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MICRO-EDM: OVERVIEW AND RECENT DEVELOPMENTS

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ABSTRACT

Micro-EDM is a process based on the thermoelectric energy between the workpiece and an electrode. Micro-EDM is a newly developed method to produce micro-parts which in the range of 50 μm -100 μm. Micro-EDM is an efficient machining process for the fabrication of a micro-metal hole with various advantages resulting from its characteristics of non-contact and thermal process. A pulse discharges occur in a small gap between the work piece and the electrode and at the same time removes the unwanted material from the parent metal through the process of melting and vaporization. This paper describes about the principles, recent developments, parameters for material removal rate and the tool wear rate that are essential in the Micro-EDM process.

***Keywords**:* Miro-EDM, EDM, Micromachining, Non-Conventional Machining,

INTRODUCTION

Micro Electrical Discharge machining (Micro-EDM) is quite similar process with the principals of Electrical Discharge Machining. According to Katz and Tibbles (2005) from the article “Analysis of micro-scale EDM process” states that Electro discharge machining (EDM) is a thermal process that uses electrical discharges to erode electrically conductive materials. EDM has a high capability of machining the accurate cavities of dies and molds (Zarepur et al., 2007). EDM is an effective technique in the production of micro components that are smaller than 100μm. EDM is a contactless process that exerts every small force on both the work piece and tool electrode. EDM is a process that provides an alternative method to produce microstructures. It is also states that the micro EDM is similar to the principal of macro EDM where the process mechanism is based on an electro-thermal process that relies on a discharge through a dielectric in order to supply heat to the surface of the work piece. The current causes the heating of the dielectric, the work piece, and the electrode. The dielectric forms a channel of partially ionized gas. The discharge power is dissipated in the plasma channel with amount between 2% and 10%. The channel acts as a heat source on the surface of the work piece. Then the work piece is locally heated beyond its melting point and removed after the material ejected solidifies within the cooler dielectric medium. The significant difference between micro and macro EDM is the plasma channel radius (Diameter). In macro EDM the plasma size is larger by several orders of magnitude than the plasma channel radius. The size of the plasma can be changed by the pulse duration because the channel radius increases as the time increases. If the pulse duration time allows the channel to expand until it is larger than the electrode diameter, the rate of its expansion will change.

PRINCIPAL OF MICRO – EDM

Micro EDM's principal of operating is just the same of the conventional EDM but the usage of small electrode size and micro scale MRR are the only differences between conventional and micro EDM.

Sinker EDM Working Principles

Sinker EDM machining process represents the typical EDM machining principal. The basic sink EDM system consists of a tool (electrode) and the work piece are supplied with electricity and placed in a dielectric (electrically nonconducting) fluids. The pulsed arc discharges occur at the gap width that is filled with dielectric fluid such as hydrocarbon oil or de-ionized water. The tool represents the positive charged body and the work piece negative charged. Thus, when the charges potential differences are sufficiently high, the dielectric breaks down and a transient spark discharges through the fluid. This is the discharge current that copies the tool shape on the work piece just like in Figure 1, from Kunieda et. al. (2007), the work piece surface erodes when the sparks created in the gap touches the work piece surface.

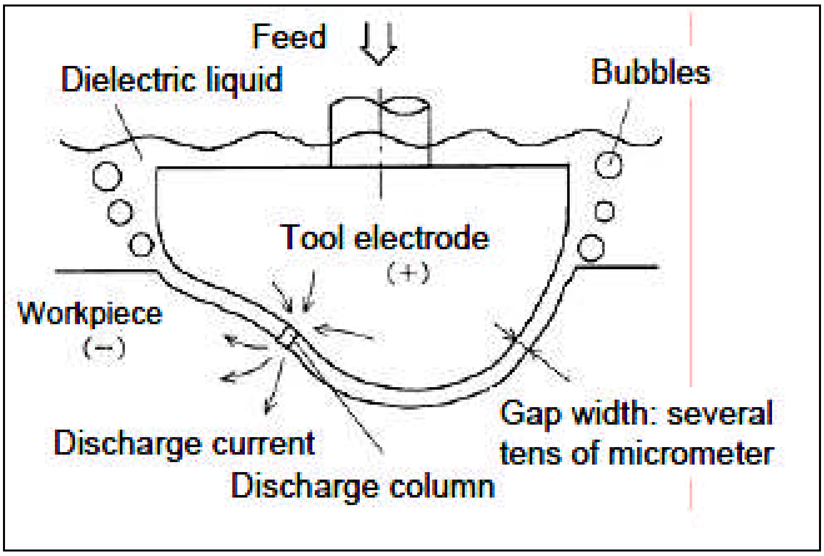

Figure 1: Sinker EDM process

Wire EDM Working Principal

Wire EDM is a non-traditional machining process in using a pulsed voltage difference between a wire electrode and an electric conductive work piece to initiate sparks that erodes the work piece material. This machining process uses wire that is usually made of brass or tungsten, as the tool in cutting the work piece. The wire diameter is around 0.30 mm for roughing cuts and 0.20 mm for finishing cuts. The wire represents the negative charged part and the work piece is the positive charged part. Dielectric fluid is supplied using a nozzle that directs the fluid straight to the cutting point. The guides control the movement and the feeding of the wire. Based on the textbook Kalpakjian and Schmid, Manufacturing Engineering and Technology, latest wire EDM is equipped with latest technology such as computer guided machining process, multi heads to cut 2 parts at the same time, features that prevents wire breakage with self threading and programmed machining strategies to optimize the operation.

Dry EDM Working Principles

According to the Abbas et. al. (2007), the electrode used is in pipe form and gas or air flows through the pipe, as shown in Figure 2, to remove debris from the gap and cools the gap surface. This technology helps to reduce vaporization that happen when dielectric fluids are used, thus cost increase to manage the vaporization waste.

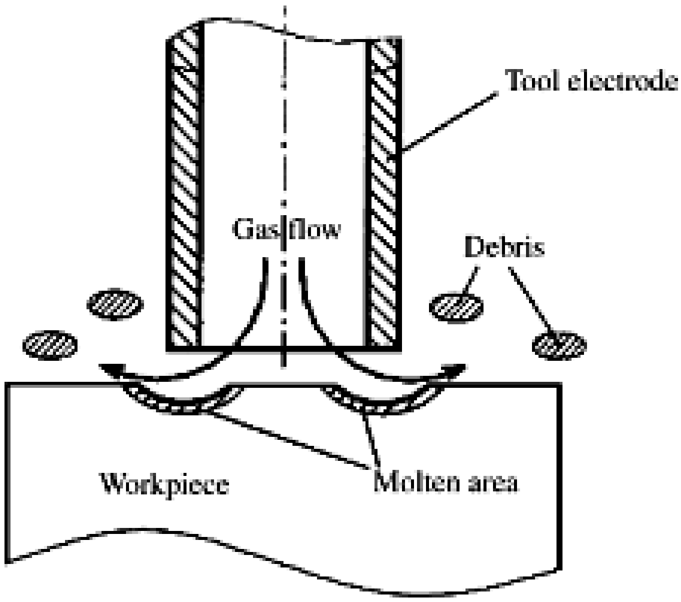

Figure 2: Dry EDM working principle

Dry EDM shows improvement in tool wear and machining time reduction as shown in Figure 3. Kunieda et al. (1997) were discovered that high constant velocity over the working gap do improve Material Removal Rate (MRR) as the concentration of oxygen in air is increased. Although dry EDM is much better than oil EDM milling, but when these two processes machining time compared with oil sink type EDM that is similar to Micro EDM, the result shows that oil sink type EDM is much better than the rest as Figure 4 shows the results. Concentration of oxygen that is required in dry EDM is essential, thus, increasing safety factor in machining process of dry EDM.

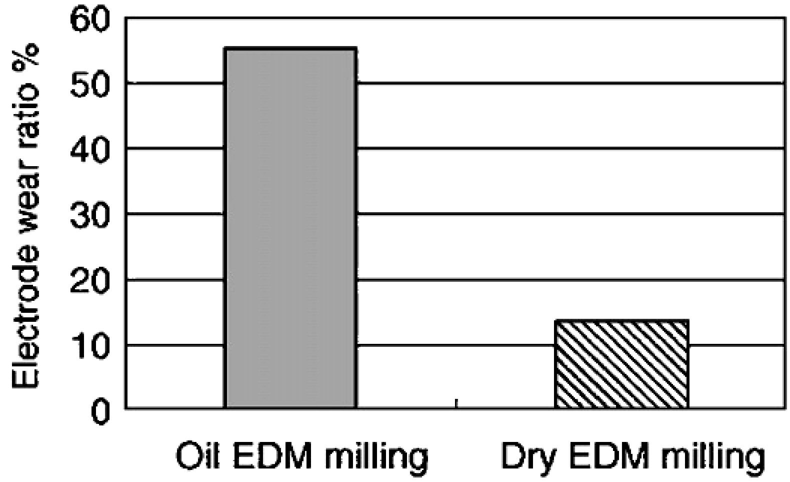

Figure 3: Dry EDM and oil milling EDM electrode wear

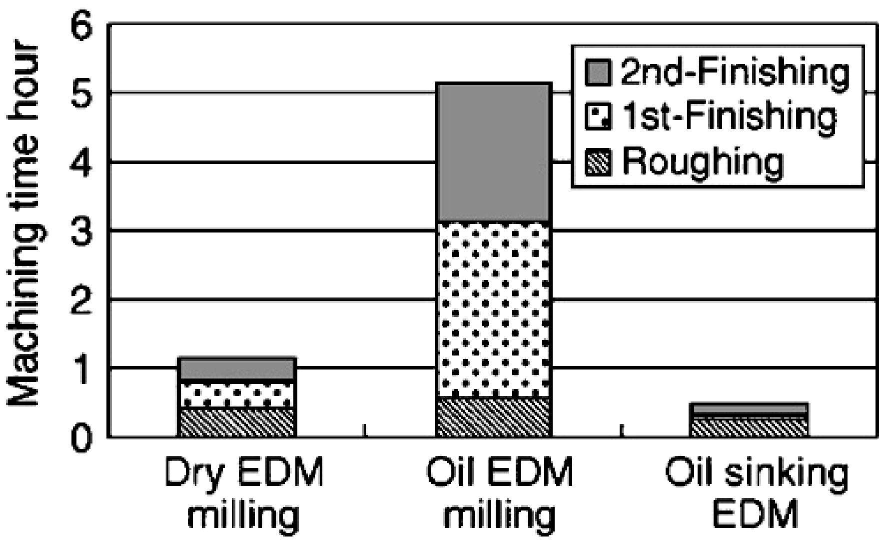

Figure 4: Machining time for dry, oil milling and oil sinking EDM

Electrodes

The electrodes for conventional EDM and Micro EDM are usually made of graphite, brass and copper. These electrodes that used as tools for the machine are basically shaped by forming, casting, powder metallurgy or CNC machining technique. The diameter of the electrodes sometimes as small as 0.1 mm and these electrodes are used to produce depth to hole diameter ratios of up to 400:1. Electrodes eventually erode away when sparks discharging occurs and this affect the shape produced because the accuracy of the electrode fades away. Thus, tool wear is an essential factor in micro EDM and a lot of studies being conduct to reduce and prevent this factor. Wear ratio, the ratio of the volume of work piece material removed to the volume of tool wear, ranges from 3:1 for metallic electrodes to as high as 100:1 for graphite electrodes. According to Davim et al. (2009), for EDM processes, copper – tungsten electrodes are much better than graphite electrode. According to the research, copper – tungsten provide better surface finish and longer life than graphite electrode. Other benefits are for complex geometry, this process is faster and cheaper, thus cost is reduced, robust electrodes that cannot be damaged easily (with graphite and even copper the electrodes can be damaged easily) and replication of artistic hand carved objects (impossible to program) into electrodes. Based on Davim et al. (2009), tool wear between graphite polycrystalline diamond (PCD) cutting tool, chemical vapour deposition diamond (CVDD) cutting tool and K10 (cemented carbide) are studied which is shown in Figure 5.

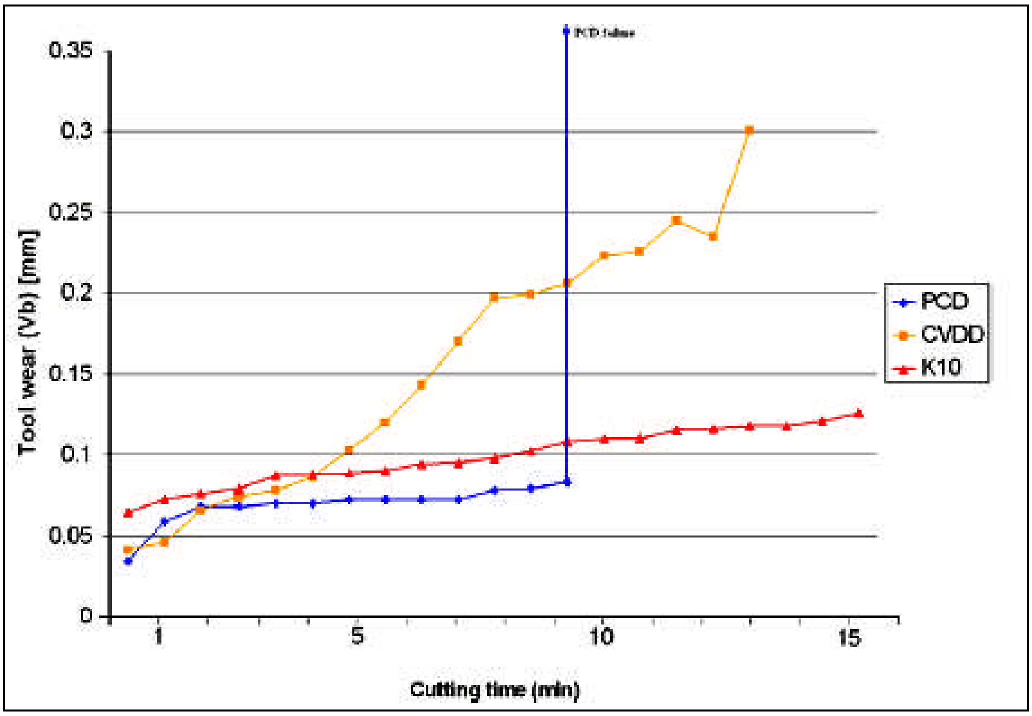

Figure 5: Graph of tool wear of PCD, CVDD, K10

From this figure, a conclusion can be made that cemented carbide is the best material between these materials because it can withstand high temperature machining and provides highest plastic strain. In micro EDM, electrode plays a very vital role in machining because suitable gap widths have to be controlled in only microns. According to Yuangang et. al. (2009), were studied the electrodes that have been gone through composite electrodeposition process have better strength than normal electrodes. This process strengthens the electrodes by depositing a layer of dispersed ceramic particles onto the electrodes surface. According to the research, composite of ZrB2 with copper results in a superior material than others. This composite provides more properties such as high melting point (3040 °C), high electrical conductivity, thermal shock stability, and anticorrosion properties. It has already been used to make as vital components in aircraft and rockets manufacturing because of its ability to perform at high temperatures. From Figure 6, Cu ZrB2 composite have more corrosion resistance than pure copper because composite electro deposition proves to improve the wear resistance of the tool but the process of deposition is very expensive and only selected materials can undergo deposition. Orbital electrode actuation is proven method in gaining high material removal rate and low wear percentage in drilling. Electrode orbiting is to actuate the electrode on a controlled, circular trajectory. If the orbiting motion is created with a device that allows the radius to be controlled electronically, the motion can be integrated into the EDM machine's control system for tight process control. This motion is controlled by piezoelectric motors and actuators that machines work piece by orbiting electrodes. Orbiting the electrodes with bigger radius reduces percentage of tool wear but the bigger is the radius of orbiting the smaller is the material removal rate.

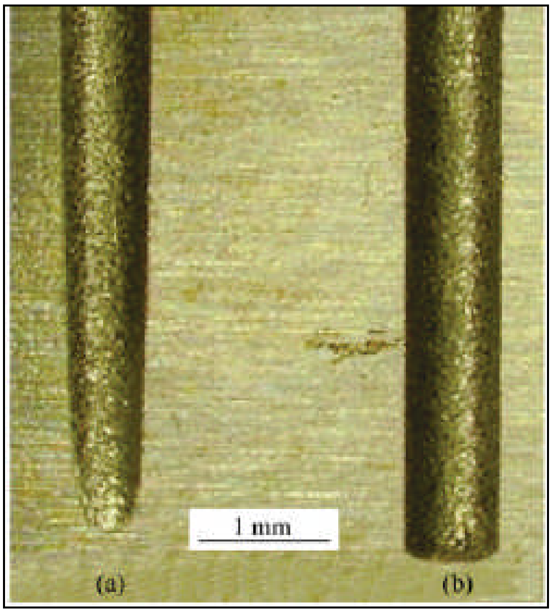

Figure 6: Difference between conventional electrode(a) and Cu ZrB2 composite(b) after machining ANK 80 steel

Dielectric Fluid

Dielectric fluids are electrically non-conducting fluids and used as a medium in EDM machines. These fluids act as an insulator until the potential is sufficiently high and as a cooling medium. It also acts as a flushing medium and carries away debris from the gap. The most common dielectric fluids used in EDM are mineral oils, although kerosene and de-ionized water are also used in specialized applications. Low viscosity fluids also can be used but there are more expensive. The machines are equipped with a filter and a pump for the dielectric fluid. Most die-sinking EDM processes use kerosene as the EDM dielectric fluid; however, kerosene relevant properties degrade during long-term machining. Another disadvantage of kerosene is air pollution and a high discharge temperature which decomposes the kerosene and causes carbon elements to adhere to the electrode surface.

Adding foreign particles in the dielectric fluid do results in better properties such as reducing the recast layer, preventing cracks, and producing a mirror like surface finish in the medical components. Although, a lot of advantages have been discovered but the effect of these particles adding to the characteristic of surface machining remains unclear. A study has been conducted by them on material removal mechanism using powder-suspension dielectric oil and surface quality. Addition of particles alters the material removal mechanism but the addictives have to be in suitable manner of particle size, particle concentration, particle density, thermal conductivity, electrical resistivity, melting point, evaporation point, specific and latent heat.

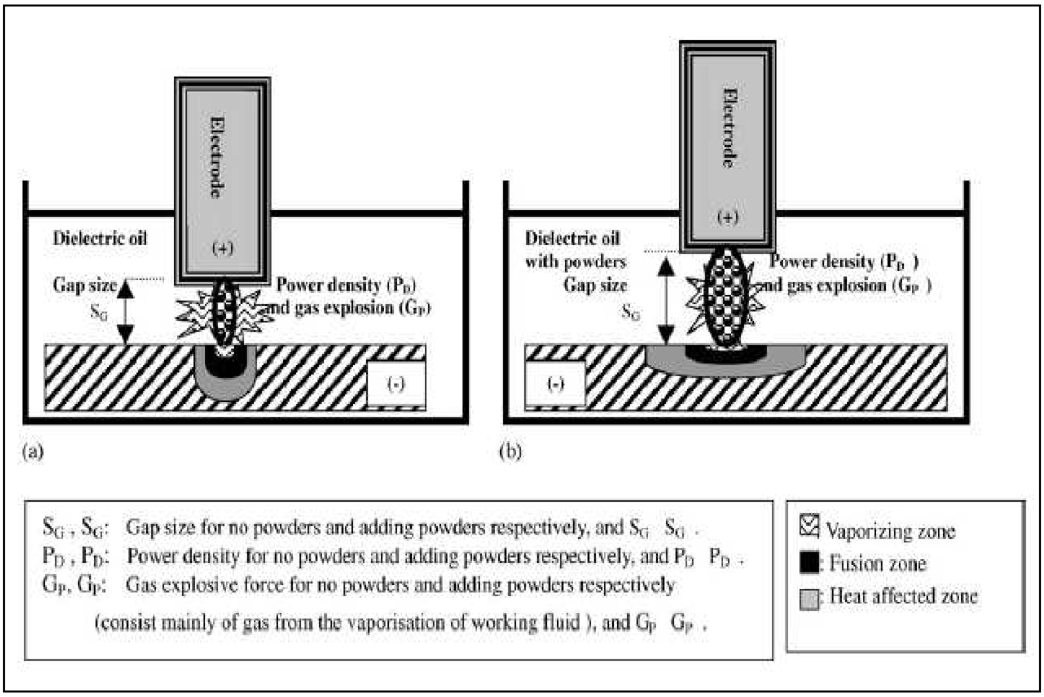

Figure 7: Difference between dielectric oil (a) and mixture of powder and dielectric powders (b)

Figure 7, shows the difference between dielectric oil with powders noted that the addition of powders results in increment of gap size that subsequently resulted in a reduction in electrical discharge power density and in gas explosive pressure for a single power pulse. Although the MRR is decreased but surface finish and tool life improves because sparks discharge is far from electrode surface. Addictives that have smallest particle size generates best surface finish. It is due to small particles producing fine cutting effects in a complementary way. Aluminum, chromium and silicon powder have been tested as addictives in dielectric oil. Result shows that aluminum powder produces best surface finish but adding aluminum powder is an environment pollution problem. This, could lead to a waste manage problem. According to Chow et. al. (2008), silicon powder (SiC) added into pure water produces high conductivity therefore, the gap was larger than using pure water in the EDM processes. Pure water and a SiC powder could spread the discharging energy that smoothens the surface roughness and also attains a higher MRR than that of pure water but. The mixture causes a larger expanding-slit and electrode wear than those of using pure water alone. These mixtures do result in higher tool wear than usage of only pure water as in Figure 8.

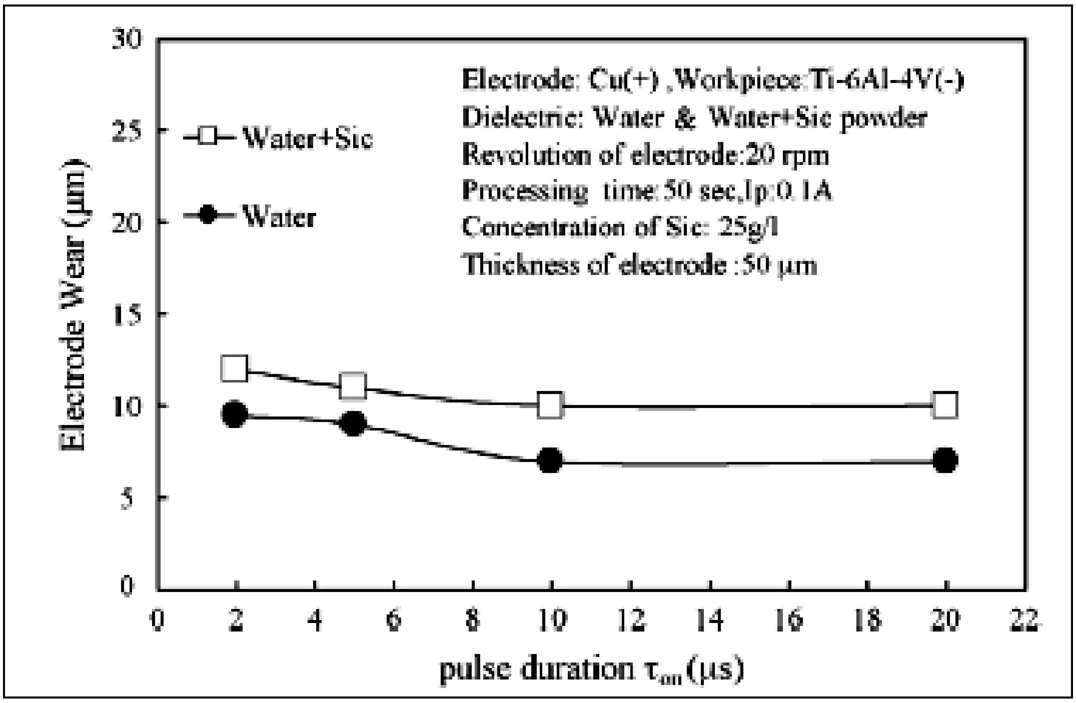

Figure 8: Relation between tool wear and pulse duration

RECENT DEVELOPMENTS

In micro EDM, the gap between the tool and work piece is only a few micron just enough to sustain the spark discharge to erode the work piece. The pulse energy that is provided during machining is about a few micro joules. Thus, tool feed control is extremely important in Micro EDM because the work piece and the electrode is being eroded. Tool wear and cutting cost aspects depend on the tool feed method, thus tool feed control is very vital in Micro EDM.

Fuzzy Logic Control

Pulse generation and mathematical model such as proportional – integral – derivation (PID) usage in EDM is highly complicated in designing much critical design, resulting in short circuit. Artificial intelligence such as fuzzy logic and neural network has been studied for so many years resulting in very stable and highly precise process. It is becoming popular to use fuzzy logic technology in Micro EDM because the technology produces fast and accurate machining. This fast machining or drilling is done by reducing short circuit and minimizing arc. 1 and 2 input fuzzy logic controls have been studied but the outcome is not as good as 3 input fuzzy logic control, Figure 9, because abnormal discharges occur and this changes the rate of the machining. The 3 inputs are spark frequency error, abnormal spark ratio error and its changes rates. The design and tuning of fuzzy logic controllers are crucial to real-time process control. The computational time for fuzzy logic reasoning grows significantly with the complexity of inference engines.

According to Kao and Shih (2009), fuzzy logic control and tuning process are divided into 2 parts, gain scheduling controller and fuzzy logic controller. Gain scheduling controller is a bench mark for the fuzzy logic controller. This controller uses difference between present and actual gain voltage, ΔVg as the main input parameter to control 6 operating conditions of servo mechanism. Each operating conditions consist certain specific speed to control the servo motor. The sign of 1Vg is used to indicate the status of the discharge gap distance. When 1Vg is negative, meaning the discharge gap is narrowing, the electrode feed speed is reduced. If the value of reduction is higher than the current electrode feed speed, then the electrode is moved away from the work piece. When 1Vg is positive, the feed speed is increased in the direction toward the work piece. The rule of adjusting the servo speed depends on the operating condition, which is determined by comparing the 1Vg to a preset value called the breakpoint. Figure 9, shows the schematic diagram of a 3 input fuzzy logic controller. The value of Vg is used to identify the current EDM status, which has six levels: open circuit, good, fair, bad, dual state, and short circuit.

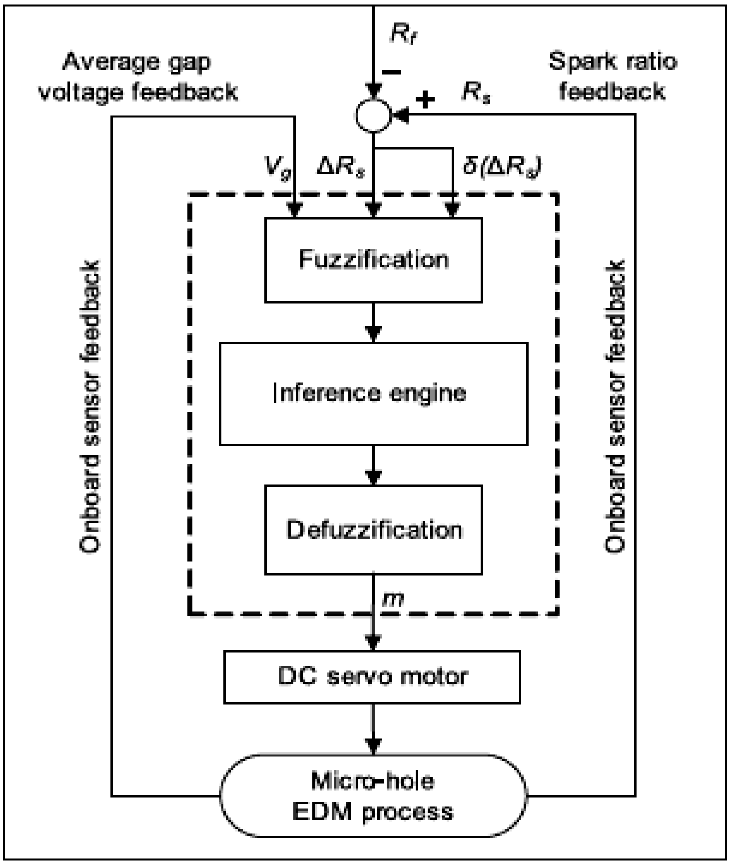

Figure 9: 3 input fuzzy logic control

Fuzzy logic aid in micro EDM drilling claims a big advantage in machining but complicated machine setup and various parameters observation have to be done. Tool wear depends on proper tuning of fuzzy logic controller. This requires a lot of test runs before real machining take place, thus it is not suitable for mass production but suits for prototype product machining. According to Boccadoro and Dauw (1995), normal die sinking conventional EDM consist of Adaptive Control Constraint (ACC), the main purpose of ACC is to maintain the risk of machining under a safe level. Adaptive Control Optimization (ACO), optimize the spark parameters and flushing condition. Although these two technology are vastly used in EDM, short circuit still occurs because of poor gap control. Thus, fuzzy logic controller replaces the old digital controller just like in Figure 10.

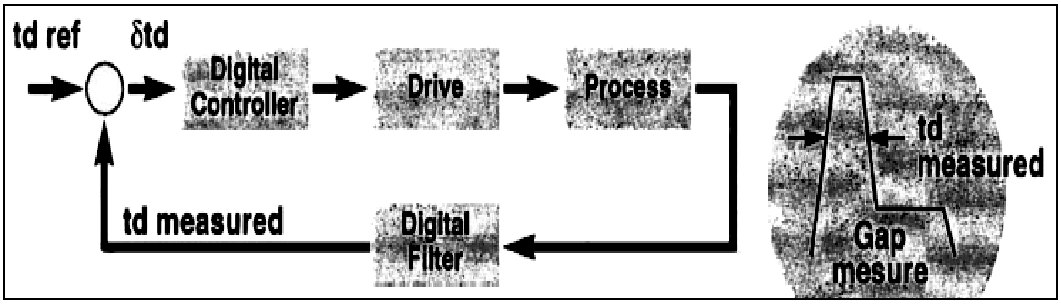

Figure 10: Conventional EDM control loop

Fuzzy logic controller works when the gap width is indirectly measured in the known way of measuring the ignition delay time of the discharges. This ignition delay is filtered digitally and subtracted from a set point value .The output of the controller gives the information to the motors to move the electrode backward or forward in order to keep the gap width constant.

Piezoactuated (PZT) Tool Feed System

The basic of ultrasonic vibration testing is the conversion of electrical pulses to mechanical vibrations and the conversion of returned mechanical vibrations back into electrical energy. The active elements in the process are polarized material with different pole electrodes attached to them. When electricity pass through these active elements, the molecules will align together resulting changes in dimension of the material. Figure 11 shows the process.

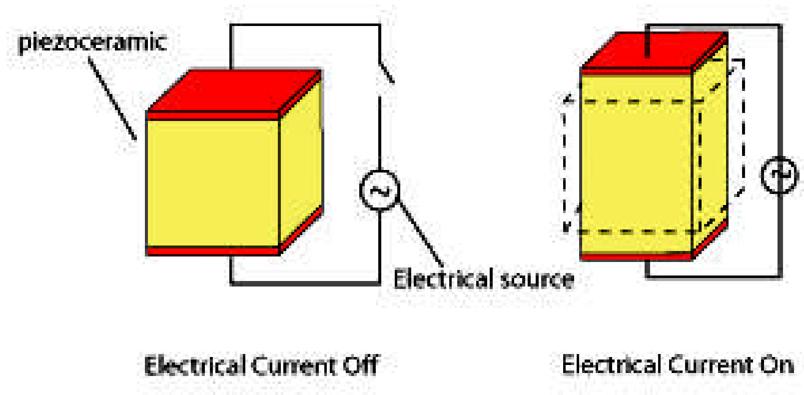

Figure 11: Piezoelectric process

The transducer plays a very important role in ultrasonic instrumentation system because it is responsible in converts electrical signals into mechanical vibrations (transmit mode) and mechanical vibrations into electrical signals (receive mode). This unique characteristic is a major aid in Micro EDM because the tool feed can be controlled by this advantage. According to Muralidhara et al. (2009), Piezoactuated tool feed system is a electromechanical process that requires high resolution closed loop positioning control system. The electrode for Micro EDM is only a few hundred micron in size, thus the actuator that controls feeds the electrode must have no high load carrying capacity. Piezoelectric actuator always used in high precision and these actuators show performances in fast response, high stiffness, low wear and tear and have compact design.

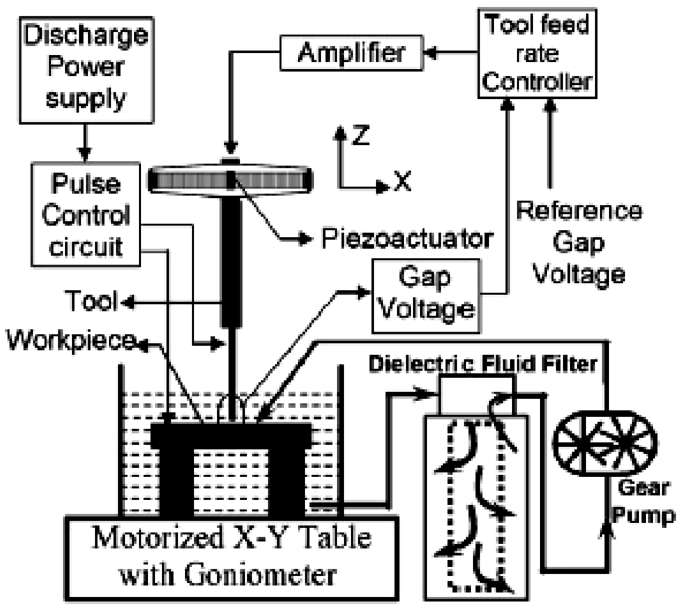

Figure 12: Micro EDM machine with PZT

Figure 12 shows the assembly of PZT with micro EDM machine. The maximum displacement of the piezoactuator is 445 mm at150V. The PZT works with whole assembly as in Figure 13. From the figure, spark gap data are being monitored by gap voltage sensor and contact sensor. Then, the data filtered from unwanted signal in noise rejection and if the gap voltage is too small, means the electrode is very far from work piece surface, the switch will be on. Finally, the data is being processed by the ramp direction and rate controller before being amplified to be read by the PZT.

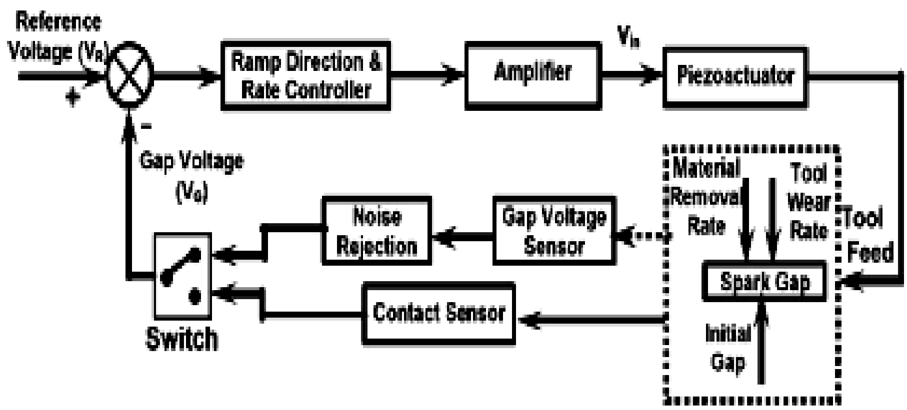

Figure 13: Tool feed control system

According to Hii et al. (2006), PZT also being used in micro milling. The PZT is assembled under the work bench, Figure 14, thus the height of the work piece can be adjusted. This means that the electrode is static but the work bench moves along the desired design. PZT shows a lot of improvement in tool feed control for Micro EDM sector. System with directly coupled piezoactuated tool feed control and the developed piezoactuator model was found to be capable of estimating the tool feed during micromachining with an average error of 7.5%.

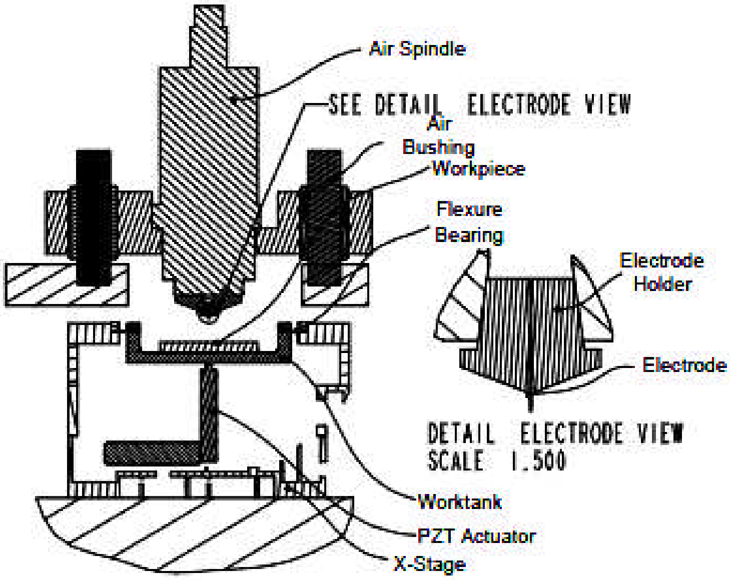

Figure 14: Micro milling with PZT

MATERIAL REMOVAL RATE

Based from the journal “Influence of pulsed power conditions on the machining properties in micro-EDM” shows that the source energy of electro discharge between the tool electrode and the workpiece is an electric one which power can be determined by the supplied voltage and current. Thus, the electro discharge energy can be expressed as shown in Eq. (1).

$$E = VIT$$

In the pulse current, if time T is substituted to an intermittent one with frequency, Eq. (1) is expressed to the following

$$E_p = V_p I_p t_{on} \frac{1}{t_{on}+t_{off}}$$

where; V_p: Voltage of a single pulse, I_p: Current of a single pulse, t_{on}: pulse on-time, t_{off}: pulse off-time.

The equation for material removal rate can be produce by multiplication of machining property. Hence the expression can be written as Eq. (3):

$$MRR = \alpha V_p I_p t_{on} \frac{1}{t_{on}+t_{off}}$$

where α is the removal constant of a material. This constant is the removal volume of a material per unit electric power. From Eq. (3) the parameters of voltage, current and pulse On-time are proportional to the material removal rate. At the same time the frequency of the pulse is also proportional to the material removal rate, but the parameter is not perfectly independent of the pulse On-time. This is because the pulse Off-time is needed sufficiently, depending on the power of a single pulse. The equation also indicates that a shorter duration is more advantageous than a longer one to make accurate machining under the same conditions. Since the removal rate is the same but the removal volume per pulse is smaller in the shorter pulse, if the ratio of pulse On-time to Off-time is the same.

TOOL WEAR RATE

The ratio of amount of electrode to the amount of workpiece removal is defined as the wear ratio (Tsai and Masuzawa, 2006). There are four methods that are known to evaluate the electrode wear ratio by means of measuring weight, shape, length, and total volume respectively. A common one is by calculating the volumetric wear ratio (υ). Usually we will measure the weight differences and transfer them into the volumes by the density of materials. However this method is unsuitable for micro-EDM because the weight change is so small making it difficult to measure it accurately. Therefore, it is important to measure and analyze removed material directly. In Figure 15, the change of electrode length and corner rounding is illustrated. In the figure the worn electrode can be divided into two parts which is V_B and V_C. V_B is the wear volume on bottom portion and V_C is the wear volumes of corner portion and V_C are assumed to be the volume of a cylinder of a revolution body, respectively, because a rotating electrode is used during machining.

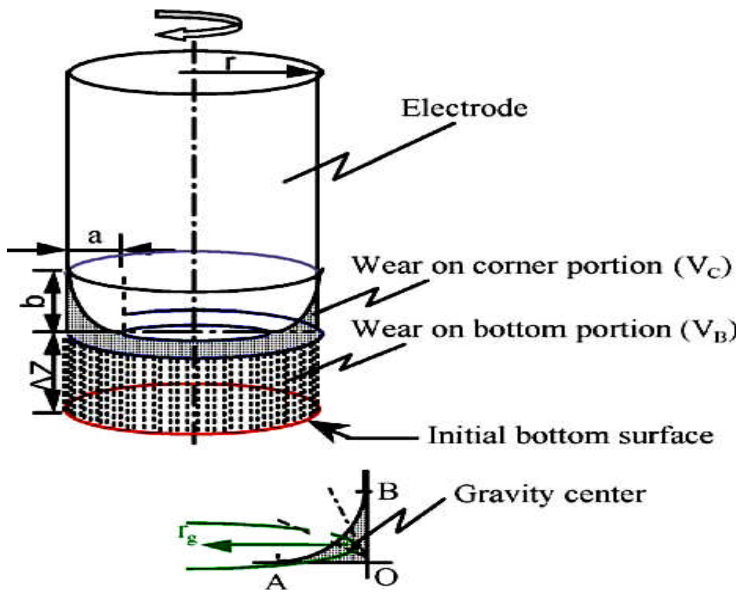

Figure 15: Wear volume of the electrode

CONCLUSION

The paper focuses on the principal of micro-EDM, the types of EDM processes, dielectric fluid, electrodes, , fuzzy logic, piezoactuated tool feed control, material removal rate (MRR) and the tool wear ratio (TWR). This paper is essential for the new development in the research for the micro-EDM machine.

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Nomenclature

V_p: Voltage of a single pulse
I_p: Current of a single pulse
t_{on}: pulse on-time
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PZT: Piezoactuator