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AN OVERVIEW OF MODELLING OF HOLE MAKING MICRO ELECTRICAL DISCHARGE MICROMACHINING

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ABSTRACT

Advancements in micro-fabrication are characterized by a progressive miniaturization leading towards higher integration. The fabrication of particular size micro hole in difficult to machine engineering materials is one of the most challenging tasks in manufacturing industry. Since micro holes are prepared in the end product therefore the rejection of product due to poor hole quality is not acceptable in modern manufacturing industries. In the past, researchers have explored a number of ways to improve the Micro electrical discharge machining (MEDM) process performance by analyzing the different factors that affect the quality characteristics. The experimental and theoretical studies show that process performance can be improved considerably by proper selection of process parameters, and operating parameters. This paper reviews the research work carried out so far in the area of theoretical and experimental modeling of MEDM.

I. INTRODUCTION

A depression type of feature created in a solid workpiece is called hole when depth-to- diameter ratio is greater than 5:1. Depending on diameter, hole can be classified as large (>1mm) or small hole (<1 mm). Holes may be blind or through and depending on orientation it may be termed as horizontal, vertical or inclined [1]. Creation of quality micro hole by micromachining method has always been a challenge to manufacturing engineers because of inaccuracies involved during production of these holes. Advances in the field of aviation, automobile, medical devices, communications, optics, electronics and computers have created a need for micro holes of different shape and sizes. The complexity and degree of integration required for these applications needs a creation of micro hole with minimum hole taper without mechanical and thermal distortion. To enhance the functional capability of products, a continuous endeavor is being made to develop products made of high characteristics materials such as superalloys, ceramics and composites. In order to enhance the efficiency, the technologically advanced industries like aerospace, nuclear reactors, automobiles etc. often requires components made of these materials with a large number of geometrically accurate micro holes [2].

II. MICRO ELECTRICAL DISCHARGE MACHINING

MEDM is an erosive micromachining process used to produce micro feature by controlled melting and vaporization of excess material from difficult to machine electrically conductive material with stringent design requirements using thermal energy generated by spark between two electrodes completely dipped into dielectric and applying a pulsating voltage between them.

The inter electrode gap in MEDM is kept less than 10 micron. To create localized melting in such a small gap, the supply energy and pulse duration is kept low. But when the energy is low, the machining time increases largely which leads to small material removal rate. However the pulse duration is still kept very low because with larger value, the radius of plasma channel will be larger and the crater size will be more. In order to generate small pulse duration, RC based circuits are used in MEDM with a pulse frequency of MHz order. Finally in MEDM where achievable precision is of the order of few microns, the least count of the individual axes are to be kept low in sub-micron range. Based on literature available, a comparison has been made between macro and micro electrical discharge machining and is listed in Table 2.1.

Table 2.1 Comparisons between Macro-EDM and Micro-EDM [1-7]

Parameter	Macro-EDM	Micro-EDM
Break Down Voltage	40-400 V	5-300 V
Break Down Current	0.5-400 A	Up to 200 mA
Discharge Energy	1-30 mJ	20-1100 µJ
Discharge Duration	90-1000 µs	30-250 µs
Pulse on-time	10-100 µs	30-80 ns
Pulse Frequency	180 Hz-10 kHz	Order of 1 MHz
Electrode Gap	25-50 µm	Order of 1 µm
Positioning Resolution	25-50 µm	Order of 0.25 µm
Aspect Ratio	400:1	10:1
Surface Roughness	0.18-3.1 µm	Order of 50 nm
Temperature of Plasma Channel	8,200-12,000 ^{o}K	6,200-10,000 ^{o}K
Pressure of Plasma Channel	8-10 bar	6-8 bar
Resolution & Repeatability	25-127µm	Order of nm
Material Removal Rate	2-400 mm^{3}/min	1-10 mm^{3}/min
Volume of Material per Discharge	10^{-6}-10^{-4} mm^{3}	Order of 10^{-7} mm^{3}
Velocity of Plasma Channel	Order of 10^{6} m/s	Order of 10^{5} m/s
Crater Radius	5-10 µm	1-2 µm
Material Removal Efficiency	25-40%	15-100%
Duty Factor	20-30%	25-50%
Resistance in Discharge Circuit	Up to 800 Ω	200-1000 Ω
Capacitance	10-100 µF	100-450 pF

Process Principle

The working principle of micro-EDM is quite similar to macro-EDM except for the fact that the feature size is in micro domain. This process is well explained by thermo-electric theory and accepted by researchers across the globe. According to this theory, when an electric field is applied between the tool and workpiece, the dielectric in the gap breaks down due to an electron avalanche which results in ionization and formation of plasma channel.

Over the period of pulse-on time, the plasma undergoes continuous expansion due to the increased pressure and prolonged avalanche in the surrounding dielectric. Inside the plasma channel the '–ve' particles and '+ve' particles move continuously with intermittent collisions causing large energy generation and subsequent heating of plasma.

The temperature of plasma reaches a very high value (around 10000^{o}K) which can eventually heat and evaporate any metals. The molten and evaporated metal on the workpiece and tool surface is retained by high pressure plasma channel. When the pulse is OFF, the plasma channel is collapsed and due to the sudden formation of low pressure gradient between tool electrode and workpiece, the molten and evaporated metal escapes with high thrust force.

This is followed by subsequent flushing of debris by surrounding dielectric which results in formation of craters on tool and workpiece surfaces. The continuous occurrence of this phenomenon over a time will result in formation of required profile on workpiece surface and substantial tool wear. Since the tool size is small, the specific energy will be substantially high on its surface and therefore the ratio of tool wear to material removed will be high. This is the reason why tool wear is the major concern in MEDM. Therefore, the dimensional accuracy of the achieved profile depends on the amount of wear encountered on the tool. The working of MEDM process is based on basic elements such as power supply system, dielectric supply system and electrode feeding system.

Power supply system is an important element of MEDM process and it is based on resistance capacitance (RC) circuit of relaxation or pulsed type. In RC circuits, charging and discharging time is decided by the value of the capacitance. The discharging time is considered as the sparking ON time and charging time as the OFF time. The only disadvantage of this type of circuit is that the current value overshoots to maximum instantaneously causing excessive heating of workpiece material.

Dielectric supply system consists of dielectric tank, pump and filter. Pump is used to draw the dielectric from the tank into the machining area. The purpose of supplying dielectric is to cool both the electrodes and flush away the debris particles from the machining zone. Debris flushing with dielectric is carried out by different techniques such as jet flushing, splash flushing, flushing through hole and motion induced flushing. The motion induced flushing refers to tool motion such as vibration and rotation in the dielectric to remove debris. These techniques are widely used for MEDM where the gap is less than 10 micron. Commonly used dielectrics are Benzene, mineral oils, EDM oil etc. The necessary properties of a good dielectric are low viscosity, high flash point, low dielectric strength, low volatility, etc. [3, 8].

Electrode feeding mechanism in MEDM process is based on impact drive mechanism (IDM) in which feeding steps varies from 0.02-0.6 μm. This mechanism utilizes friction and inertia force for rapid extension/contraction of piezoelectric element by applying pulsating voltage wave form which causes step-by-step movement of tool electrode during MEDM. The purpose of feed control is to maintain the movement of the electrode towards the workpiece at such a speed that the working gap and hence the discharge voltage remains unaltered and there is continuous normal discharge during machining. Since the gap width is so small, rapid response of the mechanism is essential for tool feeding.

Tool electrode profile generated in the workpiece is decided by the shape of the tool. Initially the tool is shaped as negative form of the required profile to generate spark in a certain specific direction. During machining, this electrode is considered as cathode because it encounters lesser heating and subsequently small amount of melting. The desired properties of tool material are high conductivity, high thermal diffusivity, high melting point and boiling point [9]. Commonly used tool electrode materials are copper, graphite, tungsten and brass. Workpiece electrode is an electrode where required profile is generated. The workpiece is generally considered as anode and it is subjected to maximum heating during machining. The desired properties for maximum material removal are low thermal conductivity, high electrical conductivity, low melting and boiling point. The various elements of MEDM are shown in Figure 2.1.

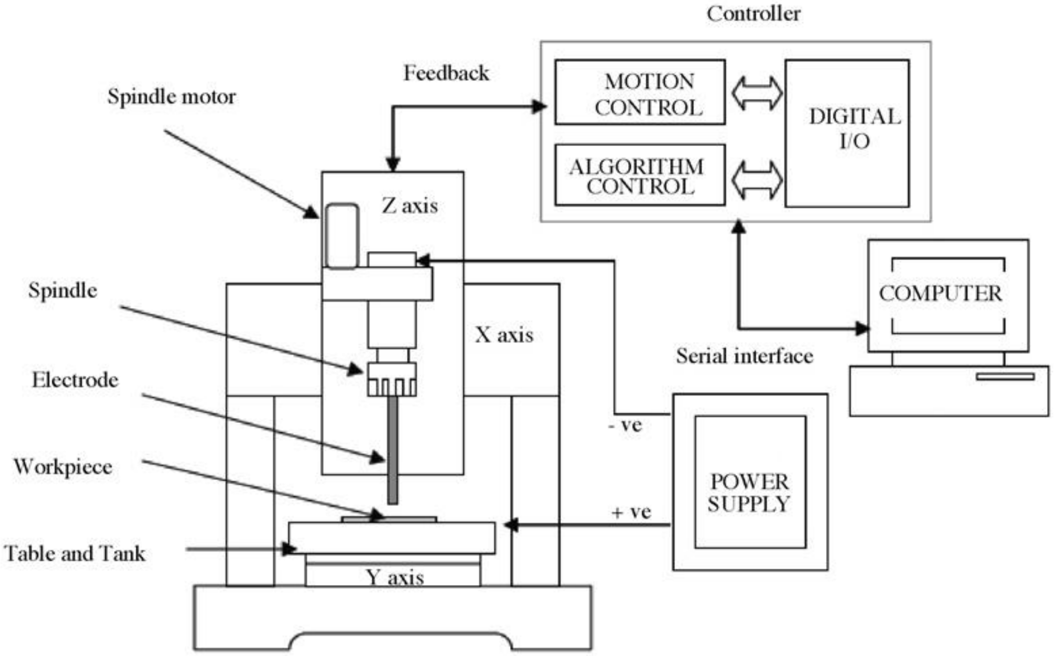

Fig. 2.1 Schematic diagram of hole making MEDM process [10]

III. REVIEW OF MODELLING STUDIES OF MEDM

Modelling of MEDM process has been performed by many researchers to study the process behavior under given conditions. An analytical model based on electro-thermal theory to calculate approximately the geometrical dimensions of micro-crater during MEDM has been proposed by Yoe et al [11]. The model incorporates voltage, current and pulse-on-time during material removal to predict the temperature distribution on the workpiece as a result of single discharge in MEDM. They verified the developed model with single discharge experiments using RC pulse generator with pure tungsten as tool electrode and AISI 4140 alloy steel as workpiece electrode for the pulse-on-time range up to 1000 ns. The experimental and theoretical results are found to be in close agreement with average volume approximation errors of 2.7% and 6.6% for the anode and cathode, respectively.

A thermo-numerical model of MEDM of Molybdenum and steel has been reported by Allen and Chen [12] to study the effect of pulse duration on crater radius, crater depth and tool wear percentage. The model estimates that the percentage of tool wear decreases with an increase in the pulse duration and is much higher for molybdenum than steel at the same machining conditions. Their coupled thermal-structural finite element analysis was performed to show how the thermal action of the MEDM process affected the surface integrity of machined workpiece. They also found that the tensile residual stresses build up near the crater boundary in all directions during the MEDM process.An analytical model proposed by Das and Joshi [13] who considered moving heat source phenomenon and the time variant heat source together with the evaluation of number of sparks in a discharge to predict MRR in micro wire-EDM of 2 mm thick copper plate workpiece with tungsten 30 µm wire tool electrode. The erosion rate evaluated by the model shows dependence on variables like voltage, wire diameter, number of sparks, and wire vibration but it is independent of the wire velocity. The experimental validation of the model shows that the trends predicted by the model are logical and match fairly well with the experimental trends.

A numerical model, based on a multiple discharge approach for recast layer prediction, has been developed by Tan and Yeo [14] for MEDM of stainless mold steel (AISI 420-MOD) workpiece for a peak discharge current of 1.45 A and pulse on time between 166 ns and 606 ns. The developed model predicted recast layer thicknesses of between

1.0 µm and 1.82 µm with above pulse conditions. It is then validated with experimentation at pulse on time settings of 244 ns and 458 ns, which generates average recast layer thicknesses of 1.18 µm and 1.56 µm respectively and fall within the limiting bounds predicted by the model. A two-dimensional geometric simulation model of MEDM drilling of 2.16 mm thick copper workpiece with Φ 200 µm diameter cylindrical WC tool electrode have been developed by Jeong and Min [15].The tool and the workpiece were modeled using a two dimensional matrix which represents the cross-section geometries of them. The material removal process was modeled considering machining condition including the sparking gap width, spark frequency, the workpiece material removal volume per spark and the tool wear ratio. The predicted results using developed model have been compared with the actual experimental ones and they found that the geometry prediction results match the experimental ones well within the error of 13%.

A surface roughness model of micro-electro discharge machined surface of SUS-304 stainless steel workpiece considering gap voltage, gap size, size of the debris particle, concentration of the debris in the dielectric, the thermo-physical properties of the plasma constituents and the dielectric into account has been proposed by Kiran and Joshi [16]. They found that the theoretical values of radius of melt cavity predicted by the model are lower at the time of consideration of the debris particles mixed with dielectic than the corresponding values of the radius of melt cavity predicted by using pure dielectric. The theoretical values of roughness are found to be in good agreement with the experimental values with the consideration of debris.

IV. CONCLUSION

The capability of machining intricate features with high dimensional accuracy in difficult-to machine electrical conductive material has made MEDM process as an inevitable and one of the most popular non-conventional micromachining processes. The above survey gives us brief information about the various modeling techniques used by researchers during Micro electrical discharge machining process. Further, researchers have excluded important factors such as plasma channel radius, thermal conductivity and electrical conductivity of workpiece material and the interaction effects among various factors during study which otherwise would affect the performance characteristics differently. From the literature it is also observed that neural network based experimental modeling gives better prediction result as compare to other experimental modeling techniques.

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