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Development Of Table Top Ultrasonic Assisted Sinking Micro Electrical Discharge Machining Set Up

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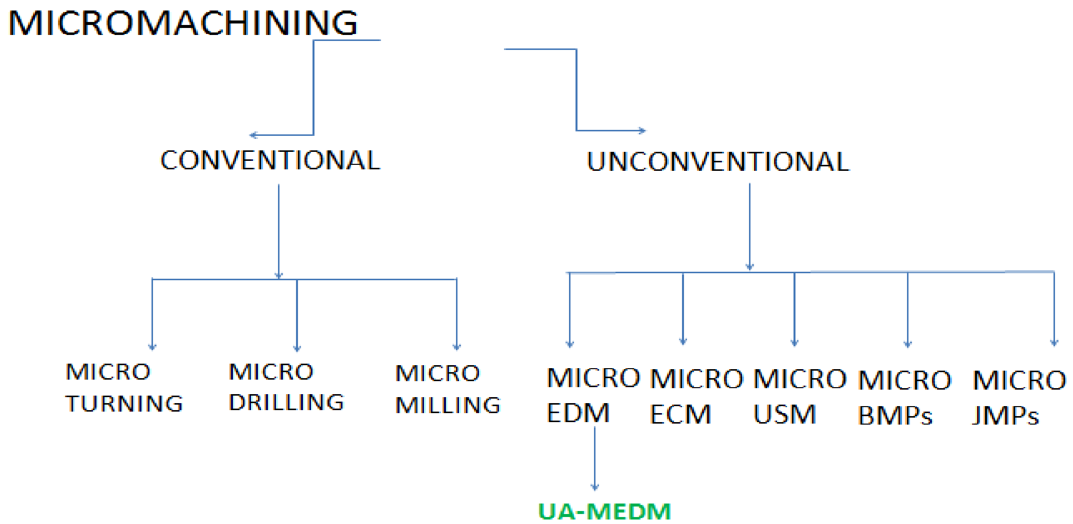


The configuration we are selecting is ultrasonic assisted micro- Electrical Discharge machining.

MICRO-EDM

Micro-EDM is a micromachining process used to produce micro features by controlled melting and vaporization ofexcess material from difficult to machine, electrically conductive material with stringent design requirements using thermal energy generated by spark between two electrodes completely dipped in dielectric and applying a pulsating voltage between them.

ULTRASONIC UNASSISTED MICRO- EDM SET UP DEVELOPMENT

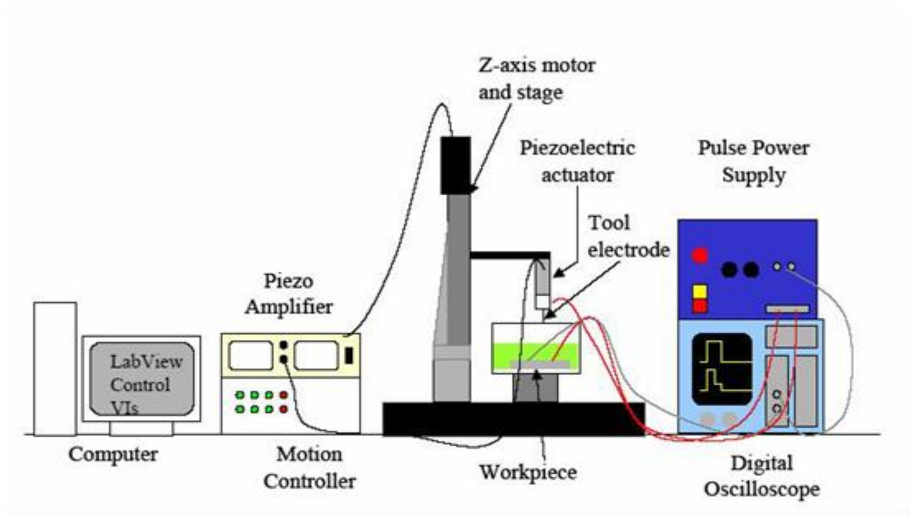


Fig 1: Ultrasonic unassisted micro EDM

APPLICATION-

1. Drilling of diesel fuel injector spray hole (150 um dia and 1 mm depth) as well as in DI gasoline engine fuel injector spray holes.
2. Inkjet printer cartridge nozzles.
3. Orifices for bio- medical devices- micro needles, micro filters and drug delivery systems.
4. Cooling vents for the gas turbine blades.
5. In Micro-electromechanical systems (MEMS), Micro-electronics (semiconductor devices and *integrated circuit* technology),micro components for cellphones and Nanotechnology.

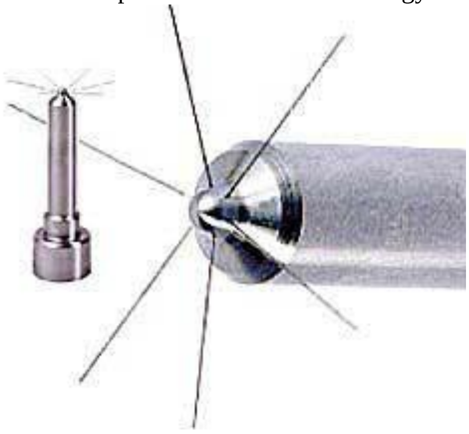


Fig 2: Nozzle for diesel injectors

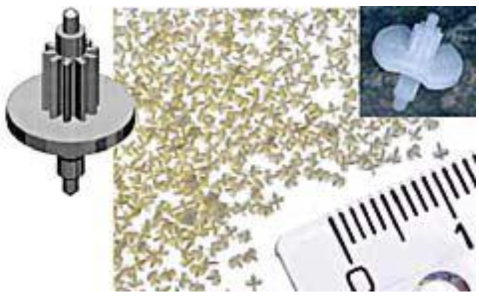


Fig 3: Plastic gear for watches using micro gear die

FEATURES OF MICRO-EDM PROCESS

In micro-EDM, machining characteristics primarily based on ***electrical***and technological ***parameters***such as current, voltage, pulse duration, pulse width, frequency, etc. and ***materialproperties***such as electrical conductivity, melting point, heat capacitance, etc. Imp. Factor which makes u-EDM very imp.in micromachining is m/c ability on any type of conductive and semi-conductive material with high accuracy ***irrespective of material hardness***.

Some limitations of this process are:-

1. It is a slow machining process.
2. Tool wear could lead to shape inaccuracies.
3. Formation of heat affected layer on machined surface.

CHARACTERISTICS OF MICRO-EDM

ADVANTAGES-

- Machining ability to machine complex shapes in electrically conductive material irrespective of any extreme mechanical properties.
- Cheaper and most widely used unconventional machining process.
- Most user- friendly in unconventional machining process.
- A softer tool is capable to machine extremely hard material.
- There is no direct contact between tool and work piece. Only image contact is required.

LIMITATIONS –

- Time and cost of machine is very high.
- Non conducting materials cannot be machined.
- Generation of thermal stresses and metallurgical changes on machined surface.
- Final shape inaccuracies because of inherent characteristic of tool wear.

PRINCIPLE OF MICRO- EDM

Thermo-electric theory:

This theory, best-supported by experimental evidence, suggests that metal removal in EDM operations takes place as a result of the generation of extremely high temperature generated by the high intensity of the discharge current.

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.

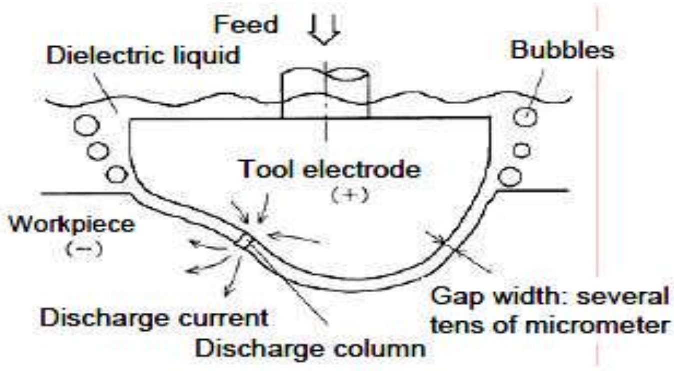


Fig 5: Micro EDM principle

The following nine illustrations show step-by-step what is believed to happen during an EDM cycle. The graphs below the illustrations show the relative values of voltage and current at the point depicted.

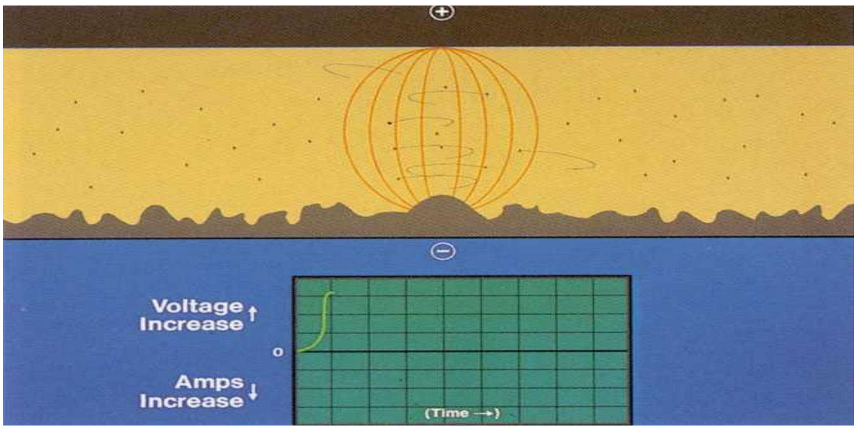


Illustration 1:

A charged electrode is brought near the workplace. Between them is insulating oil, known in EDM as dielectric fluid. Even though a dielectric fluid is a good insulator, a large enough electrical potential can cause the fluid to break down into ionic (charged) fragments, allowing an electrical current to pass from electrode to workpiece. The presence of graphite and metallic particles suspended in the fluid can aid this electrical transfer in two ways : the particles(electrical conductors) aid in ionizing the dielectric oil and can carry the charge directly; and the particles can catalyze the electrical breakdown of the fluid.

The electrical field is strongest at the point where the distance between the electrode and workpiece is least, such as the high point shown. The graph in the illustration shows that the potential(voltage) is increasing, but current is zero.

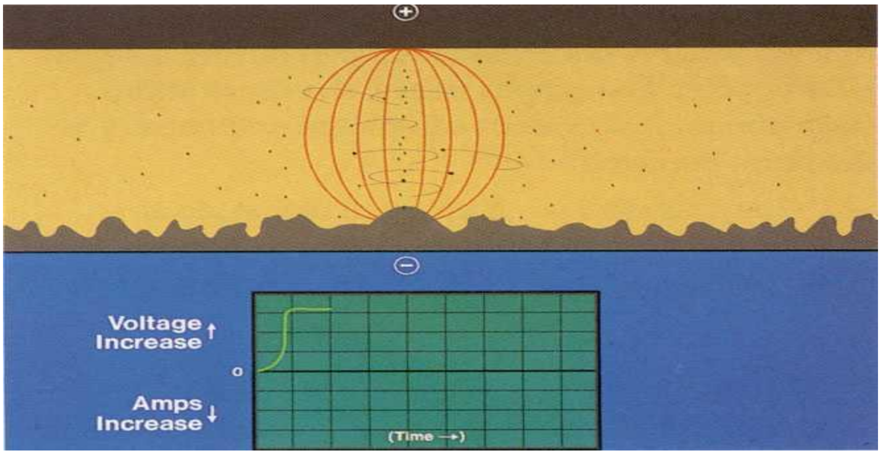
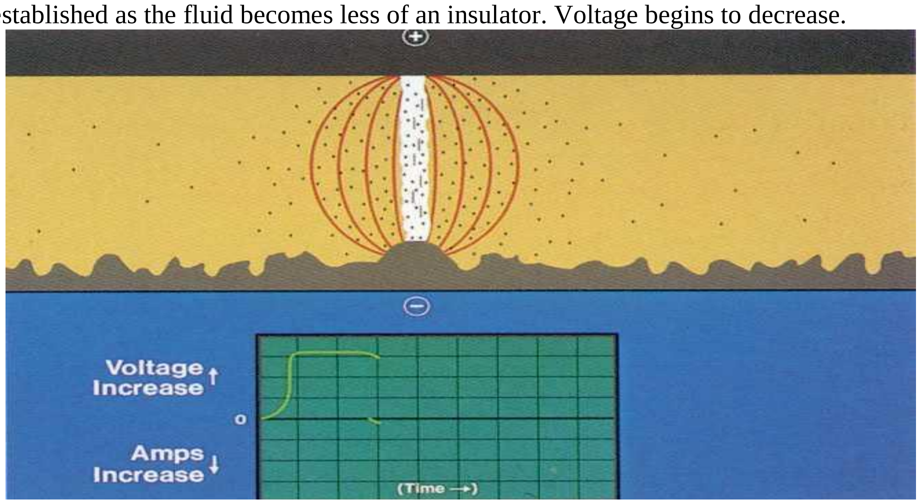


Illustration 2:

As the number of ionic(charged) particles increases, the insulating properties of the dielectric fluid begin to decrease along a narrow channel centered in the strongest part of the field. Voltage has reached its peak, but current is still zero.

Illustration 3:

A current is established as the fluid becomes less of an insulator. Voltage begins to decrease.



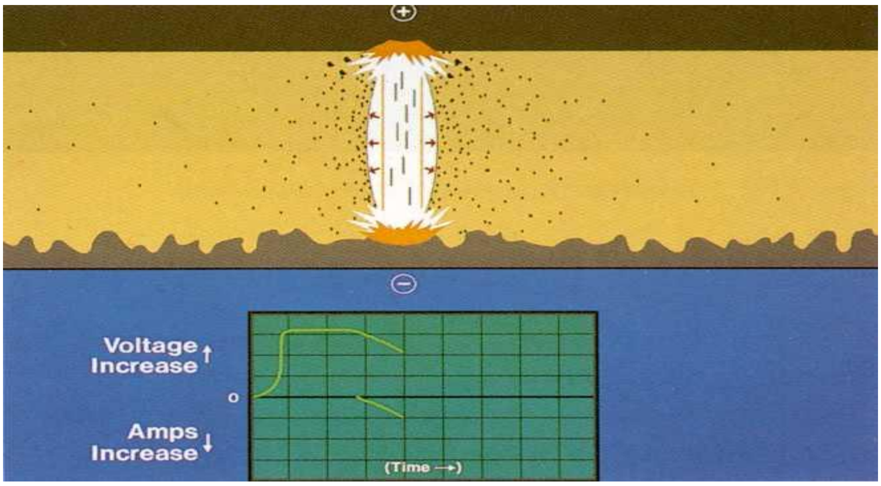


Illustration 4:

Heat builds up rapidly as current increases, and the voltage continues to drop. The heat vaporizes some of the fluid, workpiece, and electrode, and a discharge channel begins to form between the electrode and workpiece.

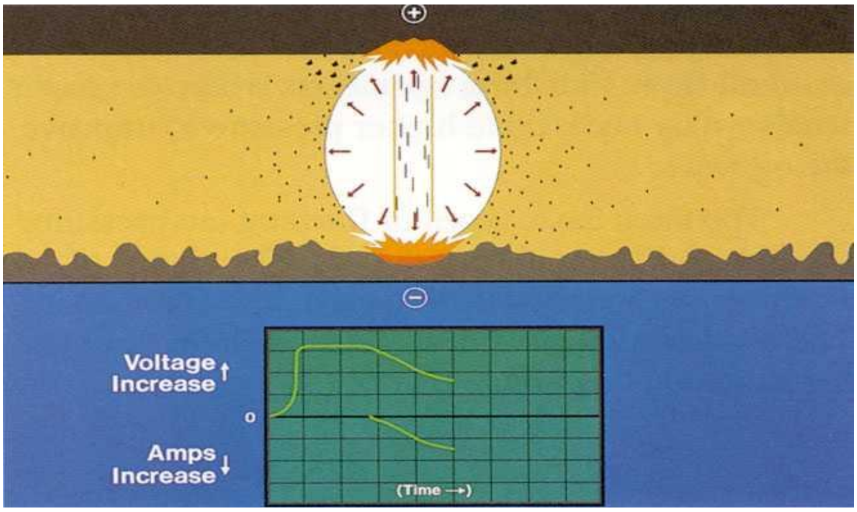


Illustration 5:

A vapour bubble tries to expand outward, but its expansion is limited by a rush of ions towards the discharge channel. These ions are attracted by the extremely intense electro-magnetic field that has built up. Current continues to rise, voltage drops.

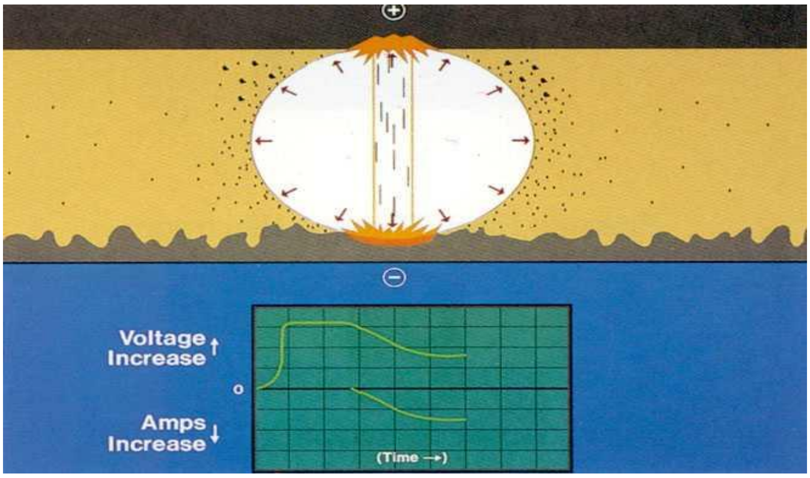


Illustration 6:

Near the end of the on-time, current and voltage have stabilized, heat and pressure within the vapour bubble have reached their maximum, and some metal is being removed. The layer of metal directly under the discharge column is in molten state, but is held in place by the pressure of the vapour bubble. The discharge channel consists now of a superheated plasma made up of vaporized metal, dielectric oil, and carbon with an intense current passing through it.

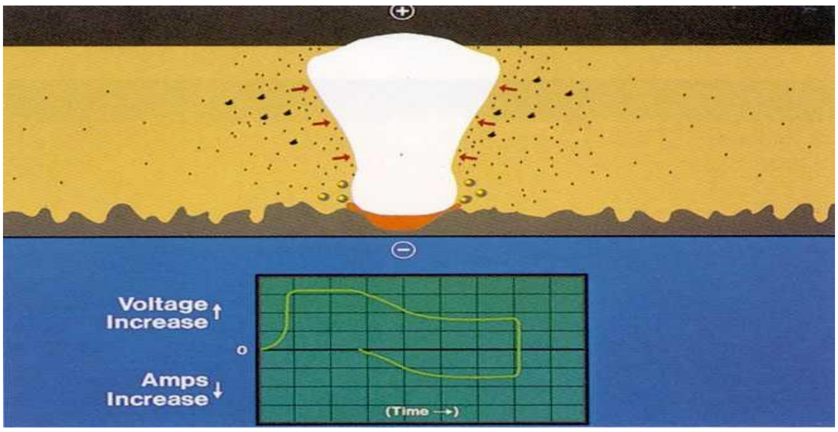


Illustration 7:

At the beginning of the off-time, current and voltage drop to zero. The temperature decreases rapidly, collapsing the vapor bubble and causing the molten metal to be expelled from the workpiece.

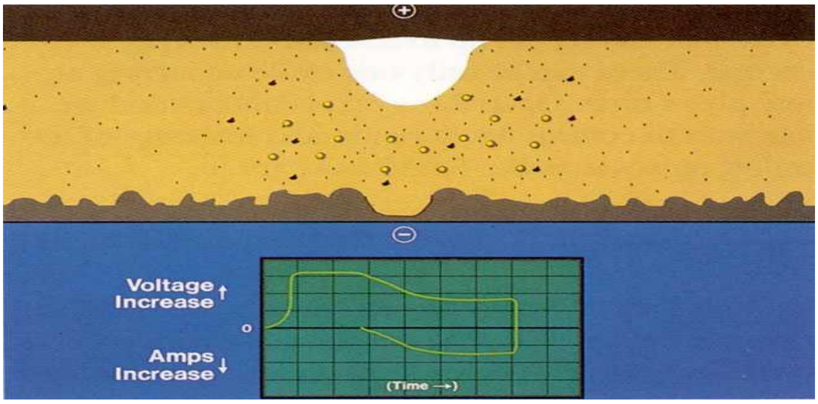


Illustration 8:
Fresh dielectric fluid rushes in, flushing the debris away and quenching the surface of the workpiece. Unexpelled molten metal solidifies to form what is known as the recast layer.

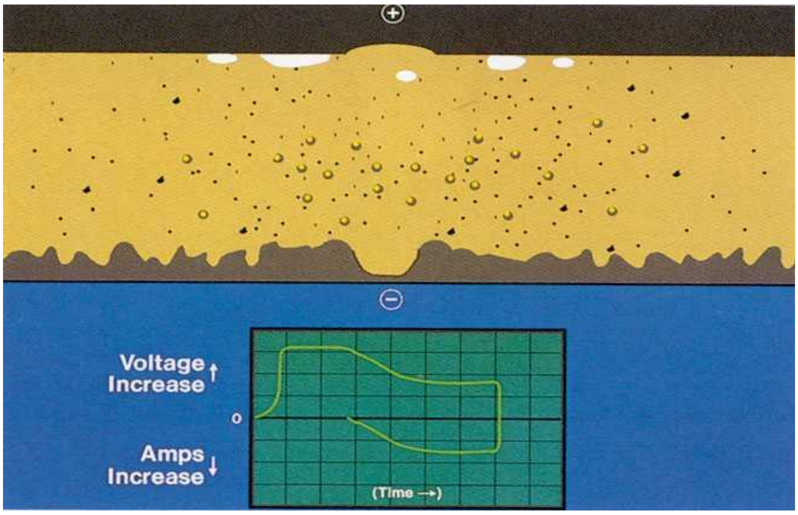
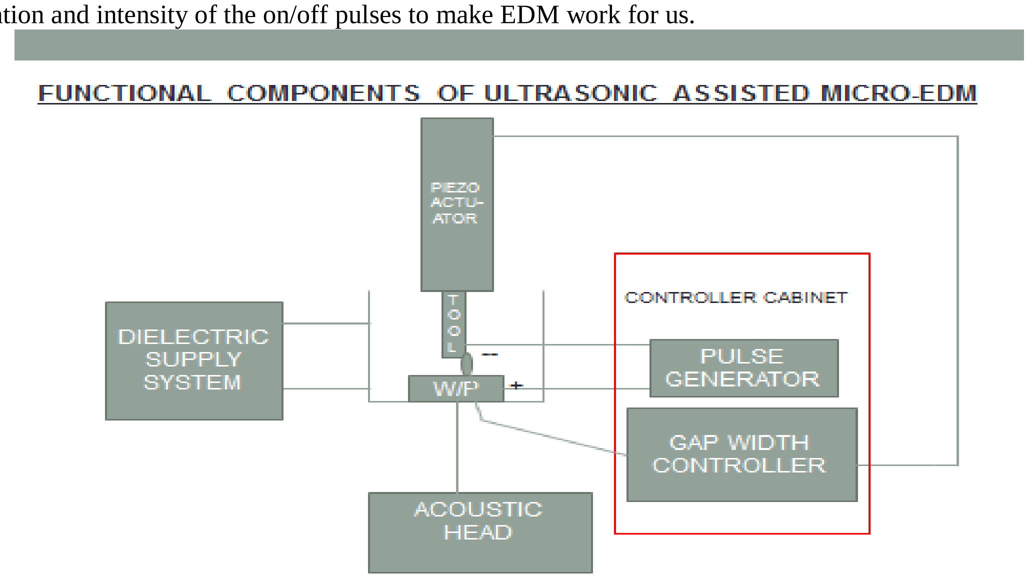
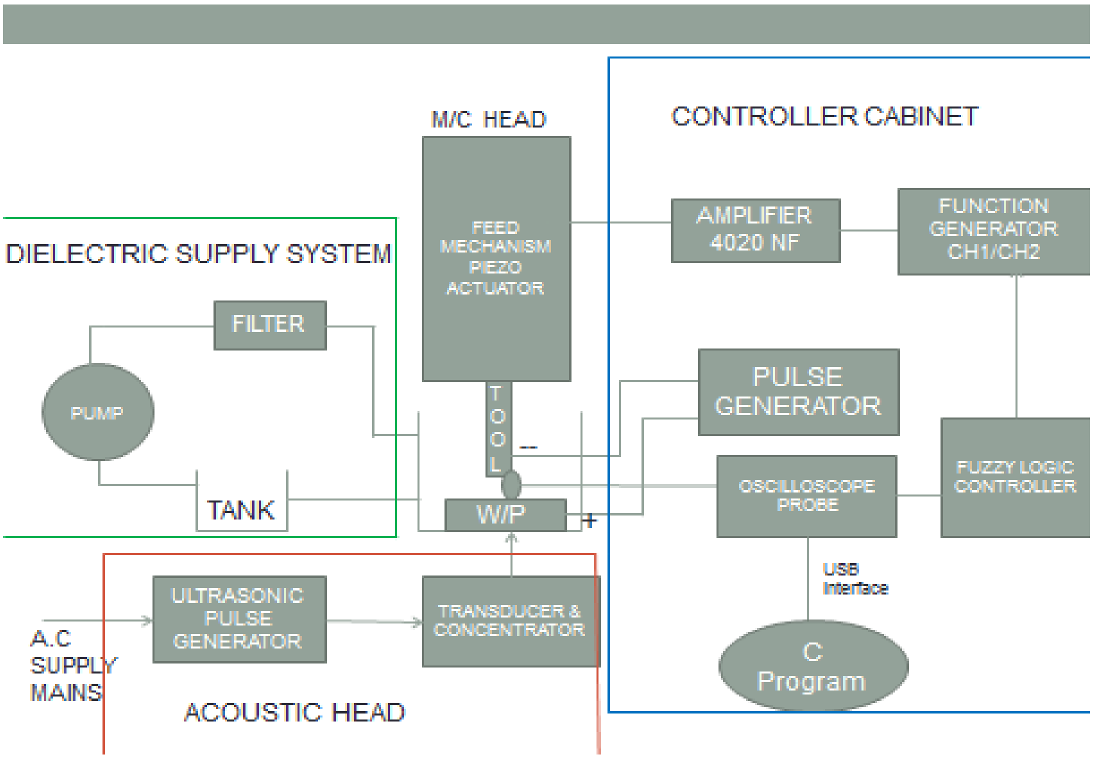


Illustration 9:
The expelled metal solidifies into tiny spheres dispersed in the dielectric oil along with bits of carbon from the electrode. The remaining vapor rises to the surface. Without a sufficient off-time, debris would collect making the spark unstable. This situation could create a DC arc which can damage the electrode and the workpiece. This on/off sequence represents one EDM cycle that can repeat up to 250,000 times per second. There can be only one cycle occuring at any given time. Once this cycle is understood we can start to control the duration and intensity of the on/off pulses to make EDM work for us.





Analysis of the gap Pulses used in the EDM Process

Performance measures such as MRR, tool wear, and surface finish for the same energy depend on the shape of the current pulses. Depending upon the situation in the gap which separates both electrodes, principally four different electrical pulses may be distinguished:

a) Open circuit or open voltage
b) Effective discharges or real Sparks
c) Arcs and
d) Short circuits

They are usually defined on the basis of time evolution of discharge voltage and (or) discharge current (Fig). Their effect upon material removal and tool wear may differ quite significantly.

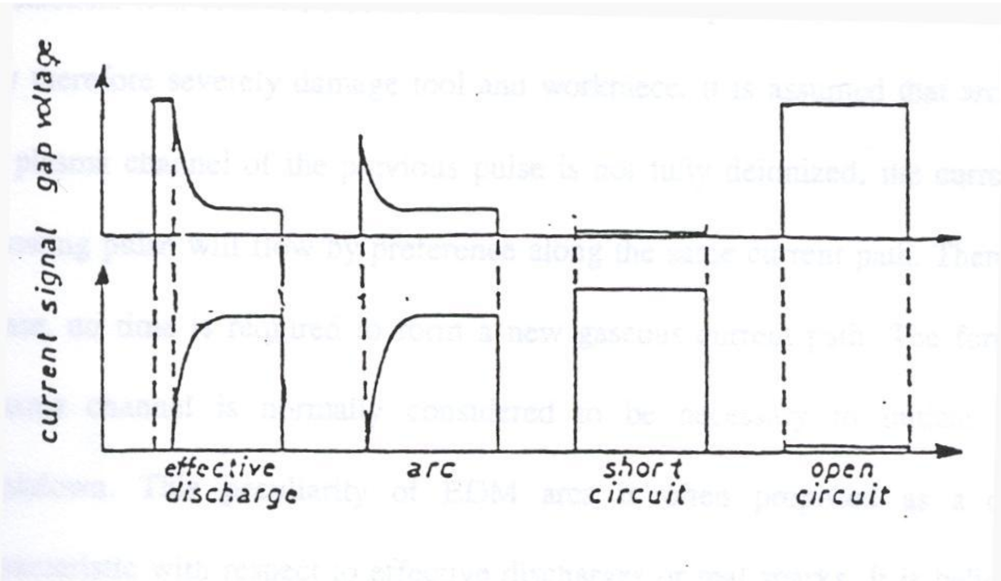


Figure 2.1 Different pulse types.

Open voltages, occurring when the distance between both electrodes is too large, obviously do not contribute to any material removal or electrode wear.

When contact between tool and workpiece takes place, a short circuit occurs which also does not contribute to material removal.The range of the electrode distances in between these two extreme cases can be considered to be a practical working gap yielding actual discharges, i.e., sparks and arcs. Both pulse types do show a characteristic voltage drop across the gap during a pulse.

The difference between sparks and arcs is quite difficult to establish. It is believed that arcs occur in the same spot, or on the electrode surface and may therefore severely damage tool and workpiece.

It is assumed that arcs occur when the plasma channel of the previous pulse is not fully deionized; the current during the following pulse will flow by preference along the same current path. Therefore, in such a case, no time is required to form a new gaseous current path. The formation of the gaseous channel is normally considered to be necessary to initiate a new spark breakdown. This peculiarity of EDM arcs is often proposed as a discrimination characteristic with respect to effective discharges or real sparks.**It is believed that only "sparks" really contribute to material removal in a desired mode. Until now it remains an open question how much arcs contribute in terms of material removal and tool wear.**

DESIGN PRINCIPLES:

Tool or electrode -The mostly used tool material is tungsten carbide .The most powerful technique for manufacturing micro-tool is WEDG (Wire Electro-Discharge Grinding).Any rod electrode diameter can be obtained by off-centering, complicated shapes such as asymmetrical, stepped and multi-rods can be formed.

Tungsten carbide (WC) electrodes with a standard diameter of 400 µm and 100 µm are used as a tool electrode. Stiffness and rigidity of tungsten carbide is very high when comparing to tool steel. This is because tungsten carbide electrode size can be reduced to very small size and prevents bending or swinging during machining. *Wear resistance of tungsten carbide* is also better than that of tool steel. This provides advantages for micro-hole drilling since less deterioration occur in the shape of target holes.

WEDG is used to prepare smaller size tool down to Ø10 µm by using electrical discharge machining principle with *reverse polarity*. Smaller size tool is prepared from larger tools. This process can be divided into two steps. At first step, the diameter of larger tool is reduced to nearly the desired smaller diameter by rough machining. At second step, the roughly machined tool diameter is reduced to the desired diameter by using finish machining parameters.

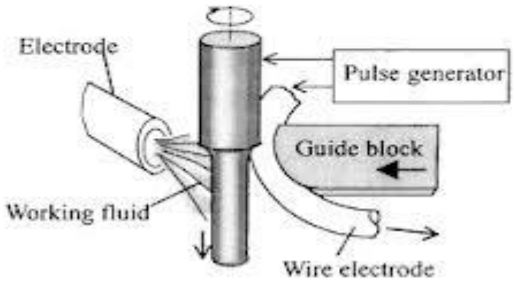
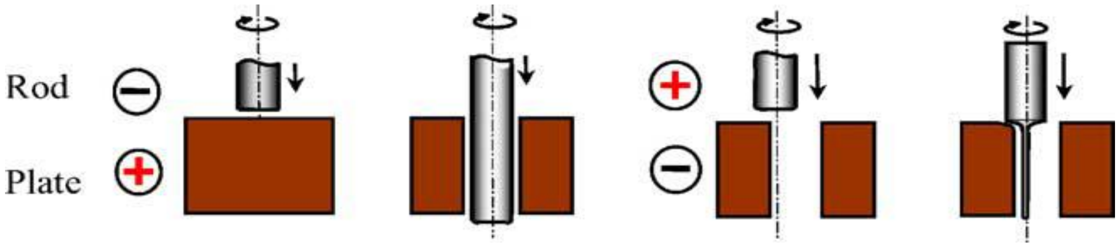


Fig 5: WEDG for obtaining micro-tool



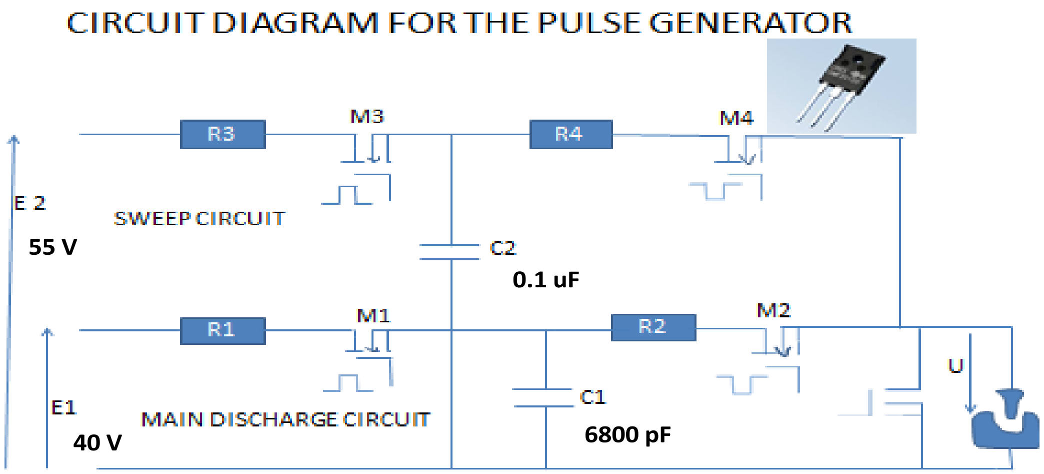
Straight polarity machining   Reverse polarity machining

Fig 6: *Principle of obtaining micro-rods*

Polarity- The workpiece is usually set as the anode (+) and the wire electrode as the cathode(-) (straight polarity machining). This is because the discharge energy distributed to the anode is normally greater than that to the cathode.

Dielectric fluid-It is a nonconductive liquid that fills between the workpiece and electrode and remain nonconductive until needed space and voltage reaches. At that point dielectric fluid ionizes, becoming an electrical conductor and cause the current or spark to flow to the workpiece.Different dielectric fluids like Kerosene, de-ionized water can be used. De ionized water generally has the advantage of faster metal removal rates .

Pulse generator - A transistor (MOSFETs)-controlled power supply.



A transistor(MOSFETs)-controlled power supply.

(REF. *Mu-Tia Yan and Tsung- liang Chan characteristics of Micro-EDM power supply*

Fig 7: Micro- EDM Generator circuit

The typical value of capacitance (C1) in main discharge circuit is about 6800 pF and in sweep pulse circuit is about 0.1 uF (C2).
Open circuit voltage for main discharge circuit (E1) is about 40 V and in sweep pulse circuit (E2) is about 55V. Similarly R4<R2 as sweep circuit current is greater than main discharge current.
The pulse control system for the micro-EDM must be designed such that it has:

- high frequency
- low energy pulse control(10^ -9 to 10^ -5 Joules)

A typical pulse in micro- EDM has a pulse duration (t on)of 30 us and a pulse interval(t off) of 40us. This gives a duty factor of 30/(30+40)=0.428=43% .Peak current values are low and are of order of 1.3 A. Open circuit voltage is of about 40V.

The **main discharge circuit** consists of three MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistor), acapacitor and two current-limiting resistors. Capacitor C1 is used to provide spark discharge energy.

When M1 is turned on, M2 is turned off and M5 is turned on. The voltage between the electrodes is pull down to zero. The process of ***spark discharge is shutoff***. At the same time, capacitor C1 is charged by an external voltage source E1, getting ready for the next discharge cycle(capacitor is charging at this time).
.

When M1 is turned off, M2 is turned on and M5is turned off, a pulse with a voltage of U is loaded between the electrodes, and the electrical energy stored in capacitor C1 is then released in the spark discharge(spark energy is released in gap during this time).

One feature of this main discharge circuit is that the charge and discharge processes of the capacitor C1 are separated. With this feature, the electric energy of each spark discharge is controllable, and the uniformity of the pulse is improved, which is beneficial to machining performance.

The differences between the main circuit and the sweep pulse circuit are as follows. The capacitance of C2 in the sweep pulse circuit is higher than that of C1 in the main circuit. Therefore, when the pulse generator runs in sweep mode, the discharge energy, which is delivered by a single pulse and then released between the electrodes, is higher. Meanwhile, the voltage loaded by the external source E2 is higher than that of E1. A higher charge voltage E2 means not only a higher electrical energy stored in the capacitor C2 and released in a discharge process, but also a higher open voltage of the sweep pulses. Furthermore, the resistance of R4 is lower than that of R2, so that the peak current of the pulse is raised.

EDM pulses can be distinguished into open pulses, ideal spark pulses and harmful pulses. Harmful pulses include arc pulses, transient arc pulses and short pulses. ***Arc pulses and transient arc pulses have very short ignition delay***, because the dielectric fluid breaks down very quickly. Also***, when short pulse occurs, the gap voltage between the tool electrode and the work piece is essentially zero***. Therefore, it is feasible to identify harmful pulses by detecting the gap voltage at the front edge of a single pulse. For that a logic of pulse discrimination is already worked upon by us.

MOSFETs in the main discharge circuit and the sweep pulse circuit are switched by the **MOSFET drivers**. At the same time, the EDM discharge signal between the tool electrode and the work piece is detected by a *pulse discharge status detecting unit* and fed back to the master FPGA controller. The discharge status of the pulse is then identified, and the corresponding control decision is made by the FPGA(field programmable gate array (FPGA) chip).

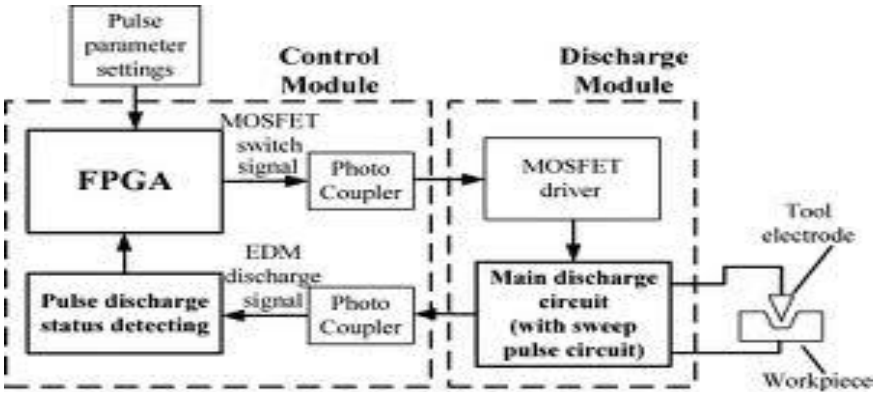
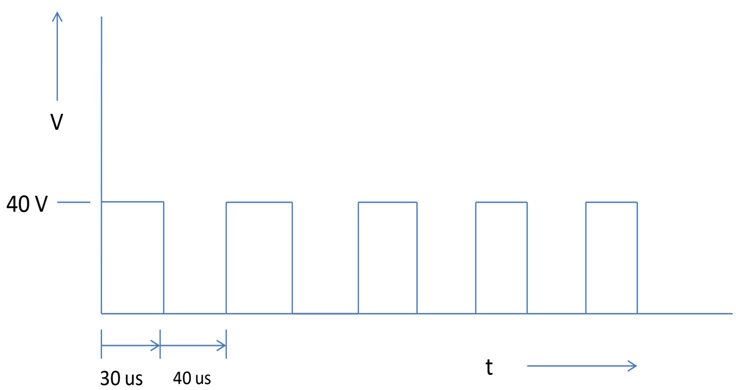


Fig 8: Complete pulse generator circuit

In order to stop the accumulation of debris as well as to recover the gap status, sweep pulses can be applied such that their explosion effect can be made use of. Once a number of harmful pulses occur successively, the FPGA gives an instruction to exit the normal mode and enter into the sweep mode. MOSFETs M1 and M2 in the main discharge circuit are turned off, and MOSFETs M3 and M4 in the sweep circuit starts to operate. Therefore, when eight successive harmful pulses appear, the pulse generator is turned into sweep mode and five sweep pulses are then applied.

INPUT PULSE FROM PULSE GENERATOR



Duty factor is the average % of the overall time such that discharge is happened.

Here **Duty factor** is of 30/(30+40)=0.428=43%

Frequency of D.C Voltage supplied= 1/(30+40)= 15 kHz

GAP PULSE DISCRIMINATION AND CONTROL SYSTEM

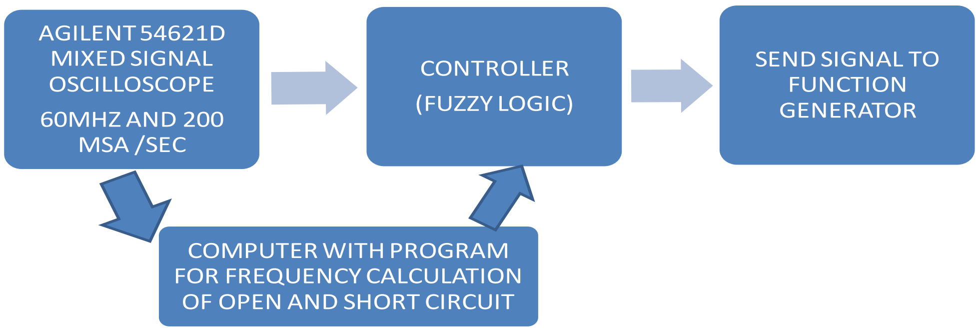
We will use oscilloscope having high sampling rate (typically 2 GHz) for real time acquisition of gap voltage. Based on a C program we can easily discriminate the gap pulses as open, normal, arc and short pulse in a given sampling time T. Based on this we can find frequency of open circuit, normal spark, arc spark and short spark as No/T ,Nn/T , Na/T , Ns/T respectively .

Capturing voltage and current pulse forms in micro-EDM is very essential since by means of the pulse forms generated during machining many parameters value and type which are decisive in machining qualities are found such as current, pulse-on/off, and discharge type such as arc, and short circuits.

An *Agilent 54621D mixed signal oscilloscope* with a value of 60MHz and 200 MSa/sec is used to display the shape of voltage and current pulse forms and also their numerical values. A connection will be installed between oscilloscope and computer by using Agilent GPIB connection card/ USB interface to transfer the oscilloscope data into the computer environment. An Agilent sample Excel data acquisition macro program is used to get a number of voltage data from the captured pulse forms.

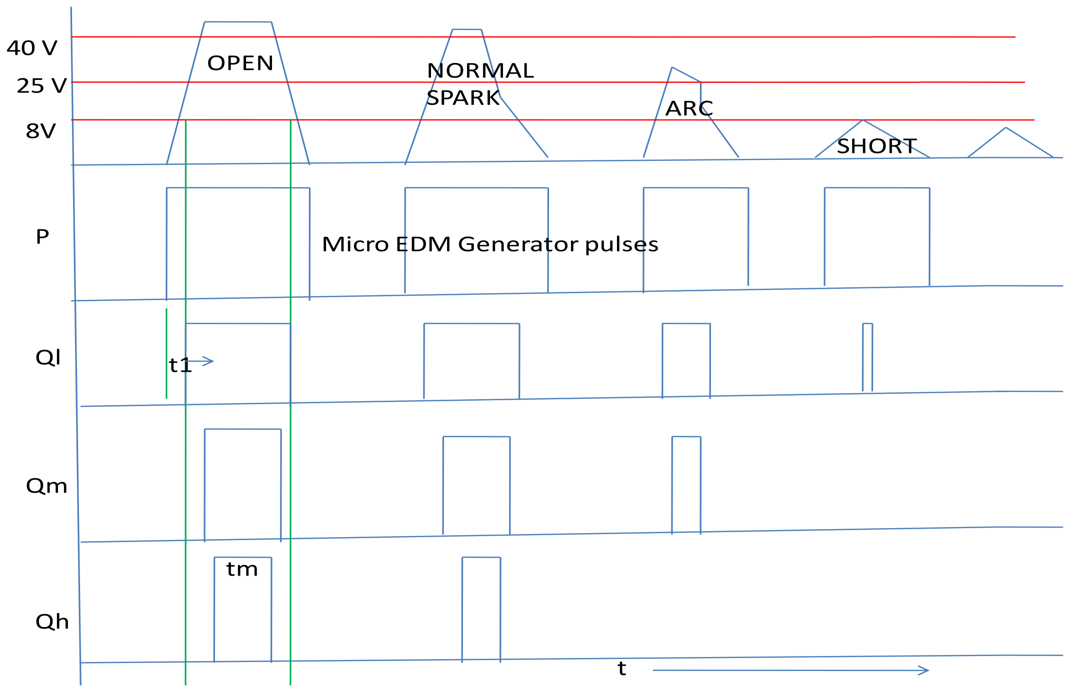
The frequency of open and short spark would then be given as input to the fuzzy logic controller which would accordingly give the displacement to the piezoactuator . The piezodriver(saw tooth signal generator and amplifier) would accordingly send the voltage signals for that corresponding movement.

PULSE DISCRIMINATION AND CONTROL SYSTEM



How to identify different gap voltage and gap current characteristics?.

- Basically we use both voltage levels as well as time duration for that voltage in the analysed gap voltage pulse as the criteria.
- For voltage levels let us set 3 voltages values (constants) Vh=40V, Vm=25V, Vl= 8 V.Let 3 variables Qh, Qm, Ql . They will attain max. value (i.e 1) when the gap voltage is higher than Vl, Vm and Vh, respectively otherwise 0.
- Let P be the pulse signal sent through the pulse generator.
- Let t1 be the time duration between P and Ql , tm be the time duration for which Ql remains high (i.e 1).



LOGIC APPLIED

- For open circuit –
  t1s=t1
  tms=tm
  P remains high and Ql, Q m, Q h remain high.

- For normal spark –
  t1 =t1s
  tm<tms
  P remains high and Ql, Q m, Q h remain high.
- For arc –
  t1=t1s
  P remains high Qm and Qh remains low.
- For short spark –
  t1>t1s
  P remains high. Qm and Qh remains low.

PROGRAM CODE FOR GAP PULSE IDENTIFICATION

Set t1s=t1 corresponding to open circuit .Similarly set tms=tm corresponding to open circuit.
Now for the time duration T :

```
If( (t1>t1s)&&( P==1)&&(Qm==0)&&(Qh==0))
Ns++;  // no. of short sparks
Else If( (t1== t1s)&&( P==1)&&(Qm==0)&&(Qh==0))
Na++; // no. of arc sparks
Else If( (t1==t1s)&& (tm<tms) &&( P==1)&&(Ql==1)&&(Qm==1)&&(Qh==1))
Nn++; // no. of normal sparks
Else If( (t1==t1s)&& (tm==tms)&&( P==1)&&(Ql==1)&&(Qm==1)&&(Qh==1))
No++; //open circuit pulses
```

Now frequency for open, normal, arc and short can be calculated using as No/T ,Nn/T , Na/T , Ns/T in the sampling period and sent to controller.

Controller design

There is a self-regulating feature in EDM but the process still needs controller for micro-hole operations.
Micro-EDM controller gives signals for the servo feed mechanism based on the sensed gap conditions. Here we are going to use fuzzy logic controller instead of PID as the process of micro EDM is highly stochastic and the difficulty of using mathematical model to precisely describe EDM process render PID controllers less competitive in preventing undesired arc and short circuit pulse.

Fuzzy logic can make use of the operator experience for controller design. The membership function for the input i.e the frequency of the open and short circuit as well as the output membership function of piezoelectric displacement can be decided by the operator .Based on experimentation, he can decide upon the rule base for displacement corresponding to input parameters.

USING FUZZY-LOGIC FOR GAP-WIDTH CONTROL

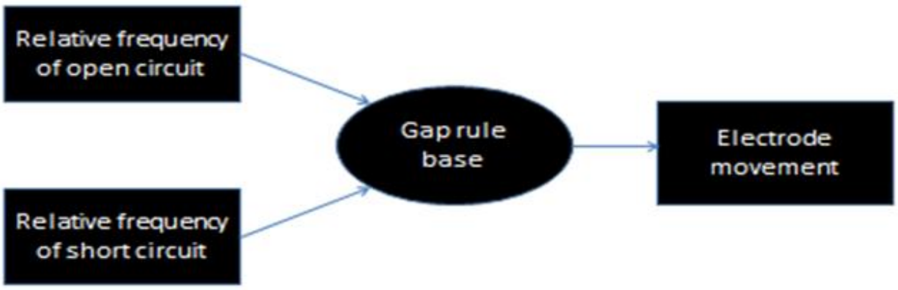
Fuzzy-technologies has been applied with big success for the control of processes whose transfer functions are unknown or hard to describe. Also in the field of EDM an increasingnumber of fuzzy process-control systems can be observed. This is supported by the following features of fuzzy logic:

• Fuzzy-Controllers are comprehensible, because their concept is close to human thinking.
• User knowledge can be integrated in the control system
• For controller design it is sufficient to formulate the coherences of the problem domain which even can have contradictory influences.

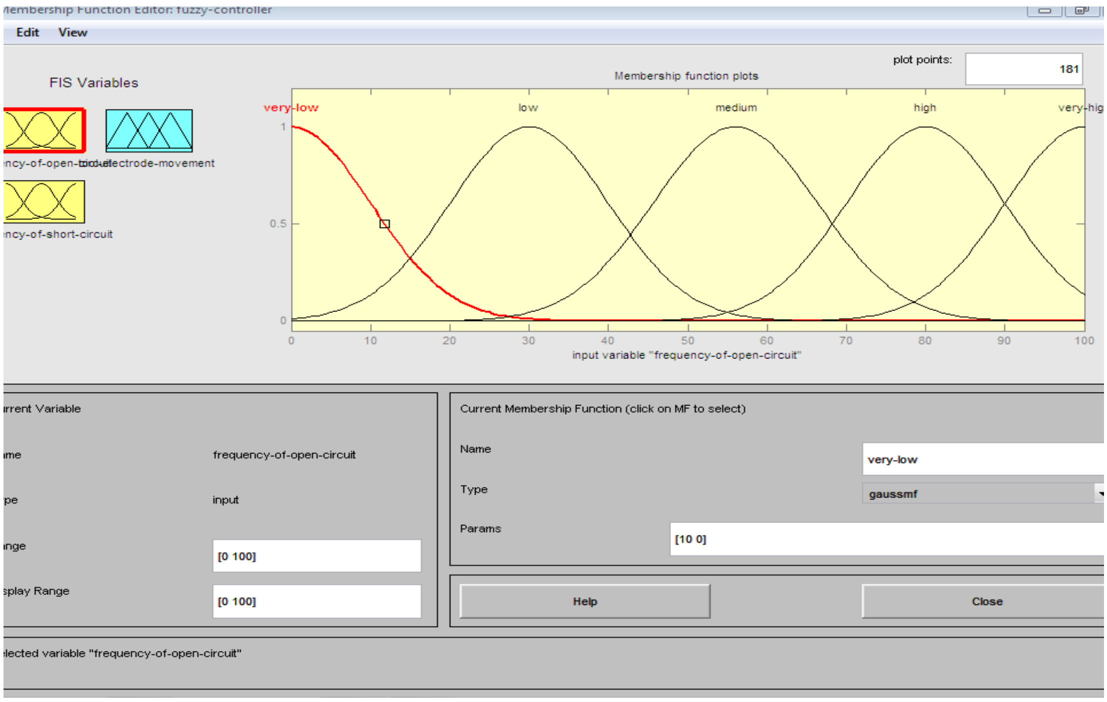
The gap-width controller based on the rel. frequency of short-circuits and open circuits can be implemented using fuzzy technologies. The strategy of this controller can be characterized as follows:

1. *If little short circuits and open-circuits don't move electrode*
2. If more short circuits move electrode backward
3. If much open-circuits move electrode forward

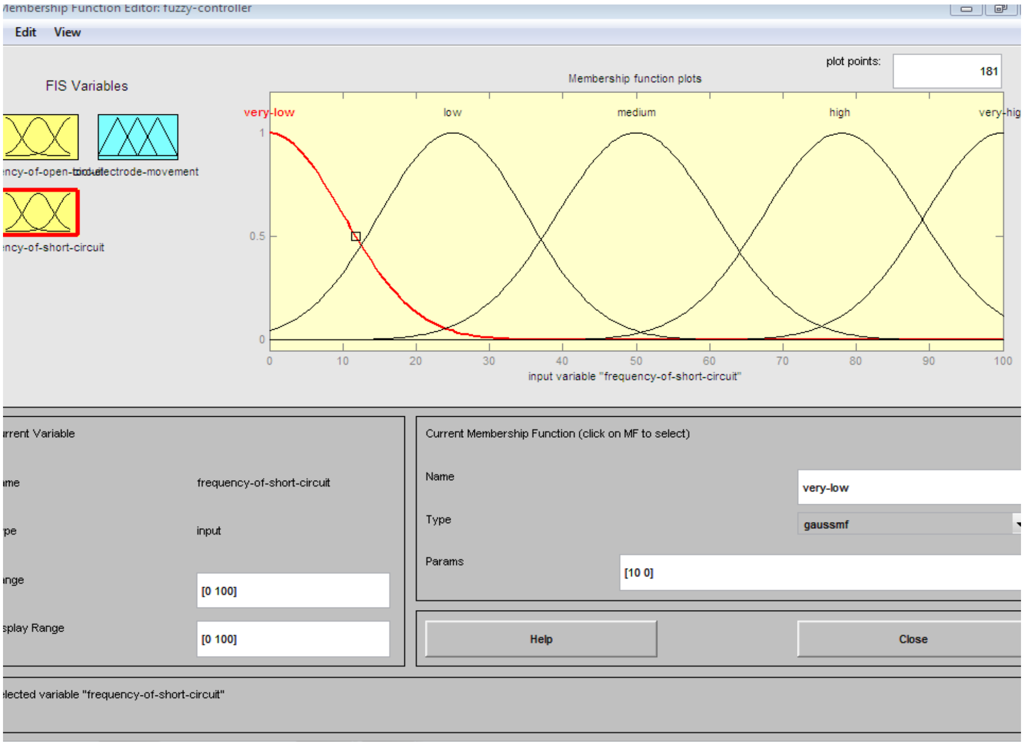
So far the fuzzy terms „little“, „more“ and „much“ were implemented using thresholds for tolerated open-circuits and short-circuits. With the possibilities of fuzzy-logic the control behaviour can much finer be graded. Figure shows the principle design of a fuzzy-controller. The measured input data must be “fuzzyfied“ before further processing. This is done inside the fuzzyfication component using membership functions. In the next step statement about the output are made inside the inference module using if ..then clauses. At the end the ouput is converted into a format thatcan be sent to an actuator.



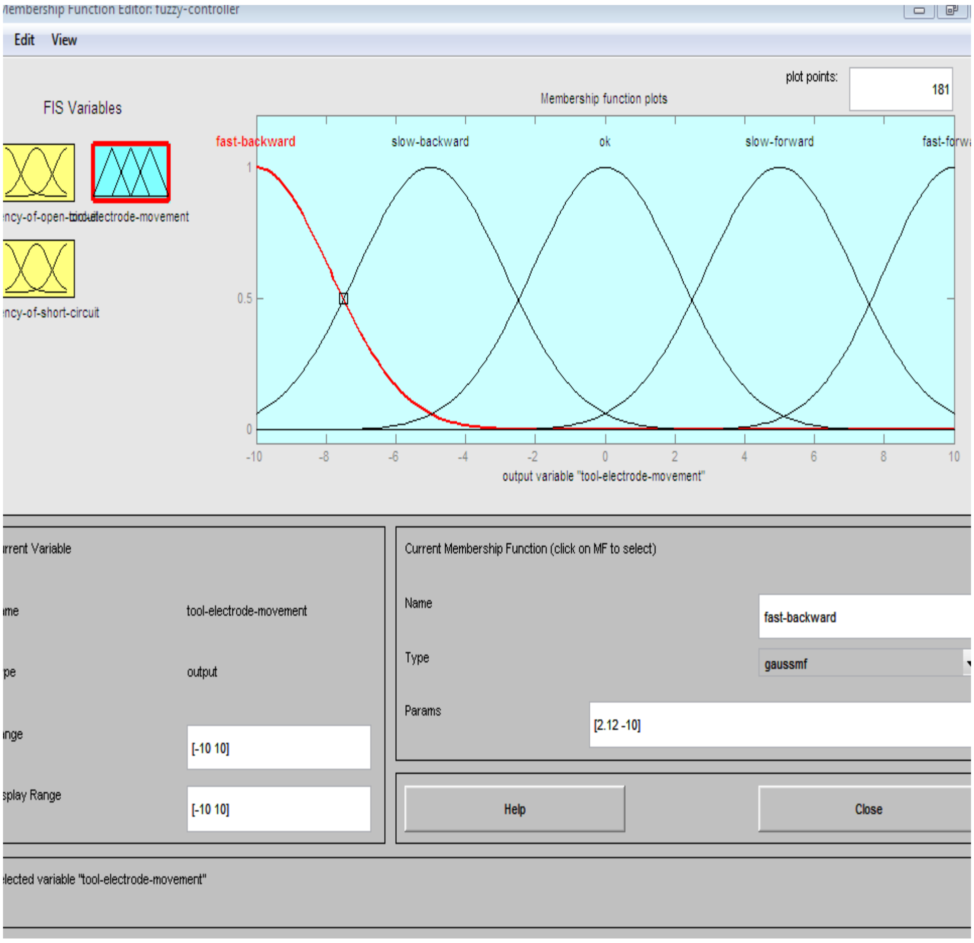
Gaussian Membership function for frequency of open circuit (input)



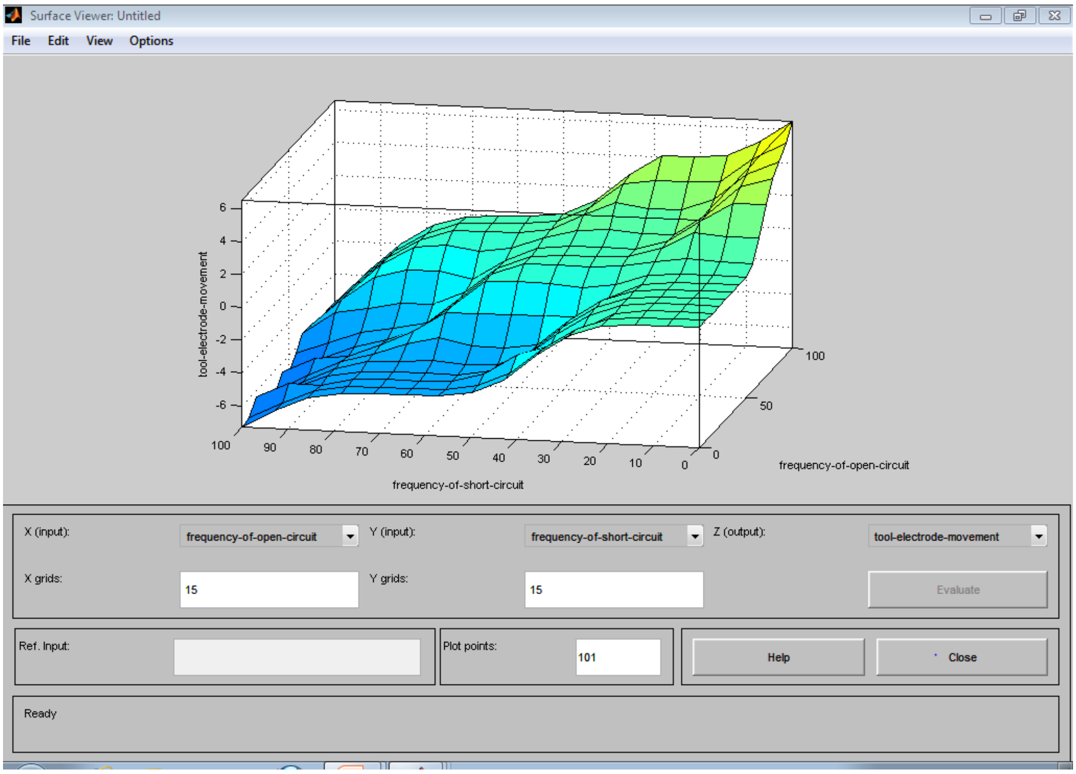
Gaussian Membership function for frequency of short circuit (input)



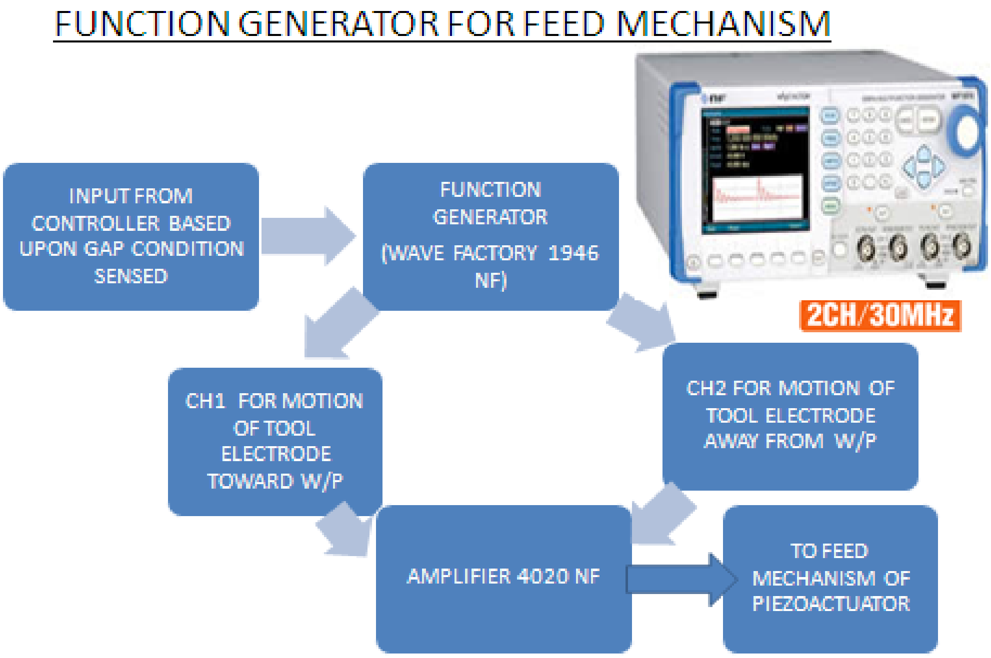
Gaussian Membership function for tool electrode movement(output)



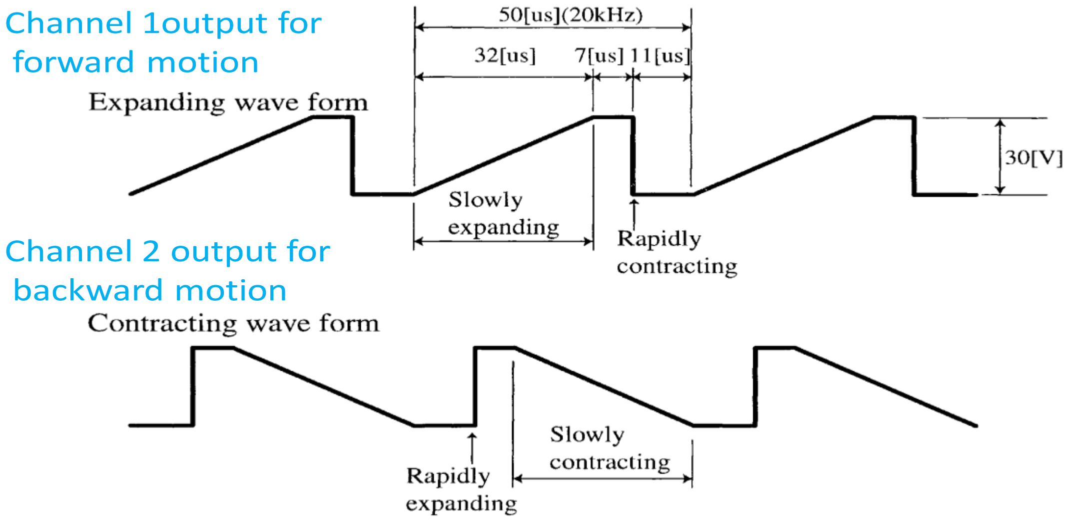
Surface map inside controller



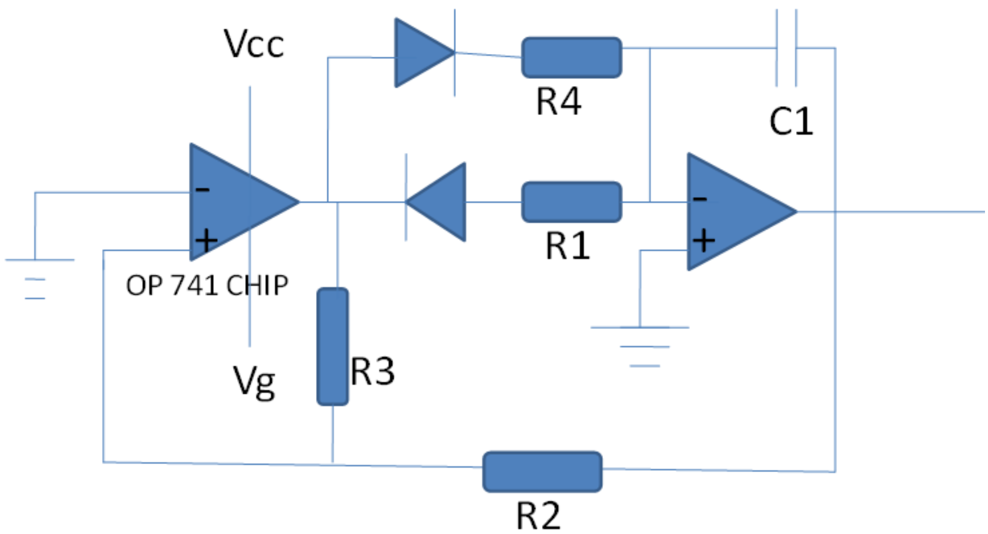
We can see the surface maps generated in controller for controlling feed in matlab using-
Fis = readfis ('fuzzy-controller');
surfview (fis);
by using matlab command
d=evalfis ([90 20],fis);
Where 90% is open circuit frequency and 20% is short circuit frequency.
we can get the distance(d) to be moved in either forward or reverse direction for controlling the gap width for spark generation.



OUTPUT FROM FUNCTION GENERATOR



CIRCUIT FOR SAWTOOTH WAVE FUNCTION GENERATOR



The function generator we will be using will be function generator (Wave-Factory 1946 NF).

The function generator had two channel output ports. One channel (CH1) will be used for expanding the IDM actuator and the other (CH2) will be used for contracting.

The trigger signal from controller to function generator will be utilized to determine which channel (CH1 orCH2) excited the actuator. The driving signal will be applied to IDM actuator through the amplifier (4020 NF).

- Peak to peak voltage amplitude is given as-
  Vopp = 2*R2*Vsat/R3
  Vsat=15V for OP-AMP.(normally)

- Fall time is given as-

Tfall=2*R4*C1*R2/R3

- Rise time is given as-
  Trise=2*R1*C1*R2/R3

As the driving frequency of the sawtooth wave is of 20 kHz .
So for forward stroke when Vpp=30 V ,trise=32 us , tfall=18 us .(CH1 Circuit parameters)

- R2=20 kΩ =R3
- R1=32 kΩ
- R4=18 kΩ
- C1=500 pF

So for Reverse stroke when Vpp=30 V ,trise=18 us , tfall=32 us.(CH2 Circuit parameters)

- R2=20 kΩ =R3
- R1=18 kΩ
- R4=32 kΩ
- C1=500 Pf

FEED MECHANISM

Feed mechanism is very essential factor to be considered to give micro feed to the electrodes; impact drive mechanism is proposed based on piezoelectric actuation. Piezoelectric actuators are widely used in micro feeding and ultra-precision positioning, because of their fine resolution, rapid response, high generative force, and easy to miniaturization characteristics.

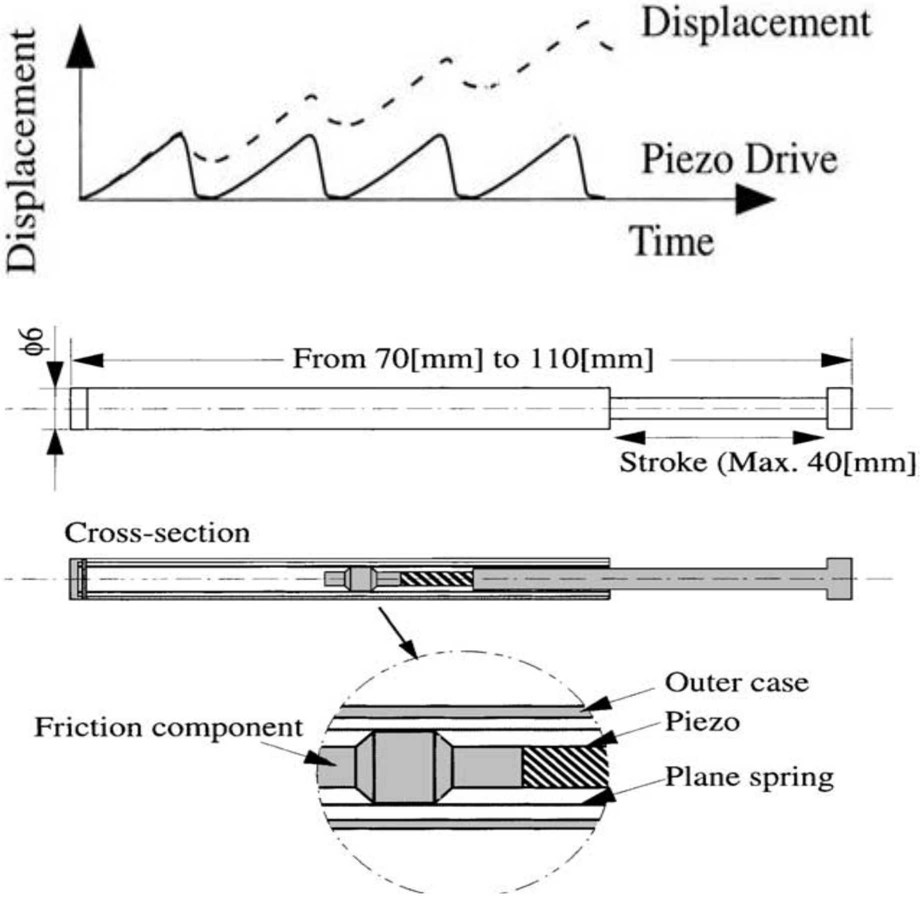


Fig 9: Micro- EDM tool feed Movement

The input voltage generates alternating slow and rapid movement. The piezo actuator drives the mover by frictional force when the input voltage is in the “slowly increased period” because the mover and the base are attached by frictional force.
On the other hand, during the “rapidly decreased period,” the mover cannot follow the quick movement and slips onthe surface of the base. At the end, the mover movement is equivalent to the slipped distance with rapid piezo shrinkage.

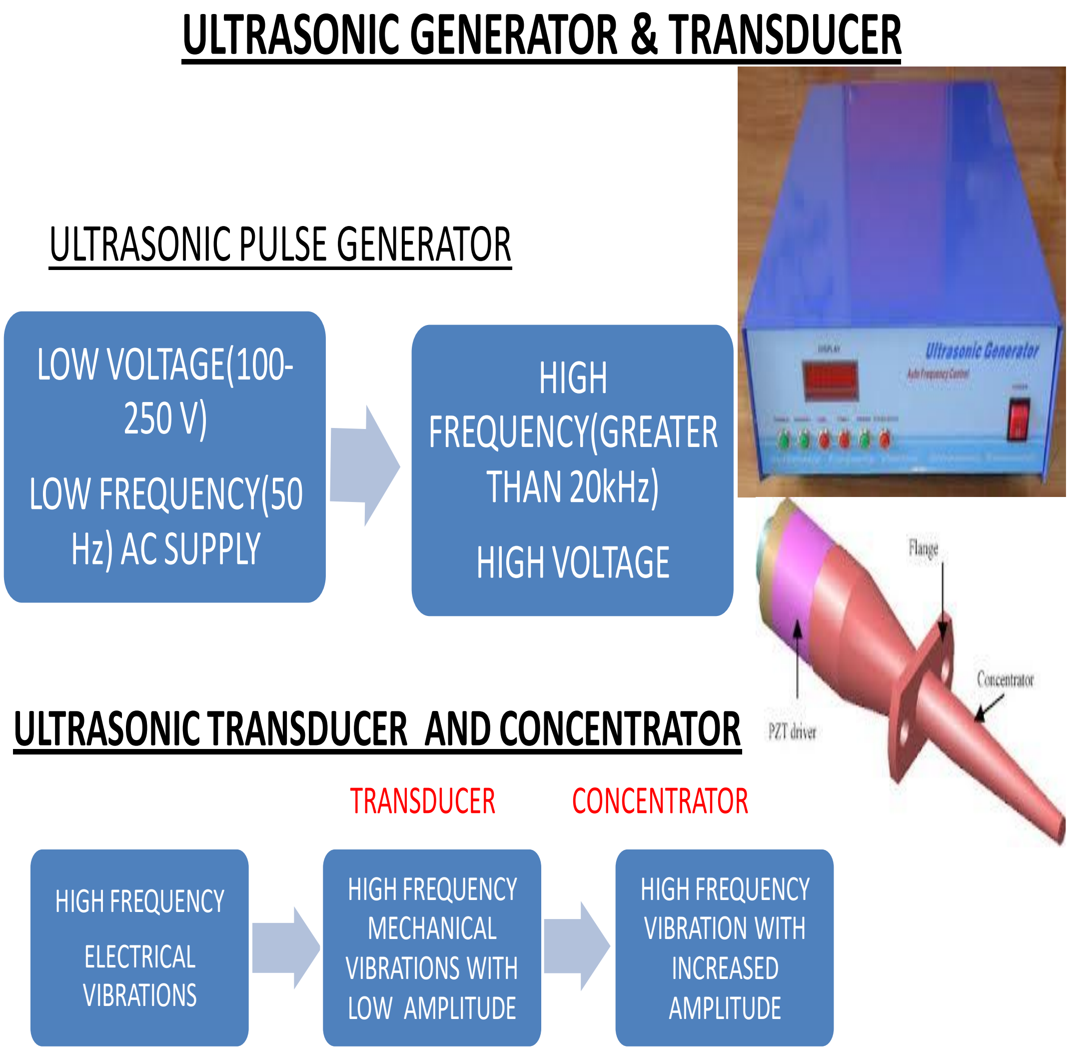
By repeating these operations, the mover could be driven with a long stroke.
To reverse the moving direction, the shapeof the electrical source is modified to what is composed of "rapidly increased period" anda "slowly decreased period.

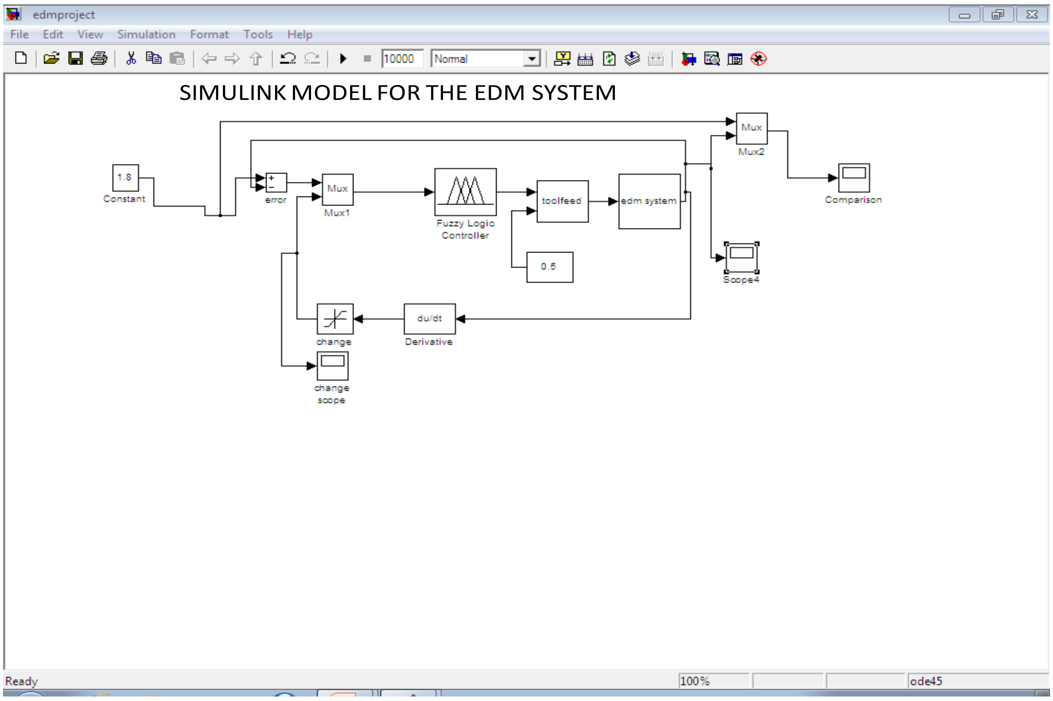
Ultrasonic generator& transducer

- Most of researchers have applied ultrasonic vibrations to tool electrode. However, in micro-EDM, ultrasonic vibration of the electrode has a problem in that a large vibration of the rotating electrode destroys the machining stability, especially when the electrode is very thin.
- In order to solve the problem stated above, ***ultrasonic vibrations can be given to work piece***. In this method ultrasonic transducer does not vibrate the tool, as in traditional ultrasonic machining, but vibrates the work piece. The work piece is directly attached to a transducer to secure the vibration.

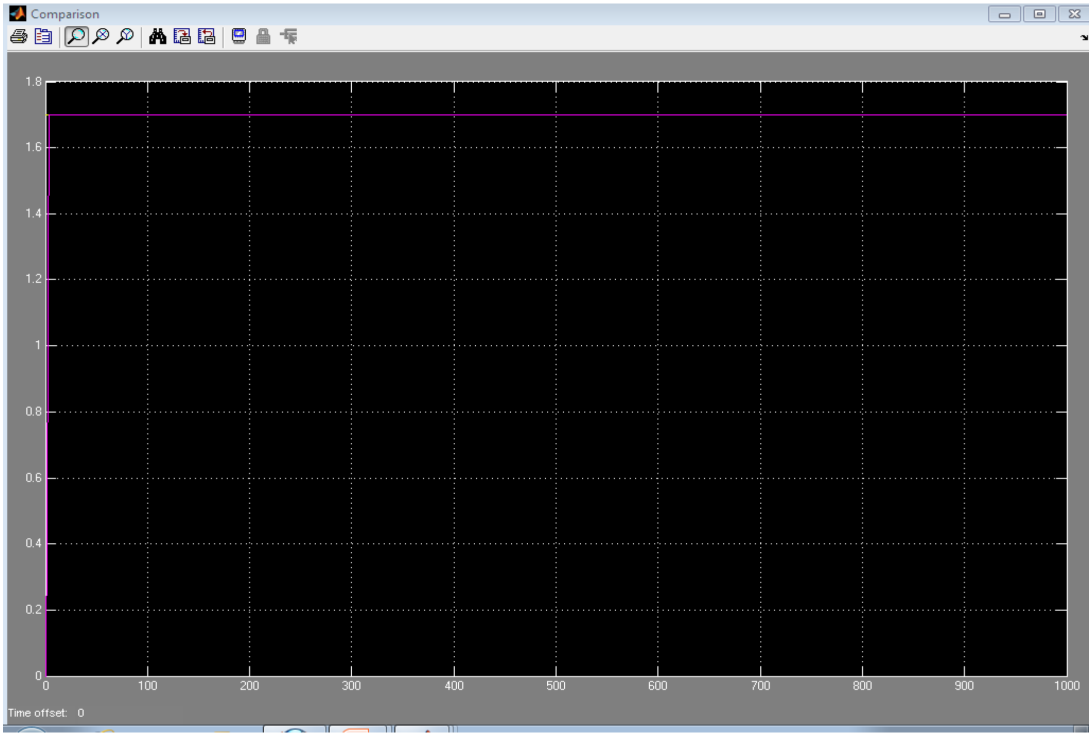
Ultrasonic pulse generator is used to convert low voltage(100 to 250 V) , low frequency(50 Hz) A.C supply to high frequency(typically greater than 20kHz) and high voltage and then the ultrasonic transducer converts them into high frequency mechanical vibrations .

The dimensions are so chosen that the natural frequency coincides with the electric supply frequency.The amplitude of vibration is increased to about 15um using concentrator(preferably exponential type).





SIMULATION RESULT –



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Dr. Vinod Yadav. “Development Of Table Top Ultrasonic Assisted Sinking Micro Electrical Discharge Machining Set Up.” IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , vol. 14, no. 4, 2017, pp. 31–39.