CHAPTER 3

NON-TRADITIONAL MACHINING PROCESS

3.1 INTRODUCTION

In the early stage of mankind, tools were made of stone for the item being made. When iron tools were invented, desirable metals and more sophisticated articles could be produced. In twentieth century products were made from the most durable and consequently, the most unmachinable materials. In an effort to meet the manufacturing challenges created by these materials, tools have now evolved to include materials such as alloy steel, carbide, diamond and ceramics. The conventional manufacturing processes in use today for material removal primarily rely on electric motors and hard tool materials to perform tasks such as sawing, drilling and broaching. Conventional forming operations are performed with the energy from electric motors, hydraulics and gravity. Likewise, material joining is conventionally accomplished with thermal energy sources such as burning gases and electric arcs. In contrast, non-traditional manufacturing processes harness energy sources considered unconventional by yesterday’s standards. Material removal can now be accomplished with electrochemical reaction, high temperature plasmas and high-velocity jets of liquids and abrasives. Materials that in the past have been extremely difficult to form, are now formed with magnetic fields, explosives and the shock waves from powerful electric sparks. Material-joining capabilities have been expanded with the use of high-frequency sound waves and beams of electrons and coherent light.
The non-conventional manufacturing processes are not affected by hardness, toughness or brittleness of material and can produce any intricate shape on any workpiece material by suitable control over the various physical parameters of the processes. The non-conventional manufacturing processes may be classified on the basis of type of energy namely, mechanical, electrical, chemical, thermal or magnetic, apply to the workpiece directly and have the desired shape transformation or material removal from the work surface by using different scientific mechanism. Thus, these non-conventional processes can be classified into various groups according to the basic requirements which are as follows:

(i) Type of energy required, namely, mechanical, electrical, chemical etc.

(ii) Basic mechanism involved in the processes, like erosion, ionic dissolution, vaporization etc.

(iii) Source of immediate energy required for material removal, namely, hydrostatic pressure, high current density, high voltage, ionized material, etc.

(iv) Medium for transfer of those energies, like high velocity particles, electrolyte, electron, hot gases, etc. On the basis of above requirements, In this research work is concentrate on the following non-conventional machining process

1. Electrical Discharge Machining (EDM)

2. Wire Electrical Discharge Machining (WEDM)

3.2 ELECTRICAL DISCHARGE MACHINING (EDM)

Electro-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. EDM can cut small and odd shaped angles, intricate contours or cavities in prehardened steel without the need for heat treatment to soften and re-harden them as well as such as titanium, kovar, carbide etc.

Electro Discharge Machining (EDM) is considered to be one of the most successful non conventional machining process, 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 alloys. The tool (electrode) and the work piece are separated by a small gap and submerged in a dielectric fluid. The metal is removed by means of melting and vaporizing of the surface layers in the work piece. 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 such as very high electrical and thermal conductivity, strength, stiffness, toughness and microstructure etc. Since that time EDM has become a sophisticated and

Ideally, EDM can be seen as a series of breakdown and restoration of the liquid dielectric in-between the electrodes. However, caution should be exerted in considering such a statement because it is an idealized model of the process, introduced to describe the fundamental ideas underlying the process. Yet, any practical application involves many aspects that may also need to be considered. For instance, the removal of the debris from the inter-electrode volume is likely to be always partial. Thus the electrical proprieties of the dielectric in the inter-electrodes volume can be different from their nominal values and can even vary with time. The inter-electrode distance, often also
referred to as spark-gap, is the end result of the control algorithms of the specific machine used. The control of such a distance appears logically to be central to this process. Also, not all of the current between the dielectric is of the ideal type described above: the spark-gap can be short-circuited by the debris. The control system of the electrode may fail to react quickly enough to prevent the two electrodes (tool and workpiece) to get in contact, with a consequent short circuit. This is unwanted because a short circuit contributes to the removal differently from the ideal case. The flushing action can be inadequate to restore the insulating properties of the dielectric so that the current always happens in the point of the inter-electrode volume (this is referred to as arcing), with a consequent unwanted change of shape (damage) of the tool-electrode and workpiece. Ultimately, a description of this process in a suitable way for the specific purpose at hand is what makes the EDM area such a rich field for further investigation and research.

To obtain a specific geometry, the EDM tool is guided along the desired path very close to the work; ideally it should not touch the workpiece, although in reality this may happen due to the performance of the specific motion control in use. In this way, a large number of current discharges (colloquially also called sparks) happen, each contributing to the removal of material from both tool and workpiece, where small craters are formed. The size of the craters is a function of the technological parameters set for the specific job at hand. They can be with typical dimensions ranging from the nano scale (in micro-EDM operations) to some hundreds of micrometers in roughing conditions.

The presence of these small craters on the tool results in the gradual erosion of the electrode. This erosion of the tool-electrode is also referred to as wear. Strategies are needed to counteract the detrimental effect of the wear on the geometry of the work piece. One possibility is that of continuously
replacing the tool-electrode during a machining operation. This is what happens if a continuously replaced wire is used as electrode. In this case, the correspondent EDM process is also called wire EDM. The tool-electrode can also be used in such a way that only a small portion of it is actually engaged in the machining process and this portion is changed on a regular basis. This is, for instance, the case when using a rotating disk as a tool-electrode. The corresponding process is often also referred to as EDM grinding.

A further strategy consists in using a set of electrodes with different sizes and shapes during the same EDM operation. This is often referred to as multiple electrode strategy, and is most common when the tool electrode replicates in negative the wanted shape and is advanced towards the blank along a single direction, usually the vertical direction (i.e. z-axis). This resembles the sink of the tool into the dielectric liquid in which the workpiece is immersed, so, not surprisingly, it is often referred to as die-sinking EDM (also called conventional EDM and ram EDM). The corresponding machines are often called sinker EDM. Usually, the electrodes of this type have quite complex forms. If the final geometry is obtained using a usually simple-shaped electrode which is moved along several directions and is possibly also subject to rotations, often the term EDM milling is used.

In any case, the severity of the wear is strictly dependent on the technological parameters used in the operation (for instance: polarity, maximum current, open circuit voltage). For example, in micro-EDM, also known as μ-EDM, these parameters are usually set at values which generates severe wear. Therefore, wear is a major problem in that area.

The problem of wear to graphite electrodes is being addressed. In one approach, a digital generator, controllable within milliseconds, reverses polarity as electro-erosion takes place. That produces an effect similar to electroplating that continuously deposits the eroded graphite back on the
electrode. In another method, a so-called "Zero Wear" circuit reduces how often the discharge starts and stops, keeping it on for as long a time as possible.

### 3.2.1 Technological Parameters

Difficulties have been encountered in the definition of the technological parameters that drive the process. Two broad categories of generators, also known as power supplies, are in use on EDM machines commercially available: the group based on RC circuits and the group based on transistor controlled pulses.

In the first category, the main parameters to choose from at setup time are the resistance(s) of the resistor(s) and the capacitance(s) of the capacitor(s). In an ideal condition these quantities would affect the maximum current delivered in a discharge which is expected to be associated with the charge accumulated on the capacitors at a certain moment in time. Little control, however, is expected over the time duration of the discharge, which is likely to depend on the actual spark-gap conditions (size and pollution) at the moment of the discharge. The RC circuit generator can allow the user to obtain short time durations of the discharges more easily than the pulse-controlled generator, although this advantage is diminishing with the development of new electronic components. Also, the open circuit voltage (i.e. the voltage between the electrodes when the dielectric is not yet broken) can be identified as steady state voltage of the RC circuit.

In generators based on transistor control, the user is usually able to deliver a train of pulses of voltage to the electrodes. Each pulse can be controlled in shape, for instance, quasi-rectangular. In particular, the time between two consecutive pulses and the duration of each pulse can be set. The amplitude of each pulse constitutes the open circuit voltage. Thus, the
maximum duration of discharge is equal to the duration of a pulse of voltage in the train. Two pulses of current are then expected not to occur for duration equal or larger than the time interval between two consecutive pulses of voltage.

The maximum current during a discharge that the generator delivers can also be controlled. Because different machine builders may also use other sorts of generators, the parameters that may actually be set on a particular machine will depend on the generator manufacturer. The details of the generators and control systems on their machines are not always easily available to their user. This is a barrier to describing unequivocally the technological parameters of the EDM process. Moreover, the parameters affecting the phenomena occurring between tool and electrode are also related to the controller of the motion of the electrodes.

3.2.2 Material Removal Mechanism

The first serious attempt of providing a physical explanation of the material removal during electric discharge machining is perhaps that of Van Dijck. Van Dijck presented a thermal model together with a computational simulation to explain the phenomena between the electrodes during electric discharge machining. However, as Van Dijck himself admitted in his study, the number of assumptions made to overcome the lack of experimental data at that time was quite significant.

Further models of what occurs during electric discharge machining in terms of heat transfer were developed in the late eighties and early nineties, including an investigation at Texas A&M University with the support of AGIE, now Agiecharmilles. It resulted in three scholarly papers: the first presenting a thermal model of material removal on the cathode, the second presenting a thermal model for the erosion occurring on the anode and the
third introducing a model describing the plasma channel formed during the passage of the discharge current through the dielectric liquid. Validation of these models is supported by experimental data provided by AGIE.

These models give the most authoritative support for the claim that EDM is a thermal process, removing material from the two electrodes because of melting and/or vaporization, along with pressure dynamics established in the spark-gap by the collapsing of the plasma channel. However, for small discharge energies the models are inadequate to explain the experimental data. All these models hinge on a number of assumptions from such disparate research areas as submarine explosions, discharges in gases, and failure of transformers, so it is not surprising that alternative models have been proposed.

Given the many available models, it appears that the material removal mechanism in EDM is not yet well understood and that further investigation is necessary to clarify it, especially considering the lack of experimental scientific evidence to build and validate the current EDM models. This explains an increased current research effort in related experimental techniques.

**Advantages and Disadvantages**

Some of the advantages of EDM include machining of:

- 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 any distortion.
- A good surface finish can be obtained.
- Very fine holes can be easily drilled.

**Disadvantages of EDM include:**

- The slow rate of material removal.
- 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.

### 3.3 **WIRE ELECTRICAL DISCHARGE MACHINING (WEDM)**

Wire EDM machining (Electrical Discharge Machining) is an electro thermal production process in which a thin single-strand metal wire in conjunction with de-ionized water (used to conduct electricity) allows the wire to cut through metal by the use of heat from electrical sparks. Due to the inherent properties of the process, wire EDM can easily machine complex parts and precision components out of hard conductive materials. Wire EDM machining (also known as "spark EDM") works by creating an electrical
discharge between the wire or electrode, & the workpiece. As the spark jumps across the gap, material is removed from both the workpiece & the electrode. To stop the sparking process from shorting out, a non conductive fluid or dielectric is also applied. The waste material is removed by the dielectric, and the process continues. In [wire EDM machining], a thin single-strand metal wire, usually brass, is fed through the workpiece. The wire, which is constantly fed from a spool, is held between upper and lower guides. The guides move in the X-Y plane, and sometimes the upper guide can also move independently giving rise to transitioning shapes (circle on the bottom square at the top). This gives the Wire EDM the ability to be programmed to cut very intricate and delicate shapes. The wire-cut uses water as its dielectric with the water's resistivity and other electrical properties carefully controlled by filters and de-ionizer units.

In wire electrical discharge machining (WEDM), also known as wire-cut EDM and wire cutting a thin single-strand metal wire, usually brass, is fed through the workpiece, submerged in a tank of dielectric fluid, typically deionized water. Wire-cut EDM is typically used to cut plates as thick as 300 mm and to make punches, tools, and dies from hard metals that are difficult to machine with other methods.

The wire, which is constantly fed from a spool, is held between upper and lower diamond guides. The guides, usually CNC-controlled, move in the x–y plane. On most machines, the upper guide can also move independently in the z–u–v axis, giving rise to the ability to cut tapered and transitioning shapes (circle on the bottom square at the top for example). The upper guide can control axis movements in x–y–u–v–i–j–k–l–. This allows the wire-cut EDM to be programmed to cut very intricate and delicate shapes.

The upper and lower diamond guides are usually accurate to 0.004 mm, and can have a cutting path or kerf as small as 0.12 mm using Ø
0.1 mm wire, though the average cutting kerf that achieves the best economic cost and machining time is 0.335 mm using Ø 0.25 brass wire. The reason that the cutting width is greater than the width of the wire is because sparking occurs from the sides of the wire to the work piece, causing erosion. This "overcut" is necessary, for many applications it is adequately predictable and therefore can be compensated for (for instance in micro-EDM this is not often the case). Spools of wire are long—an 8 kg spool of 0.25 mm wire is just over 19 kilometers in length. Wire diameter can be as small as 20 micrometres and the geometry precision is not far from +/- 1 micrometre.

The wire-cut process uses water as its dielectric fluid, controlling its resistivity and other electrical properties with filters and de-ionizer units. The water flushes the cut debris away from the cutting zone. Flushing is an important factor in determining the maximum feed rate for a given material thickness.

Along with tighter tolerances, multi-axis EDM wire-cutting machining center have added features such as multiheads for cutting two parts at the same time, controls for preventing wire breakage, automatic self-threading features in case of wire breakage, and programmable machining strategies to optimize the operation.

Wire-cutting EDM is commonly used when 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.

The work piece may undergo a significant thermal cycle, its severity depending on the technological parameters used. Such thermal cycles
may cause formation of a recast layer on the part and residual tensile stresses on the work piece.

Wire EDM (Electrical Discharge Machining) uses electric current and fine wire to cut conductive materials. The cutting typically occurs while the object is submerged in deionized water, which helps to cool the process and flush away the cut material. It leaves a smooth surface that often requires no further finishing or polishing. Note that the cutting wire should not touch the material and that the cutting itself is due to the erosion that occurs when a spark forms between the cutting wire and the raw material. The EDM process is generally computer-controlled (CNC) and as a result is highly accurate and repeatable. A typical wire EDM process will consist of several passes, moving at various speeds. The first pass is typically a fast-moving, lower accuracy cut which is used to remove large quantities of material. Later skim passes will retrace the cuts at lower speed, removing less material and improving the surface quality and accuracy of the cut. Also note that machining occurs after heat treatment so the finished dimensions of the machined items are not adversely affected by heat treatment.

Most sophisticated EDM setups allow the rotation of the cutting wire through several axes and through large angles, allowing products to be tapered and finished in 3 dimensions. The ability to taper the finished product is very useful when creating stamping dies and extrusion molds. Complex cutouts can be formed by drilling a hole through the raw material, threading the EDM wire through the hole and cutting. Materials that can be cut include most metals and metal alloys, graphite, carbide and diamond. Applications of Wire EDM include the manufacture of extrusion dies, blanking punches and metal and tool fabrication. The process is most suitable for low production volumes of items which require tight manufacturing tolerances.
3.3.1 Parameters of WEDM

The following parameters are considered in wire electrical discharge machining process

- Wire tension
- Current
- Wire speed
- Pulse on time
- Pulse of time
- Kerf

3.3.2 Benefits of WEDM

The advantages of the WEDM is given below

1. Efficient Production Capabilities
2. Fast Turnarounds
3. Reliable Repeatability
4. Without EDM--Impossible to Machine
5. Reduced Costs
6. Stress-Free and Burr-Free Cutting
7. Tight Tolerances and Excellent Finishes