ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 3, March 2017

Investigation on Machining of Silica Wafer Using Developed Micro-Electrical Discharge Machining (µ-EDM)

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Abstract:- **Miniaturization of the products/processes is no more a fashion rather it is the need of the time because one can drive multifarious benefits from such products/processes, namely they are very simple, occupy less space, low power consumption, more flexible, saving in material and many more. Hence fabrication of these miniaturized products presents challenges in many areas of engineering. Micromachining is the foundation of the technology to realize such miniaturized products. Micro-Electro Discharge Machining (µ-EDM) is one such high precision non-conventional machining process in which electrical discharges are produced between the tool electrode and the work piece electrode immersed in dielectric fluid. The electrical discharges thus produced remove the work piece material through melting and evaporation process and results in the creation of micro features on any conducting and semiconducting engineering materials irrespective of their size, shape and mechanical properties like strength, hardness, refractoriness etc. Some of the engineering materials machined using EDM are tungsten, tungsten carbide, copper, copper tungsten alloy, silver, brass, graphite, beryllium copper alloy, hardenable steels etc. Now the process is extends to machine semiconducting material like silicon wafer. In this paper, some of the results obtained while performing the investigation on machining of blind holes on silica wafer using developed µ-EDM process. Blind holes are produced on silicon wafer of 100 µm thicknesses with copper wire of 610 µm diameter as a tool electrode and stainless steel of 710 µm diameter as a tool electrode using Kerosene and Deionized water as dielectric fluids. The repeatability of the depth and surface finish of the blind holes are verified with constant time period by varying frequencies.**

Index Terms— Blind hole, Dielectric fluid, Miniaturization, silica wafer, µ-EDM

1.INTRODUCTION

Miniaturization of the products/processes is no more a fashion rather it is the need of the time because one can drive multifarious benefits from such products/processes, namely they are very simple, occupy less space, low power consumption, more flexible, saving in material and many more. Hence fabrication of these miniaturized products presents challenges in many areas of engineering. Micromachining is the foundation of the technology to realize such miniaturized products. Micro-Electro Discharge Machining (µ-EDM) is one such high precision non-conventional machining process in which electrical discharges are produced between the tool electrode and the work piece electrode immersed in dielectric fluid.

The electrical discharges thus produced remove the work piece material through melting and evaporation process and results in the creation of micro features on any conducting and semiconducting engineering materials irrespective of their size, shape and mechanical properties like strength, hardness, refractoriness etc. Some of the engineering materials machined using EDM are tungsten, tungsten carbide, copper, copper tungsten alloy, silver, brass, graphite, beryllium copper alloy, hardenable steels etc. Now the process is extends to machine semiconducting material like silicon wafer.

The operating principle of µ-EDM 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. Figure 1 shows the working principle of EDM.

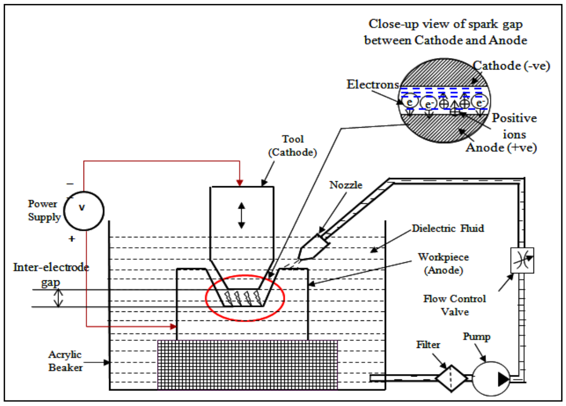

Figure-1 working principle of EDM

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It consists of a tool (cathode) and work piece (anode) separated by a small gap known as spark gap and are immersed in a dielectric (electrically non-conducting) fluid such as hydrocarbon oil, kerosene or deionized (DI) water. The electrical energy is supplied between the electrodes and when potential difference is sufficiently high, the dielectric breaks down and a transient spark discharge takes place across the gap width. Due to melting and vaporization, erosion of material takes place and the crater is produced as the shape is exactly same as that of tool shape.

S T. Masuzawa summarizes the basic concepts and applications of major methods of micromachining. [1]. Muhammad Pervej Jahan et al., described the feasibility of micro-structuring in p-type silicon, using conventional diesinking electrodischarge machining (EDM). The EDM behavior of the silicon material is studied in terms of the effect of major operating parameters on the performance characteristics during the micro-hole machining [2]. Dominick Reynaerts et al., shows the applicability of micro EDM to machine microstructures in silicon and it is proved that it is a complementary method for machining silicon [3] LI Mao-sheng et al., focused at improve machining efficiency and decrease relative wear of electrode while machining deeply small holes in TC4 alloy [4]. M.L. Chan et al., are discussed on investigation of micro electrical discharge machining as a viable method for micromachining 3D shapes in silicon. The approach integrates a two-step EDM process with standard silicon micro fabrication techniques to create smooth and axi-symmetric 3D hemispherical structures. [8].

In this paper, the experimental setup of µ-EDM is developed for machining conducting and semiconducting materials like copper, stainless steel, silicon etc. Blind holes are produced on silicon wafer of 100 µm thicknesses with copper wire of 610 µm diameter as a tool electrode and stainless steel of 710 µm diameter as a tool electrode using Kerosene and Deionized water as dielectric fluids. The repeatability of the depth and surface finish of the blind holes are verified with constant time period by varying frequencies.

II. EXPERIMENTATION

Experimental Setup

An indigenous experimental setup has been built to carry out Electro Discharge machining process with the piezo-actuated tool feed mechanism.

It consists of different units as

1. Tool Feeding Unit: Piezo-actuator is used to develop a feedback and to maintain the constant gap between the tool and the work piece. The unit consists of the components like
   a. Tool holder
   b. Piezo-actuator
   c. Micro guide way

2. Dielectric and Recirculation unit: Filtering and recirculation unit is developed to flush the debris and to get good machining. The unit consists of the components like
   a. Dielectric Beaker
   b. Work piece holder
   c. Pump and Filter

3. Pulse Generation and Control Unit: It is designed to provide pulses of specified frequency and duty cycle to the tool and the work piece. The unit consists of the components like
   a. Oscilloscope.
   b. Pulse Width Modulator
   c. DC Power Supply.

The following Figure 2 shows the developed µ-EDM setup and its parts. And Table 1 provides the detail specifications of developed micro EDM set up

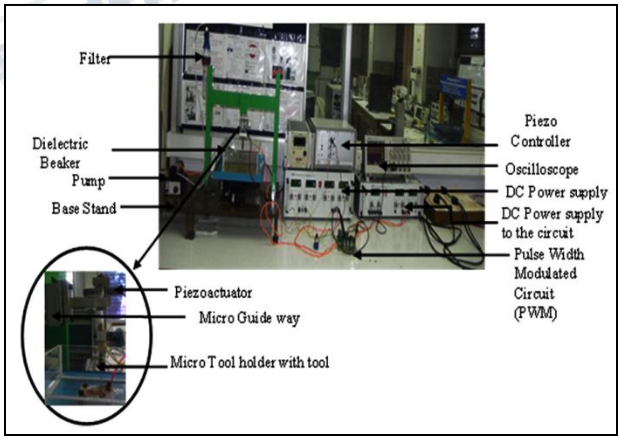

Figure-2 Photographic View of developed µ-EDM Setup

Table-1 Specifications of Developed µ-EDM setup

S. No.	Parts	Specification
0	Micro Features	Holes, Blind holes Minimum feature size: 50 µm

		Depth: upto 400 µm
1	Work piece material	Any electrically conducting materials and semiconducting material
2	Tool material	Cu, Stainless
3	Dielectric and Recirculation	*Dielectric Beaker :* 220X220mm square and 80mm depth *Pump :* Gear pump,12 V DC supply *Flow Control:* Through variable voltage supply *Flow rate :* 220ml/min. to 2.2 l/min *Dielectric Filter:* 0.5 µm
4	Tool Feed	*Feed Mechanism :* Piezoelectric actuator *Type of control :* Analog *Actuator :* Manufacturer: Cedrat Technologies, France *Maximum displacement:* 400µm *Maximum load carrying capacity*: 38N *Response Time:* 1.01ms *Resolution:* 4nm *Drive System:* Voltage Drive(0-150V)
5	Power input	*Voltage:* up to 60V *Pulse Generator:* Transistor type *Pulse frequency range*: 1 KHz – 5 KHz *Duty Cycle range :* 5% - 50%

Experimentation

Two set of experiments are conducted with two different set of machining conditions, two different tools as copper and stainless steel with kerosene and DI-water as dielectric fluids. The experimental details are explained in Part-A and Part-B as follows.

Part-A: Micro blind holes machined on Silicon wafer using kerosene (Si-Cu-Kerosene)

Blind holes are machined on silicon wafer with copper tool and kerosene as the dielectric fluid. Total 3 holes are machined by varying frequency with a constant time period 10 min. each hole is machined 3 times under same conditions to get the repeatability of responses like depth, surface finish and MRR.

The machining conditions and the selected control parameter and their levels are listed in Table 2.

Table-2: Machining conditions and control parameters used for Si-Cu-Kerosene

Machining Conditions			
Work piece Material	Silicon		
Thickness of the work piece	550µm		
Electrode (Tool) Material	Copper		
Size of the Electrode	610µm		
Duty Cycle	50%		
Input Current	0.4 A		
Voltage	30 V		
Control Parameters	**Levels**		
	1	**2**	**3**
Frequency (kHZ)	3	4	5

The data of responses Size, Depth and surface roughness are measured by using microscope and Vertical Scanning Interferometer (VSI) and MRR is calculated based on difference in work piece weight to the product of machining time and density of material. Similarly, TWR is also calculated and recorded in Table 3

Table-3: Experimental readings for Si-Cu-Kerosene

Exp. No.	**Freq. (kHZ)**	**Hole Size (µm)**	**Surface Roughness (µm)**	**Depth (µm)**	**TWR**	**MRR**
					mm^3/ min	**mm^3/ min**
1	1.2	829.9	14.25	71.3	0.0075	0.043
		841.2	7.86	67.5	0.0075	0.043
		798.4	8.13	73.9	0.0100	0.026
2	2.2	809.5	7.37	99.2	0.0050	0.034
		759.6	4.84	130.9	0.0050	0.034
		773.5	7.07	106.3	0.0075	0.025
3	3.2	739.1	14.11	70.7	0.0100	0.042
		773.1	10.16	67.2	0.0075	0.025
		737.1	6.69	64.3	0.0100	0.025

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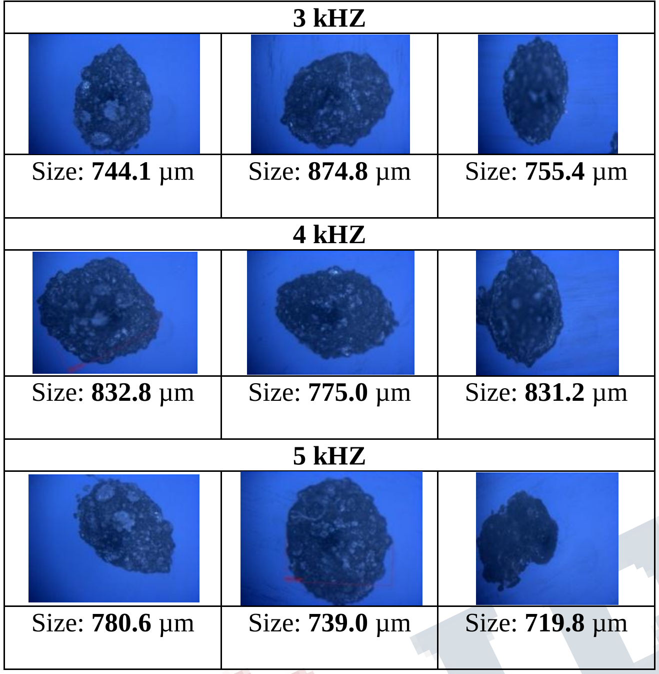
Figure-3 shows the microscope images of blind holes with 100X and 80X magnification taken from ZEISS Stemi Microscope for the different input frequency


3 kHZ

Size: **744.1** µm | Size: **874.8** µm | Size: **755.4** µm

4 kHZ

Size: **832.8** µm | Size: **775.0** µm | Size: **831.2** µm

5 kHZ

Size: **780.6** µm | Size: **739.0** µm | Size: **719.8** µm

Figure-3: Blind hole Images obtained from microscope for Si-Cu-Kerosene

Part-B Micro blind holes machined on Silicon wafer using DI water (Si-SS-DI Water)

The experiments was conducted using DI water as dielectric on silicon wafer with stainless steel (SS) as tool by taking the machining conditions and the selected control parameters and their levels are listed in Table 3. Total 3 holes are machined by varying frequency with a constant time period 5 min. each hole is machined 3 times under same conditions to get the repeatability of responses like depth, surface finish and MRR.

Table-4 Machining conditions and control parameters used for Si-SS-DI Water

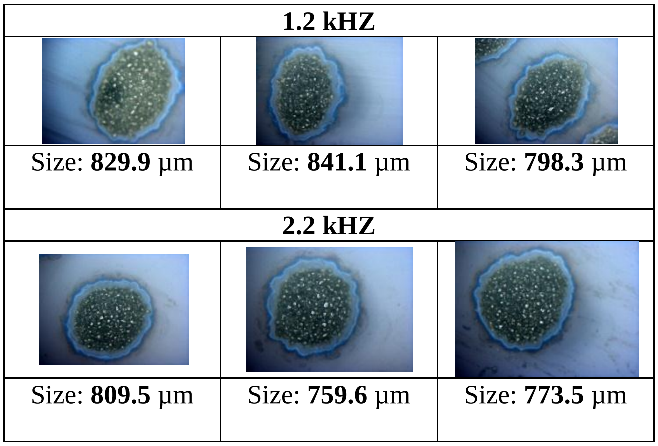
Machining Conditions			
Work piece Material	Silicon		
Thickness of the work piece	550µm		
Electrode (Tool) Material	Stainless Steel		
Size of the Electrode	710µm		
Duty Cycle	40%		
Input Current	0.5 A		
Voltage	30 V		
Control Parameters	**Levels**		
	1	**2**	**3**
Frequency (kHZ)	1.2	2.2	3.2

The data of responses Size, Depth and surface roughness are measured and MRR and TWR calculated and recorded in Table-5

Table 5: Experimental readings for Si-SS-DI Water

Exp. No.	**Freq. (kHZ)**	**Hole Size (µm)**	**Surface Roughness (µm)**	**Depth (µm)**	**TWR** mm^3/min	**MRR** mm^3/min
1	3	744.18	6.956	133.3	0.010	0.047
		874.88	8.852	112.3	0.007	0.030
		755.43	22.90	239.9	0.012	0.047
2	4	832.88	12.14	134.1	0.011	0.021
		775.04	8.642	225.2	0.003	0.017
		831.22	15.16	146.9	0.008	0.017
3	5	780.67	9.584	164.4	0.004	0.052
		739.05	12.54	193.8	0.002	0.013
		719.83	15.09	160.0	0.002	0.021

Figure-4 Shows the microscope images of blind holes with 100X and 80X magnification taken from ZEISS Stemi Microscope for the different input frequency.


1.2 kHZ

Size: **829.9** µm | Size: **841.1** µm | Size: **798.3** µm

2.2 kHZ

Size: **809.5** µm | Size: **759.6** µm | Size: **773.5** µm

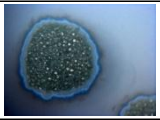
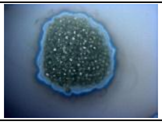
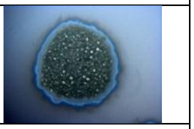
3.2 kHZ		
		
Size: **739.0** µm	Size: **773.0** µm	Size: **737.0** µm

Figure-4: Images of hole obtained from microscope for Si-SS-DI Water

III. RESULTS AND DISCUSSION

Micro blind holes machined on Silicon wafer using kerosene (Si-Cu-Kerosene)

Blind holes are machined on silicon wafer with copper tool and kerosene as the dielectric fluid in Part-A. The effects of process parameters on performance objectives like Size, Depth, Surface roughness, MRR and TWR with frequency are discussed.

The Figure 5 shows the graph for Frequency Vs. Hole Size for Experiment and it is observed that Hole size is decreased from 791.5 to 813.049 µm by increasing frequency 3 to 4 kHz and then decreasing from 813.049 to 746.52 µm with 4 to 5 kHz. This is due to with increase in frequency at constant duty factor pulse width decreased and spark seems to be almost uniformly distributed over the tool cross section without any side edge spark and tool chatter decreases.

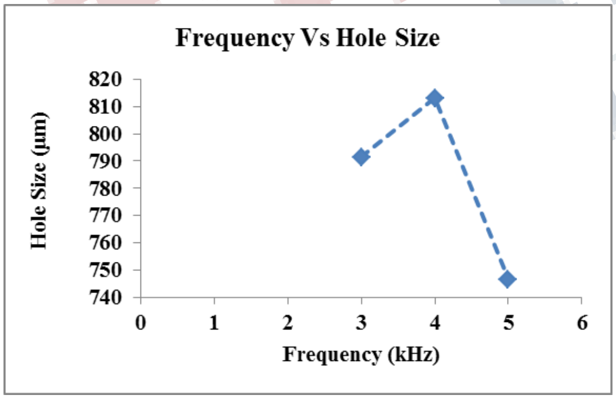


Figure-5: Frequency Vs. Hole Size for Si-Cu-Kerosene

The Figure-6 shows the graph for Frequency Vs. Depth for Exp. No: 3 and it is observed that Depth is increasing from 161.867 to 168.787 µm by increasing frequency 3 to 4 kHz and 168.787 to 172.753 µm with 4 to 5 kHz .As we know a single crater is formed with at a certain depth by single pulse discharge and from the figure it is evident that with increasing frequency, pulse discharge increases which in turn decreases the depth of crater.

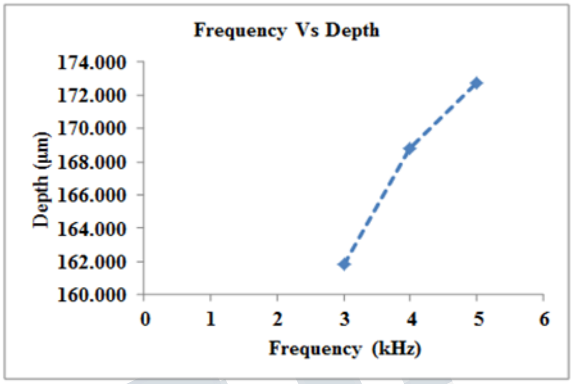


Figure-6: Frequency Vs. Depth for Si-Cu-Kerosene

The Figure-7 shows the graph for Frequency Vs. Surface finish for same experiment and it is observed that Surface finish is decreased from 12.903 to 11.981 µm by increasing frequency 3 to 4 kHz and then increased from 11.981 to 12.408 µm with 4 to 5 kHz.

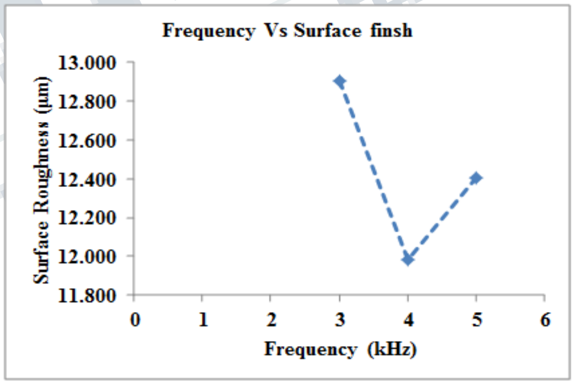


Figure-7: Frequency Vs. Surface Roughness for Si-Cu-Kerosene

Figure-8 shows the graph for Frequency Vs. MRR and it is observed that MRR is decreasing from 0.042 to 0.019 mm3/min with increasing frequency 3 to 4 kHz and then increasing from 0.019 to 0.029 mm3/min with increasing 4 to 5 kHz.

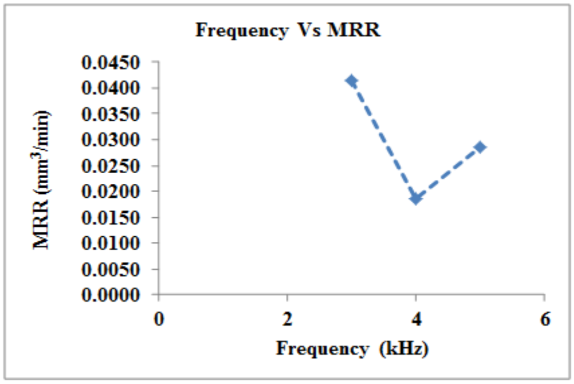


Figure-8: Frequency Vs. MRR for Si-Cu-Kerosene

From the above Figures7 and 8 it can be concluded that MRR affects the surface finish.

The Figure-9 shows the graph for Frequency Vs. TWR and it is observed that TWR is decreasing from 0.010 to 0.008 mm3/min with increasing frequency 3 to 4 kHz and then increasing from 0.008 to 0.003 mm3/min with increasing 4 to 5 kHz.

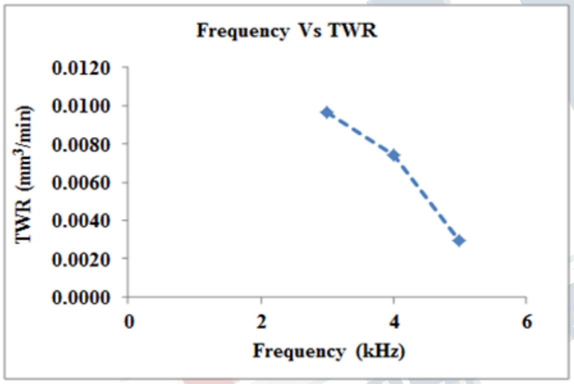


Figure-9: Frequency Vs. TWR for Si-Cu-Kerosene

From this result it is found that size of the hole and TWR has certainly reduced and MRR decreases to a certain extent and then increases.

Micro blind holes machined on Silicon wafer using DI Water (Si-SS-DI Water)
The blind holes are machined on silicon wafer with Stainless steel tool and kerosene as the dielectric fluid in the Si-SS-DI Water. The effects of process parameters on performance objectives like Size, Depth, Surface Roughness, MRR and TWR with frequency are discussed.

The Figure-10 shows the graph for Frequency Vs. Hole Size for Part-B and it is observed that Hole size is decreased from 829.986 to 759.632 µm by increasing frequency 1.2 to 2.2 kHz and then increased from 759.632 to 739.096 µm with 2.2 to 3.2 kHz. The size of the hole decreases with increasing voltage which shows that at higher value of frequency gives the nearer the hole size at constant.

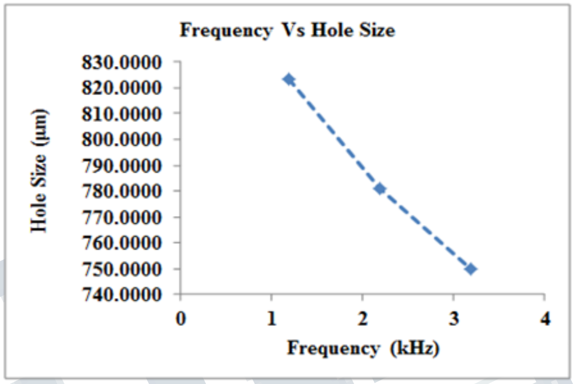


Figure 10: Frequency Vs. Hole Size for Si-SS-DI water

The Figure-11 shows the graph for Frequency Vs. Depth for Exp. No:4 and it is observed that Depth is increased from 70.913 to 112.173 µm by increasing frequency 1.2 to 2.2 kHz and then decreased from 112.173 to 67.397 µm with 2.2 to 3.2 kHz.

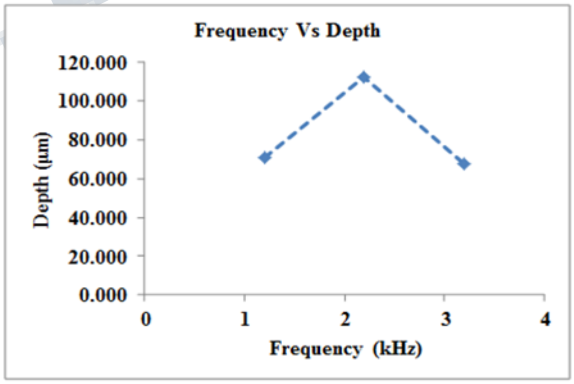


Figure-11: Frequency Vs. Depth for Si-SS-DI water

The Figure-12 shows the graph for Frequency Vs. surface roughness for Exp. No:4 and it is observed that surface finish is decreased from 10.08 to 6.42 µm by increasing frequency 1.2 to 2.2 kHz and then increased from 6.42 to 10.31 µm with 2.2 to 3.2 kHz.

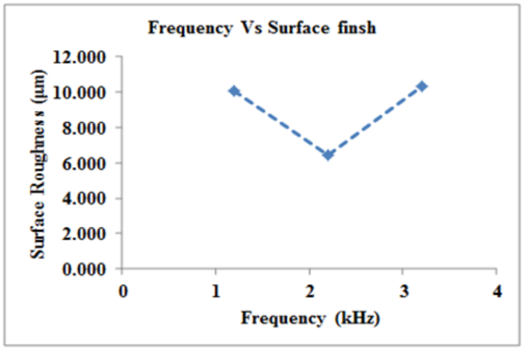


Figure-12: Frequency Vs. Surface Roughness for Si-SS-DI water

The Figure-13 shows the graph for Frequency Vs. MRR and it is observed that MRR is decreased 0.037 to 0.031 mm3/min by increasing frequency 1.2 to 2.2 kHz and then constant from 2.2 to 3.2 kHz.

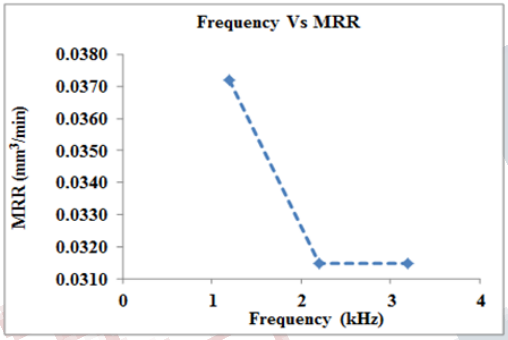


Figure-13: Frequency Vs. MRR for Si-SS-DI water

Figure-14 shows the graph for Frequency Vs. TWR and it is observed that TWR is decreased from 0.008 to 0.005 mm3/min by increasing frequency 1.2 to 2.2 kHz and then increasing from 0.005 to 0.009 mm3/min with 2.2 to 3.2 kHz.

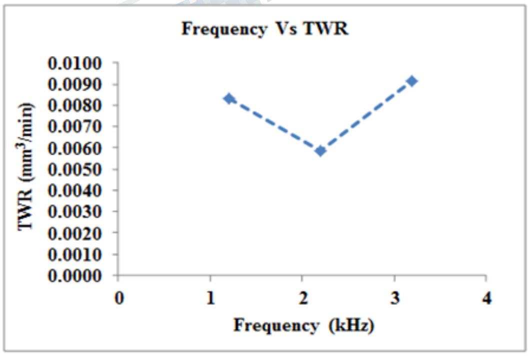


Figure-14: Frequency Vs. TWR for Si-SS-DI water

From the Figures of Exp.No:2.2.2 it is evident that the effect of frequency on Size of the hole, TWR and MRR is almost consistent with the affects observed in Exp. No. Part-A

IV. CONCLUSIONS

- In this paper, the µ-EDM setup is developed for machining micro holes with piezo-actuated tool feed mechanism.
- Micro blind holes are produced on silicon wafer with copper (610µm) and stainless steel electrodes (710µm) by using Kerosene and Deionized water as dielectric fluids.
- The repeatability of the depth and surface finish of the blind holes are verified with constant time period i.e., 10 min and 5 min by varying frequency from 3 to 5 kHz for experiment Part-A. and 1.2 to 3.2 kHz for experiment Part-B. at 30V.
- The effects of processes parameters on performance parameters like MRR, TWR, Depth, and Surface finish and Hole size were discussed in detail and the consistent results are obtained.

V. ACKNOWLEDGEMENT

This work was carried out as part of my M.Tech project "Investigation on Performance Parameters of Micro-Electrical Discharge Machining (µ-EDM)." in Precision Engineering and Instrumentation Laboratory at IIT Madras, Chennai-2013.

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