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Current and Advance Research in the Field Of EDM: A Review

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Abstract: In the present scenario, the manufacturing industries are facing challenges for the machining of advanced and hybrid materials, as that are hard and difficult to machine. To meet these challenges, unconventional machining processes are being used in order to achieve better surface finish, optimal material removal rate and dimensional accuracy with the reduction in the tool wear rate. EDM is such a well-established unconventional machining process which is used for hard, electrically conductive and geometrically complex material parts. The material removal takes place due to the melting and vaporization by thermal energy of electric spark. Electric Discharge machining, has extensive applications in the field of aerospace, automotive, micro systems industries and defence. Die Sinking-EDM, W-EDM, µ-EDM and H-EDM are some of the variants in the EDM. This paper reviews the recent development and the advancements in the field of EDM along with its variants.
Keywords: *-EDM, W-EDM,* µ-EDM, *H-EDM*

1. INTRODUCTION TO EDM

Due to the evolution of the technology in this modern era, putting enormous pressure on the manufacturing industries so that they come out from the arena of the traditional machining processes and develop the machining processes that are capable to machine advanced materials having striking properties with good surface finish and geometrical accuracy [1]. The development in the non-traditional machining processes (NTM) took place to meet these challenges. These NTM processes are further classified on the basis of their source of energy and material removal mechanism

Electric Discharge Machining (EDM), a thermal material removal process having wide applications in the field of aerospace, automotive, micro systems industries, defence and medical science [2]. EDM does not make direct contact between the work piece and the electrode; by this they can eliminate vibration problems and mechanical stresses during the machining process [3]. In EDM the electrode is moved in the downward direction toward the work piece until the spark gap small enough so as the impressed voltage is great enough to ionize the dielectric [4]. The material removed is in the formed debris is removed due to the erosion effect by the electric discharge from the work piece and the tool electrode [5]. Figure 1.2 represents the outline of variants of EDM.

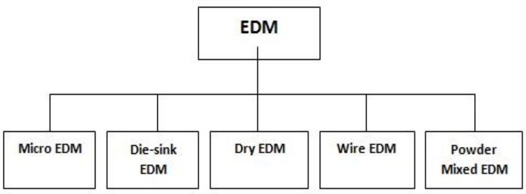

Figure 1.2 Outlines of EDM Variants [1]

The history of the machining techniques begins in 1770, when English chemist Joseph Priestly discovered the erosion effect of electric sparks or discharge [6]. The EDM process was invented by two Russian scientists, Dr. N.I. Lazarenko and Dr.B.R. Lazarenko in the year 1943 [7-8]. They make use of resistance-capacitance type of power supply in the EDM system [9-10]. Further development in the 1960's was the invention of orbiting systems as well as pulse and solid state generator which reduce previous problems with weak electrode [11]. The development in the semiconductor industries helps in considerable enhancement in the EDM machines. In 1970's the development was made to reduce the number of electrode to create cavities. Due to the revolutionary change in the late 1980's with the advent of computer along with conventional machining the computer numerical controlled (CNC) EDM was introduced in USA. Such advancement in the machining technology has resulted in enormous benefits and also influenced the research area [12-13]. Consequently, in 1990's new methods for EDM process control emerged such as fuzzy control, neural network, response surface methodology, Taguchi optimization etc [14]. The review presented in this paper is on the EDM machining along with its variants i.e. Die-Sinking EDM, W-EDM, µ-EDM, H-EDM.

2. PRINCIPLE BEHIND EDM:

The material removal mechanism in the EDM involve following steps (i) melting (ii) vaporization (iii) thermal spalling (especially those materials which are having high thermal coefficient, low thermal conductivity, and low ultimate strength) [15]. The material removal mechanism primarily makes use of electrical energy which turns in to thermal energy through the series of discrete electric discharge occurring between the work piece and the tool electrode which are immersed in the dielectric liquid medium [16]. This thermal energy generates a channel of the plasma between the anode (work piece) and cathode (tool) at a temperature range of 8000°c - 12000°c [17-18]. The pulsating direct current supply occurring at the rate of 15000-30000 Hz is turned off; due to this the plasma channel breaks down [19]. This leads to sudden reduction in the temperature and hence resulting in melting and vaporization. The circulating dielectric fluid implores the plasma channel and flushes the molten material from the surface in the form of debris. Figure 2.1 represents the mechanism of spark generation.

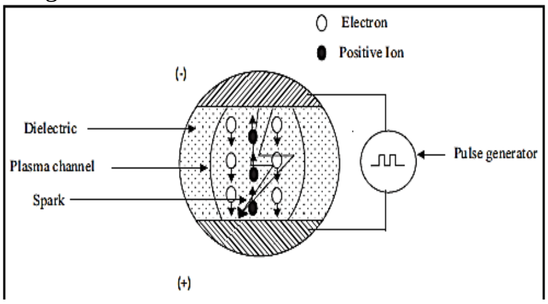

Figure 2.1 Mechanism of Spark Generation [1]

The volume of material removed in every discharge is typically in the range of 10^{6} – 10^{4} mm^{3} and the material removal rate (MRR) is usually varies between 2 to 400 mm^{3}/ min [20]. The distance between the tool electrode and work piece during the discharge is also an important factor. It is estimated to be around 10µm - 100µm. The ignition voltage applied between the electrodes is typically 200 V [21]. In order to maintain stability in the EDM process, the every successive next pulse discharge should occur sufficiently far from the previous discharge position. The pulse interval should be not so much high and not too short. If the pulse interval is too high or too short then the plasma channel generated can be fully de-ionized and it produce more surface roughness along with instability in machining [22]. Figure 2.2 represents schematic view of discharge gap.

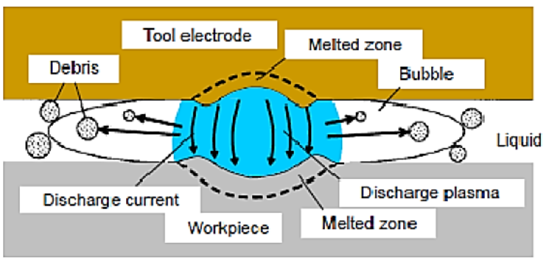

Figure 2.2 represents schematic view of discharge gap[113]

3. COMPONENTS IN EDM:

Electric Discharge Machining unit consist of following components. Figure 3.1 represents the components of the EDM system.

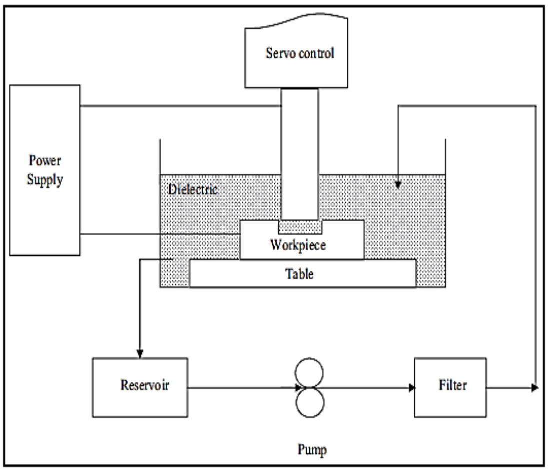

Figure 3.1 Components of EDM System [1]

3.1. Work-piece- All the conductive material can be worked by EDM. In the EDM machining process work piece serve as anode and is positively charged.

3.2. Tool Electrode- The EDM electrode is the tool that determines the shape of the cavity to be made. In the EDM machine unit tool act as cathode and it is negatively charged.

3.3. Dielectric Fluid Unit- This unit consist of a dielectric tank, a filtering unit and a pumping unit. Both work-piece and the tool electrode submersed into the dielectric fluid tank. The liquid dielectric plays a very crucial role during the whole process. It cools down the electrode; it guarantees a high plasma pressure and also provides high removing force on the molten metal [23].When the plasma collapses, it solidifies the molten metal in to small debris and then flushes these particles. Mineral oil, de-ionized water and kerosene oil is often used as the dielectric fluid [24-25].

3.4. Servo System- The servo system is governed by signals from voltage sensor system in the power supply and control the feed of electrode & work-piece to precisely match the rate of material removal. The servo feed control unit help to maintain the gap voltage as the dielectric parameters constantly fluctuate [26]. It also retracts the tool electrode if short-circuit occur. It may be electric motor driven, hydraulically operated, solenoid operated or the combination of these.

3.5. The DC Pulse Generator- It is responsible for supping the pulse at a particular voltage and current for the specific amount of time.

3.6. EDM Circuits- It helps to convert electrical energy in to the thermal energy. A capacitor is used in the EDM circuit which store electric energy before discharging each spark [27]. The power supply circuit used in the EDM process are Resistance-Capacitance (R-C) Circuit, Controlled Pulse Circuit and Rotary Impulse Generator Circuit. Resistance can be provided in these circuits in order to slow down the time required for charging the capacitor [28]. Figure 3.2 represents R-C Circuit used in EDM System.

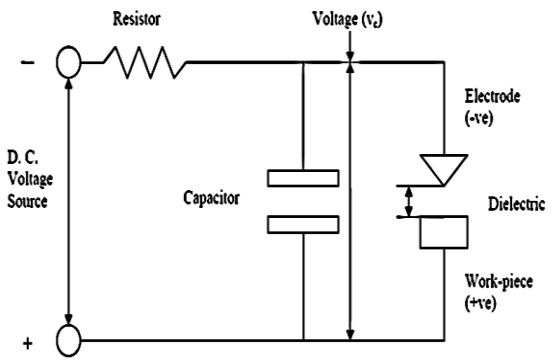

Figure 3.2 R-C Circuit Used in EDM System [51]

4. PROCESS PARAMETERS:

The process parameters in the EDM process are used to control the performance measures of the machining process. Process parameters are generally the machining input factors that help to control the conditions in which the machining process is carried out [29]. These machining conditions will directly affect the performance results. The process parameters can be broadly categories into four types i.e. Electrical, Non-Electrical, Electrode and Powder Parameters [21]. Figure 4.1 represents the Cause and Effect diagram of Process Parameters on the Performance Measures.

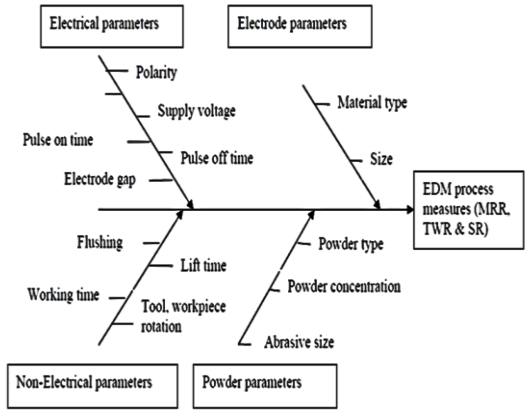

Figure 4.1 Causes and Effect Diagram of Process Parameters on the Performance Measures[51]

4.1. ELECTRIC PARAMETERS- The major electric parameters are enlisted below. As EDM process is thermal nature and having complicated discharge mechanism, therefore it is difficult to explain all the effect of these parameters on the performance results. Various research have been done on process analysis for the optimization of these parameters to identify the effect on the machining characteristics.

4.1.1. Polarity- Polarity can either be positive (+ve) or negative (-ve) connected to the work-piece or tool electrode. It affects the surface finish, wear, speed and stability of the EDM operation. When the tool electrode is connected to positive terminal, MRR increases that at the negative terminal. Experimental works concluded that MRR was low with positive polarity of work piece as compared to negative [30]. It is due to the fact that with positive polarity of the work-piece, the dissociated carbon elements present in the dielectric fluid adhere toward anode, which results to formation of recast layer [31].

4.1.2. Discharge Voltage-The discharge voltage determines the spark gap and breakdown strength of the dielectric fluid in EDM process. First the voltage is dropped by the flowing current and then it is stabilized at the working gap level. Higher voltage settings increase the gap which leads to the increased flushing condition and stabilized the cut. Also, increased open circuit voltage leads to increased tool wear rate and surface roughness due to increased field strength [32].

4.1.3. Peak Current-Peak current is the most important parameter in EDM process and is defined as the amount of power used in discharge machining measured in amperage. The peak current is the level of current present during pulse-on time. High value of currents though increases MRR, put it also has an effect on surface finish and tool wear and as a result, accuracy of machining will be hampered [33]. Graphite is an example of improved electrode material used in high currents and leads to lesser damage.

4.1.4. Average Current- It is the maximum current available for each pulse from the power supply in the circuit. Average current is the average of the spark gap measured over a complete cycle. It is mathematically calculated by multiplying duty factor by peak current [34].

Average Current (A) = Duty Factor % (D) × Peak Current

4.1.5. Pulse ON Time (T_{on})-It is also called as Pulse Duration and is measured in micro seconds. During this period the current is allowed to pass through the tool electrode toward the work-piece material with a short gap known as spark gap [35].Material removal is directly proportional to the amount of energy applied during the on time period. MRR depends on the Pulse on time duration [36]. Longer pulse duration improves the MRR from machined area and also effects on the wear behaviour of electrode. Experimental work proved that with the increase in the pulse duration surface roughness decreased but there is an increase in the crack length, crack width and thickness of recast layer [2].

4.1.6. Pulse OFF Time (T_{off})-It is also called as the pulse interval. It is the waiting interval time period during two pulses on time periods. In other words it may also be defined as the duration of time in which no machining take place (idle time period) [35]. It allows the melt material to vaporize and to remove debris. This parameter is to affect the speed and the stability of the cut. If the Pulse off time is too short, it improves MRR. The researchers concluded that the MRR is not so much sensitive to pulse interval time [36]. Figure 4.2 represents the actual profile of single EDM pulse.

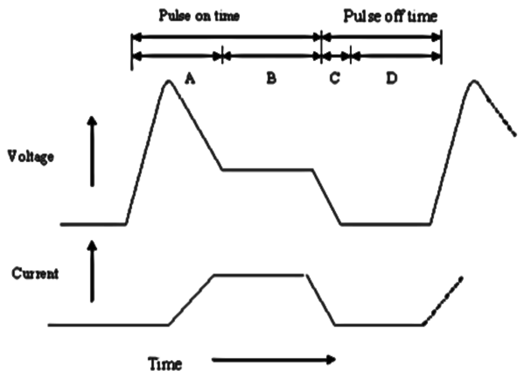

Figure 4.2 Actual Profile of Single EDM Pulse[51]

4.1.7. Pulse Frequency- It is the number of cycles produced across the gap in one second. Higher the Pulse frequency finer the surface finishes. With the increase in the Pulse frequency the length of the pulse on-time decreases which leads to very less material removal rate and create smaller craters [34]. This produce smoother surface finishes with less thermal damage to work-piece. It is mathematical calculated by dividing 1000 by the total cycle time.

Pulse Frequency (kHz) = 1000/Total Cycle Time (μs)

4.1.8. Electrode gap-Electrode gap is the gap between the tool electrode and the work piece during the process of EDM. In order to maintain the average gap voltage between the tool electrode and the work piece an electro-mechanical and hydraulic systems are used [37]. A suitable gap should be maintained for a good performance and gap stability and with the help of average gap voltage; gap width can be measured [38]. Figure 4.3 represents the Electrode Feed Control in EDM.

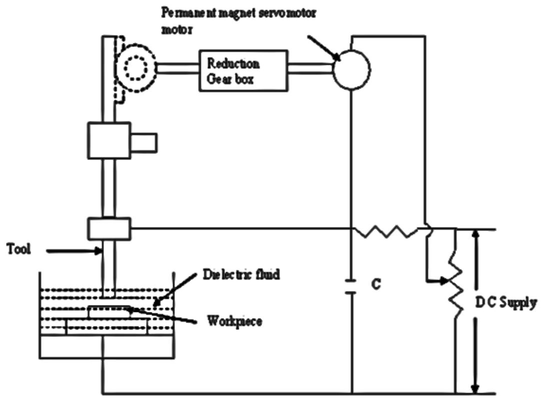

Figure 4.3 Electrode Feed Control in EDM[51]

4.1.9. Duty factor-Duty factor is the percentage of the pulse duration relative to the total cycle time. Higher the duty factors higher the cutting speed. It is mathematically calculated in percentage by dividing the pulse duration of the total cycle time (pulse ON+ pulse OFF). Duty factor at constant current, constant pulse on time leads to increase in MRR, it is because due to increase in Duty cycle the intensity of spark increases which results in higher MRR [39].

Duty Factor (%) = [Pulse Duration (μs)/ Total Cycle Time (μs)] × 100

4.1.10. Pulse waveform- A part from the normal rectangular pulse waveform, new shapes of the waveform have been developed. Tool wear is reduced by using trapezoidal wave generates. Other generates, before facilitating ignition, generates an initial pulse of high voltage low current and duration of few microseconds [40]. Figure 4.4 represents the Pulse wave form of pulse generator.

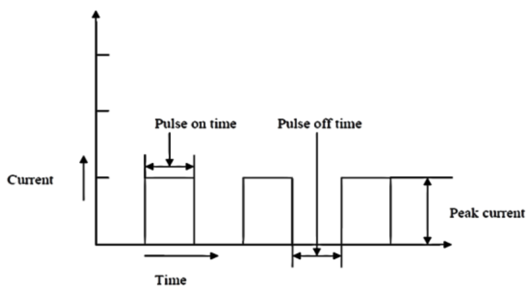

Figure 4.4 Pulse Wave Form of Pulse Generator[51]

4.2 NON-ELECTRIC PARAMETERS-Main Non-Electrical Parameters are enlisted below. These Non-Electrical parameters play a very crucial role in optimizing performance measures.

4.2.1. Rotation of tool electrode- The performance measure of the EDM process improves by introducing rotary motion to the tool electrode. It serves as an effective gap flushing technique which significantly improves material removal rate and surface roughness [41-42]. The rotational movement of electrode is normal to the work-piece as the rotational speed increases, a centrifugal force is generated causes more debris to remove faster from the machining zone [43]. While comparing the various performance measures of rotating electrode with the stationary electrode it is found that there is an improvement in the material removal rate and surface finish with a very little tool wear rate. It is just because of better sparking efficiency and flushing action [44].

4.2.2. Rotation of work-piece- In addition to the rotation of tool, the technique of applying rotational motion to the work-piece also affects the EDM performance [45]. The change in basic construction in addition to the rotary motion of the work-piece offered an accessible evacuation of debris which leads to improvement in the erosion efficiency and accuracy in the sparking process [46].

4.2.3. Nozzle flushing-Flushing removes eroded particles from the gap which helps in efficient cutting and in improving surface finish of machined material [47]. Flushing also enables fresh dielectric fluid flow into the gap and cools both the electrode and the work-piece [48]. TWR and MRR are the performance measures that are affected by the method of flushing. The flushing rate also influences the crack density and recast layer which can be minimized by obtaining an optimal flushing rate. [49]. The different types of flushing are injection flushing, side flushing, suction flushing and suction by dielectric pumping [50].

4.2.4. Type of dielectric-Dielectric fluid used in EDM have characteristics of high dielectric strength, quick recovery after breakdown, effective quenching, good degree of fluidity and should be easily available [47]. Most dielectric media are hydrocarbon compounds (mineral oil, kerosene oil) and water. De-ionized water is used because of its low viscosity and carbon free characteristics [24-25].

4.3 ELECTRODE PARAMETERS-

4.3.1. Electrode material-Engineering materials having higher thermal conductivity and melting point are used as a tool material in the EDM process. Copper, graphite, copper-tungsten, copper, graphite and brass are used as a tool material in EDM process [50]. Material removal rate, wear resistance, desired surface finish, cost of electrode material manufacture and characteristics of work material to be machined are the few factors that effects selection of electrode material [51].

4.3.2. Electrode geometry-Tool geometry is concerned with the shape of the tool electrode. It might be square, cylindrical, circular, square etc. The ratio of length/diameter of any shaped feature of material [52]. In case of rotating disc electrode the ratio become thickness/diameter. By experimental research it is concluded that the shape of the electrode effects TWR. The tool having less aspect ratio gave higher value of TWR. By increasing the size of electrode good performance of the Electric Discharge Machining can be achieved [53].

4.4 POWDER PARAMETERS- Powder parameters are of different type such as concentration of powder, type of powder and abrasives size etc. These parameters will directly affect the material removal rate [51]. Powder particles are mixed in the dielectric fluid. Powder mixed EDM process is a practical application. In order to avoid the wastage of kerosene oil a small dielectric circulation stirring system is used which avoid particle settling and pump the filter dielectric fluid [54].

5. PERFORMENCE PARAMETERS:

5.1. MATERIAL REMOVAL RATE (MRR) - It is the performance measure which helps to determine the erosion rate of the work-piece and it is typically used in order to quantify the speed at which machining process is carried out [55-57]. It is also expressed as the volumetric amount of the work-piece material removed per unit time. For the material removal rate, research work has been focused on material removal mechanism along with the method of improving material removal rate [58-60].

5.2. TOOL WEAR RATE (TWR)-It is the performance measure to determine the erosion rate of the tool electrode. This performance measure is taken in to account when we have to consider the geometrical accuracy of the machining process. It is expressed as the volumetric amount of the tool material removed per unit time [61-63]. Research work on the tool wear process and the method of improving TWR is carried out by various researchers.

5.3. WEAR RATIO (WR) – It is the ratio of the tool wear rate to the material removal rate and is used to quantifying tool-workpiece material combination pair since different material combination give rise to different TWR and MRR values. The tool-workpiece material combination with lowest wear ratio gives optimal TWR and MRR [21].

5.4. SURFACE QUALITY (SQ) – Surface quality is a performance measure used to describe the condition of the surface after machining. It comprise of some other performance measures such as surface roughness, heat affected zone, recast layer and micro-cracks density [64].

5.5. SURFACE ROUGHNESS (SR)-It is the classification of surface quality which is used to describe the amplitude feature, which translates to roughness of the surface finish. The most common of the parameter available to quantify surface roughness are maximum peak to valley surface roughness (R_{max}), arithmetical mean surface roughness (R_a) and root mean square surface roughness (R_q) [65].

5.6. RECAST LAYER THICKNESS-The recast layer refers to the region where the molten metal re-solidifies as the top most layer of the machined surface [66]. It is usually located above the heat affected zone. It is also termed as the white layer [67].

5.7. HEAT AFFECTED ZONE (HAZ)-It refers to that region of the work-piece that do not melts during the electric discharge machining process but experiences a phase transformation, similarly in the case of heat treatment process [68]. Figure 5.1 represents the EDM Heat Affected Zones.

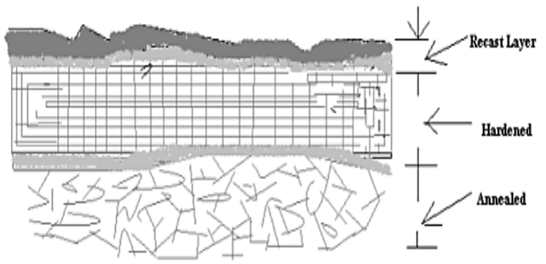

Figure 5.1 EDM Heat Affected Zones [113]

6. VARIANTS IN EDM:

EDM can be used to perform different operations depending upon the need such as drilling, milling, grinding etc. A number of variants in EDM based on the basic configuration have emerged in order to cope up with the machining of the advanced hybrid materials. Some of the important and favourable variants of EDM are enlisted and explained below.

6.1 DIE SINKING EDM- It is one of the most widely used EDM technique used for the fabrication of die and mould cavitiesand is also called as cavity type EDM. In this machining process the tool electrode is the replica of the machined profile of the work-piece. This machining process solves the problem of manufacturing complex as well as accurate shapes. The work-piece can be formed either by replication of a shaped tool electrode or by 3-Dimentional movement of the simple electrode [69]. The NC monitors the gap between the electrode and the work-piece and synchronously controls the axis along with pulse generator. In this machining process the relative speed between the tool and work-piece is coincident with the penetration speed in the work-piece [70]. This process has wide applications in wire drawing industries, die manufacturing industries, automotive industries and so on. Figure 6.1 represents the die sinking electric discharge machine.

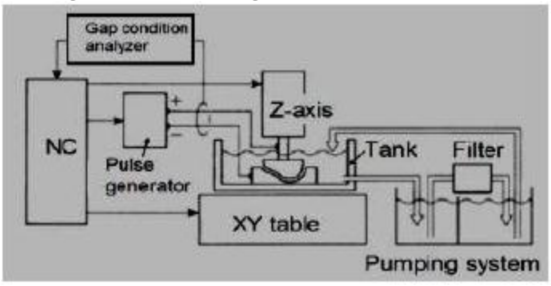

Figure 6.1 Die Sinking Electric Discharge Machine [34]

6.2 W-EDM- It is also called as Spark EDM. W-EDM is electro-thermo machining process in which a thin single-strand metal wire in conjunction with de-ionized water which is used to conduct electricity, allows the wire to cut through metal by the use of heat generated by the electric sparks [71-73]. It is typically used to cut plates as thick as 300mm and to make punches, dies and tools from the hard materials. The diameter of the wire is in the range of 0.1-0.3 mm [74]. The wire and the work-piece are mounted on a CNC controlled worktable. It produces burr-free machining provided that the work-piece is electrically conductive and its mechanical properties impose no limitations on the machining process [75-77]. Figure 6.2 represents Wire-Cut EDM.

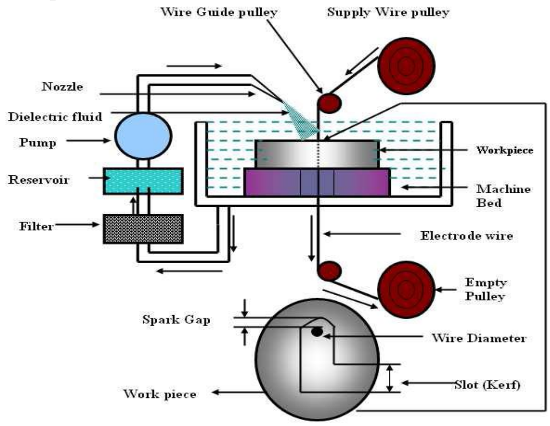

Figure 6.2 Wire-Cut EDM [21]

6.3 MICRO-EDM- Micro-EDM is one of the developments in the field of EDM which is used to machine between the range 5μm to 10μm used for manufacturing various micro scale components [78].The plasma size in micro EDM is larger as compared to the plasma radius. The electrical pulse generated in micro EDM is of very short duration i.e. a few discharge energy is employed in micro EDM in order to enhance the machining process. Micro EDM is a very effective process for the Machining of conductive and semi-conductor materials. Micro EDM can be relied upon due to the fact that irrespective of material hardness, it is capable of giving high surface finish with precision. Manufacturing of micro dies and micro structures such as micro holes, micro slots and micro gears are done by using micro EDM [79-80]. Micro EDM provides various advantages like low setup cost, high aspect ratio, enhanced precision, moreover and due to the fact that there is no direct contact between tool and the electrodes, mechanical stress is thus eliminated. Micro Electric Discharge Milling, Micro Electric Discharge Contouring, Micro Electric Discharge Die-sinking, Micro Wire Electric Discharge Grinding, etc. all are some of the derivatives of micro EDM process [81].

6.4 HYBRID-EDM- Hybrid advanced machining process is the combination of two or more material removal processes in which different forms of energies is used in different ways at the same time or on the same zone of impact [82]. This hybrid machining is sub divided in to two types (i) Assisted hybrid machining process (ii) Pure hybrid machining process. In assisted process, the main material removal takes place from the primary source and the secondary source only assist the material removal but in case of Pure hybrid process, several material removal mechanism are present [83]. One of the most hybridized advanced machining processes is the EDM process. H-EDM will enhance the characteristics effect and at the same time reduce the adverse effects that are associated with individual processes. So, that the hybrid EDM process clubs the advantages of both processes which can increase performance and efficiency as compare to EDM process alone [84]. Figure 6.3 represents the EDM- based Hybrid Machining Processes.

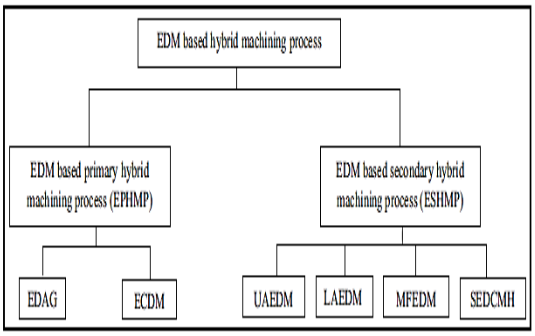

Figure 6.3 EDM-Based Hybrid Machining Processes[1]

6.4.1. Electric Discharge Grinding - Electric discharge grinding is a hybrid machining process with combination of Electric Discharge Machining (EDM) and Mechanical Grinding used for machining of hard, brittle and electrically conductive materials [85]. EDG has been developed by replacing the stationary electrode used in EDM with rotating electrode. In EDG material removal mechanism is melting and vaporization as same as in case of EDM but there are ample difference with EDM instead of mechanism of material [86]. In EDG process an electrically conductive wheel (metallic grinding wheel without abrasive particles/ graphite wheel) is used as a tool electrode and there is no contact with work piece and tool except during electric discharge. The grinding wheel used rotates in horizontal axis and is having no other abrasive particles [87]. EDAG is the main development of the EDG process but the main difference is the use of the metallic bonded abrasive wheel or composite wheel in place of rotating wheel without abrasive [88]. EDAG is further developed in to different grinding configurations: Electric Discharge Abrasive Cut-Off Grinding (EDACG), Electric Discharge Abrasive Face Grinding (EDAFG) and Electric Discharge Abrasive Surface Grinding (EDASG). Figure 6.4 represents Electric Discharge Grinding [89].

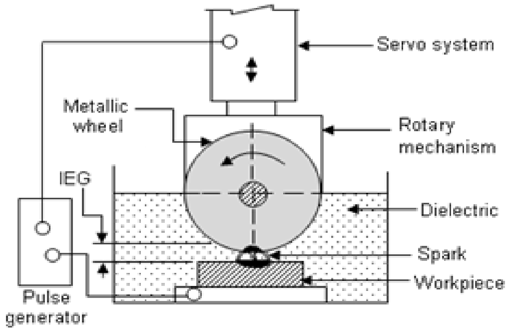

Figure 6.4 Electric Discharge Grinding [85]

6.4.2. Electric Chemical Discharge Machining- Electric Chemical Discharge Machining (ECDM) is a hybrid process which combine both EDM and ECM process, and is used for machining of non-conductive materials [90]. Many researchers have given the different name to ECDM process as Electro-chemical Arc Machining (ECAM), Electro-chemical Spark Machining (ECSM) and Electro-erosion Dissolution Machining (EEDM) [91]. The main material removal mechanism is ECDM is melting, so it is important in this process is to achieve the melting temperature to soften the work piece material. In this process an anode and cathode is connected to the DC power [92]. The gap between the anode and cathode is called as the machining gap and electrolyte is used to fill this gap. Micro-arc produced in electrolyte between the tool and the work piece. This arc produce the discharge erosion and thus machining of work piece (anode) is been done by the effect of both electro-chemical dissolution (Chemical Erosion) and discharge erosion (Thermal Erosion) [93]. The MRR is higher in ECDM as compared both ECM and EDM process [94]. Figure 6.5 represents Electric Chemical Discharge Machining.

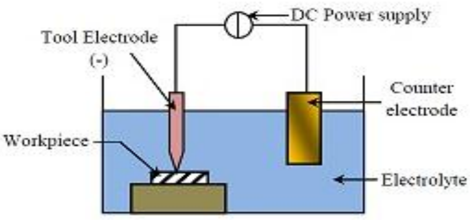

Figure 6.5 Electric Chemical Discharge Machining [90]

6.4.3. Powder Mixed Electric Discharge Machining - Powder-Mixed Electric Discharge Machining process is a hybrid machining process in which the dielectric electrolyte is mixed with additives of abrasive and metallic powder to improve the machining efficiency [95]. The powder mixed electrolyte makes the discharge easier, as it widens and enlarges the discharge gap and passage which leads to evenly distributed etched cavity [96]. Machining characteristics are affected by the powder characteristics such as particle size, type, concentration and conductivity. Powder reduces the insulating strength which makes the EDM process more stable and hence increases the machining efficiency; MRR and surface finish (nearly mirror surface effect) [97-98]. Graphite, silicon, aluminium, crushed glass, silicon carbide and molybdenum sulphide with different grain size are used as the abrasive powder for the machining purpose [99-100]. Figure 6.6 represents Powder Mixed Electric Discharge Machining.

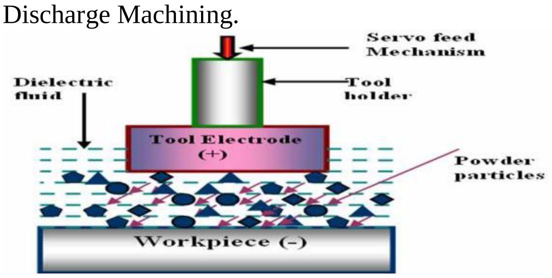

Figure 6.6 Powder Mixed Electric Discharge Machining [21]

6.4.4. Ultrasonic Vibration Electric Discharge Machining - Ultrasonic Vibration Electric Discharge Machining is the combined hybrid process of Ultrasonic Machining (UM) and Electric Discharge Machining (EDM) processes [101]. In USEDM process the abrasive slurry in the UM is replaced by suitable dielectric fluid (kerosene, distilled water) as in case of EDM [102]. It is a non-contacting material removal proves and the material removal mechanism involves ultrasonic movement of work-piece or tool in combination heat generated by the cyclic electric discharge produced by the electrode [103]. The vibratory motion of the tool or work-piece helps to improve the slurry circulation and pumping action, by pushing the debris away and sucking the fresh dielectric helps in ideal discharge, increases machining efficiency and gives higher MRR [104]. Figure 6.7 represents Ultrasonic Vibration Electric Discharge Machining.

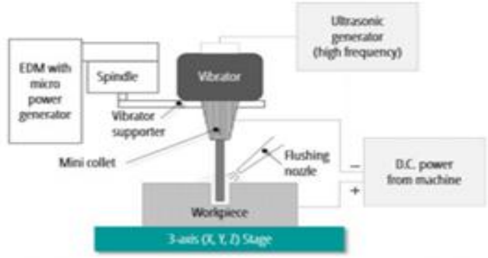

Figure 6.7 Ultrasonic Vibration Electric Discharge Machining [101]

6.4.5. Laser-Assisted Electric Discharge Machining - Laser-Assister Electric Discharge Machining is a hybrid machining process of Laser Beam Machining (LBM) and Electric Discharge Machining (EDM) [105]. Hybrid LAEDM take less time in machining process and machining efficiency is also high. Various researchers have tried to use nanosecond pulsed laser drilling without using EDM and it is found that a large recast layer and HAZ is produced [106]. Researchershave used LBM and EDM sequentially for micro-drilling. They initially drilled holes by nanosecond pulsed laser beam and then used EDM drilling for finishing. It is found that this machining process eliminate the formation of recast layer and HAZs [107]. They also found that the hybrid process took 70% less time in drilling as compared to EDM drilling. Figure 6.8 represents Laser-Assisted Electric Discharge Machining.

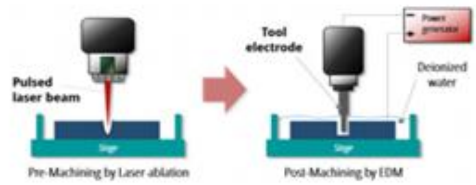

Figure 6.8 Laser-Assisted Electric Discharge Machining [105]

6.5 DRY-EDM- In this variant of EDM the conventional mineral oil or liquid based dielectric is replaced by a high-pressure gaseous dielectric [108]. It is a green environmental friendly machining process and does not produce any toxic fumes as well as there is no fire hazard [109]. Thin walled pipe is used as tool electrode through which high velocity gas is supplied which facilitates removal of debrisand also prevents excessive heating of tool and work-piece at the discharge spot [110]. It is characterised by low tool wear rate and high surface integrity in term of thin recast layer and lower residual stresses [111]. This technique was developed to decrease the pollution which is caused due to liquid dielectric as it produces vapour during machining and cost to manage that waste. High MRR can be obtained in machining of high strength materials with the presence of oxygen gas with copper tool [112]. Figure 6.9 represents Dry-Electric Discharge Machining.

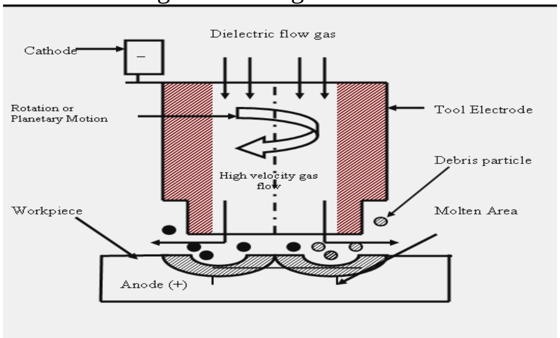

Figure 6.9 Dry-Electric Discharge Machining[21]

7. REMARKS & FUTURE RESEARCH TRENDS:

Due to the advancement in the EDM machine there is an increase in the area of application of this process. Now days, it is used in nuclear industry, automotive industry, aerospace industries, tool, dies, mould industries etc. A keen research is been carried out in other to improve the machining characteristics. The EDM research is broadly classified in to four different major areas. Figure 7.1 represents the classification of major EDM research area.

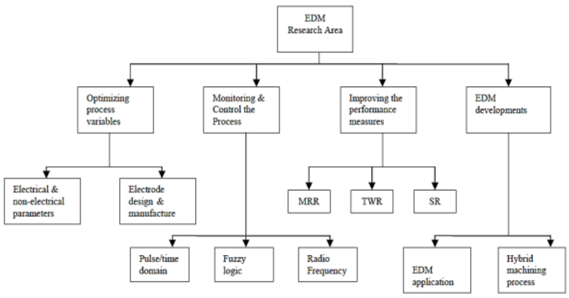

Figure 7.1 Classification of Major EDM Research Area [33]

The main objective of this review is to report the work of the various researchers in the field of Electric Discharge Machining, so as to bridge the gap between the previous research and the untouched area. After reviewing the previous research in the field of EDM, following remarks emerge that are enlisted below.

- A very less work has been done in order to improve MRR using powder of the alloying elements like chromium, vanadium etc.
- There is not so much work reported on the machining of composite and hard material by using hybrid-EDM especially ultrasonic vibration assisted EDM.
- Copper electrode is mostly used as electrode material in UV-EDM. Other materials need to be investigated.
- Some Non-Electric Parameters like work-piece and electrode rotation while machining improves the flushing condition and hence improve material removal rate. Impacts of these parameters are yet to evaluate for more work-piece materials.
- Hollow tube or eccentric drilled holes types' electrode improves the flushing condition and has a positive impact on material removal rate. Such design need to be investigated for more work-piece material to note their effect.
- Performance of water based dielectric is yet to investigate in case of the machining of composite and carbide work-piece materials.
- New techniques such as Multi Spark EDM and Multi Electrode EDM are in the initial stage. These techniques show an improvement in the Material Removal Rate.
- There is a very less published work reported on comparative analysis of EDM techniques of material removal rate improvement with same or different work material.
- Dry-EDM technique in combination with other EDM process may be tried in order to optimize the performances measures such as material removal rate, tool wear rate and surface roughness etc.

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