Electrical Discharge Machining (EDM): A Review

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Abstract: *In recent years, EDM researchers have explored a number of ways to improve the sparking efficiency including some unique experimental concepts that depart from the EDM traditional sparking phenomenon. Despite a range of different approaches, this new research shares the same objectives of achieving more efficient metal removal coupled with a reduction in tool wear and improved surface quality.*
Electrical discharge machining (EDM) is a well-established machining option for manufacturing geometrically complex or hard material parts that are extremely difficult-to-machine by conventional machining processes. The non-contact machining technique has been continuously evolving from a mere tool and die making process to a micro-scale application machining alternative attracting a significant amount of research interests.

Keywords: *Electrical discharge machining (EDM)*

I. INTRODUCTION

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 eliminating mechanical stresses, chatter and vibration problems during machining. Today, an electrode as small as 0.1 mm can be used to 'drill' holes into curved surfaces at steep angles without drill 'wander' .The basis of EDM can be traced as far back as 1770, when English chemist Joseph Priestly discovered the erosive effect of electrical discharges or sparks However, it was only in 1943 at the Moscow University where Lazarenko and Lazarenko exploited the destructive properties of electrical discharges for constructive use. They developed a controlled process of machining difficult-to-machine metals by vaporizing material from the surface of metal. The Lazarenko EDM system used resistance–capacitance type of power supply, which was widely used at the EDM machine in the 1950s and later served as the model for successive development in EDM .There have been similar claims made at about the same time when three American employees came up with the notion of using electrical charges to remove broken taps and drills from hydraulic valves. Their work became the basis for the vacuum tube EDM machine and an electronic-circuit servo system that automatically provided the proper electrode-to-work piece spacing (spark gap) for sparking, without the electrode contacting the work piece .It was only in the 1980s with the advent of computer numerical control (CNC) in EDM that brought about tremendous advances in improving the efficiency of the machining operation. CNC has facilitated total EDM, which implied an automatic and unattended machining from inserting the electrodes in the tool changer to a finished polished cavity or cavities .These growing merits of EDM have since then been intensely sought by the manufacturing industries yielding enormous economic benefits and generating keen research interests

II. EDM

This section provides the basic fundamentals of the EDM process and the variations of process combining other material removal methods.

2.1. EDM process

The material erosion mechanism primarily makes use of electrical energy and turns it into thermal energy through a series of discrete electrical discharges occurring between the electrode and work piece immersed in a dielectric fluid .The thermal energy generates a channel of plasma between the cathode and anode at a temperature in the range of 8000 to 12,000 ^{0}C or as high as 20,000 ^{0}C initializing a substantial amount of heating and melting of material at the surface of each pole. When the pulsating direct current supply occurring at the rate of approximately 20,000–30,000 Hz is turned off, the plasma channel breaks down. This causes a sudden reduction in the temperature allowing the circulating dielectric fluid to implore the Plasma channel and flush the molten material from the pole surfaces in the form of microscopic debris. This process of melting and evaporating material from the work piece surface is in complete contrast to the conventional machining processes, as chips are not mechanically produced. The volume of material removed per discharge is typically in the range of 10^{-6} –10^{-4} mm^3 and the material removal rate (MRR) is usually between 2 and 400 mm^3/min depending on specific application. Since the shaped electrode defines the area in which the spark erosion will occur, the accuracy of the part produced after EDM is fairly high. After all, EDM is a reproductive shaping process in which the form of the electrode is mirrored in the work piece .

III. EDM APPLICATIONS

This section discusses some of the applications of EDM commonly found in the industry. It also includes other experimental interests providing a feasible expansion of EDM applications.

3.1. Heat-treated materials

In some applications, EDM has replaced traditional machining processes such as the milling of heat-treated tool steels. Milled material has to be within an acceptable hardness range of less than 30–35 HRC with ordinary cutting tools . However, EDM allows tool steels to be treated to full hardness before machining, avoiding the problems of dimensional variability, which are characteristic of post-treatment .

3.2. Micro-EDM

The recent trend in reducing the size of products has given micro-EDM a significant amount of research attention. Micro-EDM is capable of machining not only micro-holes and micro-shafts as small as 5 mm in diameter but also complex three-dimensional (3D) micro cavities . This is unlike mechanical drilling, which can produce holes just up to 70 mm, or the micro-fabrication process such as laser machining, which can only create holes of 40mm.

3.3. Ceramic

The EDM of advanced ceramics has been widely accepted by the metal cutting industry owing to the competitive machining costs and features. There are different grades of engineering ceramics. In the same paper, they proved the feasibility of machining boron carbide (B4C) and silicon infiltrated silicon carbide (SiSiC) using EDM and WEDM. A HMP combining USM and EDM was also experimented to enhance the dielectric circulation in the spark gap, when machining engineering ceramics with significant improvement in the performance measures and reduction in the thickness of the white layer.

3.4. Modern composite materials

The development of different modern composite materials in the last decade has led to an expansion of EDM applications. The various machining processes performed on metal matrix composites (MMC) and experimented with the machining of Al2O3/6061Al composite using rotary EDM coupled with a disc-like electrode. The feasibility of machining ceramic–metal composite steel plate coated with WC– Co (tungsten carbide–cobalt) using plasma spraying was also examined . The coating of WC–Co onto parts by means of plasma spraying is used extensively in the automobile and aerospace industry to prevent erosion and wear.

IV . EDM PERFORMANCE MEASURES

A significant number of papers have been focused on ways of yielding optimal EDM performance measures of high MRR, low tool wear rate (TWR) and satisfactory SQ. This section provides a study into each of the performance measures and the methods for their improvement.

4.1. Material removal

4.1.1 Material removal mechanism

Several researches have explained the material removal mechanism (MRM) in terms of the migration of material elements between the work piece and electrode. Soni and Chakraverti showed an appreciable amount of elements diffusing from the electrode to the work piece and vice versa. These elements are transported in solid, liquid or gaseous state and alloyed with the contacting surface by undergoing a solid, molten or gaseous-phase reaction . The types of eroded electrode and work piece elements together with the disintegrated products of dielectric fluid significantly affect the MRM relating to the three phases of sparking, namely breakdown, discharge and erosion . In addition, reversing the polarity of sparking alters the material removal phenomenon with an appreciable amount of electrode material depositing on the work piece surface

4.1.2. Methods of improving material removal rate

The application of CNC to EDM has helped to explore the possibility of using alternative types of tooling to improve the MRR. EDM commonly employs 3D profile electrodes, which are costly and time-consuming to manufacture for the sparking process. However, experimental work has been performed with a frame electrode generating linear and circular swept surfaces by means of controlling the electrode axial motion. A similar machining technique using a wire frame electrode was conducted to compare the time taken to machine a cubic cavity using a 3D solid electrode.

4.2. Tool wear

4.2.1. Tool wear process

The tool wear process (TWP) is quite similar to the MRM as the tool and work piece are considered as a set of electrodes in EDM. Tool wear is affected by the precipitation of carbon from the hydrocarbon dielectric onto the electrode surface during sparking. They also argued that the rapid wear on the electrode edge was due to the failure of carbon to precipitate at difficult-to-reach regions of the electrode.

4.2.2. Methods of improving tool wear rate

The orbiting of the electrode relative to the work piece is the most common machining strategy of compensating the tool wear. It involves the electrode making a planetary motion producing an effective flushing action, which improves the part accuracy and process efficiency . The orbiting technique also reduces the number of different electrodes required for initial roughing and final finishing operations. In order to optimize the electrode trajectory in real-time, a computer integrated planetary machining strategy based on continuous adaptation of machining parameters was developed.

4..3. Surface quality

4.3.1. Surface quality analysis

The electrical discharge machined (EDMed) surface is made up of three distinctive layers consisting of white layer/recast layer, heat affected zone (HAZ) and unaffected parent metal provided a review on the metallurgy of EDMed surface, which is dependent on the solidification behavior of molten metal after the discharge cessation and subsequent phase transformation. The thickness of the recast layer formed on the work piece surface and the level of thermal damage suffered by the electrode can be determined by analyzing the growth of the plasma channel during sparking .

4..3.2. Methods of improving surface quality

***Surface alloying*:**

The surface alloying method using the composite electrode to improve the surface properties of the work piece has been reported by a number of authors . The composite electrode is also referred to as the green compact, sintered or powder metallurgy (PM) electrode. It has low thermal conductivity allowing the composite material to disintegrate from the electrode and alloy onto the work piece surface producing less cracks ,high corrosion and wear resistance.

4.3.3. Major areas of WEDM research

The authors have organized the various WEDM research into two major areas namely WEDM process optimization together with WEDM process monitoring and control.

4.3.4 WEDM process optimization

Today, the most effective machining strategy is determined by identifying the different factors affecting the WEDM process and seeking the different ways of obtaining the optimal machining condition and performance. This section provides a study on the numerous machining strategies involving the design of the process parameter and the modelling of the process.

4.3.5 Process parameters design

The settings for the various process parameters required in the WEDM process play a crucial role in producing an optimal machining performance. This section shows some of the analytical and statistical methods used to study the effects of the parameters on the typical WEDM performance measures such as CR, MRR and SF. 4.1.1.1. Factors affecting the performance measures. WEDM is a complex machining process controlled by a large number of process parameters such as the pulse duration, discharge frequency and discharge current intensity. Any slight variations in the process parameters can affect the machining performance measures such as surface roughness and CR, which are two of the most significant aspects of the WEDM operation

V. DISCUSSION AND FUTURE EDM RESEARCH DIRECTION

The authors have classified the numerous EDM research interests referred in the paper into four different which is used in this section to discuss the various research areas and possible future research directions.

5.1. Optimizing the process variables

The EDM process has a very strong stochastic nature due to the complicated discharge mechanisms making it difficult to optimize the sparking process. The optimization of the process often involves relating the various process variables with the performance measures maximizing the MRR, while minimizing the TWR and yielding the desired SR. In several cases, S/N ratio together with the analysis of variance (ANOVA) techniques are used to measure the amount of deviation from the desired performance measures and identify the crucial process variables affecting the process responses. The process variables include not only the electrical but also non-electrical parameters, which have received quite a substantial amount of research interest. In addition, the feasibility of manufacturing the electrode using the RP technique has been extensively studied to improve the performance of tools and sparking. Therefore, with the continuous research effort made in understanding the initialization and development of sparking process, the different means of optimizing the various process variables will continue to be a major area of further development reducing the stochastic sparking characteristic.

5.2. Monitoring and control of the process

The monitoring and control of the EDM process are often based on the identification and regulation of adverse arcing occurring during the sparking process. Most of the approaches measure pulse and time domain parameters to differentiate the arc pulses from the rest of EDM pulses. The option of using emitted RF has also been experimented but generates very little research interest. As for the adaptive control system, it mainly relies on the application of fuzzy logic to maintain the machining process.

5.3. EDM developments

The different advances made at the EDM machine have jointly progressed with the growing applications of EDM process. EDM has long been employed in the automotive, aerospace, mould, tool and die making industries. It has also made a significant inroad in the medical, optical, dental and jewellery industries, and in automotive and aerospace R&D areas . These applications demand stringent machining requirements, such as the machining of HSTR materials, which generate strong research interests and prompt EDM machine manufacturers to improve the machining characteristics.

VI. CONCLUDING REMARKS

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 EDMed 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.

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