Chapter-1

INTRODUCTION
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1.1 INTRODUCTION

Manufacturing / Production is undergoing various changes due to the unending needs of the customers for qualitative, reliable and sophisticated parts and products in the modern and technological world. To meet such requirements on one side and global market on other side, manufacturers around the world are striving for lower price solutions in order to maintain their competitiveness on machined components and manufactured goods. Thus the manufacturing of goods involves the machining of parts or components with the cutting tools set or loaded on the machine tools. Accordingly, the Production / Manufacturing of any part depends on the effective working of the cutting tool and thus leading to meet the production schedules and cost effective. To meet such demands in Production / Manufacturing the technology has been playing enormous role in advancing the metal working industry and creating opportunities in the reduction of cost and improvement in quality with dimensional accuracy.

Technologically advanced industries such as aeronautics, nuclear reactors, automobiles, etc., have been demanding materials like high strength temperature resistant (HSTR) alloys having high strength to weight ratio. It is no longer possible to find tool materials to cut materials like Titanium, Stainless Steel, Nimonic and other High Strength Temperature Resistant (HSTR) alloys, Fiber Reinforced Composites, Stellites, Ceramics and difficult to machine alloys. Production of complex shapes in such materials is also difficult by conventional methods. Other high quality level requirements such as better finish, low values of tolerances and sophistication are the need of the day. Making of holes in difficult to machine materials is another area which demands appropriate processes. To meet such demands, advanced machining processes have come into existence. Such advanced machining processes have specific characteristics compared to conventional
machining methods. The basic principle of machining by such methods is to apply some form of energy without direct contact between the tool and the work piece either Mechanical energy or Electrical energy. The combination of Thermo electric energy and Chemical energy are the other forms of energies are being used during the machining. One of such unconventional machining processes is the Electrical Discharge Machining (EDM) has come up in production of parts with quality, sophistication and dimensional accuracy. Further, the growth of the fast computing systems and integration of such Computer Systems with EDM and electrodes led to the Wire-EDM (WEDM), [Ho, et al., 2004 (45)]

Effect of two machining methods dry and wet-EDM and surface integrity and the effect of pulse current and gap voltage on surface roughness during wet and dry wire EDM of stainless steel are investigated, [Abdul Kareem, et al., 2011 (2)].

As such, the Wire-EDM is gaining importance in the present modern manufacturing industry to meet not only the customer demand but also at the Global level. Therefore, the present research work is taken up to conduct experiments on three different materials. Wire-EDM is one of the most popular techniques of the Unconventional Production / Manufacturing processes in the present Global Manufacturing scenario. The Wire-EDM utilises the wire which acts as a tool upon passing the current so as to erode the work material by the generation of spark(s) between the work and tool. Referring Figure-1.1, the work and the tool are immersed in a die-electric fluid and then allowed to pass through to remove the material by erosion and such machining helps to produce parts with good surface quality and dimensional accuracy. Such dimensional accuracy with surface quality has been proved by the experimental investigation on AISI D5 Tool Steel, [Ahmed Hascalyk, et al., 2004, (3)]; P20 Die-Tool Steel, [Bhaskar Reddy, et al., 2012 (17)].

The other important capabilities of the Wire-EDM are the production of parts (i) with micro-level accuracy, [Ravindra, et al., 2008 (149)] and (ii) with improved productivity, [Nixon, et al., 2011 (122)]. Before the Wire EDM is explained, Introduction to UMM and the basics of EDM are explained in the following.
1.2 INTRODUCTION TO UNCONVENTIONAL MACHINING METHODS (UMM)

With the development of technology, more and more challenging problems are faced by the scientists and technologies in the field of manufacturing industries like aeronautics, automobiles, nuclear reactors, etc. The difficulty in adopting the traditional manufacturing processes can be attributed mainly, new materials with low machinability, Dimensional accuracy requirements and higher production rate and economy. To make efficient use of modern machining processes, it is necessary to know the exact nature of the machining problem. It is to be understood that (i) the methods cannot replace the conventional machining processes and (ii) a particular machining method found suitable under the given conditions may not be equally efficient under other conditions. A careful selection of the process for a given machining problem is, therefore, essential. Before selecting the process to be employed the following aspects must be studied: (i) Physical parameters (ii) Properties of the work material and the shape to be machined (iii) Process capability (iv) Economic considerations. Hence, Researchers in the area of material science are developing materials having a high strength, hardness, toughness and other diverse properties. This also needs the development of improved cutting tool materials so that the productivity is not hampered. The production of complex shapes in such materials by traditional methods is still more difficult. So to meet such demands a different class of machining process (i.e. advanced machining processes / Non – conventional machining processes) has been developed.
1.3 UNDERSTANDING EDM

The EDM is no longer a “non-conventional” machining method. It is claimed that EDM is the fore-most popular machining method in present manufacturing after the milling, turning, and grinding. One of the major reasons for the turn around is today’s EDM machines have dramatically increased their cutting speed. In today’s highly competitive world, it is essential to understand the electrical discharge machining (EDM) process. Before going to Wire-EDM every manufacturer needs to learn and understand the many advantages of EDM. There are three basic EDM processes namely Ram EDM, Micro-hole EDM drilling and Wire EDM. All the three types of EDM work on the principle of spark erosion. As the name indicates, material is eroded from the work piece by means of electrical discharges that create sparks, [Jain, 2010 (53)]. The principle of working of the above three methods are explained in the following sub-sections.

1.3.1 Different Types of EDM

[i] **Ram EDM**: Ram EDM, also known as conventional EDM or Sinker EDM or Die Sinker or Vertical EDM or Plunge EDM, is generally used to produce blind cavities. In Ram EDM, sparks jump from the electrode onto the work piece. That jumping causes the removal of material from the work piece. The basic working principle of an EDM is shown in Figure-1.1. It can be seen that the work piece takes the shape of the electrode. Electrical Discharge Machining (EDM) is one of the most extensively used non-conventional material removal processes. Its unique feature of using thermal energy to machine electrically conductive parts regardless of hardness has been its distinctive advantage in the manufacture of mould, die, automotive, aerospace and surgical components. In addition, EDM does not make direct contact between the electrode and the work piece, thus eliminating the mechanical stress, chatter and vibration problems during machining.

[ii] **Microhole Drilling**: In the present day EDM is being used to drill small hole and micro level holes also. The principles of such small hole drilling are shown in Figure – 1.2 (a) and micro-hole drilling, Figure-1.2 (b). Small-hole
EDM drilling, also known as fast hole EDM drilling, hole popper and start hole EDM drilling, uses a hollow electrode to drill holes by means of electrical discharge machining by eroding material from the work piece as shown in Figure -1.2 (a).

[ili] **Wire-EDM:** The Wire-EDM which has gained importance in the present UMM Scenario is the main topic of present Research Work and is discussed in detail in the next Chapters.

![Figure-1.2: (a): Principle of Small-hole Drilling with EDM](Carle and Steve 2005 (22))

![Figure-1.2: (b): Principle of Micro-hole Drilling with EDM](Carle and Steve 2005 (22))
1.3.2 Electric Discharge Machining (EDM) Applications

EDM has been widely used in Industry to obtain better surface conditions at micro level and MRR. An over view on EDM with specific reference to micro electrical discharge machining technologies and its related applications in die and mould making as an alternative to Hot Embossing, Micro Injection Moulding and Bulk Forming has been brought-out to show the importance of EDM in Production Industry, [Eckart Uhlmann, 2005 (30)]. Further, the EDM has been extended to many other applications such as (i) usage of Copper tool Electrode on AISI P20 Steel in Finish machining, [Amorim and Weingaertner, 2005 (7)]; (ii) Study the influence of machining parameters on Surface Roughness while machining the AISI P20 Steel, [Kiyak and Akir, 2007 (76)]; (iii) Obtaining Surface condition to Nano Scale on FE-Mn-Al Alloy [Guu and Hou, 2007 (42)] and (iv) Enhancement of MRR while machining of Ti$_3$SiC$_2$ Ceramic material, [Hu, et al., 2008 (49)]. As the developments brought-in with the technical growth, the Wire-EDM has been in forefront. Hence, the Wire-EDM is taken for Research.

1.4 WEDM MACHINE

Wire-EDMs are manufactured in various sizes and styles of flush or submerged type machines to fit the needs of the consumer. Large scale EDM can handle work pieces weighing over ten thousand pounds and can cut over 50 cm thick. Automatic Wire Threaders (AWD) are usually standard equipment on most models. In addition to the X-Y table travels, wire-EDMs have U/V travels of wire for providing the movement to cut tapers. Most machines can cut tapers of 20-30 degrees depending on work piece thickness.

Wire EDM which represents current technology is shown in Figure - 1.3(a). The system consists of a Computer Numerical Control, Power supply with Anti-electrolysis Circuitry, Automatic Wire Threading, Hand held pendant, Programmable Z-axis, Water chiller and Filtration system. Wire EDM cutting process is shown in Figure-1.3(b).
1.4.1 Major Components of WEDM System

A Wire EDM machine system is comprised of four major components,

1. Computerized Numerical Control (CNC)
2. Power Supply: Provides energy to the spark
3. Mechanical Section: Work Table, Work Stand, Taper unit and Wire Drive Mechanism.
4. Dielectric System: The water reservoir where filtration, condition of the water resistivity/conductivity and temperature of the water are provided and maintained.

1.4.2 Principle of Wire-EDM

In Wire-EDM, the conductive materials are machined with a series of electrical discharges (sparks) that are produced between an accurately positioned moving wire (the electrode) and the work piece. High frequency pulses of alternating or direct current is discharged from the wire to the work piece with a very small spark gap through an insulated dielectric fluid (water).

Many sparks can be observed at one time. It is because actual discharges can occur more than one hundred thousand times per second, with discharge sparks lasting in the range of 1 / 1,000,000 of a second or less. The volume of metal removed during that short period of spark discharge depends on the desired cutting speed and the surface finish required.
The heat of each electrical spark, estimated at around 8315° to 11648° Centigrade, erodes away a tiny bit of material that is vaporized and melted from the work piece. (Some of the wire material is also eroded away). Such particles (chips) are flushed away from the cut with a stream of de-ionized water through the top and bottom flushing nozzles. The water also prevents heat build-up in the work piece. Without this cooling, thermal expansion of the part would affect size and positional accuracy. One has to keenly observe that it is the ON and OFF time of the spark that is repeated over and over removing material, not just the flow of electric current.

1.4.3 Mechanism of Metal Removal

The removal of material in Electrical Discharge Machining is based on the erosion effect of electric sparks occurring between two electrodes. Several theories have been forwarded in attempts to explain the complex phenomenon of "erosive spark", [Mikell Groover, 2010 (114)].

The following are the theories:

a. Electro-Mechanical Theory

b. Thermo-Mechanical Theory

c. Thermo-Electric Theory.

Electro-Mechanical Theory suggests that abrasion of material particles takes place as a result of the concentrated electric fluid. The theory proposes that the electric field separates the material particles of the work piece as it exceeds the forces of cohesion in the lattice of the material. This theory neglects any thermal effects. Experimental evidence lacks supports for this theory.

Whereby, Thermo-Mechanical Theory suggests that material removal in EDM operations is attributed to the melting of material caused by “Flame Jets”. These so-called flame jets are formed as a result of various electrical effects of the discharge. However, such theory does not agree with experimental data and fails to give a reasonable explanation of the effect of spark erosion.
Thermo-Electric Theory is best-supported by experimental evidence, suggests that metal removal in EDM operations takes place as a result of the generation of extremely high temperature generated by the high intensity of the discharge current. Although well supported, this theory cannot be considered as definite and complete because of difficulties in interpretation.

Wire EDM uses a travelling wire electrode that passes through the work piece. The wire is monitored precisely by a computer-numerically.

1.4.4 Steps Involved in Wire EDM Process

The steps involved in Wire-EDM are briefly presented in the following.

1. Power Supply Generates Volts and Amps

De-ionized water surrounds the wire electrode when the power supply generates volts and amps to produce the spark. The power supply generates volts and amps is shown in Figure-1.4

![Figure 1.4: Power supply generates Volts and amps](Image)

[Carle and Steve, 2005 (22)]
2. During on-time Controlled Spark Erodes Material.

The process of on-time melting of material to obtain the Précised sparks and vaporization of material is shown in Figure - 1.5.

![Diagram of on-time melting the material](image1.png)

**Figure-1.5 : On-time melting the material [Carle and Steve, 2005 (22)]**

3. 'Off Time' allows Fluid to remove eroded particles

The immediate cooling of the material by pressurized dielectric fluid and eroded particles of the material during the off cycle are flushed out cools are shown in Figure-1.6.

![Diagram of Off Time to Remove Eroded Particles](image2.png)

**Figure -1.6 : Off Time to Remove Eroded Particles [Carle and Steve, 2005 (22)]**
4. Filter removes Chips while the Cycle is repeated

The eroded particles are removed and separated by a filter system as shown in Figure -1.7.

![Diagram showing filter removes chips and the cycle is repeated](image)

**Figure-1.7 : Filter Removes Chips the Cycle is repeated**

[Carle and Steve, 2005 (22)]

1.4.5 Capabilities of WEDM

In 1969, the Swiss firm Agie produced the world's first wire EDM machine. Typically, these first machines in the early 70s were extremely slow, cutting about 21mm²/min. Today, machines are equipped with automatic wire threading and can cut over 20 times faster than the beginning machines.

Whether cutting soft aluminum, hot rolled steel, super alloys, or tungsten carbide, manufacturing are discovering it is less expensive and they receive higher quality with today's high-speed wire EDM machines for many production parts. It also possible to analyse the materialistic structure through anodic polarization curve on the HSS based powder metallurgical parts made through WEDM, {Huang, 2003 (50)}. A few parts produced using the WEDM process are shown in Figures -1.8 and Figure -1.9.
Some machines cut to accuracies of up to +/- 0.0025 mm, producing surface finishes to 0.037 Ra μm and lower. WEDM can cut parts of weight up to 4.48 KN (453.6 Kg). Machining of some large and heavy parts using WEDM are shown in Figure – 1.10.
1.4.6 Advantages of Wire EDM

Some of the advantages of WEDM are given in the following.

1. Efficient production capabilities

Due to the precision and high-speed of wire EDM, Manufacturers are increasingly discovering that many parts can be more economically produced with wire EDM, rather than with conventional machining.

2. Production reliability

The constant reliability of wire EDM Process is one of the greater advantages and this is due to the programs are computer generated and the electrode is constantly being fed from a spool (the wire electrode is used only once), the last part is identical to the first part. The cutter wear found in conventional machining does not exist. In addition, tighter machining tolerances can be maintained without additional cost.

3. Difficult – to – machine shapes

Instead of using costly setups and complicated machining procedures to produce parts of difficult to machine shapes by conventional manufacturing methods, Wire EDM is often cost effective and alternative machining process.
4. Reduced Costs

To be competitive in today’s market it is important to make advantage of every cost-saving procedure available. The high-speed cutting Wire EDM Machines of today have dramatically reduced costs for many manufactured parts. Conventional machining leaves sharp edges and often burrs when machined, but a radius can be made with Wire EDM without any additional cost.

5. Stress-Free and Burr-Free Cutting

Wire EDM is a non-contact, force-free, metal-removing process which eliminates cutting stress and resultant mechanical distortion. Extremely thin sections can be machined because; the wire electrode never contacts the material being cut. Materials cut with Wire EDM are totally burr-free and the edges are perfectly straight. Thin parts can be stacked and cut without leaving any burrs.

6. Tight Tolerance and Excellent Finishes

The wire path is controlled by a CNC Computer-Generated Program, with part accuracies up to +/- 0.0025 mm. Dowel holes can be produced with wire EDM to be either Press or Slip fit. The extremely fine finish from the standard Wire EDM Process often eliminates the need for grinding or other finishing operations.

7. Program Files Downloadable

Many job shops can accept the files directly into the systems by transfer of data in case the parts to be produced are programmed through CAD.

1.4.7 Disadvantages of Wire EDM

Some of the disadvantages of Wire EDM are:

1. Problem of formation of recast layer.
2. Not applicable to very large work piece.

1.4.8 Applications of WEDM

The present application of WEDM process includes automotive, aerospace, mould, tool and die making industries. WEDM applications are also found in the medical, optical, dental, jewelery industries and in the automotive, and aerospace R & D areas [Ho, et al., 2004 (45)].
The machines ability to operate unattended for hours or even days, further increases the attractiveness of the process. Machining thick sections of material, as thick as 200 mm, in addition to using computer to accurately scale the size of the part, make the process especially valuable for the fabrication of dies of various types. The machining of press stamping dies is simplified because the punch, die, punch plate and stripper, all could be machined from a common CNC Program. The fabrication process requires many hours of electrode fabrication as well as many hours of manual grinding and polishing with the conventional EDM technique. But in WEDM, the overall fabrication time is reduced by 37%, whereas the processing time is reduced by 66%. Another popular application for WEDM is the machining of extrusion dies and dies for Powder Metal (PM) compaction.

1.5 BACK GROUND OF THE PRESENT RESEARCH WORK

Though so much of importance is found with WEDM, the research on the WEDM is yet to pick-up with the investigation and identification of Composite materials as well as Tool Steels. Therefore, the present research has taken up on the experimental research work on three materials namely EN19 (AISI 4140), P20 Die Tool Steel (AISI P20) and SS420 (AISI 420). The experiments conducting are based on the Design of the Experiments using Taguchi Technique are reported in seven Chapters as explained in the following.

1.6 ORGANISATION OF THESIS

The organization of the thesis and over all research plans are shown in the following. The study of project has been reported in the seven chapters as given in the following.

Chapter-1: INTRODUCTION: Deals with introduction about the importance of the AISI Steels and the need of EDM and then the Wire-EDM are explained with the need of present work.

Chapter-2: LITERATURE REVIEW AND OBJECTIVE OF THE PRESENT RESEARCH WORK: Deals with the review of the earlier work done and reported in more than 204 papers on the EDM and WEDM in the areas of experimentation, optimization and modeling methods of WEDM process are presented in the chapter.
The objective of the present work is also presented in this chapter.

Chapter-3: DESIGN OF EXPERIMENTS AND MODELLING: Deals with design of experiment by using Taguchi technique.

Chapter-4: EXPERIMENTATION AND METHODOLOGY IN Wire-EDM: Deals with the complete details of experimental setup, work materials and tool materials used for experimentation, process parameters and Experimental Methodology.

Chapter-5: ANN MODELLING: Deals with ANN model development for WEDM process.

Chapter-6: RESULTS AND DISCUSSIONS: Results and discussions are presented.

Chapter-7: CONCLUSIONS AND FUTURE SCOPE: Deals with Conclusions and Future Scope of research work.

1.7 SUMMARY

A brief introduction to Unconventional Machining Process, EDM and WEDM processes, Types of EDM and their basic principles are brought out. WEDM machine with Basic principle, mechanism of metal removal, steps involved in wire EDM process, capabilities are explained. Advantages of WEDM, applications of WEDM are discussed. The need of WEDM and the background of the present research work is explained. The organization of the thesis is explained. The next chapter deals with literature review.