Gap in the Knowledge Base of Electro Discharge Machining

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Abstract: ***Inspite of extensive research and industrial application, the process of Ele1ctro Discharge Machining (EDM) still remains a black box process whereby input output relationships are known but the associated mechanisms are not properly understood. This paper brings out such Gap which can be targeted by researchers of both academic and industrial R and D units.***

Keywords: SEDM, WEDM, Keying Ratio, Hiatuses (Gap), EDM

1. Introduction

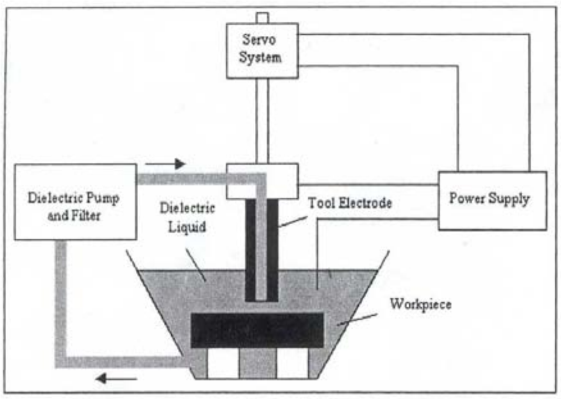
The capabilities of EDM process have been extensively exploited in the engineering industry and it can no longer be considered as a dark horse. However the knowledge of theories and mechanism associated with several of its characteristic features are not properly understood. Several such lacunae have been presented in this study. Several subjects like Physics, Electrical Engineering, Thermo mechanical properties of Materials, Control systems for the process performance and adaptive control etc are associated with the EDM process and the general tendency is to accept any speculative theory which appears logical but without scrutiny of its validity. One must admit the difficulty in the understanding and explanation of every feature of EDM owing to its extremely fast spark trains and narrow spark gaps. But not to seriously investigate the underlying mechanism is certainly a glaring hiatus in EDM research.

2. The EDM Process and Its Variations

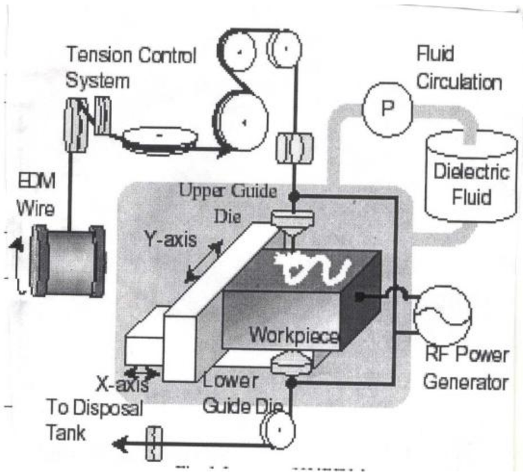
Electro Discharge Machining (EDM) employs high frequency sparks for machining difficult to machine materials and contours. The tool and work piece form a pair of electrodes, separated by about 20 to 200 μm in a liquid dielectric medium through which the spark discharges occur.

There are two forms of EDM. In one, the tool is rigid and preformed to the shape of the desired contour of the machined surface. This process is termed as sinking type EDM (SEDM) (Fig. 1. a). The present day advanced SEDM systems do not need a fully pre-shaped electrode but have a CNC programmed electrode which operates just similar to the die sinking process. The other process employs a flexible wire of less than 0.25 mm diameter as the electrode, continuously passing through the machining zone of work piece. The wire path is CNC programmed in the wire cut EDM or simply WEDM (Fig. 1. b). The other difference in these two processes is the dielectric fluid, which is kerosene in SEDM and deionized water in WEDM.

The dielectric in the gap becomes ionized and forms a plasma channel, which becomes a conducting medium immediately after the pulse is applied. At the end of pulse the plasma breaks down and becomes non-conducting. The spark occurs through a very narrow channel of a few μm diameters and the energy density is so high that temperatures of the order of several thousand degrees are produced causing melting or even evaporation at the spot of spark impingement. The explosive nature of the spark causes the ejection of molten metal as fine atomized droplets, which undergo rapid solidification on coming into contact with the surrounding dielectric leaving behind a neat spherical crater. The machined surface has a matte appearance consisting of overlapping craters due to the high frequency sparks. As the machining progresses the tool is fed by a servo control to maintain uniform gap and stable machining.



(a) SEDM



(b)WEDM

Figure 1: The Schematic of the two types of EDM processes

3. Resume of Popular Research Areas

Some of the typical and popular research areas are listed in Fig 2. Experimental research generally targets regression analysis of process parameters and modeling to optimize the process characteristics. (1) This involves maximization of machining rate and minimization of tool wear and surface roughness. This also helps in the development of adaptive control systems. The advances in computer applications in manufacturing processes and their control has led to the development of artificial intelligence approaches in the form of expert systems, neutral networks and fuzzy logic. (2) towards optimization and other control systems like prevention of wire rupture (3,4) However most of the experimental research has a simplistic approach and tries the variation of dielectric (hydrocarbons and water based) and electrode materials (Copper, tungsten, graphite etc), method of gap flushing (tool rotation, vibration or oscillation, magnetic and ultrasonic fields application) (5,6,7) and studies of surface integrity (hardness, residual stress, defects like micro cracks, alloying with electrode material) (8). The other type of popular research area is hybridization of EDM with another assisting process for combining the beneficial features of both processes. In the case of EDM the assistance of electro chemical machining (9) Ultrasonic machining (7) and magnetic field (10) have been reported. Inspite of being so extensively researched there are considerable grey areas in the literature on the EDM process and the associated theories and mechanism.

4. The Hiatuses with knowledge base of EDM

The Fig 3 lists some of the grey areas identified from the available reports. One must qualify this report to be limited owing to the space constraints therefore it just tries to illustrate their existence as possible targets for investigation.

5. Dietetic Break Down and Spark Generation

There are several research reports on the theories and mechanisms of the breakdown of liquid dielectrics but these are generally limited to the fields of physics and electrical engineering, particularly high voltage engineering and breakdown of transformer oils and insulation where the dielectric break down is an undesirable phenomenon. In EDM field there has not been much of an effort for experimental or theoretical analysis though the dielectric break down and the resultant spark is desirable for effective erosion.

With an increase in voltage, the current (leakage current) gradually increases and at point B the conductive current sharply increases such that $d/du \rightarrow \alpha$ and the dielectric is supposed to have yielded (Breakdown) similar to metal yielding under stress (Fig. 4) A strong conductive channel is formed (Breakdown channel or spark channel in EDM terminology) which practically produces short current between the electrodes.

The point of breakdown generates a spark. The parameter, which is used to describe the resistance of dielectric to breakdown, is called "electric strength" or "breakdown strength" given by

$$E_{Br} = V_B / h \quad Volts / m$$

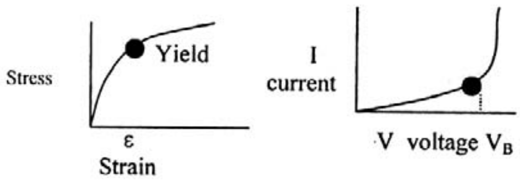


Figure 4: Analogy between metal and dielectric breakdown

Where V_b is the voltage and h is the inter electrode gap. The electric field between the electrodes is non-uniform (like stress concentration in stressed metals) due to the following reasons.

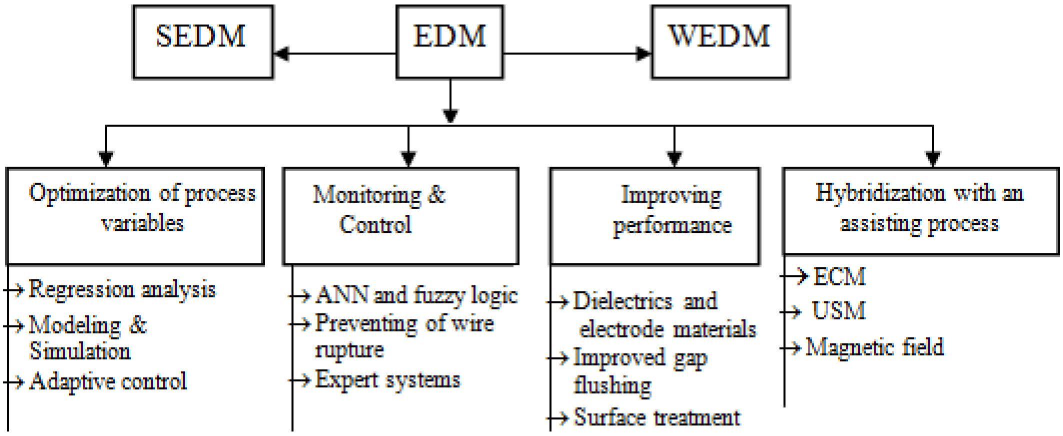


Figure 2: Some typical research areas in EDM

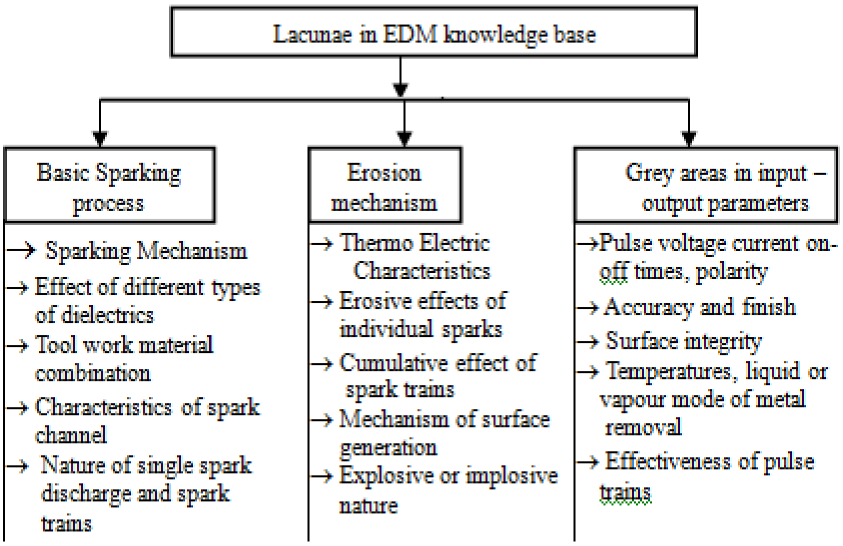


Figure 3: The relatively unexplored areas of EDM

The edges have higher concentration than average electrical field.

1) Irregularly of the surfaces of electrodes (making variable "h").
2) Polar contaminants (impurities) causing concentration of electrical field.

The breakdown is initiated by the field emission of electrons at a favorable site on the cathode surface to cause the formation of a low-density region called cavitation, which develops into a tree like streamer. The growth of the streamer occurs by space charge multiplication by impact ionization which causes bridging of electrodes with a conductive plasma channel. This leads to the spark discharge which is ionic with absorption of electrons at anode and ions at Cathode. Since EDM requires discrete sparks at randomly varying locations, the power source employs pulse generator triggering square pulses. The grey areas are the actual mechanism of dielectric breakdown, exact nature of spare discharge, energy distribution at cathode and anode, effect of polarity on metal erosion rate and tool wear etc., The erosive effects of these sparks also do not have any clear explanation.

Thermal and thermo mechanical theories (5) are the two basic mechanisms suggested. The thermal nature of metal erosion is however accepted by all researchers. The material removal might occur by vaporization or atomization from the molten state depending upon the temperatures realized during spark discharge. The thermal shock, whereby the metal may come off due to high temperature gradients between melting or vaporizing metal and the relatively cold metal a few microns away, may yet to be another contributing factor for metal erosion. Electric field forces and ionic forces can be sufficient to cause rupture. Paradoxically there is no agreement in published reports about the exact nature of plasma channel collapse i.e. whether it is explosion or implosion which causes ejection of metal from the spots of spark impingement.

The other unexplained feature is the polarity. Though in spark as well as arc discharge major energy concentration is supposed to be at anode, in EDM there are several instances where the reverse is true. Electrode negative is employed in SEDM with relaxation circuits and in all situations of WEDM whereas in most of the SEDM applications electrode positive is employed with rare exceptions of some tool work material combinations. One possible explanation is that tool electrode should be cathode for short duration pulses (WEDM and SEDM with relaxation circuit) but anode for long duration pulses (SEDM with square pulses). One of the reasons attributed (11) is that in short duration pulses, ions with large mass compared to electrons do not achieve sufficient kinetic energy to cross spark gap to deliver their energy to cathode work piece and cause effective erosion. On the other hand long duration pulses cause large plasma channel expansion due to mutual repulsion of electrons because of their light mass which results in low energy density at anode.

6. Other Unexplored Phenomena are

1) Ignition delay (time lapse between initiation of voltage pulse and actual spark discharge), keying ratio (Pulse On time Vs Off time).
2) Effectiveness of pulse trains (open circuit and short circuit pulses are ineffective). This defect is the effectiveness of servo control of tool feed.
3) Effects of different dielectrics (Their ionization and deionisation characteristics. The former effects ignition delay and the latter, pulse off time).
4) Assistance of doping the dielectric with metal powder or electrolyte for improved sparking.
5) Effectiveness of tool work material combination for improved performance.

7. Concluding Remarks

The extremely fast process of spark erosion and narrow spark gaps are the major handicaps in the observations and analysis of the mechanisms associated with EDM. There will always be lacunae in the analysis proffered by researches and one will have to be satisfied by what is termed in legal parleys as circumstantial evidence. However there must be an attempt to substantiate the theories, however speculative they may be, with some theoretical backing to provide sufficient logical satisfaction. EDM is a highly fascinating process and has unlimited scope of further research. Though only some typical hiatuses are presented here, a discerning scholar can find several more grey areas for fundamental research. Owing to the numerous process parameters, exact regression modeling may be difficult and herein lies another prospective area of research through application of A.I. techniques for the development of expert systems and optimizations with ANN and fuzzy logic approach.

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