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An analytical study on Electric Discharge Machining Process

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Abstract: In this manuscript the authors has described the analytical study of Electric discharge machining process. In the process technology, as there are numerous advances at rapid rate, a large number of new materials are being developed everyday. These materials have the combination of properties, like light weight, corrosive resistance, high strength etc., which is not easy to obtain in general. The important aspect is that they satisfy the demands of today's industry, but the major problem is that it is very difficult to machine the newly developed materials. So, in order to manipulate them, newer machining methods have been developed. These methods are more efficient than the conventional ones. Electric discharge machining (EDM) is one of the most widely used methods among the new techniques. The main reason behind the popularity of the EDM is that its capability of machining the hard to machine materials and intricate shapes. It enables high accuracy on tools & dies, even highly delicate sections & weak materials can be machined without any fear of distortion because there is no direct contact between the electrode and the workpiece. A liquid dielectric like kerosene oil is always used in the process.

I. INTRODUCTION

1.1 INTRODUCTION TO NON-TRADITIONAL PROCESSES

Traditional machining processes work on the principle that the tool is harder than the work-piece. Some materials, however, are too hard or too brittle to be machined by conventional methods. The use of very hard nickel-based and titanium alloys by the aircraft engine industry, for example, has stimulated non conventional machining methods. By conventional methods their machining is not only costly but also results into poor surface finish and shorter tool life.
Technologically advanced industries like aeronautics, automobiles, nuclear reactors, missiles, turbines etc. requires materials like high strength temperature resistant alloys which have higher strength, corrosion resistance, toughness, and other diverse properties. With rapid development in the field of materials it has become essential to develop cutting tool materials and processes which can safely and conveniently machine such new materials for sustained productivity, high accuracy and versatility at automation.

Consequently, non-traditional techniques of machining are providing effective solutions to the problem imposed by the increasing demand for high strength temperature resistant alloys, the requirement of parts with intricate and compacted shapes and materials so hard as to defy machining by conventional methods. The processes are non-conventional in the sense that these don't employ a conventional tool for the material removal. Instead these utilize energy in direct form to remove the materials from workpiece. The range of applications of newly developed machining process is determined by workpiece properties like electrical and thermal conductivity, melting temperature, electrochemical equivalent etc. These techniques can be classified into three categories,

1. Mechanical Metal Removal Processes.
2. Electro-chemical Metal Removal Processes.
3. Thermal Metal Removal Processes.

The mechanical non-conventional techniques (abrasive jet machining, ultrasonic machining, and water jet machining) utilizes kinetic energy of either abrasive particles or a water jet to remove the material. In electro-thermal method (plasma arc machining, laser beam machining, and electron beam machining) the energy is supplied in form of heat, light, and electron bombardment which results melting, or vaporization and melting both of work material. In the chemical machining, etching process is being done. On the other hand, in Electro-chemical machining an anodic dissolution process is going on in which high material removal rate can be achieved. The selection of a process is depend upon various factors like- process capabilities, physical parameters, shape to be machined, properties of workpiece material to be cut, and economics of process.

1.2 ELECTRIC DISCHARGE MACHINE

Electrical discharge machining (EDM) is one of the most extensively used non-conventional material removal processes. In this process the material is removed by a succession of electrical discharges, which occur between the electrode and the workpiece. There is no direct contact between the electrode tool and the workpiece. These are submersed in a dielectric liquid such as kerosene or deionized water. Its unique feature of using thermal energy to machine electrically conductive parts regardless of hardness has been its distinctive advantage. The electrical discharge machining process is widely used in the aerospace, automobile, die manufacturing and moulds industries to machine hard metals and its alloy.

1.3 HISTORY OF ELECTRIC DISCHARGE MACHINING

In dates back to 1770, English chemist Joseph Priestly discovered the erosive effect of electrical discharges on metal. After a long time, in 1943 at the Moscow University where B.R. and N.I. Lazarenko decided to exploit the destructive effect of electrical discharges for constructive use. They developed a controlled process of machining to machine metals by vaporizing material from the surface of workpiece. Since then, EDM technology has developed rapidly and become indispensable in manufacturing applications such as die and mould making, micro-machining, prototyping, etc. In 1950s the RC (resistance–capacitance) relaxation circuit was introduced, in which provided the first consistent dependable control of pulse times and also a simple servo control circuit to automatically find and hold a given gap between the electrode (tool) and the workpiece. In the 1980s, CNC EDM was introduced which improved the efficiency of the machining operation.

1.4 WORKING PRINCIPLE OF EDM

The working principle is based on the thermoelectric energy (conversion of electrical energy into thermal energy). The thermoelectric energy (in form of spark) is created between a workpiece and an electrode submerged in a dielectric fluid with conduction of electric current. The work-piece and the electrode are separated by a specific small gap, the so-called 'spark gap', and pulsed discharges occur in this gap filled with an insulating medium [5-8]. The insulating effect of the dielectric medium has some importance in avoiding electrolysis effects on the electrodes during machining process. The electrode moves toward the workpiece until the gap is small enough so that the applied voltage is high enough to ionize the dielectric fluid [9]. Dielectric liquid must be selected to minimize the gap (10-100 µm) to obtain precise machining. However, a certain minimum gap width is needed to avoid short circuiting, particularly with the electrodes that are sensitive to vibration (like wire electrodes) or deformation. The ignition of the discharge is initiated by a high voltage, overcoming the dielectric breakdown strength of the small gap. Short duration discharges are generated in a liquid dielectric gap, which separate electrode and workpiece. The material is removed with the erosive effect of the electrical discharges from tool and workpiece [10].

In this process, there is no direct contact between the electrode and the work-piece thus eliminating mechanical stresses, chatter and vibration problems during machining [1]. The mirror image of electrode is copied with an offset equal to the gap size. A channel of plasma (ionized, electrically conductive gas with high temperature) is formed between the electrodes and develops further with discharge duration. As the metal removal per discharge is very small, discharges should occur at high frequencies (103-106 Hz). For every pulse, discharge occurs at a single location where the electrode materials are evaporated and/or ejected in the molten phase. As a result, a small crater is generated both on the tool electrode and workpiece surfaces. Removed materials form several hundreds of spherical debris particles, which are then flushed away from the gap by the dielectric flow. After the end of the discharge duration, the temperature of the plasma and the electrode surfaces contacting the plasma rapidly drops, resulting in a recombination of ions and electrons and a recovery of the dielectric breakdown strength. After each discharge, the capacitor is recharged from DC source through a resistor, and the spark that follows is transferred to the next narrowest gap (Figure 1.1).

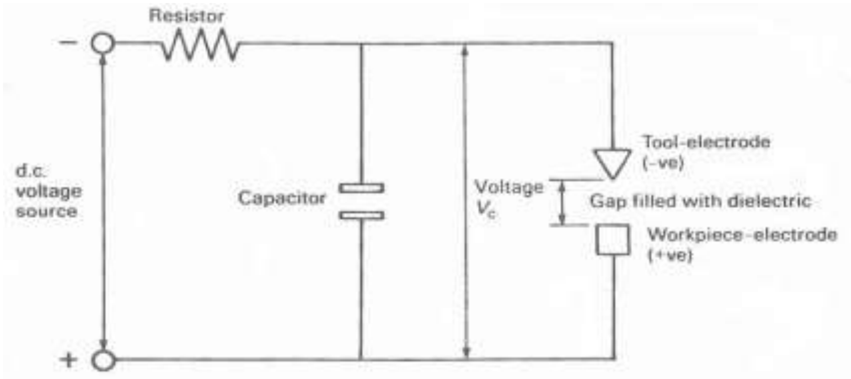

Figure 1. Relaxation circuit for EDM

2. LITERATURE REVIEW

This section gives an extensive review of literature upon various fields related to EDM especially on PMEDM and its effects on Material removal Rate and Tool Wear rate along with hardness and roughness of the surface.

EDM Process

EDM is an electro-sparking method of metal working which involves electric erosion effect. This electric erosion effect connects the breakdown of electrode material which accompanies any form of electric discharge. Researchers are actively engaged in experimentation related to EDM process. The areas of focus have been to select parameters for improving material removal rate (MRR), tool wear rate, use of additives for process improvement and surface quality work carried out by some researchers is briefly presented here. Many researchers have worked on the work pieces, using EDM machine, to see the effect of additives in dielectric fluid, changes in the re-solidified layer, etc. Given below is the work of some of the researchers.

Y.S Wong et al. [1998]:- Has investigated near-mirror-finish phenomenon in EDM using powder-mixed dielectric. This paper presents a study of the near-mirror-finish phenomenon in electric discharge machining (EDM) when fine powder is introduced into the di-electric fluid as a suspension at the tool-workpiece or inter-electrode gap during machining. For this study, the dielectric system of a conventional die-sinking EDM machine was specially modified to inject & distribute the powder into the dielectric fluid, especially at the gap between the tool & workpiece. Machining was performed using copper electrode on various types of steel like SKD-11, SKD-61, SKH-51, SKH-54, AISI O1 tool steel with different types of powder suspensions like Graphite, Silicon, Aluminium, Crushed glass, Silicon carbide, Molybdenum Sulphide at a Peak current of around 1 ampere, Spark gap, Pulse duration, Polarity as process parameters. From the study, it can be seen that when mixed with dielectric in EDM, some types of powders, notably graphite and silicon powders, have been found to distribute the discharges in the spark gap to generate fine to glossy finish surfaces even at relatively high pulse currents of up to 2 A. The presence of the powder has the effect of lowering the breakdown voltage so that discharges can occur at a wider inter-electrode gap, the wider gap facilitating flushing and reducing servo hunting so that machining is more stable.

S.L Chen et al. [1999]:- Has investigated influence of kerosene and distilled water as dielectrics on the electric discharge machining characteristics of Ti–6A1–4V. In electrical discharge machining (EDM), a process utilizing the removal phenomenon of electrical discharge in dielectric, the working fluid plays an important role affecting the material removal rate and the properties of the machined surface. In this paper the machining characteristics of Ti–6A1–4V were investigated using copper electrode with kerosene and distilled water as the dielectrics. The results show that the material removal rate is greater and the relative electrode wear ratio is lower, when machining in distilled water rather than in kerosene. By using X-ray diffraction, it is confirmed that carbide (TiC) and oxide (TiO) are formed on the workpiece surface when using kerosene and distilled water, respectively. The lower removal rate when machining Ti–6A1–4Valloy in kerosene can be explained by both the formation of TiC, which has a higher melting temperature and therefore requires a larger discharge energy, and carbon deposition on the electrode, causing further retardation of the discharge process. A larger amount of debris and more micro cracks are also found when using distilled water as the dielectric.

Han-Ming Chow et al. [2000]:- Has investigated study of added powder in kerosene for the micro-slit machining of titanium alloy using electro-discharge machining. This paper presents a revised EDM process by quantitatively and qualitatively measuring the process using different dielectric fluids. The revised EDM process is developed by modifying the discharging circuit to minimize the discharging current and introducing a new driven mechanism with horizontal rotating electrode. By applying a thin copper diskette electrode, titanium alloy is machined using micro-slit EDM with various dielectric fluids. The dielectric fluids used herein are kerosene, kerosene with aluminum powder, and kerosene with SiC powder. The effects of the various fluids used during the machining process are numerous. Such effects are more clearly accounted for by closely examining the material removal depth, the electrode wear rate, the slit expansion, the surface roughness, and the waveform of the discharging condition.

3. RESULTS FOR S/N RATIO OF TWR

The S/N ratio consolidates several repetitions into one value and is an indication of the amount of variation present. The S/N ratio has been calculated to identify the major contributing factors and interactions that cause variation in the TWR. TWR is “Lower is better” type response which is given by:

$$\text{LB: S/N ratio} = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n} Y_i^2\right]$$

Table 4.11 below shows the ANOVA results for S/N ratio of TWR at 99% confidence interval. Results show that current is the only significant factor which affects the S/N ratio of TWR. All other factors are found to be insignificant as F-critical > F-test.

Table 1: ANOVA for S/N ratio of TWR

Source	SS	DOF	Variance	F test	F critical	SS´	C%	
Current (A)	899.99	2	449.998	53.02	10.9	884.08	81.03	S
Pulse-on time (B)	41.886	2	20.943	2.467	10.9			NS
Pulse-off time (C)	16.698	2	8.349	0.984	10.9			NS
Powder Conc. (D)	8.691	2	4.3455	0.512	10.9			NS
A×B	47.344	4	11.836	1.394	9.15			NS
A×C	12.728	4	3.182	0.375	9.15			NS
A×D	12.678	4	3.169	0.373	9.15			NS
error	50.92	6	8.486					
Total	1090.94	26	41.959					
e-pooled	190.943	26	7.955					

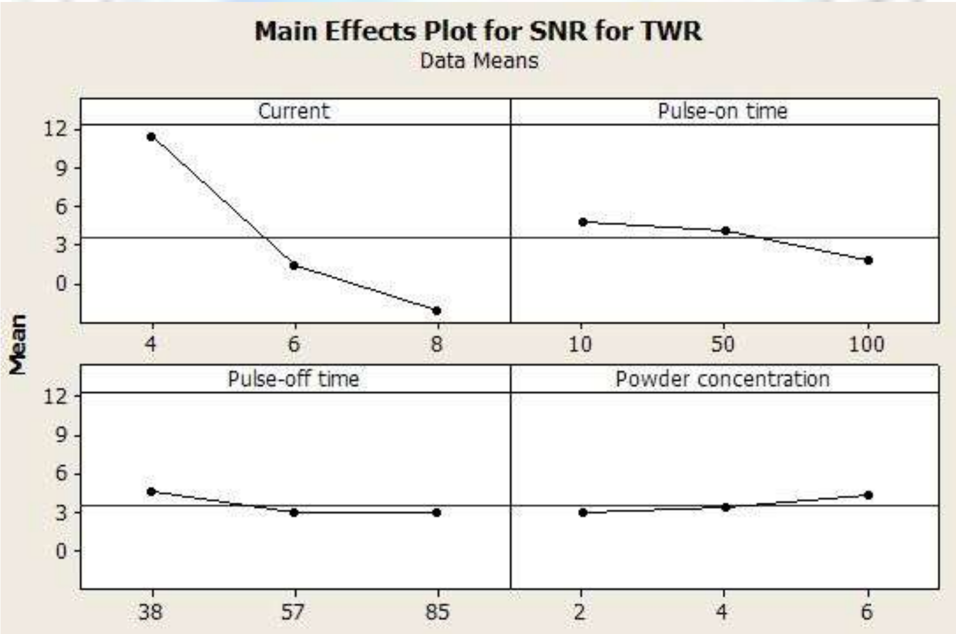

Fig. 2. Main effects plot for TWR of S/N ratio

Experimental results for Surface Roughness

Fig 4.8 below shows the effect of various factors i.e. current, pulse on-time, pulse off-time and powder concentration upon the roughness of the surface. The results are discussed as below:

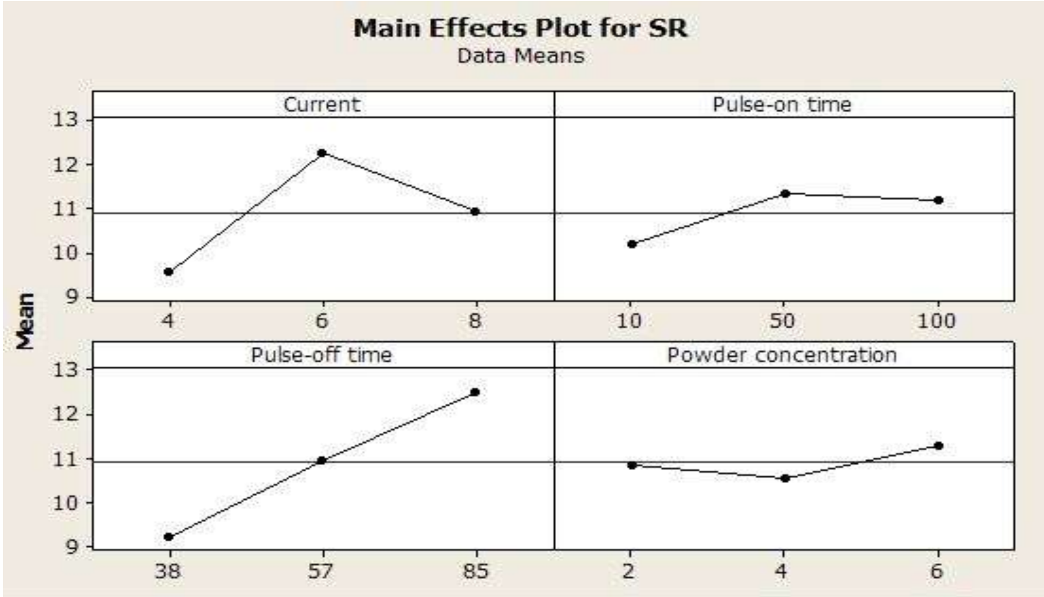

Fig 3: Effect of various factors on the SR

CONCLUSIONS

This section gives the details of the experimental work performed on EDM machine along with the results of the experimental work. It is concluded that the powder mixed dielectric has been found to be a promising machining technique for obtaining desired dimensional accuracy and intricacy from hard & tough die steels like high carbon high chrome materials. The result of the present work identifies the significant process parameters & optimizes the machining conditions in the presence of chromium powder in the dielectric fluid to get maximum machining rate from AISI D2 die steel. Within the range of parameters selected for the present work, the following conclusions are discussed in the next chapter..

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