

Influence of Pulse Duration on Electric Discharge in Dielectric Medium

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ABSTRACT: A standard electric discharge cell for machining consists of two electrodes at a pre-set distance in a gaseous or liquid dielectric. Depending on the cell construction, beyond a threshold external potential between the electrodes, breakdown of the dielectric takes place and discharge occurs. During the discharge, continuous bombardment of ions and electrons on the electrodes take place. Application of pulsed potential ensures the rapture of the plasma channel at the end of the pulse to cease the discharge for better control of the erosive effect for machining. Higher the external potential above the threshold value, higher energy discharge takes place. The effect of cell parameters such as the dielectric medium, pulse amplitude and pulse duration is investigated for the initiation of the discharge. An empirical relation among these parameters is presented to predict the minimum external potential required to initiate electric discharge for a given cell.

KEYWORDS: Dielectric breakdown; Electric discharge; Discharge energy; Cell parameters, Pulsed potential; Empirical relation.

I. INTRODUCTION

The dielectric breakdown to establish an arc or spark is a well-known and well discussed phenomenon in the field of physics and electrical engineering. The discharge in liquid medium when properly controlled can be used for machining materials and termed as electrical assisted machining. The earliest of such technique of machining is electrical discharge machining (EDM), where kerosene or deionised water is the medium. More recently the discharge through electrolyte is named as Electrochemical Discharge Machining (ECDM) or Electrochemical Arc Machining (ECAM). The discharge energy is controlled more precisely so that very small amount of material is removed per discharge leading to better machining accuracy with better surface integrity. The correct requirement of discharge cell condition is established mostly by trials with the cell parameters. All the machining system uses discharge thorough liquid dielectric in a small inter electrode gap, in the order of 10-15 μ m.

There are two main classes of theories for the electrical breakdown of insulating liquids (dielectric). One based on electronic multiplication by collisional ionization and the other on thermal bubble formation mechanism [1]. The electronic theories are analogous to the Townsend theory of gas breakdown, in which electrons gain sufficient energy from the electric field for collisional ionization [2]. The resulting exponential increase in electron avalanche leads to breakdown. In the thermal breakdown (bubble) theories the current in the high field region causes local heating, which vaporizes the liquid to form bubbles. Gas breakdown occurs within each bubble, causing further heating, and the bubbles grow until complete breakdown of the gap occurs. Micro-bubbles can pre-exist in the liquid [3] or may form electrically, i.e. from heat released by small electron avalanches in the liquid or by field emission near electrode asperities [4, 5]. The generation and initial expansion of pre-breakdown cavities shows that micro bubbles ($\leq 10\mu$ m in diameter) create, grows to a maximum size set by ambient pressure, and then collapses at discharge. These expansion and collapse processes are described by the Rayleigh model of cavitation [6]. Above works indicate that for electric discharge in any medium; the plasma channel is the route. The formation and maturing of this channel to initiate and propagate the discharge, which is a stream of ion depends on the cell construction and requires finite time.

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In the study of electrochemical discharge between the electrode (cathode) and the electrolyte, Basak and Ghosh [7] suggested the isolation between the electrode and the aqueous electrolyte due to the formation of the vapour bridge leads to the discharge. The discharge voltage is as low as 15VDC to 30VDC. The rapid generation of bubble took place due to electrochemical action and also ohmic heating in the discharge zone. They termed the process as Electrochemical Discharge Machining (ECDM). A later study [8] had shown the capability of such discharge to machine electrically non conducting materials particularly in strong alkaline electrolyte medium. Nguyen et. al [9] reported Micro-EDM in deionized water using short voltage pulses to suppress the electrochemical reaction and concluded that pulse-on time is the main factor that affects the electrochemical reaction rate. Pulse-on time is under a critical value (300 ns) dissolution of material from work piece could be effectively suppressed. The influence of the pulse duration on discharge voltage in EDM reported by Das et. al.[10], which shows that with decrease of pulse duration voltage requirement increases. The influence of open-circuit voltage on high-speed wire electrical discharge machining was reported by Houet. al. [11], using insulating zirconia as work piece material and the results indicated that the machining gap as well as discharge time increases with increased open circuit voltage. Nandi et. al. [12] investigated the discharge voltage requirement for different cell conditions with pulse duration of 2.5ms and noticed that the required discharge voltage mainly depends on circuit resistance and inter-electrode distance. The flow condition of dielectric raises the discharge voltage by small magnitude. The study of Patel KM et. al. [13] showed that the discharge current and duty cycle to be most significant parameters, along with pulse-on time and gap voltage, on material removal rate and surface roughness. A number of recent reports [14, 15, 16] are available on optimisation of EDM cell parameters for difficult to machine materials.

It is confirmed from the published works that to complete the events for discharge require a finite time which is function of applied potential and its type, electrode gap, properties of the dielectric and to some extent the shape of the electrodes. The machining accuracy in EDM is strongly dependent on the spark energy, which depends on the discharge voltage as well as discharge current, which in turn depends on the voltage pulse duration. Assessment of minimum discharge voltage, which delivers minimum energy, is not reported so far. The present work is aimed to investigate this area. The influence of pulse duration on discharge voltage was reported by Das et. al.[10] and the relation between discharge voltage and inter-electrode gap discussed by Nandi et.al [12]. By taking the lead from these works an empirical relation among the cell parameters to predict the minimum voltage requirement for discharge is attempted in the present work.

II. RELATED WORK

The present work is targeted to establish the effect of the DC pulse duration on the discharge voltage through dielectric medium. A set up is designed to read the discharge voltage for particular pulse duration schematically shown in fig 1.

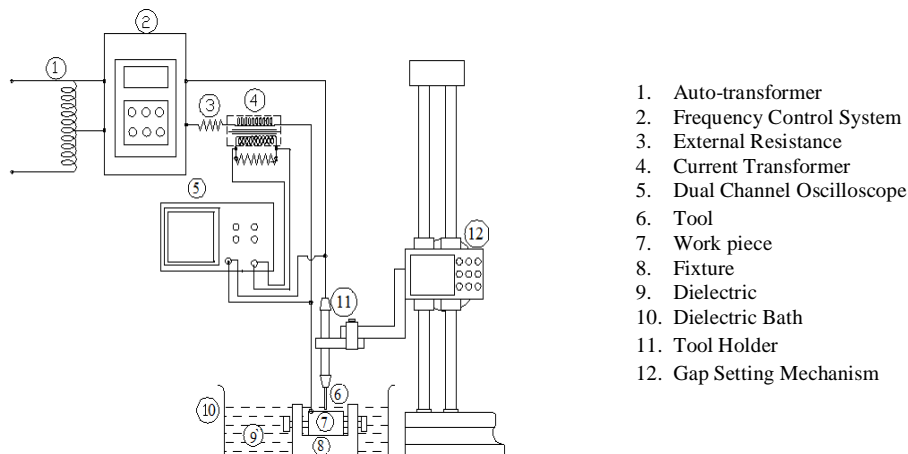


Fig 1. Experimental setup

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The input voltage is controlled by the autotransformer and the frequency controller sets the desired frequency and duty ratio of the voltage pulse. The potential range is 0-250VDC and the cycle duration 1ms- 500ms with on-off ratio 1 to 99. A resistor of cold resistance 15Ω is connected in series in the electrical circuit to control the current at the event of short circuit or formation of arc. A dual channel oscilloscope is used to record the input voltage shape and to detect the circuit current. The spikes in the current wave confirm the discharge in the dielectric bath, though the actual magnitude of the discharge current is not possible to measure by this method. A height gage is used to set the tool at the preset distance from the work piece. Prior to each experiment the contact between the electrodes were detected to establish the zero gap setting or the datum. For simplicity of experiments tools are taken cylindrical of 0.78mm diameter and the work pieces as flat surface. The surfaces were prepared and finished to surface roughness of $R_a= 0.25$ to $0.20\mu\text{m}$.

The present work has been conducted with double distilled water with conductivity $3.8\mu\text{S}/\text{cm}$ as dielectric, as the other popular dielectric kerosene is discouraged now a day due to many hazards. The conductivity of the dielectric was monitored at regular interval during the experiments. When it reaches $5\mu\text{S}/\text{cm}$, it is replaced for consistency of the experimental condition. Copper (Cu), Steel (Fe) and Aluminium (Al) were used as electrode materials.

III. EXPERIMENTAL OBSERVATIONS

The tool and the electrode are set at a predetermined gap and the input potential was increased gradually from zero to the voltage till the discharge occurs, for particular pulse duration. The literature survey indicates that the single discharge time is much lesser than 2.5ms. Pulse duration higher than the single discharge time leads to multiple discharges in a single pulse. Therefore, observations were made choosing the cell condition with lesser pulse time between 0.0625ms and 2.5ms. For all the experiments the cycle time was 5ms and the pulse on times is set by controlling the duty factor, so that when the on time of the pulse is decreased, the interval between two successive pulses is increased. This allows the dielectric between the electrodes sufficient time for deionization, particularly for stagnant condition. The pulse duration- discharge voltage are plotted to find their relation. Figure 2a and 2b show the characteristic curves for Cu-Al, Cu-Fe and Cu-Cu as electrode material combination for different pulse on time at the onset of discharge. Inter electrode gap chosen were 0.005mm, 0.010mm and 0.015mm to cover the micromachining range. Both the stagnant and flowing dielectric condition are shown in the figure. Higher voltage requirement for discharge is noticed for flowing dielectric condition than the stagnant condition in the pilot experiments. The pattern observed in all such combinations was same in nature, but magnitude differs. Therefore, only the characteristic curves for Cu-Fe electrode combination in stagnant dielectric condition for different inter electrode gap has been shown in figure 3.

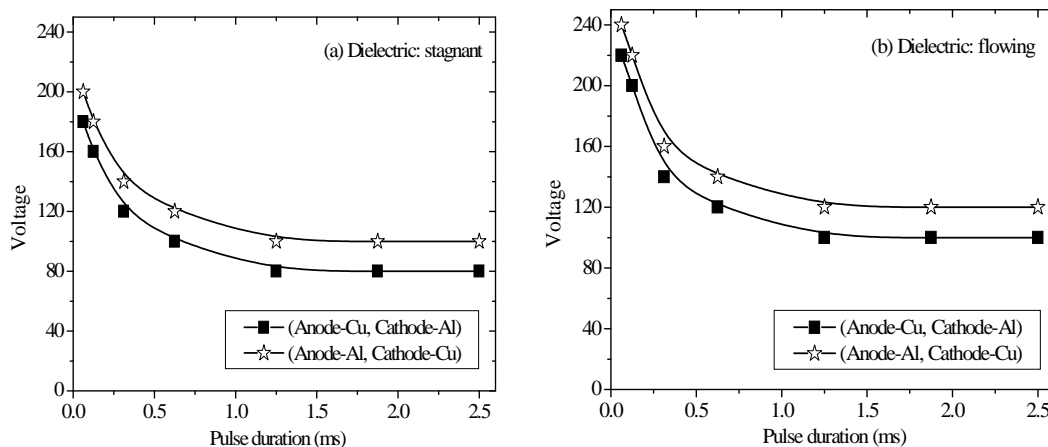


Fig 2a. Discharge voltage – pulse duration characteristic for different combination of Cu and Al electrode (Inter electrode gap = 0.005mm)

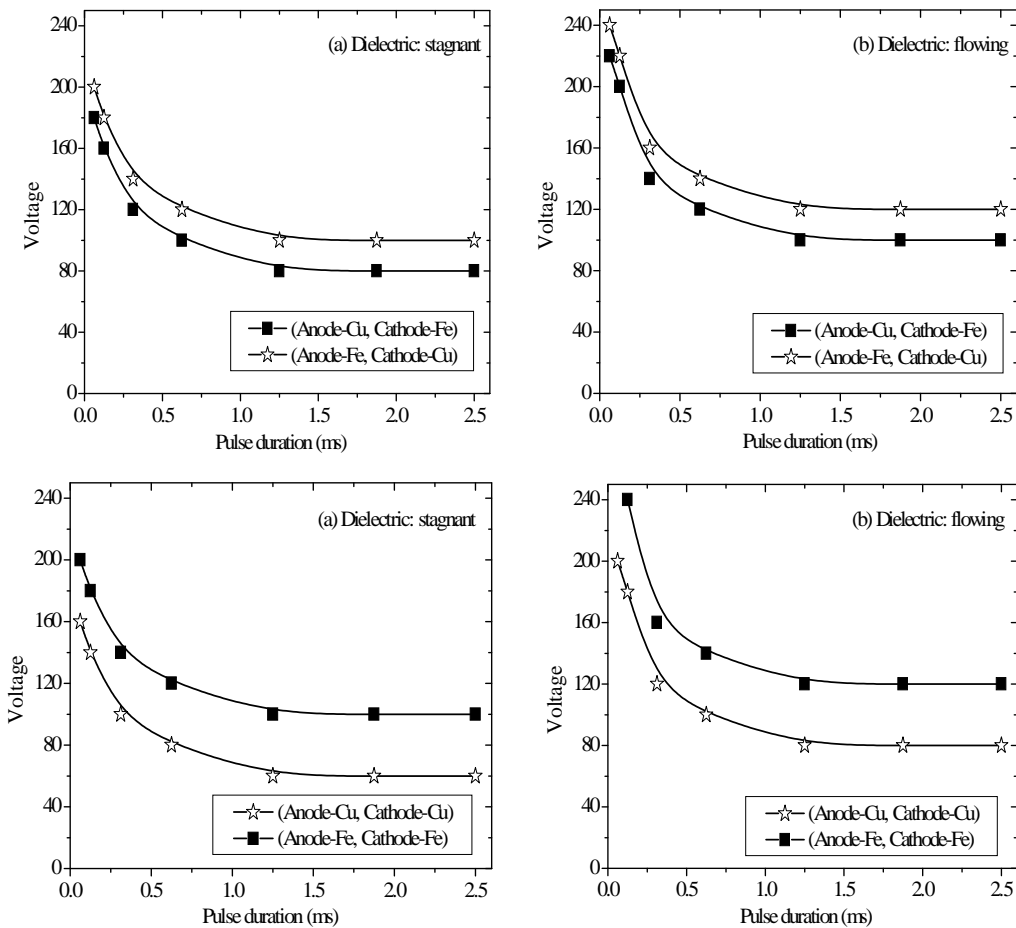


Fig 2b. Discharge voltage – pulse duration characteristic for different combination of Cu and Fe electrode (Inter electrode gap = 0.005mm)

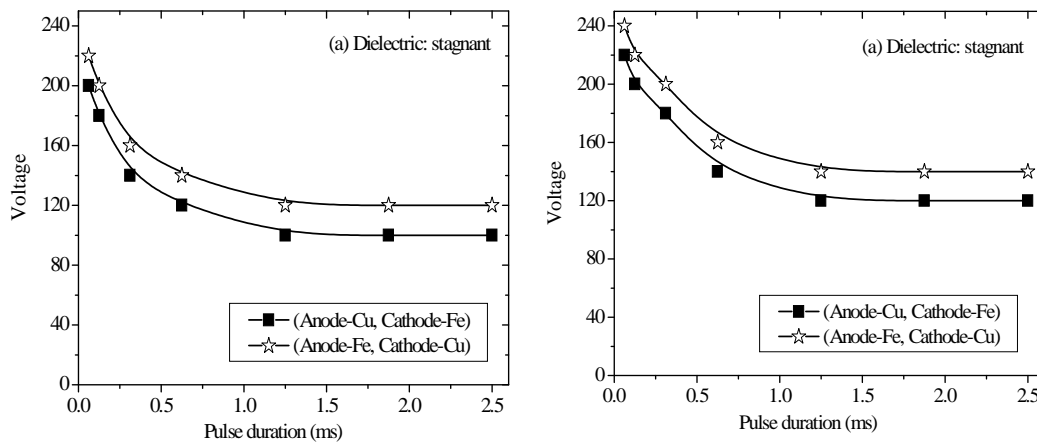


Fig 3. Discharge voltage – pulse duration characteristic for different combination of Cu and Fe electrode (Inter electrode gap = 0.010mm, 0.015mm)

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IV. ANALYSIS OF THE OBSERVATIONS

The significantly information obtained from this set of curves is that the discharge voltage increases gradually below certain pulse duration for initiation of discharge. This is due to the critical time requirement to complete the discharge prerequisite. As the time allowed is lessened higher voltage become necessary to complete the discharge channel. The flat portion of the curves at the longer pulse duration is due to the excess time allowed than the critical one where multiple discharges take place within a single pulse. This was noticed as multiple spikes in the current trace on the oscilloscope in a single long pulse of applied voltage. The magnitude of flat constant voltage region is different for different cell conditions. The generation of bubble is the primitive need of the discharge initiation. Electrical and thermal conductivity of the dielectric liquid plays an important role in the generation of bubble. The bubbles may be vapour bubble due to local ohmic heating or may be that of the product of chemical break down of the dielectric and are due to electrolysis/pyrolysis. The purity of the dielectric degrades due to contamination from the debris, the electrical conductivity increases and the experiments become unstable. In present experiments distilled water is used and more and more free ions accumulate in the medium and increase its conductivity.

V. PROPOSED RELATION

Based on the pattern of the discharge voltage with pulse duration a negative power equation with the pulse duration is fitted and expressed as an empirical relation $V_{\min} = V^*(\tau/\tau^*)^{-n}$, where, V_{\min} is the discharge voltage, V^* is the nominal voltage represented by the flat constant portion of the characteristic curves which is cell condition dependent, τ is the pulse duration in millisecond, τ^* is the minimum pulse time for single discharge and n is an index. The elaborate discussion to estimate V^* has been made by Nandi et. al. [12]. It showed that with the increase of the circuit resistance and interelectrode gap V^* increases. Ideally, in the machining setup the circuit resistance should be as small as possible to bring down the discharge voltage. It is observed from the curves that below the pulse duration of 1.2ms the V_{\min} value starts to increase. In other word it is the minimum time required for a given cell condition. Therefore, the magnitude of τ^* is 1.2ms in the empirical relation. The best matching value of n found to be 0.25, from mathematical interpolations. Hence the proposed relation can be expressed as $V_{\min} = V^*(\tau/1.2)^{-0.25}$, where V^* is the discharge voltage required for a discharge cell for long pulse or pure DC and τ is the pulse duration less than 1.2ms in the short duration pulse machining condition. The value of the index (-0.25) in the proposed empirical relation can be explained as the result of the initiation time as well as propagation time of the charges (discharge channel). To establish the validity of the proposed relationship, experimental observations by Nandi et. al. [12] as well as new sets of experiments from the same set up with Cu-Fe combination was conducted and some of the results are tabulated in Table 1. It shows the comparison between the predicted value of discharge voltage by the proposed empirical relation and observed values from the experiments and the percentage deviations.

VI. CONCLUSION

The inter electrode or tool work piece distances and other cell parameters are chosen so that finishing EDM as well as the micro-EDM range is covered. The present experiments are done with copper, steel and distilled water and only, which are the primitive and fundamental elements in EDM related research. Special dielectric medium such as EDM oils, high strength modern materials used in bio-medical, space and other specialised field should be tested with this empirical relationship. As the discharge voltage is the strong factor for the discharge energy, controlling of it will result in better control of the discharge energy, which is essential for precision machining. The optimum duration of the pulse need to be established for best machining condition of a give material (alloy) for a given cell condition. For strong flushing condition, additional factor must be incorporated in the proposed relation, based on the flushing velocity to obtain more precise prediction.

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Table 1: Comparison between the predicted and observed discharge voltage
(D= Distilled water; K= Kerosene; S= Stagnant dielectric; F= Flowing dielectric)

Dielectric	Flow condition	Inter electrode distance, h (mm)	Pulse Duration, τ (ms)	Calculated V_{min} (volt)	Observed V_{min} (volt)	Deviation, %	Dielectric	Flow condition	Inter electrode distance, h (mm)	Pulse Duration, τ (ms)	Predicted V_{min} (volt)	Observed V_{min} (volt)	Deviation, %
Anode= Copper; Cathode= Steel						Anode= Steel; Cathode= Copper							
K	S	0.010	0.0625	209	200	-4.46	K	F	0.015	0.6250	224	240	+7.31
D	S	0.010	0.1250	176	180	+2.26	D	S	0.005	0.0625	230	200	-13.14
D	S	0.010	0.6250	122	120	-1.33	D	S	0.005	0.1250	194	180	-7.04
D	F	0.005	0.3125	132	140	+5.71	D	S	0.005	0.3125	154	140	-9.08
D	F	0.005	0.6250	104	100	-4.00	D	S	0.005	0.6250	129	120	-7.32
K	F	0.005	0.0625	167	180	+7.49	K	F	0.005	0.0625	144	140	-2.86
Anode= Copper; Cathode= Copper						Anode= Steel; Cathode= Steel							
D	S	0.020	0.6250	141	140	-0.89	D	S	0.015	0.6250	224	200	-10.58
K	S	0.020	0.3125	168	180	+7.15	D	S	0.010	0.6250	209	200	-4.50
K	S	0.020	0.6250	152	160	+5.00	K	F	0.010	0.3125	252	240	-4.17
K	F	0.020	0.3125	184	200	+8.00	K	S	0.015	0.3125	266	240	-9.77

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