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Key Engineering of Electrical Discharge Machining: A Review

Anil kumar[1], Khempal[2]
[1,2](P.G.SCHOLOR) Mechanical Department, University Institute of Engineering and Technology, Kurukshetra University

Abstract— ***EDM is one of the most extensively used non-conventional material removal processes. Both electrode (tool) and work piece must be electrically conductive. The spark occurs in a gap filled with dielectric solution between the tool and work piece. The process removes metal via electrical and thermal energy, having no mechanical contact with the work piece. Its unique feature of using thermal energy is to machine electrically conductive parts regardless of their hardness; its distinctive advantage is in the manufacture of mould, die, automotive, aerospace and other applications. In addition, EDM does not make direct contact between the electrode and the work piece, eliminating mechanical stresses, chatter and vibration problems during machining. In recent years, EDM researchers have explored a number of ways to improve EDM Process parameters such as Electrical parameters, Non-Electrical Parameters, tool Electrode based parameters & Powder based parameters. This new research shares the same objectives of achieving more efficient metal removal rate reduction in tool wear and improved surface quality. This paper reviews the research work carried out from the inception to the development of die-sinking EDM, Water in EDM, dry EDM, and Powder mixed electric Discharge Machining. Within the past decade briefly describing the Current Research technique Trend in EDM, future EDM research direction***
Key Word-Electrical Discharge Machining (EDM), Dry EDM, PMEDM, MRR, TWR, SQ

I. INTRODUCTION

Electrical Discharge Machining (EDM) is a thermoelectric process that erodes work piece material by series of discrete but controlled electrical sparks between the work piece and electrode immersed in a dielectric fluid. It has been proven to be especially valuable in the machining of super-tough, electrically conductive materials such as the new space-age alloys. These materials would have been difficult to machine by conventional methods, but EDM has made it relatively simple to machine intricate shapes that would be impossible to produce with conventional cutting tools. In EDM process, the shapes of mould cavities are directly copied from that of tool electrodes, so time consuming preparation work must be done on the fabrication of the corresponding tool electrodes. When the shape of the expected cavities changes or the wear of the tool electrodes exceeds a certain limit, they must be remade, wasting both time and money. The history of EDM Machining Techniques goes as far back as 1770, when English chemist Joseph Priestly discovered the erosive effect of electrical discharges or sparks. The EDM process was invented by two Russian scientists, Dr. B.R. Lazarenko and Dr. N.I. Lazarenko in 1943. The spark generator used in 1943, known as the Lazarenko circuit, has been employed over many years in power supplies for EDM machines and proved to be used in many current applications. The Lazarenko EDM system uses resistance capacitance type of power supply, which was widely used at the EDM machine in the 1950's and later served as the model for successive development in EDM. Developments in the 1960's of pulse and solid state generators reduced previous problems with weak electrode as well as inventions of orbiting systems. In the 1970's the number of electrodes is reduced to create cavities. Finally, in the 1980's a computer numerical controlled (CNC) EDM was introduced in USA.

II. PRINCIPLES

The principle of EDM is to use the eroding effect of controlled electric spark discharges on the electrodes. It is thus a thermal erosion process. The sparks are created in a dielectric liquid, generally water or oil, between the work piece and an electrode, which can be considered as the cutting tool. There is no mechanical contact between the electrodes during the whole process. Since erosion is produced by electrical discharges, electrode and work piece have to be electrically conductive. Thus, the machining process consists in successively removing small volumes of work piece material, molten or vaporized during a discharge. The volume removed by a single spark is small, in the range of 10^{-6}-10^{-4} mm^3 but this basic process is repeated typically 10’000 times per second. Figure 1 gives a simple explanation of the erosion process due to a single EDM discharge. First, voltage is applied between the electrodes. This ignition voltage is typically 200 V. The breakdown of the dielectric is initiated by moving the electrode towards the work piece. This will increase the electric field in the gap, until it reaches the necessary value for breakdown. The location of breakdown is generally between the closest points of the electrode and of the work piece, but it will also depend on particles present in the gap. When the breakdown occurs the voltage falls and a current rises abruptly. The presence of a current is possible at this stage, because the dielectric has been ionized and a plasma channel has been created between the electrodes.

The discharge current is then maintained, assuring a continuous bombardment of ions and electrons on the electrodes. This will cause strong heating of the work piece material (but also of the electrode material), rapidly creating a small molten metal pool at the surface. A small quantity of metal can even be directly vaporized due to the heating. During the discharge, the plasma channel expands. Therefore, the radius of the molten metal pool increases with time. The distance between the electrode and the work piece during a discharge is an important parameter. It is estimated to be around 10 to 100 μm (increasing gap with increasing discharge current). At the end of the discharge, current and voltage are shut down. The plasma implodes under the pressure imposed by the surrounding dielectric. Consequently, the molten metal pool is strongly sucked up into the dielectric, leaving a small crater at the work piece surface (typically 1-500 μm in diameter, depending on the current).

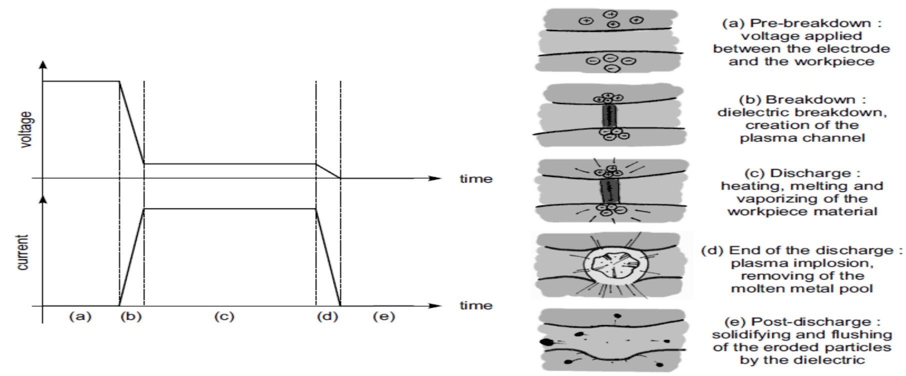

Fig 1 Principle of the EDM process

The liquid dielectric plays a crucial role during the whole process: it cools down the electrodes, it guarantees a high plasma pressure and therefore a high removing force on the molten metal when the plasma collapses, it solidifies the molten metal into small spherical particles, and it also flushes away these particles. The post-discharge is in fact a crucial stage, during which the electrode gap is cleaned of the removed particles for the next discharge. If particles stay in the gap, the electrical conductivity of the dielectric liquid increases leading to a bad control of the process and poor machining quality. To enhance the flushing of particles, the dielectric is generally flowing through the gap. In addition, the electrode movement can be pulsed, typically every second, performing a large retreat movement. This pulsing movement also enhances the cleaning, on a larger scale, by bringing "fresh" dielectric into the gap. The material removal rate can be asymmetrically distributed between the electrode (wear) and the work piece (erosion). The asymmetry is mostly due to the different materials of the electrodes. But it also depends on the electrode polarity, on the duration of the discharges and on the discharge current. Note that by convention, the polarity is called positive when the electrode is polarized positively towards the work piece, negative otherwise. By carefully choosing the discharge parameters, 0.1% wear and 99.9% erosion can be achieved.

III. MAJOR PARAMETERS OF EDM

EDM Parameters mainly classified into following categories.

A. Electrical Parameters

1) Spark On-Time (Pulse Time Or Ton): The duration of time (µs) the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is really controlled by the peak current and the length of the on-time.

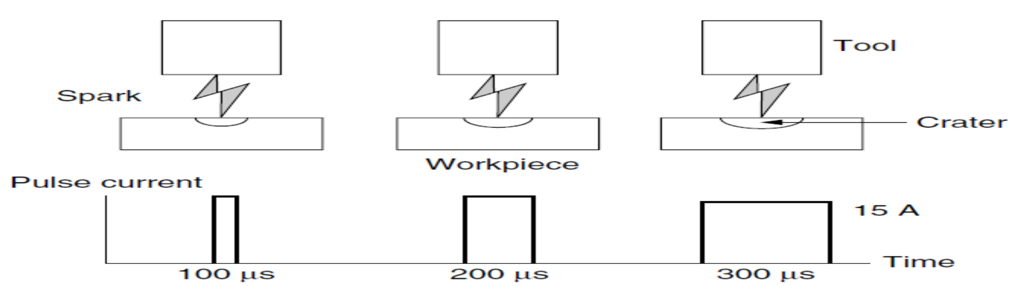

Fig 2 MRR is directly proportional on-time

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2) Spark Off-Time (Pause Time Or Toff): The duration of time (µs) between the sparks (that is to say, on-time). This time allows the molten material to solidify and to be wash out of the arc gap. This parameter is to affect the speed and the stability of the cut. Thus, if the off-time is too short, it will cause sparks to be unstable.

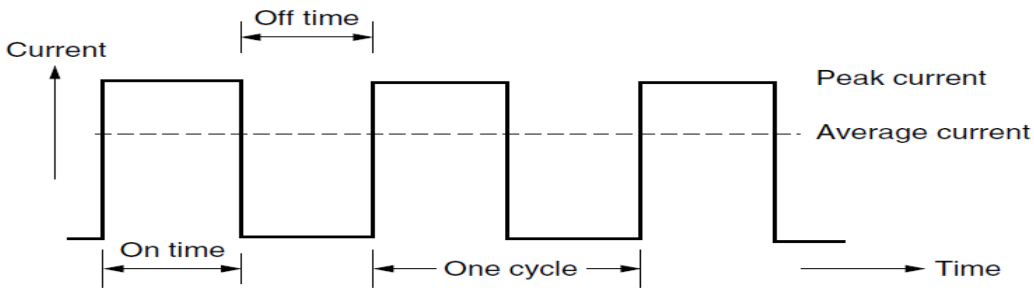

Fig-3 show on time and off time

3) Arc Gap (Or Gap): The Arc gap is distance between the electrode and work piece during the process of EDM. It may be called as spark gap. Spark gap can be maintained by servo system

4) Discharge Current (Current Ip): Current is measured in amp Allowed to per cycle. Discharge current is directly proportional to the Material removal rate. As shown in fig-4

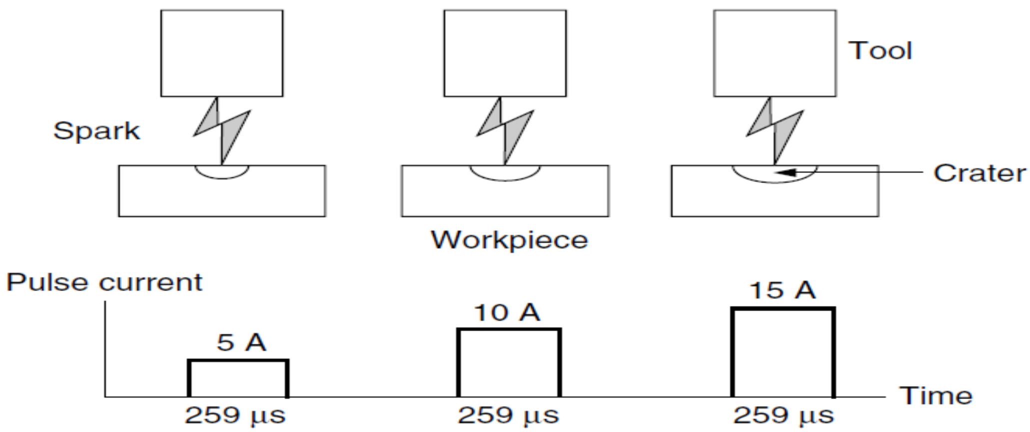

Fig- 4 Effect of current on MRR

5) Duty Cycle (τ): It is a percentage of the on-time relative to the total cycle time. This parameter is calculated by dividing the on-time by the total cycle time (on-time pulse off time). $\tau = \frac{ton}{ton + toff}$

6) Voltage (V): It is a potential that can be measure by volt it is also effect to the material removal rate and allowed to per cycle.

7) Over Cut: It is a clearance per side between the electrode and the work piece after the marching operation.

B. Non Electrical Parameters

Non-electrical parameters such as the Rotational movement of electrode, flushing of dielectric fluid and aspect ratio (tool shape) together play a significant role in delivering optimal performance measures. This section discusses the effects of non-electrical parameters on the various performance measures.

1) Rotation Of Tool Electrode: It is the rotational effect of cylindrical (pin shaped) or disc shaped electrode tool measured in revolution/minute. The rotational movement of electrode is normal to the work surface and with increasing the speed, a centrifugal force is generated causes more debris to remove faster from the machining zone. The centrifugal force generated throws a layer of dielectric in to the machining gap, induces an atmosphere for better surface finish, prevent arching and improves MRR. The results concluded an improvement in MRR due to the better flushing action and sparking efficiency with little tool wear but the surface finish was improved.

2) Injection flushing: Flushing removes eroded particles from the gap for efficient cutting and improved surface finish of machined material. Flushing also enables fresh dielectric oil flow into the gap and cools both the electrode and the work piece. Basic characteristics required for dielectric used in EDM are high dielectric strength and quick recovery after breakdown .There

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variations of EDM processes can be classified according to the type of dielectric fluid used. Most dielectric media are hydrocarbon compounds and water. The hydrocarbon compounds are in the form of refined oil; better known as kerosene. While the fluid properties are essential, the correct fluid circulating methodology is also important. The dielectric fluid not only forms a dielectric barrier for the spark between the work piece and the electrode but also cools the eroded particles between the work piece and the electrode. The pressurized fluid flushes out the eroded gap particles and removes the debris from the fluid medium by causing the fluid to pass through a filter system.

*3) Tool Geometry:*Tool geometry is concerned with the shape of the tool electrodes is Square, rectangle, cylindrical and circular Etc. The ratio of length /diameter of any shaped feature of material. It concluded that shape of the electrode effects EWR. The tool having less aspect ratio gave higher value of EWR.Thus with increasing the size of electrode more good performance of ED Machining takes place.

4) Tool Material (Electrode): Engineering materials having higher thermal conductivity and melting point are used as a tool material for EDM process of machining. Copper, graphite, copper-tungsten, silver tungsten, copper graphite and brass are used as a tool material (electrode) in EDM. They all have good wear characteristics, better conductivity, and better sparking conditions for machining. Copper with 5% tellurium, added for better machining properties. Tungsten resist wear better than copper and brass .Brass ensures stable sparking conditions and is normally used for specialized applications such as drilling of small holes where the high electrode wear is acceptable (Metals Handbook, 1989). The factors that affect selection of electrode material include metal removal rate, wear resistance, desired surface finish, cost of electrode material manufacture and material and characteristics of work material to be machined.

C. Performance Parameters

1) Material Removal Rate (MRR & VRR) - The material MRR is expressed as the ratio of the difference of weight of the work piece before and after machining to the machining time and density of the material.

$$MRR = \frac{Wjb - Wja}{t}$$

Whereas
Wjb = Weight of work piece before machining.
Wja = Weight of work piece after machining.
t = Machining time
Volumetric removal rate (VRR), in mm3/min is given by

$$VRR = (4x10^4)\ iT_w^{-1.23}$$

Where i=current
T_w=Melting point of the work piece (°C).

2) Tool Wear Rate (TWR) - TWR is expressed as the ratio of the difference of weight of the tool before and after machining to the machining time. That can be explain this equations

$$TWR = \frac{Wtb - Wta}{t}$$

Whereas
Wtb = Weight of the tool before machining.
Wta = Weight of the tool after machining.
t = Machining time
Wear rate of the electrode tool material (W_t) is also given by
$W_t = (11x10^3)\ iT_r\text{-}^{2.38}$
Where w_t=wear rate of the tool, mm^3/min
i=current, Amp
T_t=melting point of the tool, °C
T_r= ratio of the work piece to tool melting point

3) Wear Ratio (WR)- WR is the ratio of TWR/MRR and is used as a performance measure for quantifying tool work piece material combination pairs since different material combinations gives rise to different TWR and MRR values. A material combination pair with the lowest WR indicates that the tool-work piece material combination gives the optimal TWR and MRR condition.

$$^{R}{}_{w}=2.25T_r\text{-}2.3$$

Where w_t=wear rate of the tool, mm^3/min
i= current, Amp

T_t= melting point of the tool, °C
T_r= ratio of the work piece to tool melting point

C.4 Surface roughness (SR) **-** SR is a classification of surface parameter used to describe an amplitude feature, which translates to roughness of the surface finish. Of the many parameters available to quantify SR, the most commonly used in EDM are arithmetical mean surface roughness (*Ra*), maximum peak-to-valley surface roughness (*Rmax*) and root mean square surface roughness (*Rq*).
Average roughness can be expressed in terms of pulse current i_p (A) and pulse duration t_p (μs) by

$$R_a=0.0225\ i_p^{0.29} t_p^{0.38}$$

IV. TYPES OF EDM

A. Die-Sinking EDM

In the Sinker EDM Machining process, two metal parts submerged in an insulating liquid are connected to a source of current which is switched on and off automatically depending on the parameters set on the controller. When the current is switched on, an electric tension is created between the two metal parts. If the two parts are brought together to within a fraction of an inch, the electrical tension is discharged and a spark jumps across. Where it strikes, the metal is heated up so much that it melts. Sinker EDM, also called cavity type EDM or volume EDM consists of an electrode and work piece submerged in an insulating liquid such as, more typically, oil or, less frequently, other dielectric fluids. The electrode and work piece are connected to a suitable power supply. The power supply generates an electrical potential between the two parts. As the electrode approaches the work piece, dielectric breakdown occurs in the fluid, forming plasma Channel, and a small spark jumps. These sparks usually strike one at a time because it is very unlikely that different locations in the inter-electrode space have the identical local electrical characteristics which would enable a spark to occur simultaneously in all such locations. These sparks happen in huge numbers at seemingly random locations between the electrode and the work piece. As the base metal is eroded, and the spark gap subsequently increased, the electrode is lowered automatically by the machine so that the process can continue uninterrupted. Several hundred thousand sparks occur per second, with the actual duty cycle carefully controlled by the setup parameters.

B. Wire-Cut EDM

Wire EDM Machining (also known as Spark EDM) is an electro thermal production Process in which a thin single-strand metal wire (usually brass) in conjunction with de-ionized water (used to conduct electricity) allows the wire to cut through metal by the use of heat from electrical sparks. a thin single-strand metal wire, usually brass, is fed through the work piece, submerged in a tank of dielectric fluid, typically deionizer water. Wire-cut EDM is typically used to cut plates as thick as 300mm and to make punches, tools, and dies from hard metals that are difficult to machine with other methods.
Wire-cutting EDM is commonly used when low residual stresses are desired, because it does not require high cutting forces for removal of material. If the energy/power per pulse is relatively low (as in finishing operations), little change in the mechanical properties of a material is expected due to these low residual stresses, although material that hasn't been stress-relieved can distort in the machining process. Due to the inherent properties of the process, wire EDM can easily machine complex parts and precision components out of hard conductive materials.

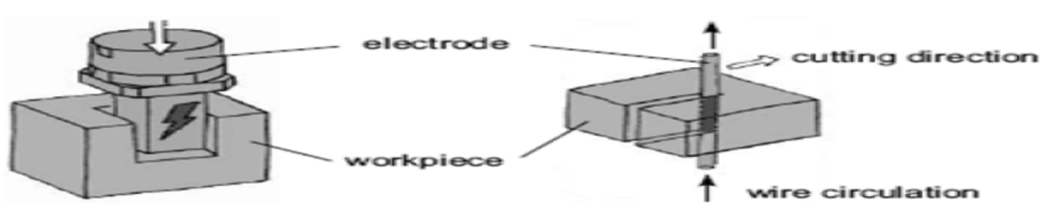

Fig-5 Main types of EDM: die-sinking and wire-cutting.

V. RESEARCH PROGRESS BY USING WATER AS DIELECTRIC FLUID

Water as dielectric is an alternative to hydro carbon oil. The approach is taken to promote a better health and safe environment while working with EDM. This is because hydrocarbon oil such as kerosene will decompose and release harmful vapour (CO and CH4). Machining in distilled water resulted in a higher material removal rate and a lower wear ratio than in kerosene for high pulse energy range.

Year	Researcher Contribution
2008	Han-Ming Chow et al .using pure water as an EDM dielectric fluid for titanium alloy yields a high MRR and relatively low electrode wear and small expanding-slit by employing negative polarity (NP) processes.
2005	Yan B.H. et al TiN was synthesized on the machined surface by chemical reaction that involved elements obtained from the work piece and the urea solution in water as dielectric during EDM: the surface modification of pure titanium metals exhibited improved friction and wear characteristics. Ekmekci. B. et al Stresses are found to be increasing rapidly with respect to depth, attaining to its maximum value around the yield strength and then fall rapidly to compressive residual stresses in the core of the material since the stresses within plastically deformed layers are equilibrated with elastic stresses. Kang & Kim In the case of the kerosene electrical discharge (ED) machined specimens, it was observed that carburization and sharp crack propagation along the grain boundary occurred after the heat treatment. However, the deionized ED machined specimen after the heat treatment underwent oxidation and showed no crack propagation behaviour. Sharma A. et al. investigated the potential of electrically conductive chemical vapor deposited diamond as an electrode for micro-electrical discharge machining in oil and water. While doing a comparative study on the surface integrity of plastic mold steel ,
1999	Chen S.L. et al The MRR is greater and the relative wear ratio is lower when machining in distilled water rather than in kerosene.
1993	Koenig W. et al EDM sinking process can be made more cost effective through the use of water based media, significantly improving competitiveness with other process. Yoshiro et al A machine tool maker has established technologies for water-immersion machining, greatly improved the surface finish so that post process manual polishing is not required.
1987	Koenig W. et al The erosion process in water based media consequently possesses higher thermal stability & much higher power input can be achieved especially under critical condition. Use aqueous solution of organic compounds as medium for EDM sinking almost completely excludes any fire hazard, permitting safe operation of plant.
1984	S. Tariq Jilani et al The best machining rates have been achieved with tap water as the dielectric medium; zero TWR possible when using Cu tool with negative polarities.
1981	Jeswani M.L Machining in distilled water resulted in higher MRR and lower wear ratio than in kerosene when high pulse Energy range was used.

VI. RESEARCH PROGRESS BY DRY EDM

The principle of dry EDM and compared its performance with EDM in oil as dielectric. Dry electrical discharge machining is a process that uses gas as dielectric medium. The principle of dry EDM is shown in Fig. 8.This dry technique has been firstly presented by Kunieda.for environmental preservation, human health and prevention of fire hazards. The authors found that the material removal rate is increased due to the enlarged volume of discharged crater and more frequent occurrence of discharge.
Dry EDM is a green environment friendly Electric discharge machining Technique in which the liquid dielectric is replaced by a gaseous dielectric. Gas at high pressure used as the dielectric medium. In dry EDM, tool electrode is formed to be thin walled

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pipe. The flow of high velocity gas into the gap facilitates removal of debris and prevents excessive heating of the tool and work piece at the discharge spots.

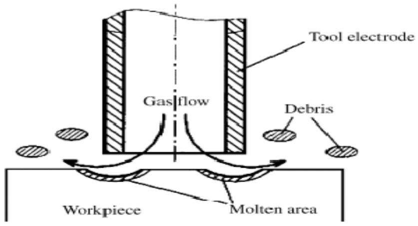

Fig-6 Dry EDM

Year	Researcher Contribution
2013	Roth R. et al. Heat energy from the oxidation has only a little effect on the material removal rate and that the main difference between oxygen and less oxidizing gases is to find in different stability and time efficiency of the process. Wang T. et. Al. Main advantages of dry finishing of WEDM such as better straightness, lower SR and shorter gap length.
2011	Masahiro Fujiki Achieve high material removal rate in tool path planning for the near-dry Electrical discharge machining (EDM) milling process using tubular electrode with a lead angle.
2006	Zhan Bo et al. Optimum combination of depth of cut, gas pressure & pulse duration 25µm it is lead to maximum material removal rate & minimum tool wear.
2004	Kunieda et al improvement of dry EDM by controlling the discharge gap using a piezoelectric actuator. Wang T. et al the explosive force and electrostatic force acting on wire electrode decrease in dry WEDM. Zhang et al ultrasonic vibration improves MRR in gas by increasing the effective discharge. Li L.Q discharge passage extends rapidly in the gas medium of dry EDM.
2003	Wang et al dry EDM removes environmental pollution due to liquid dielectric. Better straightness with dry EDM. Kunieda et al oxidation of work pieces due to the usage of oxygen electrode wear is almost negligible increase MRR. Curodeau et al a thermoplastic composite electrode used in dry EDM using air as dielectric medium. Z. B. Yu et al dry EDM is suitable for 3D milling of difficult to cut materials such as cemented carbide.
2001	Kunieda et al narrower gap, no corrosion of work piece and high finish cutting in dry EDM .

VII.RESEARCH PROGRESS BY USING POWDER MIXED EDM

Powder mixed electric discharge machining (PMEDM) is one of the new innovations for the enhancement of capabilities of electric discharge machining process. In this process, a suitable material in fine powder is properly mixed into the dielectric fluid. The added powder improves the breakdown characteristics of the dielectric fluid. The insulating strength of the dielectric fluid decreases and as a result, the spark gap distance between the electrode and work piece increases. Enlarged spark gap distance makes the flushing of debris uniform. This results in much stable process thereby improving material removal rate and surface finish. Fig. show the principle of powder mixed EDM.

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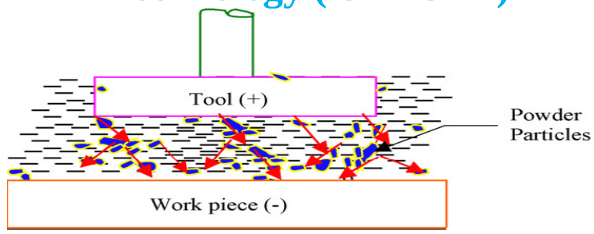

Fig-7 Powder Mixed EDM

Year	Researcher Contribution
2011	Sharma S. et al. Study the effect of graphite powder on the machining performance of conventional EDM. The machining performance is evaluated in terms of tool wear rate. Concentration of graphite powder, polarity, electrode type, peak current, pulse on time, duty cycle gap voltage and retract distance is taken as the input parameters and their effect are presented on machining performance. Conventional copper electrode and cold treated copper electrodes were used during the experimentation. It is found experimentally that with the addition of the powder particles in the dielectric and the use of cold treated electrode Tool Wear Rate decreased.
2010	Kumar S., et al., Found that significant amount of material transfer takes place from the manganese powder suspended in dielectric fluid to the machined surface under appropriate machining conditions which changes the surface composition and its properties. They reported that percentage of manganese increased to0.95% from 0.52% and that of carbon to 1.03% from 0.82% that result in increase in the micro hardness. For surface alloying favourable machining conditions were found to be low peak current (4 A), shorter pulse on-time (5µs), longer pulse off time (85µs), Singh P. et al., investigate the Concentrations of aluminium powder and grain size of powder mixed in dielectric fluid strongly affects the machining performance of EDM process Sharma S. et al Study the effect of aluminium powder on the machining performance of conventional EDM with reverse polarity. The machining performance is evaluated in terms of material removal rate, tool wear rate, percentage wear rate, surface roughness. Concentration and grain size of aluminium powder are taken as the input powder parameters and its effect are presented on machining performance. It is found experimentally that powder characteristics significantly affect machining characteristics.
2009	Kung et al., Reported that the material removal rate and electrode wear ratio in powder mixed electrical discharge machining of cobalt-bonded tungsten carbide by suspending aluminium powder in dielectric fluid. They observed that the powder particles disperses and makes the discharging energy dispersion uniform. Prihandana G.S., et al Presents a new method that consists of suspending micro-MoS2 powder in dielectric fluid and using ultrasonic vibration during µ-EDM processes. It was observed that the introduction of MoS2 micro-powder in dielectric fluid and using ultrasonic vibration significantly increase the MRR and improves surface quality. Kibria G., et al. Compares different dielectrics in micro- EDM machining operation and reported that the machining characteristics are greatly influenced by the nature of dielectric used during micro-EDM machining. From the available literature, it is concluded that the machining characteristics of some hard and difficult to cut material can be studied by suspending powder of some material in the dielectric fluid of EDM.
2008	Bari and Anil Performed experimentation on EDM of AISID2 steel in kerosene with copper tungsten (30% Cu and 70% W) electrode (made through Powder Metallurgy technique) and conventional Cu electrode. An L18 orthogonal array of Taguchi methodology was used to identify the effect of process input factors (viz. current, duty cycle and flushing pressure) on the output factors (viz. material removal rate and surface roughness). It was recommended to use conventional Cu electrode for higher MRR and CuW electrode made through PM for low SR.

2007	Norliana Mohd Abbas et al Have reported a review on current research trends in electrical discharge machining (EDM). They have observed that Fine abrasive powder is mixed into the dielectric fluid. The hybrid material removal process is called powder mixed EDM (PMEDM) where it works steadily at low pulse energy and it significantly affects the performance of EDM process.
1989	Narumiya H., et al., Used silicon, aluminium and graphite as powder materials. The concentration range of the powder was between 2gm/l to 40gm/l. Their conclusion showed that the gap distance increases with the powder concentration and is larger for the aluminium powder but there is no direct relation between the surface roughness and the gap distance. The best results concerning the surface finish were achieved for low powder concentrations levels and that also for silicon and graphite powders.

VIII. FUTURE EDM RESEARCH DIRECTION

The authors have classified the numerous EDM research interests referred in the paper into four different major areas. Fig. 1 shows the classification, which is used in this section to discuss the various research areas and possible future research directions.

A. Optimising The Process Variables

The EDM process has a very strong stochastic nature due to the complicated discharge mechanisms making it difficult to optimise the sparking process. The optimisation of the process often involves relating the various process variables with the performance measures maximising the MRR, while minimising the TWR and yielding the desired SR. In several cases, S/N ratio together with the analysis of variance (ANOVA) tech niques 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. These research works explored new and different ways of delivering a more efficient and stabilised sparking process improving the commonly observed performance measures. In addition, the feasibility of manufacturing the electrode using the RP (rapid prototyping) technique has been extensively studied to improve the performance of tools and sparking. Therefore, with the continuous research effort made in understanding the initialisation and development of sparking process, the different means of optimising the various process variables will continue to be a major area of further development reducing the stochastic sparking characteristic.

B. 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 radio frequency signal 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. The fuzzy logic provides a control strategy that is equivalent to the expertise and experience of a skilled operator. However, it is not easy to establish the pulse discriminating function, which is based on trail-and-error means of differentiating the various EDM pulses. Therefore, there is a need to develop a highly stable EDM servo control system either to improve the current machining performance or to meet the future needs of machining advanced materials. Moreover, with the perpetual push towards unattended EDM operation, adaptive control system will continue to receive a definite amount of research attention. Such a move will in turn create considerable economic benefits for EDM in terms of training and operating costs.

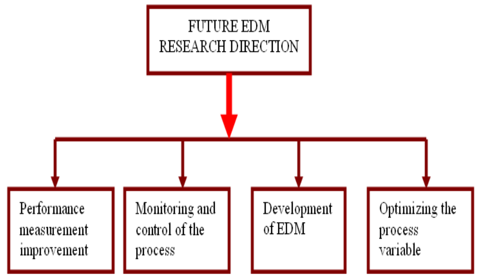

Fig-8 future research direction

C. Improving The Performance Measures

This can be done by the use of CNC to EDM for facilitating the MRR and improving the tool wear compensation techniques, it results the potential of using simple tooling to generate complex 3D cavity without employing a costly 3D profile electrode. This technique benefits the EDM process by reducing the large proportion of cost and time factors of producing the electrode which account for almost 45% of the total machining cost.

D. 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. This clearly distinguishes the types of machine features and affecting performance measures, machining capacity and auxiliary facilities of EDM machine. In addition, the short product development cycles and growing cost pressures have forced the die and mould making industries to increase the EDM efficiency. One of the unique options of improving the machining performance involves the hybrid machining process combining EDM process with other material removal processes. The most popular and highly effective arrangement includes the USM delivering ultrasonic vibration to the electrode, which assists the sparking and flushing operations. That the current trend in tool and die manufacturing is towards replacing the EDM process with new machining techniques such as (HSM) high-speed machining. HSM process is just as capable as the EDM process in machining hardened materials with 40–60 HRC. Therefore, HMP involving EDM will continue to draw intense research interests seeking innovative ways of improving the machining performance and expanding the EDM applications.

IX. SUMMARY

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. The major research development resulting in improvement in material removal rate is summarized in Table 1in chronological order. 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/modelling in future.

Year	Researcher Contribution
2015	Anil has reported that EDM of EN-24(PEARLITE & FERRITE + 40% BAINITE) alloy steel using copper graphite and brass electrode. The input variable parameters are current, pulse on time and duty cycle. The effect of the variable parameters mentioned above upon machining characteristics such as material removal rate (MRR), tool wear rate (TWR)) is studied and investigated With the help of MINITAB software an orthogonal array of input variables was created using the design of experiments (DOE) and observed The results reveal that the primary factor affecting the MRR is peak current subsequently followed by material, pulse on time and duty cycle and in case of TWR the primary factor affecting TWR is material then peak current then duty cycle and at last pulse on time
2010	Yan-Cherng Lin et al. has reported that Electrical Discharge Energy on Machining of **Cemented Tungsten Carbide** using an electrolytic copper electrode. The machining parameters of EDM were varied to explore the effects of electrical discharge energy on the machining characteristics, such as MRR, EWR, and surface roughness. Moreover, the effects of the electrical discharge energy on heat-affected layers, surface cracks and machining debris were also determined. The experimental results show that the MRR increased with the density of the electrical discharge energy. The EWR and diameter of the machining debris were also related to the density of the electrical discharge energy. When the amount of electrical discharge energy was set to a high level, serious surface cracks on the machined surface of the cemented tungsten carbides caused by EDM were evident

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2009	Wang and Lin discuss the optimization of W/Cu composite martial are used the Taguchi method. **W/Cu composites** are a type of cooling material highly resistant to heat corrosion produced through powder metallurgy. The Taguchi method and L18 orthogonal array to obtain the polarity, peak current, pulse duration, duty factor, rotary electrode rotational speed, and gap load voltage in order to explore the material removal rate, electrode wear rate, and surface roughness. The influenced of each variable and optimal processing parameter will be obtained through ANOVA analysis through experimentation to improve the process.
2004	P. Narender Singh et al. discuss the evolution of effect of the EDM current (*C*), Pulse ON-time (*P*) and flushing pressure (*F*) on MRR, TWR, taper (*T*), ROC, and surface roughness (SR) on machining as-cast **Al-MMC with 10% SiCp** . And use of metal matrix composites. ELEKTRAPULS spark erosion machine was used for the purpose and jet flushing of the dielectric fluid, kerosene, was employed. Brass tool of diameter 2.7mm was chosen to drill the specimens. An L27 OA, for the three machining parameters at three levels each, was opted to conduct the experiments. ANOVA was performed and the optimal levels for maximizing the responses were established.
2004	Moro et al. [44] studied application of electrical discharge coating (EDC) to improve cutting tool life instead of Physical Vapor Deposition (PVD) or Chemical Vapours Deposition (CVD). The substrate material used was S45C (JIS).Tool electrode prepared by semi-sintering of TiC powder at 900^{o}C for 1 hour. The experiment were carried out for 16 min with discharge current of 8 amps, Ton time of 8 µs, and duty factor as 5.9%. The relation between a wear rate of an electrode and maximum thickness has been investigated.
2004	Yu et al. Compared machining Characteristics between dry EDM milling, oil EDM milling and oil die sinking EDM with Cemented carbide Copper tungsten electrode by using Discharge current, Discharge duration, discharge interval as electrical parameter and Electrode rotation as non electrical parameter
2002	B.Mohan and Satyanarayana evolution the of effect of the EDM Current, electrode marital polarity, pulse duration and rotation of electrode on metal removal rate, TWR, and SR, and the EDM of **Al-Sic with 20-25 vol. % SiC**, Polarity of the electrode and volume present of SiC, the MRR increased with increased in discharge current and specific current it decreased with increasing in pulse duration. Increasing the speed of the rotation electrode resulted in a positive effect with MRR, TWR and better SR than stationary. The electric motor can be used to rotate the electrode(tool) AV belt was used to transmit the power from the motor to the electrode Optimization parameters for EDM drilling were also developed to summarize the effect of machining characteristic such as MRR, TWR and SR.
2002	Zhao et al. Performed experimental research on machining efficiency and surface roughness of Steel with Copper and used Current, pulse-on time, pulse-off time as electrical parameter
2000	Kunieda and Muto Investigated and compared machining characteristics Of Multi-spark EDM electrode with those of conventional EDM electrode and steel SUJ2 used as work piece or used Copper as tool. in process Voltage, current, polarity used as electrical parameters
1999	Chen et al Investigated Machining characteristics with kerosene and distilled water as the dielectrics by using Titanium alloy (Ti– 6A1–4V) as work piece and Copper as tool material and Current, Pulse duration taken as electrical parameter and Type of dielectric fluid used as non electrical parameter\
1997	Kunieda and Yoshida Investigated dry EDM method and compared its performance with EDM in oil taking Steel (S45C)as work piece and Copper as tool material by using Voltage, current, pulse duration, Polarity taken as electrical parameter and Wall thickness of pipe electrode, air pressure, rotation and plenary motion of tool taken as non electrical parameter

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