Advance Manufacturing Processes Review Part IV: Electrical Discharge Machining (EDM)

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***Abstract** - Electrical Discharge machining (EDM) is a comparatively new machining method which has several decades of history with efficient work flow. EDM process is a non-conventional and non-contact machining operation which is generally used in industry for high precision products. It was developed as a precision machining generally method for hard materials. EDM is basically known for machining hard and brittle conductive materials since it can melt any electrically conductive material regardless of its hardness. The workpiece machined depends on electrical resistivity, thermal conductivity, and melting points of the materials. EDM process is usually evaluated in terms of surface roughness, existence of cracks, voids and recast layer on the surface of product, after machining. In recent years, several researches and methods based on the electrical discharge phenomena have been proposed with the advancements and process optimisation. Mirror like finish machining, machining of insulating materials and micro products manufacturing are noted among these researches and methods in Electrical Discharge Machining.*

***Keywords:** Electric Discharge Machining, Dry EDM, Wire EDM, EDM*

1. INTRODUCTION OF EDM:

Electro discharge machining is also known as spark erosion, electro-erosion or spark machining. It is a no-traditional machining process based on the principle of erosion of metals by an interrupted electric spark discharge. These discharges are repeated many thousand times/sec in the selected area of workpiece. In this method, all operations are carried out in a single setup. It can be applied to machine steels, super alloys, refractories, etc. No complicated fixtures are needed for holding the job and even very thin jobs can be machined to the desired dimensions and shape.

2. LITERATURE SURVEY

1. DWAIPAYAN De, TITAS Nandi, ASISH Bandyopadhyay studied parametric study for wire cut electrical discharge machining of sintered titanium and discussed in 21st century, it has been observed that Wire Cut Electrical Discharge Machining (WEDM) has evolved as one of the most important non-traditional machining processes. The popularity and its success lie because of its uniqueness towards producing different components which are very difficult to machine like titanium, tungsten carbide, Inconel materials etc and provides a platform in producing intricate complex shape which in many cases become impossible to machine by traditional machining methods. Pure sintered titanium bears very high specific strength, abrasion and corrosion resistances and thus machining this type of materials by conventional techniques becomes very difficult though this material finds immense applications in bio-plant and aerospace components. In the present work, WEDM on pure sintered titanium is studied. The different input parameters of WEDM like, pulse on time, pulse off time, wire tension and wire feed have been varied to investigate the output response like MRR, Surface Roughness (Ra), Kerf Width and Over Cut. A response surface methodology (4 factors 3 level) design of experiment (DOE) has been applied in this context to examine the machining ability of pure sintered titanium and results are found to be satisfactory and verified by confirmatory test. The machining parameters like pulse on time, pulse off time, wire tension and wire feed shows immense effect on the output responses and present study provide an optimal conditions of these input parameters to get the best output responses through RSM [1].

2. Mahendra.U. Gaikwad, Sharad Dikule, Shubham There, Adesh Handeand Akshay Hatkar reviewed on Experimental Investigation of Process Parameters in EDM Process and discussed electrical discharge machining (EDM) is one of the nontraditional machining processes based on thermo electric energy between the work piece and an electrode. In this process the material removal is occurred electro thermally by a series of successive discrete discharge between electrode and work piece. This paper presents a review of research work carried out for Aluminum material worked on Die sink EDM in Powder mixed EDM, EDM in water and Micro EDM..The input parameters consider are current, Pulse on time and Pulse off time whereas output parameters related to surface roughness, material removal rate, and tool wear rate[2].

3. Narinder Singh, Onkar Singh Bhatia studied analysis of the influence of EDM parameters on material removal rate of low alloy steel and electrode wear of copper electrode and discussed the various process parameters affecting the quality characteristics of the EDM during the process were identified using the Ishikawa diagram. In this paper, the optimization of the parameters of the EDM machining has been carried out by using the taguchi's method for design of experiments (DOE). In recent years many ways have been found for improving the MRR of the WORK PIECE. Taguchi method has been used for design of experiments with three input parameters and their three levels using L-27 array. In the research twenty-seven experiments had been done along with circular and square copper tool material as well as Low Alloy Steel material had been used as a work piece. The dielectric used is EDM oil. The main objective of the research is the analysis to optimize the process parameters of EDM with the help of taguchi method and using Minitab software in terms of MMR and EWR. The different parameters considered while carrying out the experiments on EDM would be the current, Ton, Toff. The research findings show that the circular copper electrode having high material removal rate with respect to square copper electrode [3].

4. Amandeep singh, Neel kanth grover, Rakesh Sharma reviewed recent advancement in electric discharge machining and discussed Electric discharge machining is non-conventional machining process used for machining of hard materials which cannot machined by conventional machining process. Electric discharge machining is an electro sparking method of metal working involving an electric erosion effect. A pulse discharge occurs in a small gap between the work piece and the electrode and removes the unwanted material from the parent metal through melting and vaporizing [4].

5. Asfana Banu and Mohammad Yeakub Ali reviewed electrical discharge machining (EDM) and discussed Electro discharge machining (EDM) process is a non-conventional and non-contact machining operation which is used in industry for high precision products. EDM is known for machining hard and brittle conductive materials since it can melt any electrically conductive material regardless of its hardness. The workpiece machined by EDM depends on thermal conductivity, electrical resistivity, and melting points of the materials. The tool and the workpiece are adequately both immersed in a dielectric medium, such as, kerosene, deionised water or any other suitable fluid. This paper provides an important review on different types of EDM operations. A brief discussion is also done on the machining responses and mathematical modeling [5].

6. Shaaz Abulais reviewed current research trends in electric discharge machining (EDM) and discussed Electrical discharge machining (EDM) is one of the earliest non-traditional machining processes. EDM process is based on thermoelectric energy between the work piece and an electrode. A pulse discharge occurs in a small gap between the work piece and the electrode and removes the unwanted material from the parent metal through melting and vaporising. The electrode and the work piece must have electrical conductivity in order to generate the spark. There are various types of products which can be produced using EDM such as dies and moulds. Parts of aerospace, automotive industry and surgical components can be finished by EDM. This paper reviews the research trends in EDM on ultrasonic vibration, dry EDM machining, EDM with powder additives, and EDM in water [6].

7. C. Bhaskar Reddy, G. Jayachandra Reddy, C. Eswara Reddy reviewed on growth of electrical discharge machining and its applications and discussed globalization is making the manufacturers to invest and invent in the manufacture / production of sophisticated and quality products to meet ever changing needs of the customer. Thus, the research in manufacturing has been concentrated towards the high speed machining involving CNC Machines, Robots and Automated Handling Systems with the emergence of computers in Engineering on one side and the development Unconventional Machining such as Chemical Machining, Laser Beam Machining (LBM), Electron Beam Machining (EBM) and Electron Discharge Machining (EDM) on the other side. Out of them, the environment of Chemical Machining is found to be hazardous, whereas LBM and EBM require huge investments in comparison to EDM. Therefore, the EDM is widely used in manufacturing. In the present paper, about 111 research papers are reviewed on the major topics of EDM research. It also reports on the research related to the adoptive monitoring and control of process and the feasibility of different strategies of obtaining the optimal machining conditions. EDM as well as WEDM industrial applications are reported together with the hybrid machining process [7].

8. Mahendra G. Rathi, Deepak V. Mane perform experimental Study on Effect of Powder Mixed dielectric in EDM of Inconel 718 and discussed electrical discharge machining (EDM) is one of the most extensively disseminated manufacturing technologies, in particular as regards the generation of precise and difficult geometrical shapes on hard metallic components. The objective of this paper is to Study on Effect of Powder Mixed dielectric in EDM of Inconel 718. The effect of various powder mixed in dielectric is studied input parameters like Duty cycles, current, pulse on time and powder media in that Silicon

carbide, Aluminium oxide, Graphite powder used. Machining characteristics measured in terms of Material removal rate, tool wear rate. To obtain the optimal process parameter combination, optimization is carried out by the Signal-to-Noise (S/N) ratio analysis of Taguchi method using L18 Orthogonal Array. An analysis of variance (ANOVA) is used to present the influence of process parameters on material removal rate, tool wear rate. Results obtained by Taguchi method and by ANOVA method, are compared and found that they match closely with each other. As the MRR is depends mostly on current. Current carrying capacity of any material depends on its electric conductivity. Here Graphite is having highest electric conductivity than Aluminium oxide and Silicon carbide and therefore MRR is higher in case of Graphite powder. As well as TWR is less and concluded powder mixing into the dielectric fluid of EDM is one of the innovative developments that ensure better machining rates at desired surface quality and at reduced tool wear rate. The present work on addition of powder in Kerosene based on trial and main experiments resulted in high MRR and minimum TWR. The results are obtained from the present investigation for selecting the optimum machining conditions for Inconel-718 work material, which is extensively used in steam turbine, rocket engine, and exhaust system of formula one car. Within the range of parameters selected the following specific conclusions are drawn from the experimental results. (1) Maximum MRR is obtained at a high peak current of 18 A, a moderate Ton of 5μs, duty cycle 85% and Graphite as powder media. (2) Low TWR is achieved at a current of 12 A, a moderate Ton of 20 μs, duty cycle 90% and SiC as powder media [8].

9. Anbesh Jamwal, Ankur Aggarwal, Nishant Gautam, Akhil Devarapalli studied electro-discharge machining: recent developments and trends and discussed in the present manufacturing scenario, the industrial product not only requires the high precision and quality but should be produced in the minimum time in order to sustain their position in the global market competition. Thus, it is required to regulate the input process parameters for achieving the desired output or the performance. EDM is the most popular machining process in the present time among all the machining processes. EDM is the widely used non-conventional machining process that is capable to machine the hard materials such as alloys, composite and even the ceramics also. EDM has wide range of application in automobile, aerospace, defense and precision engineering industries. In the past years, the many studies have been done to improve the EDM process. This paper reviews the current research trends and recent developments in EDM process and modeling techniques [9].

3. DEFINITION OF EDM

- electro-discharge machining is an electro-thermal non-traditional machining process, where electrical energy is used to generated electric spark and material removal mainly occurs due to thermal energy of the spark.
- EDM is mainly used to machine difficult to machine materials and high strength temperature resistant alloys, used for making stamping tools, wire drawings and extrusion dies, intricate mould cavities etc.
- It can be used to machine complex geometers in small batches. The work material to be machined should be electrically conductive. (10)

4. PRINCIPLE OF WORKING

- EDM works on the principle that heat energy generated by a spark is used to remove material from the work piece.
- The tools and work piece are separated by a small gap called as spark gap. The gap varies from 0.01 mm to 0.5 mm. The tool and work piece both immersed in the dielectric fluid.
- When the supply is made 'ON', thousands of sparks are produced per second. The duration of each spark is very short.
- When the spark comes in contact with the dielectric fluid in the spark gap, the fluid gets ionized. It allows current to flow between the tools and workpiece. (11)

5. WORKING OF EDM:

1. Tool Electrode and Workpiece:

The tool and work piece is kept in a reservoir and is connected to a DC power supply. The tool is connected to negative terminal, so that it becomes cathode, while work piece is connected to positive terminal and become anode. Tool electrode has the shape basically same to that of the product desired with allowance for side clearance and over cut.

2. Dielectric fluid system:

The dielectric fluid is spark conductor, coolant and also flushing medium. The common dielectric fluids used are paraffin oil, transformer oil and kerosene. Dielectric fluid is stored in a tank and circulated through a pump with the help of nozzle at the gap between tool and workpiece. Dielectric is continuously flushed into the spark gap. The used dielectric is filtered and recirculated into the reservoir. The dielectric fluid is pumped at a pressure of 2 kg/cm^2 or less.

3. Electrical power supply and spark generator:

The D.C. power supply with current density in the range of 10,000 A/cm^2 and the power density of 500 mw/cm^{2}is used. The voltage is about 40-450 volts is applied. Spark generator is the circuit consist of RC combination. The capacitor is continued to charge as long as the voltage in the capacitor reaches to the value of breakdown voltage. This circuit helps to produce spark between the gap of tool and workpiece. When the supply is made 'ON' the capacitor voltage starts rising continuously. When the capacitor voltage equals the breakdown voltage, (of dielectric fluid) a spark discharge will occur in the spark gap. The spark persists until the capacitor voltage falls below that which is required to maintain sparking. After the capacitor discharge, sparking ceases and the dielectric fluid in the spark gap gets deionized. The capacitor is then recharged and the cycle repeats itself. The time taken by the capacitor to recharge upto the breakdown voltage should be sufficient to allow the dielectric to ionize. Resistor R in the circuit prevents the charging of capacitor before the spark gap is ionized.

4. Tool feed mechanism/ Servo system:

A servo-controlled electrode feeding arrangement is provided which continuously senses the spark gap and moves the tool electrode to maintain the gap. The servo system advances the tool electrode according to the machining required. The tool feed control prevents.

- Too large gaps which may prevent the formation of spark.
- Short circuits which will damage both tool and the workpiece.

The servo system may work electromechanically or hydraulically (10). Since during operation both the tool and work piece are eroded, it is necessary to feed the tool continuously towards the workpiece so as maintain the spark gap. This can be achieved by a suitable tool feed control mechanism along with servo mechanism system (11).

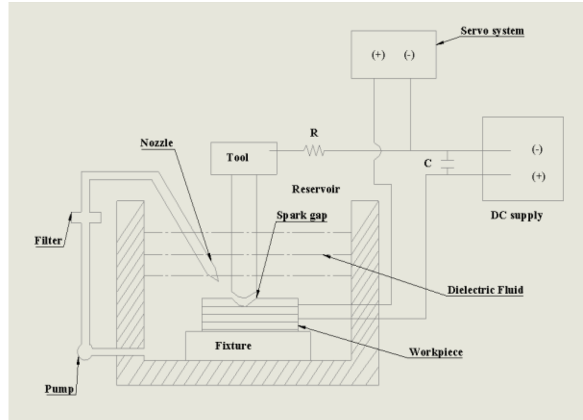

Figure 1: Setup for Electrical Discharge Machining

6. APPLICATIONS OF EDM:

1. Machining dies for forging, blanking, extrusion etc.
2. Machining of hydraulic valve spools.
3. Internal threads, internal helical gears can be cut in hardened materials.
4. Felting of delicate parts in to vacuum tubes.
5. Machining of exotic materials used in aerospace industries, refractory metals, hard carbides, hardened steels.

7. ADVANTAGES OF EDM:

1. Any material can be machined irrespective of its hardness.
2. Any complicated shape can be produced on the work piece.
3. There is no contact between the tool and workpiece; therefore, no stresses are produced in the workpiece.
4. Delicate workpiece (small electronic parts) which cannot withstand cutting forces can be machined.
5. Very fine holes can be easily drilled. Micro holes, deep hole, like in fuel injecting nozzles.
6. A very good surface finish can be obtained.
7. The process is generally automated, hence little operator skill is required.
8. Time of machining is less than conventional machining.

8. DISADVANTAGES OF EDM:

1. **High tool wear rate:** the wear rate of tool electrode is considerably higher, sometimes more than one electrode may be required to finish the job.
2. **More energy required:** the EDM process needs more energy for the machining than conventional machining. high specific power consumption.

3. Workpiece should be **electrically conductive** to be machined by EDM.
4. **Reproduction of sharp corners:** it causes reproduction sharp corners at the workpiece surface.
5. **Surface cracking due to sparks:** some materials may surface cracking due to higher energy given by the sparks.
6. **High machining cost**: the setup requires high cost and power hence higher machining cost.
7. **Dielectric fluid:** Dielectric fluid is used to fill the gap between tool and workpiece. It is stored in a tank and circulated through high pressure pump. A dielectric fluid is a liquid which acts as an insulator between consecutive spark discharge and as a conductor during the spark discharge. It has dielectric properties, to act as an insulator at one time and to acts as conductor at other time. Most commonly dielectric fluids are hydrocarbon fluids, silicon-based oils, deionised water, kerosene and water with glycol are also used. Kerosene is suitable for machining intricate shaped jobs as it will give high accuracy, lower tool wear and better quality of surface.

9. FUNCTIONS OF DIELECTRIC FLUID:

1. It should act as an insulator until the required breakdown voltage is attained.
2. It should act as a conductor, once the breakdown voltage is reached.
3. It should clean the spark gap by carrying away the molten metal.
4. It should deionize the spark gap rapidly after the discharge has occurred.
5. It should cool the tool, workpiece and spark region.

10. CHARACTERISTICS OF DIELECTRIC FLUID:

1. Stable dielectric strength:
The dielectric fluid should have sufficient and stable dielectric strength to serve as an insulation between the tool and work till the breakdown voltage is reached.

2. Rapid deionisation:
At should de-ionise rapidly after the spark discharge has taken place.

3. Low velocity and good wetting capacity:
It should provide effective cooling and remove the swarf particles from the machining gap.

4. Chemically neutral:
It should be chemically neutral so as not to attack the electrode, work piece other components of setup.

5. High flash point:
Dielectric should have high flash point to prevent dire hazards.

6. Nontoxic:
It should not emit any toxic vapours or have an unpleasant odour.

7. Stable properties:
It should maintain above properties in varying temperature contaminations of wear debris, etc.

8. Economical and easily available:
It should not be too costly. It should be easily available in the nearly market. (11)

11. THE SELECTION PARAMETERS OF ANY DIELECTRIC FLUID

a) Workpiece size
b) Types of shape
c) Tolerance
d) Surface finish
e) Metal removal rate (11)

12. FLUSHING METHODS:

Flushing is defined as providing a fresh dielectric fluid between the tool and workpiece. Due to successive spark discharge, the particles eroded from the tool and workpiece contaminates the dielectric. This reduces its insulation strength and hence spark may occur easily. To prevent this premature occurrence of discharge, due to the eroded particles, flushing is necessary. The various methods of flushing are:

1. **Injection flushing:** Dielectric fluid is injected through the hollow tool or hollow workpiece.
2. **Side flushing:** Dielectric fluid id flushed from side of the tool.
3. **Suction flushing:** Dielectric fluid is sucked either through workpiece or tool (12).

13. TOOL ELECTRODES:

Tool electrodes is connected to the negative terminal and it is made of conducting materials generally brass or copper or its alloys. As the tool does not come into contact with the work, life of the tool is long and less wear and tear takes place. The tool made of softer materials than the workpiece materials can be used to machine a material of any hardness. In the EDM process, the shape of the electrode is impressed on the workpiece in its complimentary form. The shape and accuracy of the electrode plays a very important role in the final accuracy of the workpiece machined (11).

Materials used for tool electrodes:

The material used for the tool influences the tool wear and the side clearance and amterial removal arte along with finish obtained. The electrode materials generally classified as:

- Metallic materials (copper, brass etc.)
- Non-metallic materials (graphite, etc.) (12)

14. CHARACTERISTICS AND REQUIREMENTS OF TOOL MATERIAL:

1. It should be a good conductor of electricity.
2. It should be a good conductor of heat.
3. It should be an easily machinable to any shape at a economical cost.
4. It should have efficient arte of material removal from the workpiece during machining.
5. It should resist deformation during the machining by erosion process.
6. It should have low or minimum wear rate.
7. It should be available in a variety of shapes.

15. PROCESS PARAMETERS OF EDM: PROCESS PARAMETERS IN THE EDM PROCESS ARE

1. Spark gap: it is very small gap between tool and workpiece about 0.0125-0.125 mm. Decrease in spark gap results in lower metal removal rate.
2. Current: the D.C. power supply with a current of 0.5 – 400 A is used in this process.
3. Voltage (DC): it is the voltage which is provided by the power supply system. The voltage supplied in the range of 50 – 400 volts.
4. Pulse duration: it is the duration between successive pulses for producing sparks. It is about 2 – 2000 μs. Pulse duration has effect on tool wear rate. Increase in pulse duration results in lower metal removal rate.
5. Dielectric pressure: it is the pressure under which the dielectric fluid is forced or circulated. It is less than 0.2 MPa.
6. Surface finish: it is the finish obtained after machining. It is about 3 – 10 μm for rough machining and 0.8 – 3 μm for machining.
7. Material removal rate: it is the volume of metal removed per unit time. It depends of the material to be cut and spark frequency.
8. The material removal rate (MRR) varies inversely as the melting point of the metal.
9. During roughing out of steel with graphite, electrode MRR is about 400 mm^3 / min with 50 A.

16. OUTPUT CHARACTERISTICS:

1. **Metal removal rate:**
- It is the volume of metal removed from the workpiece per unit time.
- The metal removal rate depends upon the current density.
- It increases with increases in the current.
- The metal removal rate in EDM is 5 to 80 mm^3/sec, which is very low as compared to conventional machining rate.

2. **Tool wear:**
- As sparking takes place, tool wear is inevitable.
- Increases in pulse duration decreases tool wear.
- It depends upon metal removal rate, current and the spark gap.

3. **Surface finish:**
- Surface finish depends on the metal removal rate.
- High metal removal arte produces poor surface finish.
- For enough cuts heavy current is used and for finish cuts less current is used.
- Increase in spark frequency results in improved surface finish.

4. **Accuracy:**
- Tolerance value of ± 0.05 could be easily achieved in EDM.
- By close control of several variables, a tolerance of ± 0.003 mm can be obtained.
- An overcut of minimum of 100 micron is produced.
- The overcut increases with high current.

17. CONCLUSION

EDM is one of the widely used unconventional machining method that is capable of producing the complex shapes. The only limitation in that in EDM the work piece should be conductive in nature. With the time there is lot of improvements in the EDM and its assisted processes as well as in optimization techniques and process parameters, which made some new research scopes in the EDM. Some studies found that non-electrical parameters also play an important role in the performance of the Electrical Discharge Machining. Developments in modeling techniques and processes have made new research scopes in the EDM and improves the performance of EDM process.

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