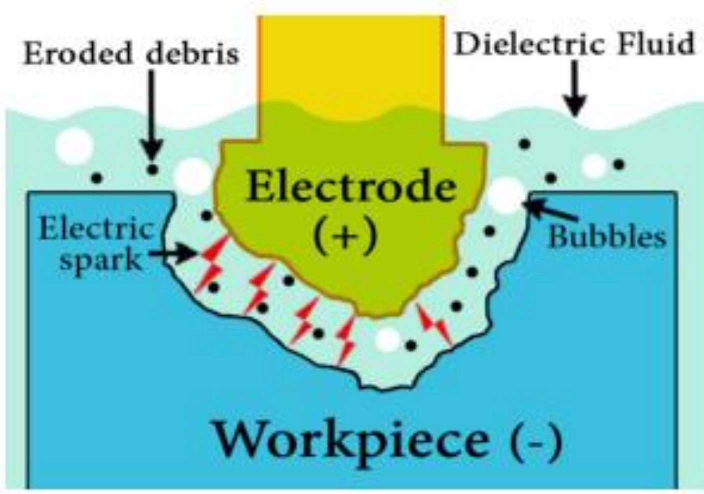



**Figure 2.** Principle of EDM.

## *EDM Process Parameters*

The EDM process is driven by both electrical and non-electrical parameters. The major electrical parameters are discharge voltage, peak current, pulse duration and interval, electrode tool gap, polarity and pulse waveform. The non-electrical parameters include rotation of the electrode tool, the flushing action of the dielectric fluid and the properties of the workpiece. These parameters are described in this section.

The discharge or machining voltage is the average voltage in the spark gap during machining. The electrical potential drops sharply after the open gap voltage because of the discharge and the current flow rises. The machining will begin at the working voltage. The discharge voltage directly influences the size of spark gap and overcut. A low voltage is normally used with electrode tool and workpiece materials that possess high electrical conductivity. In contrast, materials with low conductivity use a much higher voltage. The peak current, which is defined by the maximum power spent in discharge machining, is a parameter that highly influences the EDM process. The peak current is represented by the maximum level that is reached during the on-time of each pulse. This parameter has a direct effect on the material removal rate (MRR), tool wear rate (TWR) and machining accuracy. These characteristics make it very important and has resulted in research into high wear resistance that can occur with high current conditions.

The pulse on-time is the duration for which the discharge is applied. A high-temperature plasma channel heats both the electrode tool and the workpiece during the discharge. The amount of energy generated during the pulse on-time has a direct effect on the MRR. Increasing the discharge energy by applying longer pulse on-times increases the MRR. Debris form during the discharging period, creating an insulation layer and lead to arcing. This layer can be flushed away during pulse-off time. The pulse off-time is the time in which no discharge is applied. Proper selection of the pulse off-time provides stable machining. A shorter period can increase the machining speed but off-time should be long enough to allow flushing away of debris from the gap; otherwise, it may result in unsuitable conditions for the next on-time pulse, taking into account that long breaks between pulses can cause overcooling the machined material which has impact on MRR. The pulse wave form is usually rectangular in shape, to reduce electrode tool wear other pulse shapes have been used, for example, trapezoidal. Another generator has recently been developed to facilitate initiation of the main pulse by producing a high voltage pulse with a low current for a short period before the main pulse.

The effect of the EDM process parameters on performance cannot be easily explained because of the stochastic nature of the discharge mechanism. Thus,

many studies related to EDM have explored the influence of the process parameters on performance measures and have introduced the concept of optimal process parameters that achieve best performance.
The electrode tool polarity in the EDM process can be positive or negative and this determines the direction of the electrical current, from or toward the electrode tool. The choice of polarity depends on many factors, including electrode tool and workpiece materials, current density and pulse length. In die-sinking EDM, the generators have the flexibility to switch to either a positive or a negative electrode tool polarity based on the machining requirements. Positive electrode tool polarity is generally used in EDM operations because electrode tool wear will be lower. The negative electrode tool polarity is a better choice if a high MRR is more important than precision. Nevertheless, this is at the cost of very high electrode tool wear. Negative electrode tool polarity machining conditions are suitable for machining materials, such as carbide, titanium and copper alloys, amongst others. In the wire-EDM process, the electrode "wire" usually has a negative polarity because a high machining rate is required and the wire wear is not important because the wire can be fed continuously to replace the eroded portion.
The necessary sparks do not occur if the electrode tool and the workpiece touch each other. Thus, the electrode tool and the workpiece are separated by a small distance called the "inter-electrode gap." The discharge gap is controlled by the discharge gap servo that maintains the proper separation which is normally between 0.005 mm and 0.1 mm. The electrode tool is moved up and down during machining to enable proper evacuation of the debris. The discharge occurs during the down period and the up period allows the flushing of the debris away from the machining area. For finishing and micro EDM processes, RC generator is usually used. The RC pulse generator is a low-cost power source for EDM and principally a relaxation oscillator with a resistor and a capacitor. It can produce very small pulse energy that generates small craters which in turn lead to produce small surface roughness. However, lack of precision control is the main disadvantage of RC generator especially for timing and slow charging. The main non-electrical parameters are the flushing of the dielectric fluid, workpiece and electrode tool rotation. The EDM process needs a dielectric fluid medium that submerges both the electrode tool and the workpiece to at least a suitable distance above the gap between them. In addition to high dielectric strength, the dielectric fluid must have a flushing ability and fast recovery after breakdown. The dielectric fluid provides insulation against premature discharging, reduces the temperature in and around the machined area and cleans away the separated debris. For the die-sinking EDM,

the dielectric fluid is a hydrocarbon and silicone-based dielectric oil and kerosene with an increased flash-point. Some die-sinking EDMs use de-ionized water for high-precision machining, such as fine hole drilling. De-ionized water and oil are also used with wire EDM. Many studies have recently been conducted to explore the use of oil-based synthetics to avoid harmful effects to the worker and the environment. Previous studies have reported that the dielectric type, flushing method and flushing pressure influence the MRR, TWR, surface roughness (SR) and surface quality (SQ). Dielectric flushing is improved with workpiece and electrode tool rotation. The improvement in flushing due to electrode tool rotation achieves a better SR and a higher MRR. Selecting the optimal flushing pressure can minimize the density of the crack and the recast layer.

## Performance Measure Parameters

The performance parameters are the factors that measure the performance of the EDM process. These parameters include the MRR, TWR and SQ. The MRR is a measure of the performance of the erosion rate of the workpiece surface and an indication of the machining ratio. The MRR is usually expressed as the volume of the removed material per unit time. Techniques and methods to improve the MRR have attracted attention because the MRR represents the machining speed. The TWR is a measure of the erosion rate of the electrode tool and has a direct influence on the shape of the machined cavity because of the continual change in the electrode tool profile during the machining process. Similar to the MRR, the TWR can be expressed by the volume of material removed per unit time. Previous studies focused on reducing the TWR because the wear of the electrode tool affects the electrode tool profile and leads to a lower precision. The SQ is a measure of the quality of the machined surface and includes many components, such as the SR, extent of the heat affected zone (HAZ), recast layer thickness and micro-crack density. Many research studies have explored utilization of the EDM process in surface treatment and have reported the SQ generated by the process.

## Electrical Discharge Machines (EDM)

Wire EDM machines utilize a very thin wire (.0008 to .012 in.) as an electrode. The wire is stretched between diamond guides and carbide that conduct current to the wire and cuts the part like a band saw.

Material is removed by the erosion caused by a spark that moves horizontally with the wire.

## Types of EDM Processes
## Die-Sinking EDM

In the die-sinking EDM process, the workpiece is machined by a controlled electrical spark generated in the gap between the electrode tool and the workpiece. Sparking is repeated until the electrode tool shape is replicated in the workpiece surface facing the electrode tool. The heat produced by the electrical spark causes a sharp temperature rise in the area to be machined (i.e., 8000 to 12,000 °C).
EDM machines contain a unit that controls and monitors the machining variables, such as the gap and axis movements. Furthermore, this system shows the process execution sequence.
Normally, copper or graphite is used as the electrode tool material in this process with hydrocarbon dielectric because of its positive effect on the SR and EWR (Electrode tool Wear Rate). The dielectric flows through the cooling system, carrying the debris and eroded material with it, is filtered to remove the suspended particles and is returned to the system. In the die-sinking EDM process, the electrode should be re-shaped to carry out the finishing operations. Figure 3 shows a schematic diagram of the die-sinking EDM.

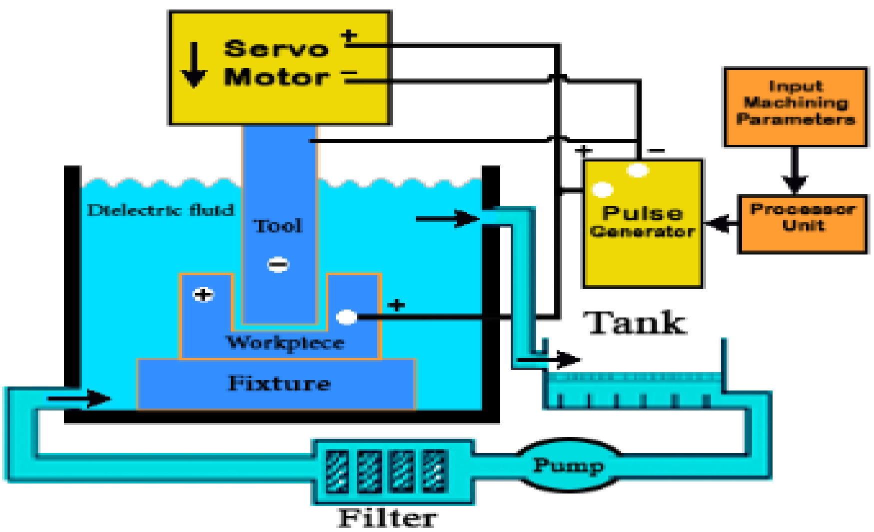
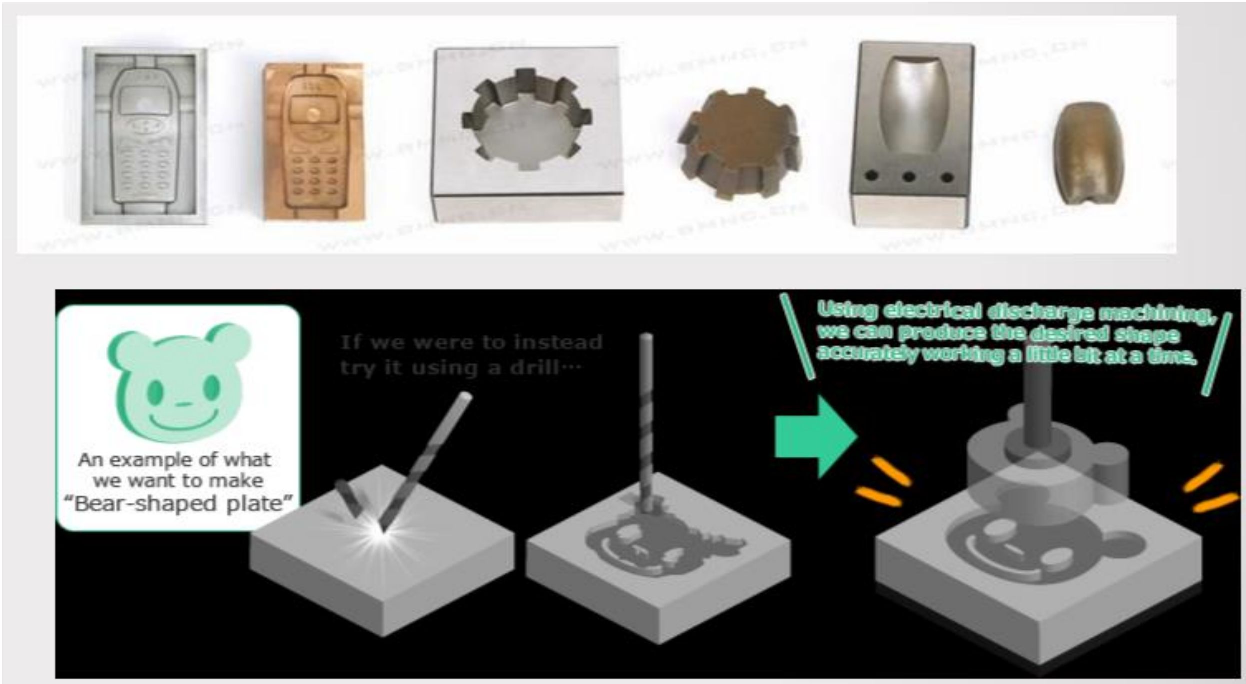



Figure 3. Schematic diagram of the die-sinking EDM.

## Typical Parts Die-Sinking EDM

1 Injection Molds
2 Dies
3 Complex shapes




## Wire EDM

In the wire EDM, a metallic thin wire is used to cut the workpiece along a well-defined path. Discrete sparks between the wire and the workpiece cause eroding in the machined area. The wire used is usually thin, the standard EDM wire is 0.25 mm. Micro-wires dimeter can range from 0.020 mm to 0.15 mm and is normally copper, brass or coated steel materials. As with the die-sinking EDM, the wire and the workpiece do not have any contact during machining and both should be immersed in a dielectric fluid. A high peak current of short duration is applied in this process. The machining variables and the movement of the worktable that holds the workpiece are controlled by the control units. Thus, complicated shapes can be produced using this process. The control unit contains a microprocessor to maintain the gap between the wire and the workpiece in a suitable range, normally between 25 µm and 50 µm. In addition, the unit controls the feeding of the wire through the workpiece at a suitable speed that produces surfaces with very high accuracy. De-ionized water is a common dielectric fluid used in this process. The wire EDM process has a wide range of applications, such as in die making, electronics and automotive industries. Closed operations, which do not start from the edges of the workpiece, require the drilling of a full-depth hole to start the machining process. Figure 4 shows a schematic diagram of the wire EDM.

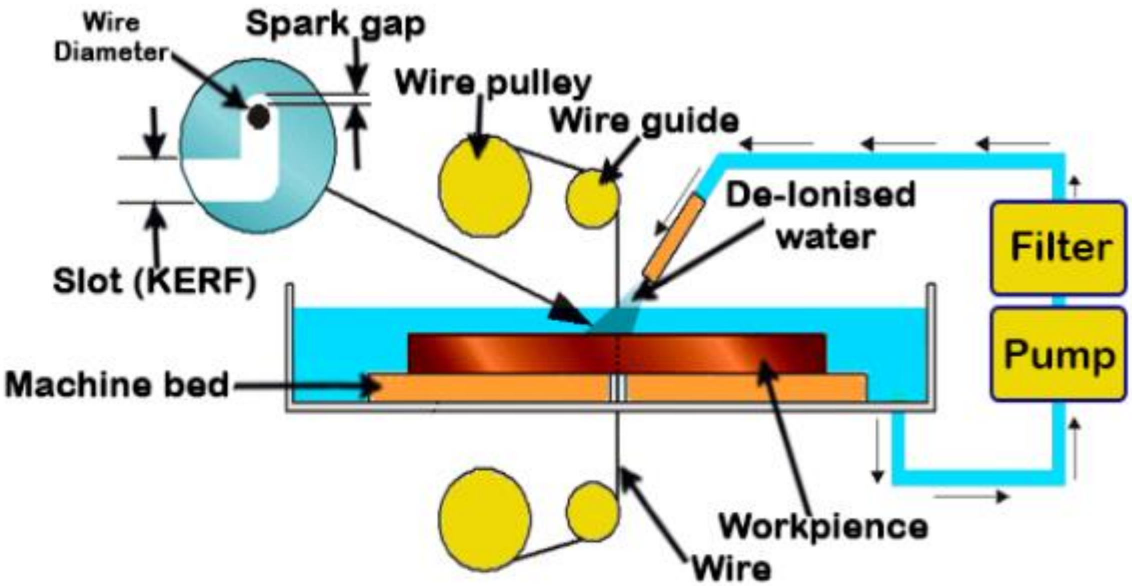
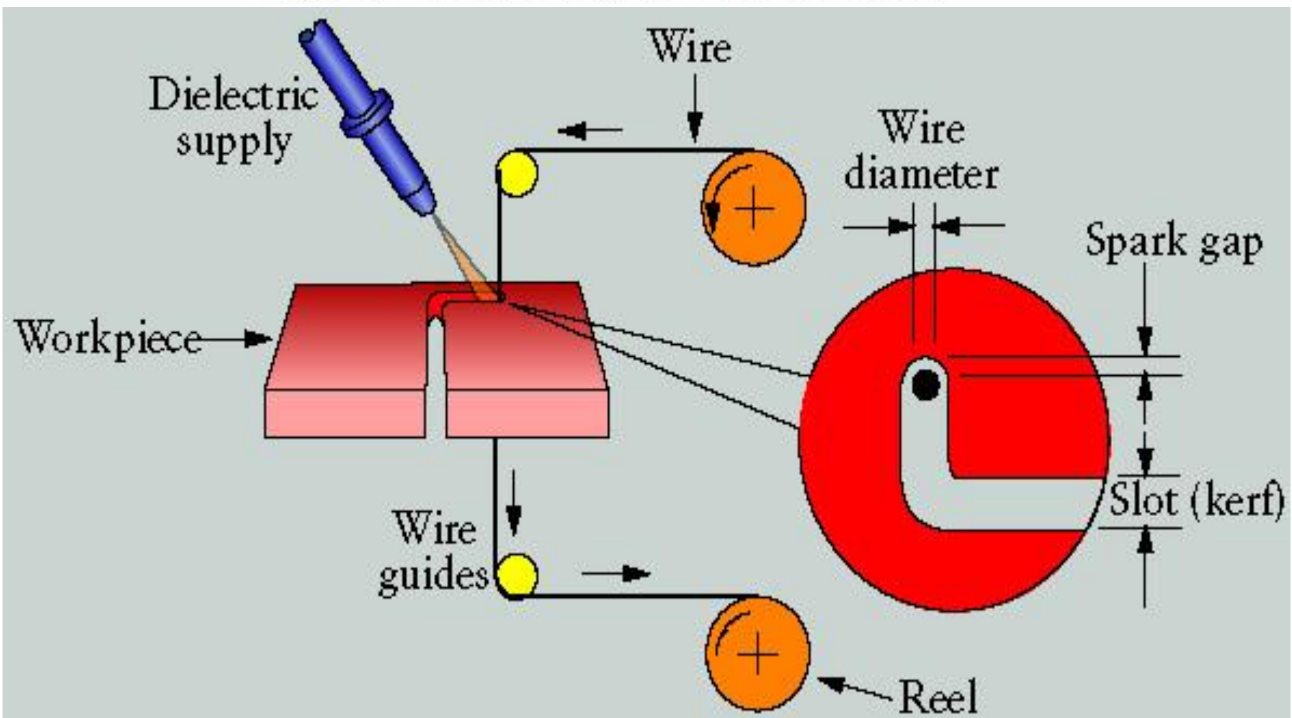
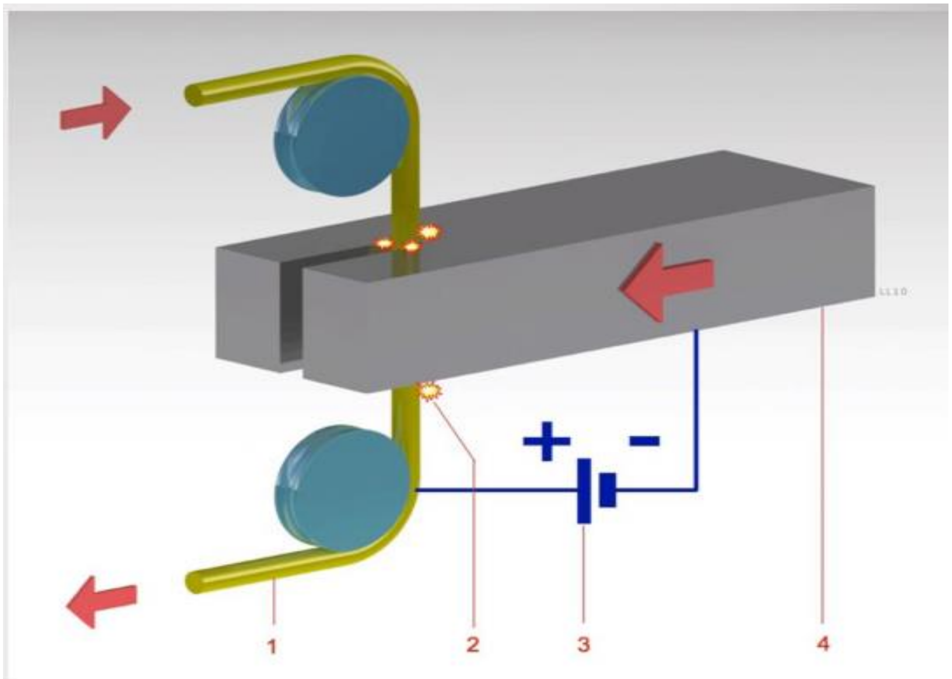


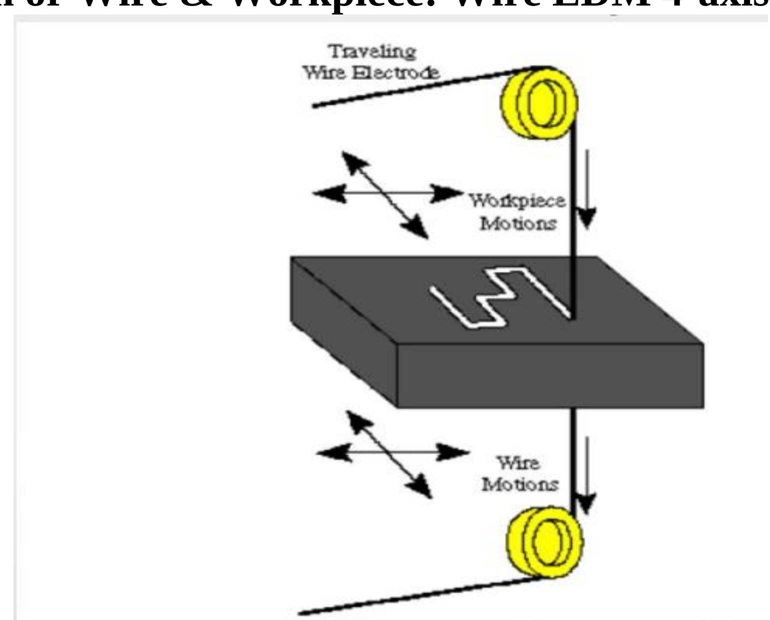

**Figure 4.** Schematic diagram of the wire EDM.



1 Wire.
2 Electrical discharge erosion (Electric arc).
3 Electrical potential.
4 Workpiece.




## Motion or Wire & Workpiece: Wire EDM 4-axis motion possible

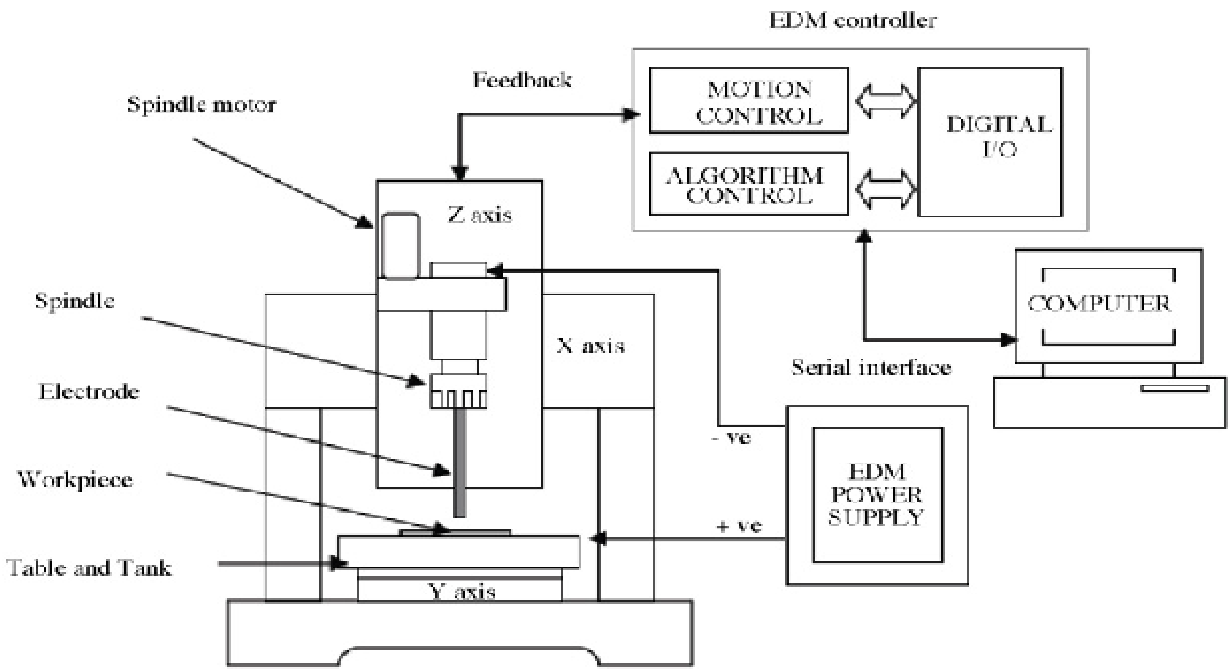


# 4-axis Motion

- With the 4-axis Wire EDM
- Different shapes can be produced on top and bottom of a workpiece


## Micro EDM

The micro-EDM is a machining process that follows the same principles as the die-sinking EDM and wire EDM. The process removes material at the micro-scale for components smaller than 100 µm, including micro-holes, micro-shafts and 3D micro-cavities. The only principled difference from the other EDM processes is the power involved. The MRR will be in nano meters because the machine part is at the micro level and the required voltage and current will be several times less than those used in the die-sinking EDM or any other normal-level EDM process. This process can produce a hole or shaft diameters of only 5 µm, while holes of up to 70 µm and 40 µm can be produced by drilling and laser machining, respectively. EDM at the micro-scale level is available in many machining processes, such as die-sinking micro-EDM, micro-wire EDM, micro-EDM drilling and micro-EDM milling. In the micro-wire EDM, a wire with a diameter less than 20 µm is used. The minimum machinability of cavities in other micro-EDM processes have diameters of 5 µm. The grain sizes of workpiece materials have significant impact on the characteristics of micro EDM. The MRR for micro-EDM has a direct relationship with the grain size of the machined workpiece because the effective thermal conductivity and local effective melting point of polycrystalline materials vary with grain sizes of these materials since the grain boundary volume fractions change. It is worth emphasizing that the material microstructure of the processed workpiece plays a significant role in the performance of the micro EDM process. In particular, the refined material microstructure can give a better surface quality when compared with the results for the course grained microstructure of the same material. This conclusion is explained by the heterogeneity of the course grained material microstructure that normally leads to more anisotropic behavior of the microstructure and the more homogenous response of the refined microstructure that results in more isotropic/consistence behavior.




Schematic diagram of micro-EDM

## Powder-Mixed EDM

As the name implies, powder of a suitable material, such as nickel, is mixed with the dielectric fluid. The presence of this powder makes the process mechanism substantially different from the conventional EDM process. The powder particles fill the gap between the electrode tool and the workpiece when a voltage is applied during machining. This particle aggregation forces the electrode tool and the workpiece to move a small distance further apart by an amount equal to the gap filled by the powder particles. The gap between the electrode tool and the workpiece can increase by 100% to 300% (from 25–50 µm to 50–150 µm). The presence of the powder particles between the electrode tool and the workpiece leads to earlier and faster sparking, which causes a higher erosion rate.

## Dry EDM

The dry EDM uses dielectric high-pressure gas instead of dielectric liquid. Here, the electrode tool is in the form of a thin-walled pipe through which high-pressure gas or air is supplied. The pressurized gases flow outwards through the gap between electrode tool and machined surface and carry away the debris being formed. The gases also reduce the machining area temperature. Using gas instead of fluid in this process can reduce harmful environmental effects. Most notably the dielectric fluid and the powder-mixed dielectrics in the EDM processes are associated with evaporation from the fluid surface during machining. Utilizing gas can also decrease the cost of managing the debris waste and enhance the machining performance and the environment as regards worker health. From this point of view, this process could be named as the “Green EDM.” The dry EDM process positively influences the MRR and reduces the EWR. Under ideal conditions, this process allows to obtain very good accuracy and surface layer quality.
In addition to the previous main types of EDM, there are other types such as EDM milling, in this type the final shape is obtained using a simple electrode tool which is moved in a 3D path along several directions and may also subject to rotations. A combination of the two cutting systems can also be applied. Also, EDM grinding, when the electrode tool design as a rotating disk.

### Mathematical Modeling of the Thermos-Physical Phenomenon in EDM

EDM involves removal of material from the workpiece due to heat generated from electric discharge in the inter-electrode gap. Plethora of research study and analyses this phenomenon; mathematical models are developed to provide better understanding of the EDM process. A quasi-static model is proposed by, the model computes the material removal rate based on predicted distribution of the temperature in the workpiece. Equation of transient heat conduction is employed to predict the distribution. The model assumes Gaussian heat flux since it gives better results as demonstrated by. Finite element method is used to solve the model and obtain the results, which show significant closeness to the experimental results. Vaporization of workpiece and tool materials is studied by. The model is used to predict the aerosol emission of EDM process. 70% of the aerosol is found to be vaporized material from the workpiece and the tool, the rest comes from the dielectric fluid. The electric field generated in the interelectrode gap is modelled by. The model represents the electric field at two stages. First; before-discharge stage, where Laplace equation is used to model the electrostatic field. Second; during–discharge state, where Poisson equation is used to model the spatial discharge from electrode and particles of the dielectric fluid. Fluid flow in the interelectrode gap is modelled by. The model attempts to study the motion of the debris particle as well as the drag force between the particles and the dielectric fluid. The purpose is to improve the removal of debris from the machining zone. Fluent software is used to build 3D model of drilling high aspect ratio of a hole. The effect of incorporating ultrasonic vibration is verified using the proposed model; optimal amplitudes and frequencies are determined using the model based on a set of process parameters.

**Application of EDM**

The EDM process has the ability to machine hard, difficult-to-machine materials. Parts with complex, precise and irregular shapes for forging, press tools, extrusion dies, difficult internal shapes for aerospace and medical applications can be made by EDM process. Some of the shapes made by EDM process are shown in Figure 3.

Figure 3: Difficult internal parts made by EDM process

## Advantages EDM include machining

- Complex shapes that would otherwise be difficult to produce with conventional cutting tools.
- Extremely hard material to very close tolerances.
- Very small work pieces where conventional cutting tools may damage the part from excess cutting tool pressure.
- There is no direct contact between tool and work piece. Therefore, delicate sections and weak materials can be machined without perceivable distortion.
- A good surface finish can be obtained; a very good surface may be obtained by redundant finishing paths.
- Very fine holes can be attained.
- Tapered holes may be produced.
- Pipe or container internal contours and internal corners down to R .001".

## Disadvantages of EDM include

- Difficulty finding expert machinists.
- The slow rate of material removal.
- Potential fire hazard associated with use of combustible oil based dielectrics.
- The additional time and cost used for creating electrodes for ram/sinker EDM.
- Reproducing sharp corners on the workpiece is difficult due to electrode wear.
- Specific power consumption is very high.
- Power consumption is high.
- "Overcut" is formed.
- Excessive tool wear occurs during machining.
- Electrically non-conductive materials can be machined only with specific set-up of the process.