Chapter 5

DEVELOPMENT OF TABLE TOP DRY MICRO WEDM SETUP
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Necessity:
The current industrial scenario invites necessity of producing miniaturized components for specialized application which has lead towards research and development of micro manufacturing setups. The era of bigger machines is about to fade and necessity of miniaturized/table top models is gathering pace. Miniaturization of machine tool leads to advantages like:
1. Energy and space saving
2. Light weight
3. Improved appearance
4. Cost effectiveness etc.

The miniaturized machine tools are portable so that they can be easily carried and fixed to certain point of a work-piece at any time. Several EDM machine tool builders such as Agie Charmilles ltd. of Switzerland; Fanuc ltd., Sodick Inc. and Makino of Japan, Mikrotool ltd. of Singapore have developed micro WEDM. Such available machines are extremely costly and have reservations towards commercial use in India due to lack of technical knowhow. Also all these commercially available machines use only liquid dielectric. The disadvantages of using liquid dielectric are already discussed in literature survey.

Hence it was strongly felt necessary to develop Micro WEDM setup indigenously and explore its capabilities while processing difficult to machine materials. The setup needs to be equipped with special pulse generator capable of working as per requirements of micro WEDM viz., low current pulses at high frequency.

This chapter discusses the retrofit design concepts to develop a table top Micro WEDM setup along with development of power supply. The idea is to develop a novel and eco-friendly machine which is cost effective.

5.1 Workstation: Desirable Attributes

The table top micro WEDM needs to furnish following requirements:
1. Capable of machining different materials.
2. Machine power supply capable of generating low energy discharge at high frequency necessary for micro WEDM.
3. Capable of machining using wire spools of varying diameters.
4. A machine competent of working with different dielectrics (liquid, mixture of liquid plus gas and gaseous).
5. To be portable, economical, easy to maintain and literally no installation (Small foot print i.e. $< 1 \text{ m}^3$ so that can be moved easily).

**5.2 Conceptual design of experimental setup**

Figure 5.1 represents the proposed conceptual table top micro WEDM. The setup comprises of following important constituents:

1. Main structure (C frame style): Column and Base
2. Wire Transport Mechanism
3. Dielectric Supply System
4. Power supply / Pulse Generator

![Conceptual Design of Micro WEDM](image)

**5.3 Development of setup:**

**5.3.1 Application of Retrofit Design Concepts**

Retrofitting refers to the addition of new technology or features to older systems. Principally retrofitting describes the measures taken in the manufacturing industry to allow new or updated parts to be fitted to old or outdated assemblies. The following attempts have been undertaken in current work in order to comply the concepts of retrofitting:

1. An old metallurgical microscope has been used for base as well as column (i.e. it has served as main structure) of the setup.
2. Manually actuated (locally manufactured) precision X-Y slide was fitted on the main frame (travel 25 mm for both axes with step size of 1 µm).

3. A wire transport mechanism is developed in house with various components manufactured using WEDM. It contains five sub-systems: Wire feed spool mechanism, Tension control mechanism, Wire winding mechanism, Tension measurement mechanism, Upper and Lower wire guides.

4. Two separate dielectric supply systems, one for liquid dielectric and another for gaseous dielectric.
   Liquid dielectric supply system consists of following parts: A Storage Tank, Pump for lifting the dielectric, Flow control arrangement, Dielectric drain tank and Fixture for workpiece.
   Gas dielectric supply system consists of following parts: A gas cylinder, gas nozzle and allied piping’s.

5. RC type pulse generator (power supply) has been successfully developed and integrated with the machine to give desired pulsating power.

5.3.2 Stages in Development

The entire individual assembly elements are represented in Figure 5.2 (a – h) and are selected from either scraps or manufactured in house. A metallurgical microscope as shown in Fig. 5.2 (a) is selected for providing C type main frame of the machine.

Stage I: C Frame

Figure 5.2 (a) Original Microscope

Figure 5.2 (b) C Frame for setup
Stage II: Wire Transport Mechanism

Different types of wire winding mechanisms are used by previous researchers however roller mechanism is widely used. The current work explores a innovative tension control mechanism using a simple DC motor. Wire tension is strongly related to wire bending and vibration. It is very difficult to accurately control the tension in a micro diameter wire with a diameter smaller than 70µm by the conventional roller drive-brake mechanism, as the friction force would be very high for thin wires. The machine needs to have special wire guides to support ultra thin wires and will add to cost of the system. Also special guides would be needed to accommodate wires of different diameters. These approaches are costly and they are not applicable to small machines specifically designed for making micro-parts, as there is insufficient space to implement the measurement sensors and setups. Moreover, all the mechanisms studied so far are of bulky nature viz. comprising of large space and more number of components. Hence, development of novel wire winding mechanism was undertaken.

The travel of micro wire starts from the wire supporting spool. It passes through a brush (which gives it negative power supply) and then passes through the tension control mechanism as shown in Figure 5.2 (c), where a DC motor is attached to the spool over which the wire is wound. It is kept straight and vertical between the two wire guides, one above and one below the actual cutting area. Finally the wire gets wound on a wire spool assembly which is also driven by a 50 rpm simple DC motor as shown in Figure 5.2 (d).
While changing direction from horizontal to vertical the wire passes through a V groove in a shaft. This shaft is attached to a frame with the help of springs and as the shaft moves downwards the tension increases. This vertical displacement of the shaft is proportional to the tension in the wire and can be measured with the help of vertical scale attached to the frame of wire tension measurement mechanism. A wire winding mechanism which is a driver mechanism for wire (in current mechanism) is mounted at the bottom of frame as shown in Figure 5.2 (d). The machine is capable of accommodating wires made of various materials that range in the diameter from 30 to 300µm. A simple mechanism is designed and developed to accommodate wire giving spool and is mounted on the wall above the machine.

**Stage III: XY Slides**

As the setup will be used with liquid dielectric also provision to avoid splashing of dielectric needs to be undertaken and hence an auxiliary tank (light in weight) is mounted on the slide as represented in Figure 5.2 (e). Also a fixture is mounted inside this auxiliary tank for holding the workpiece and the X-Y table is manually positioned so that the machining operation will be accomplished at the correct location as shown in Figure 5.2(f). This aspects needs to be further improved by automation i.e. through servo control.

![Figure 5.2 (e) XY slide](image1)

![Figure 5.2 (f) Fixture for workpiece](image2)
Stage IV: Provision for using different dielectric

The effect of variation in dielectric (gas and liquid) on machining needs to be analysed hence the dielectric supply system for both the condition are designed and represented in Figure 5.2 (g) and Figure 5.2 (h).

The liquid dielectric is stored in the storage tank. From there, the dielectric is pumped using a submersible pump to the nozzle. The nozzle is directed at the work-piece which is mounted on the fixture. From the auxiliary tank, the dielectric along with the debris is flushed and collected in the drain tank. The dielectric is drained from the drainage tank via the bulk-head union. The bulk-head union acts as a connector between the drainage tank and the pipe which redirects the flushed dielectric back into the storage tank.

![Figure 5.2 (g) Using liquid dielectric](image1)

![Figure 5.2 (h) Using gas dielectric](image2)

A dielectric supply arrangement is developed to supply gas between work-piece and wire. Gas is supplied in the gap between work-piece and wire through a nozzle which is connected to the gas cylinder. The developed dielectric supply system is shown in the Figure 5.2(h).

Stage V: Assembly

All the mechanical components of the machine were tested and calibrated and the developed setup is represented in Figure 5.3; however development of the power supply is discussed in next section.
5.4 Development of RC power supply

The allowable tensile force for the thin wires is very low (to avoid breakage) and depends on the discharge energy and part accuracy. Hence the equipments using ultra thin wires must be coupled with power supply capable of giving low energy pulses. Hence development of a special power supply was also felt necessary. In this work, a special RC type power supply (pulse generator) is built and integrated with the machine to supply low energy pulses with high frequency; capable of generating spark using liquid as well as gaseous dielectric.

The effectiveness of the EDM process is largely determined by the type of power supply used, as spark is the main reason for erosion. A Power supply needs to be coupled to the machine in order to give unipolar pulses between workpiece and tool.

The designed circuit should fulfill the following operational requirements:

Table 5.1 Specifications of power supply

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>80V to 150V</td>
</tr>
<tr>
<td>Current</td>
<td>(Range) 0.05 to 0.1 mA</td>
</tr>
<tr>
<td>Capacitance</td>
<td>1.1µF</td>
</tr>
<tr>
<td>Polarity</td>
<td>Tool +ve; Workpiece –ve</td>
</tr>
<tr>
<td>Frequency</td>
<td>100 KHz, square wave</td>
</tr>
<tr>
<td>$T_{on}/T_{off}$</td>
<td>5µsec</td>
</tr>
</tbody>
</table>
Features:
- In Micro WEDM operations the switching frequency between positions charging and discharging is very higher i.e. 100 KHz. So for this operation an Insulated Gate Bipolar Transistor (IGBT) is used as a switch.
- The power supply is used to convert the alternating current into direct current required to produce the spark. The voltage given at the input determines the energy produced during the spark.
- Different materials require different voltage levels during machining. Hence a voltage range of 80-150V is required.
- Current in the range of few mill amperes is essential. The higher current values will lead to excess amount of heat (which is undesirable) and will results into breakage of tool wire.
- Generally a square wave is used for trigger applications due to their instantaneous transition from maximum to minimum. The circuit is composed of components like Rectifier unit, IGBT, RC circuit, IC555, IC7812 etc.

Design of Power supply (pulse generator)
The basic principle of designing this circuit is to convert the 230V, 50 Hz, AC supply into 80V, DC supply with a square wave of 100 KHz frequency. Hence various components (due to their specific capabilities) are incorporated in the circuit as shown in block diagram (Figure 5.4) in order to achieve the task mentioned.

![Block Diagram of Circuit Developed](image)

Figure 5.4 Block diagram of circuit developed

The working of above circuit can be divided into three parts:
I. Conversion of 230V (50Hz) AC supply into 80V DC.
II. Generate a square wave of 100 KHz frequency.
III. IGBT circuit

**Stage I: Conversion of 230V, 50Hz, AC supply into 80V DC supply**

**Working:**

- 230 V AC supply (50 Hz) is given as an input to the High Voltage Power Supply which is then passed through a step-down transformer. Transformer is used to convert 230V AC supply into 60V AC.
- It is then passed through a 4 diode (1 N 5408) rectifier circuit which converts AC to DC. Here 4 diodes are used so we get a full wave DC at output i.e. negative component of AC is not wasted.
- After rectifier a LED is used for purpose of indication. A resistance of 120KΩ is used to control the current through LED.
- Two 1200μF 160V capacitors are used for the purpose of filtration connected in parallel with each other. The capacitors tend to fill the valleys between two consecutive peaks. Due to this we get peak value of voltage instead of RMS value. The peak voltage is 1.414 times RMS voltage.
- So we get output of 80V DC supply instead of 60V DC supply.

![Figure 5.5 High voltage power supply](image)

**Stage II: Generate a square wave of 100 KHz frequency**

- To generate 100 KHz square wave IC 555 is used as a frequency generating circuit.
- At the input of IC 555, we require a 12V DC supply hence we have used a low voltage supply.
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Figure 5.6 Low voltage power supply

**Working:**

- Here first the AC supply is given to a step down transformer which lowers the voltage from 230 V to 15 V.
- Then this AC current is passed through a 4 diode (1 N 4007) rectifier which converts AC to DC. Here 4 diodes are used so we get a full wave DC at output.
- Capacitor of capacity 1000 µF and 35 V is used as Filter to remove ripples from rectified output of diodes. Ripples are unwanted ac components.
- Due to the capacitor used for filtration the voltage increases from 15 V to 22 V. The capacitors tend to fill the valleys between two consecutive peaks. Due to this we get peak value of voltage instead of RMS value. The peak voltage is 1.414 times RMS voltage. So we get 22V DC instead of 15V.
- This is given as an input to IC LM7812 which keeps the output constant to 12 V.
- Then one LED is used for indication with 1 KΩ resistance to control the current. Then 12 V. DC supply is achieved at output.

**Oscillatory circuit:-**
The output from the Low Voltage power supply is given to control circuit.

It has an oscillator IC 555 which generates positive and a negative square wave of frequency 100 KHz. It acts as a Pulse Width Modulator (PWM).

The required frequency can be controlled by the values of the capacitor and resistance used in circuit. Frequency can be varied from 20-400 KHz.

The output is given as an input to the IGBT (Insulated Gate Bipolar Transistor) circuit which is used for switching the voltage supply to the tool and workpiece.

**Stage III: IGBT circuit**

- The high voltage output of 80V DC is given as input to IGBT circuit which consists of a resistance, a capacitor and a IGBT.
- The resistance used here is 1 kΩ which used to control current in the circuit.
- 100 KHz square wave is given as input at the gate of IGBT for switching.
- When input is given at gate, IGBT is switched on and capacitor gets charged.
- When input pulse is not given at gate, IGBT gets switched off and capacitor gets discharged through workpiece and tool.
Working:

- In this circuit constant resistor, capacitor and IGBT are the main components. This circuit is used to provide final output to machine i.e. to wire (tool) and work piece.
- IGBT is transistor which is in ON state only when gate pulse is applied to it. Gate pulse of 100 KHz will give 100 KHz switching frequency of IGBT.
- The input is in the form of square pulses obtained from frequency control circuit. It is applied to 20A 1200V IGBT (Insulated Gate Bipolar Transistor) at its drain (D) and output is obtained at source (S).
- A constant resistor of 1KΩ 50W is used to maintain the pulses. It is then passed through 1.1 μF 550V capacitor.
- The capacitor capacity controls the number of pulses at the output to wire and workpiece. When a pulse is given to the capacitor, it charges till its capacity during negative pulse and when it is fully charged, during positive pulse it discharges through wire and work piece giving output and sparks in intermittent forms. Hence sparks are generated at wire and work piece gap and metal is being cut.

5.5 Experimentation

Experimentation has been planned in order to establish the capability of the setup developed using power supply developed with different combinations of dielectric.

5.5.1 Initial Trials

Copper is selected as a work piece because it is available in purest form. A Tungsten wire of 70µm diameter was used as a tool to cut the material. Test specimen of size 90 x 40 x 0.16 mm was selected.
Total EDM-3 oil (white kerosene), was selected as a liquid dielectric due to its high flash point, less volatility, high auto ignition temperature, less odor and low viscosity. Also Nitrogen as a gas dielectric was chosen. The specimen surface was cleaned, polished and contaminants were removed with acetone.

Table 5.2 Properties of white Kerosene

<table>
<thead>
<tr>
<th>Property</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling Point</td>
<td>175-325°C</td>
</tr>
<tr>
<td>Freezing Point</td>
<td>-40°C</td>
</tr>
<tr>
<td>Density</td>
<td>0.8 g/mL (25°C)</td>
</tr>
<tr>
<td>Flash Point</td>
<td>179°F</td>
</tr>
<tr>
<td>Hazard Class</td>
<td>3.1</td>
</tr>
<tr>
<td>Water Solubility</td>
<td>5 – 10 mg/L</td>
</tr>
</tbody>
</table>

Table 5.3 Properties of Nitrogen

<table>
<thead>
<tr>
<th>Properties</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular Weight</td>
<td>28.013 g/mol</td>
</tr>
<tr>
<td>Melting Point</td>
<td>-210°C</td>
</tr>
<tr>
<td>Boiling Point</td>
<td>-195.8°C</td>
</tr>
<tr>
<td>Gas Density</td>
<td>4.6096 kg/M³</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>0.967</td>
</tr>
<tr>
<td>Water Solubility</td>
<td>0.02348 vol/vol</td>
</tr>
</tbody>
</table>

Figure 5.9 Copper Workpiece
5.5.2 Experimental Procedure
The details of the procedure and experimentation carried out are presented in subsequent parts of this chapter. Experimentation were carried for machining copper in mainly five conditions of varying dielectric in order to identify the best possible condition for maximum MRR.

1. Liquid (White Kerosene)
2. Air
3. Nitrogen
4. White Kerosene and Nitrogen
5. White Kerosene and air

The plate was mounted using fixture. Current and voltage are adjusted to the required level. Spark gap of 10 microns is maintained between work-piece and tool. Feed is given to the X-Y slides manually. The time required for the machining is noted using stop watch. Three cuts each of length 2mm for each condition were taken and the kerf width for every cut was observed under metallurgical microscope at various points and average value was estimated.

5.5.3 Waveform analysis
The waveform analysis is undertaken to investigate the resulting power, pulse on time, pulse off time provided by the power supply developed. The pulse waveform and pulse on/off time provided by the pulse generator needs to be investigated in order to establish the capabilities of power supply developed. The pulse waveform was analyzed using DSO in order to record $T_{on}/T_{off}$.

Figure 5.10 Waveforms captured on Oscilloscope during machining
The development of micro WEDM has been represented in this chapter. The setup developed has been successfully implemented under different dielectric conditions viz., from liquid to almost near dry. The initial experiments were conducted and have shown promising results. However the capabilities of setup would be precisely gauged when the setup would be fully automatic/ i.e. mechanized slide is incorporated. The results and discussion based on trials conducted are represented in next chapter i.e. Results and discussion.

Figure 5.11 Measurement $T_{on}$ and $T_{off}$