Analysis of Material Removal Rate in Electrical Discharge Machining (EDM) – A Review

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Abstract— Electrical discharge machining is an unconventional machining process that uses the concept of controlled spark discharges which increases the temperature of the surface of work-piece and results into the removal of material from work-piece. EDM is used to machine materials which are hard in nature and have very high strength. There is no direct contact between the tool and work-piece, hence there is no mechanical energy involved in this process. There are three main performance characteristics of EDM –Material removal rate, Electrode wear rate and Surface roughness. In this paper we are going to review multiple published research papers which are mainly focused on the Analysis of the Material removal rate of work-piece by optimising different combination of process parameters like peak current, voltage, pulse-on time, interval time, rotating speed of electrode, arc gap and addition of electrically conductive particles in dielectric.

Key words: EDM, Material removal rate (MRR), Tool Wear rate (TWR), Surface roughness (SR), Taguchi Method

I. Introduction

EDM is the process of machining electrically conductive materials by precisely controlled sparks. This process is capable of producing complex and intricate shapes. It can machine hard materials which cannot be easily machined by conventional machines, hence it finds wide acceptance in industries. The foundation of electric discharge machining can be traced in 1770s when English physicist Joseph Priestley discovered the erosive effect of Electric discharges. However, the electric discharge has been exploited for constructive purpose in the year of 1943 at Moscow University by Lazarenko. The Lazarenko EDM system used resistance- capacitance type of power supply which was used at EDM machines in 1950s and later served as model for further development in EDM. Electric Discharge Machining is a non-traditional machining process. It is an electro-thermal process which does not involve direct contact between tool and work-piece. Here, electrical energy is used to generate sparks which removes material of work-piece due to their thermal energy. It is widely used in manufacturing of tools and dies, surgical instruments, aerospace components, automotive parts etc. EDM can also machine three dimensional complex micro components and microstructures from metallic substrate and semiconductor substrate and can machine small hole easily. It has been effectively used in machining hard, high strength and temperature resistance materials. Thus, the comprehensive study of the effects of EDM process parameters on the performance characteristics such as material removal rate, surface roughness, electrode wear rate is of great significance.

Different researchers use different process parameters to analyze & optimize performance characteristics of EDM.

Schematic diagram of EDM machine
(Picture taken from internet)

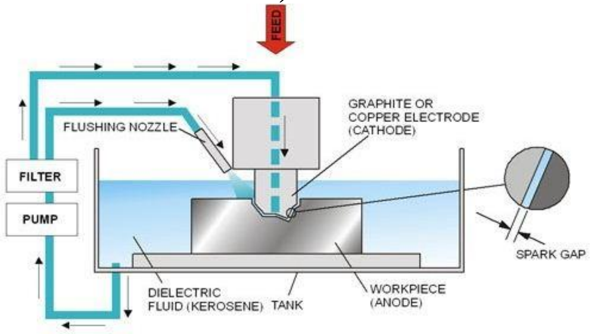

Fig. 1: Electric Discharge Machining

II. Specifications of edm

Mechanism of process	Melting & Evaporation of work-piece material with the help of electric spark.
Work material	High hardness materials like Tungsten Carbide, Advanced Ceramic materials, Inconel 718 etc.
Tool material	Graphite
Dielectric medium	Kerosene
Temperature	8000-12000 C
Gap	10 to 120 microns
Voltage	30-250 V
Current	5-60 A

Table 1:

III. Mechanism in MRR

The mechanism of material removal of EDM process is the conversion of electrical energy into thermal energy. During the process of machining the sparks are produced between work piece and tool. Each spark produces a tiny crater and crater formation leads to the erosion of the work piece material. Material Removal Mechanism is the process of transformation of material elements between the work-piece and electrode. The transformation are transported in solid, liquid or gaseous state, and then alloyed with the contacting surface by undergoing a phase reaction.

IV. Process parameters

A. Pulse-On Time:

It is the time during which the machining takes place. Material removal is directly proportional to the energy applied during the pulse-on time. The length of pulse-on time controls that energy. The material removal rate increase with pulse on time but after certain time it starts decreasing.

B. Peak Current:

This is the most important parameter for machining any work material in EDM. It is measured in units of ampere. It is the amount of power used in discharge machining. Higher current will increase the pulse energy.

As the current increases the material removal rate also increases but it also affect the surface finish & electrode wear rate.

C. Discharge Voltage:

In the EDM, discharge voltage is related to the spark gap and breakdown strength of the dielectric. Before current can flow, the open gap voltage increases until it creates an ionization path through the dielectric.

Once the current starts to flow, voltage drops and stabilizes at the working gap level.

D. Interval time:

It is the time interval between the two consecutive sparks. If off time is too short it will cause spark to be unstable. If interval time increases, material removal rate decreases.

E. Arc Gap:

It is distance between work-piece and the electrode during the process of EDM. It may be called as spark gap.

F. Rotating speed of electrode:

It is found that MRR and Surface roughness improves with rotary EDM due to effective flushing of eroded debris. Research on rotary electrode for EDM has been carried out for many years in order to analyze its effect on MRR and SR.

G. Addition of electrical conductive particles in dielectric

With addition of electrically conductive particles like Al or fine graphite powders in dielectric, both surface roughness and material removal rate improves.

V. LITERATURE REVIEW

A. Author: Norliana Mohd Abbas, Darrius Solomon

Journal: International Journal of Machine Tool & Manufacture
Published: 17 August 2006

This paper reviews the research trends in EDM on ultrasonic vibration, dry EDM machining, EDM with powder additives, EDM in water and modeling technique in predicting EDM performances.

Ultrasonic vibration EDM is suitable to produce deep and small holes products. Cu is most frequently selected as the tool electrode either in gas machining or in dielectric machining. This is maybe due to the characteristics of the material which stable under sparking condition. The range of the ultrasonic frequency used during the experiment is between 17 and 25 kHz. Most of the experiments are evaluating on the performance of steel based work piece materials since these materials are widely used in industries. However the harder material such as alumina ceramic is also evaluated. This method starts with vibrating the electrode followed by vibrating the work piece in year 1999, which gains popularity from year 2003 and continues until year 2006.

B. Author: K.H. Ho, S.T. Newman

Journal: International Journal of Machine Tools & Manufacture 43 (2003)
Published: 10 June 2003

This paper reviews the research work carried out from the inception to the development of die-sinking EDM within the past decade. It reports on the EDM research relating to improving performance measures, optimizing the process variables, monitoring and control the sparking process, simplifying the electrode design and manufacture. A range of EDM applications are highlighted together with the development of hybrid machining processes. The final part of the paper discusses these developments and outlines the trends for future EDM research.

The introduction of EDM to the metal cutting has been a viable machining option of producing highly complex parts, independent of the mechanical properties of work-piece material. This is by virtue of the capability of EDM to economically machine parts, which are difficult to be carried out by conventional material removal processes. With continuous improvement in the metal removal efficiency and the incorporation of numerical control, the viability of the EDM process in terms of the type of applications can be considerably extended. The basis of controlling the EDM process mostly relies on empirical methods largely due to the stochastic nature of the sparking phenomenon involving both electrical and non-electrical process parameters. The complicated interrelationship between the different optimized process parameters is therefore a major factor contributing to the overall machining efficiency. However, several means of improving the machining performance commonly measured in terms of MRR, TWR and SR have been made with an overwhelming research interest being paid to the metallurgical properties of EDM part. Thus, the EDM process needs to be constantly revitalized to remain competitive in providing an essential and valuable role in the tool room manufacturing of part with difficult-to-machine materials and geometries.

C. Author: Rajesh Purohit, C. S. Verma and Praveen Shekhar

Journal: Research And Applications (IJERA) ISSN: 2248-9622 Vol. 2, Issue 2,
Published: March- April 2012

According to this paper, MRR increases with decrease in grain size of SiC particulates and increases with increase of hole diameter of electrode. Some of the findings of this paper are -

- The MRR increases with increase of rotating speed of electrode.
- The TWR increases with decrease of grain size of SiC particulates.
- The TWR decreases with increase of hole diameter of the electrode.
- The TWR is minimum with medium speed and maximum with maximum speed so it overall increases with increase of rotating speed of electrode.

D. Author: Abdus Sabur, Mohammad Yeakub Ali, Md. Abdul Maleque, Ahsan Ali Khan

Journal: Procedia Engineering 56 (2013)

This paper reviews the effect of different process parameters on non-conductive ceramic materials like ZrO2.The use of nonconductive ceramic materials is increasing rapidly in industrial and engineering applications due to its high hardness, low thermal conductivity, and resistance to oxidation. Machining operations for fabricating structures from nonconductive ceramic materials are difficult and most of the traditional machining techniques are not applicable because of its high brittleness. Electro discharge machining (EDM) technique, a noncontact machining process, is applied for processing nonconductive ceramic ZrO2 using assisting electrode. In this technique, pyrolytic carbon layer on the ceramic surface formed by the cracked carbon from the carbonic dielectric plays the key role for continuous EDM. The formation of pyrolytic carbon and its stability depends upon the input power, work-piece material, tool electrode material, dielectric substance, polarity, and discharge duration. In this study, experiments were done to investigate the effect of input power on the material removal rate (MRR) and to explore the material removal mechanism. The experimental results show that the material is removed in EDM of nonconductive ZrO2 ceramic mostly by spalling and it increases with the increase of input power.

E. Author:Kuldeep Ojha, R.K Garg, K.K Singh

Journal: Journals of Minerals & Material Characterization & Engineering, Vol.9, No8, Pp. 709-703, 2010

In this paper, review of EDM research work related to MRR improvement has been presented along with some insight into the basic EDM process and material removal mechanism. It is found that the basis of controlling and improving MRR mostly relies on empirical methods. This is largely due to stochastic nature of the sparking phenomenon involving both electrical and non-electrical process parameters along with their complicated interrelationship. Being an important performance measure, the MRR has been getting overwhelming research potential since the invention of EDM process, and requires more study/experimentation/modeling in future.

F. Author: Prof. S.R.Nipanikar

Journal: Journal of Engineering Research and Studies E-ISSN0976-7916

This paper states that Electrical Discharge Machining or EDM is a machining method primarily used for hard metals or those that would be impossible to machine with traditional techniques. The non-contact machining technique has been continuously evolving from a mere tool and dies making process to a micro-scale application machining alternative attracting a significant amount of research interests. EDM is especially well-suited for cutting intricate contours or delicate cavities that would be difficult to produce with a grinder, an end mill or other cutting tools. Metals that can be machined with EDM include hardened tool-steel, titanium and carbide, Inconel etc. One critical limitation, however, is that EDM only works with materials that are electrically conductive. EDM is a thermoelectric process in which heat energy of spark is used to remove material from the work-piece. The work-piece and the tool should be made of electrically conductive material. A spark is produced between the two electrodes (tool and work-piece) and its location is determined by the narrowest gap between the two.

Some of the findings of this paper are-

- The material removal rate (MRR) mainly affected by peak current.
- Duty cycle (t) has least effect on MRR.
- The electrode wear rate (EWR) is mainly influenced by peak current.
- The effect of gap voltage (Vg) is less on EWR and has least effect on it.
- In Taguchi L9 orthogonal matrix experiment, no interactions between the input factors are considered. But some interaction effect may be present during the experiment. This may result in some observations which do not go with the theoretical belief. Some portion of the material is conductive and some portion is non-conductive. But EDM requires conductive work-piece. So the composite properties of the work-piece may also lead to some observations which contradict the theoretical belief.

G. Author: Shaaz Abulais

Journal: International Journal of Scientific & Engineering Research, Volume 5, Issue 6, June-2014 100 ISSN 2229-5518

In this review paper, the review of the research trends in EDM with powder additives is presented. However, many more issues need to be investigated before the method can be formally accepted by the industry.

The ultimate goal of the WEDM process is to achieve an accurate and efficient machining operation. Several researchers have studied methods to improve the surface quality and increase the material removal rate of the WEDM process. However, the problem of selecting the cutting parameters in the WEDM process is not fully solved, even though the most up-to- date CNC WEDM machines are presently available.

H. Author: Harmanpreet, Manpreet Singh, Bipendeep

Journal: IJRET: International Journal of Research in Engineering and Technology ISSN: 2319-1163 | ISSN: 2321-7308

This paper reviews research for the optimization and improvement of various performance parameters measured in the experimentation on EDM by using Taguchi technique. In the study the main objectives of optimization is to minimize the tool wear rate (TWR) and surface roughness, and to maximize the material removal rate (MRR).

This paper states that Electrical discharge machining is assessed on the basis of Material Removal Rate (MRR), Tool Wear Rate (TWR), and Surface Roughness (SR). Process parameters that mostly affected the EDM Process are Pulse on Time, Pulse off Time, Discharge Current, Arc Gap and Duty Cycle.

Taguchi Method is widely used in the industry to optimize and improve various performance parameters associated with different machining processes. This paper also deals with the review of some of the work reported with the use of Taguchi method in last two decades.

From this review paper it can be concluded that -

1) Taguchi Method is widely used and most effective technique for the optimization of machining parameters.
2) Review also reveals that machining by EDM and WEDM is generally assessed on the basis of MRR, TWR & SR.

3) Paper also revealed that Pulse on Time, Pulse off Time, Duty Cycle, Dielectric Flushing Pressure, Peak Current, Cycle Voltage are some of the factors that affects the machining characteristics of EDM process.

I. Author: Raghuraman, Thiruppathi, Panneerselva M,Santosh

Journal: International Journal of Innovative Research in Science, Engineering and Technology Vol. 2, Issue 7, July 2013

This paper aims to investigate the optimal set of process parameters such as current, pulse ON and OFF time in Electrical Discharge Machining (EDM) process to identify the variations in three performance characteristics such as rate of material removal, wear rate on tool, and surface roughness value on the work material for machining Mild Steel IS 2026 using copper electrode. According to this paper, Optimization is one of the techniques used in manufacturing sectors to arrive for the best manufacturing conditions, which is an essential need for industries towards manufacturing of quality products at lower cost. Based on the experiments conducted on L9 orthogonal array, analysis has been carried out using Grey Relational Analysis, a Taguchi method. Response tables and graphs were used to find the optimal levels of parameters in EDM process. The confirmation experiments were carried out to validate the optimal results. Thus, the machining parameters for EDM were optimized for achieving the combined objectives of higher rate of material removal, lower wear rate on tool, and lower surface roughness value on the work material considered in this work. The obtained results show that the Taguchi grey relational analysis is being effective technique to optimize the machining parameters for EDM. Some of the finding of this paper are-

1) Taguchi's Signal – to – Noise ratio and Grey Relational Analysis were applied in this work to improve the multi-response characteristics such as MRR (Material Removal Rate), TWR (Tool Wear Rate) and Surface Roughness of mild steel IS 2026 during EDM process.
2) The conclusions of this work are summarized as follows: The optimal parameters combination was determined as A3B2C1 i.e. pulse current at 26A, pulse ON time at 55µs and pulse OFF time at 5µs.
3) The predicted results were checked with experimental results and a good agreement was found.
4) This work demonstrates the method of using Taguchi methods for optimizing the EDM parameters for multiple response characteristics.

J. Author: C. R. Sanghani1, Dr. G. D. Acharya

Journal: C. R. Sanghani et al Int. Journal of Engineering Research and Applications SSN: 2248-9622, Vol. 4, Issue 1(Version 2), January 2014, pp.433-450

This paper reviews research on improvement and optimization of various performance measures of spark erosion EDM and finally lists down certain areas that can be taken up for further research in the field of improvement and optimization for EDM process.

After analysis of the literature, the following conclusions can be drawn -

1) Various approaches like powder additives, different dielectric fluid, tool-work piece rotation, vibration, cryogenic cooling of electrode, different tool material, etc. have been used by different researchers for improvement in EDM process performance.
2) The researches in optimization of performance measures using latest optimization techniques such as SA, fuzzy logic, PSO, PCA, desirability, utility are mostly focused on multi response optimization. The application of latest optimization techniques in optimizing performance measures of EDM process positively gives good results compared to conventional techniques as proven from the literature.
3) It is also found that most of the research work has been carried out on improvement and optimization of same performance measures like MRR, EWR, Surface roughness for different materials, but some performance measures like power consumption, dimensional deviation, hardness, etc. are either not much focused or not focused yet. So, this area is yet to be explored more.

VI. CONCLUSION

After reviewing various published research papers on EDM, we can conclude that there are several possible ways to improve EDM efficiency in terms of Material Removal Rate (MRR) , Tool Wear Rate (TWR) and Surface Roughness (SR). Hence with change in combination of parameters or optimization methods, further study and experiments can be done.

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