DESIGN AND DEVELOPMENT OF MICRO EDM USING MICRO ACTUATOR TOOL FEED SYSTEM

THINESH CHANDER S/O SAWALINGAM

BACHELOR OF ENGINEERING

UNIVERSITI MALAYSIA PAHANG

2010

DESIGN AND DEVELOPMENT OF MICRO EDM USING MICRO ACTUATOR TOOL FEED SYSTEM

THINESH CHANDER S/O SAWALINGAM

Report submitted in partial fulfillment of the requirements
for the award of the degree of
Bachelor Mechanical Engineering

Facultyof Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2010

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled “*Design and Development of Micro EDM Using Micro Actuator Tool Feed Control System*“ is written by *ThineshChander*s/o*Sawalingam*. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

Ms. NurAzhaniAbdRazak
Examiner Signature

SUPERVISOR’S DECLARATION

I hereby declare that I have checked this project report and in my opinion this project report is sufficient in terms of scope and quality for the award of the Bachelor of Mechanical Engineering.

Signature :
Name of Supervisor : MR. MAHENDRAN SAMYKANO
Position : LECTURER
Date : 6 DECEMBER 2010

STUDENT'S DECLARATION

I declare that this report titled "*Design and Development of Micro EDM Using Micro Tool Feed System*" is my result of my own research except as stated in the references. This thesis/report has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :
Name : THINESH CHANDER S/O SAWALINGAM
ID Number : MA08001
Date : 6 DECEMBER 2010

Dedicated to my parents who have been the full support during this project and to my supervisor.

ACKNOWLEDGEMENTS

Firstly I am grateful and would like to express my sincere gratitude to mysupervisor Mr. Mahendren A/L Samykano for his germinal ideas, invaluable guidance, continuous encouragement and constant support in making this research possible. He has always impressed myself with his outstanding professional conduct, his strong conviction for science, and his belief that a Bachelor Degree program is only a start of a life-long learning experience. I am truly grateful for his progressive vision about my training in science, his tolerance of my naïve mistakes, and his commitment to my future career. I am also sincerely thanking him for the time spent proofreading and correcting my mistakes. I would also like to thank anyone that contributed indirectly or directly for this project.

ABSTRACT

This project aims in revealing varieties of methods in tool feed control for Micro electric discharge machining (EDM) process with new advanced technology achieved. Although Micro EDM usage is essential in manufacturing sector but the gap phenomena still remains complicated and unstable. Recent research improves the gap control problem with latest technology such as servomechanism, fuzzy logic, Piezoelectric transducer (PZT), ultrasonic vibration and many more. PZT tool feed control system is used in this project as the main system to prevent any adhesion and to reduce tool wear. This project also aims in discussing factors influencing tool wear and new tool materials in Micro EDM. Tool wear prevention in EDM is essential because quality and precision of the product machined by EDM depends on the tool wear. If the tool wear is high, the product machined depth will be inaccurate with low surface quality. In future prospect, Micro EDM should be equipped with self learning and user friendly utilities for mass production usage. Future Micro EDM will be a package of integrated self learning and fast production machine.

ABSTRAK

Projek ini bertujuan untuk membangunkan mesin Mikro Electric Discharge Machining atau EDM dengan penggunaan sistem Piezoelectric Transducer atau PZT dan mengungkap pelbagai kaedah yang berkaitan sistem kawalan alat mesin untuk proses EDM yang penting dalam sektor pembuatan yang maju. Walaupun Mikro EDM penting dalam pembuatan tetapi fenomena pengawalan celah antara alat mesin dan bahan masih merupakan masalah yang belum jelas dan tidak stabil. Kajian terbaru terbukti telah menolong dalam memperbaiki fenomena kawalan celahan antara alat mesin dan bahan seperti teknologi pengunaan motor servo, fuzzy Logic, PZT dan lain – lain. Sistem PZT dipilih dalam projek ini sebagai sistem yang menghalang kejadian penghakisan alat mesin. Projek ini juga bertujuan untuk membincangkan faktor – faktor yang mempengaruhi hakisan alat mesin Mikro EDM. Pencegahan hakisan adalah penting dalam EDM kerana kualiti bahan yang dimesin bergantung kepada keadaan alat mesin. Jika hakisan alat mesin adalah tinggi, lubang yang dimesin di permukaan bahan tidak akan tepat. Di masa hadapan, Mikro EDM haruslah disertakan dengan teknologi yang boleh menolong mesin tersebut dalam mengesan kesilapan dan memperbaikinya.

TABLE OF CONTENTS

Page

EXAMINER'S DECLARATION ii

SUPERVISOR'S DECLARATION iii

STUDENT'S DECLARATION iv

ACKNOWLEDGEMENTS vi

ABSTRACT vii

ABSTRAK viii

TABLE OF CONTENTS ix

LIST OF TABLES xii

LIST OF FIGURES xiii

LIST OF SYMBOLS xvi

LIST OF ABBREVIATIONS xvii

CHAPTER 1 INTRODUCTION 1

1.1 Project Background 1
  1.1.1 Design Consideration for EDM 2
  1.1.2 Advantage and Disadvantage of EDM 2
1.2 Problem Statement 3
1.3 Project Objective 4
1.4 Scope of Project 4
1.5 Conclusion 4

CHAPTER 2 LITERATURE REVIEW 5

2.1 Introduction 5
2.2 Types of EDM 5
  2.2.1 Sink EDM 5
  2.2.2 Wire EDM 7
2.3 Electrode 9
2.4 Dielectric Fluid 12

2.5 Pulse Generator 17

2.6 Micro EDM 19

2.7 Servo Feed Control 19

2.8 Ultrasonic Vibration 20

2.8.1 Micro Holes Machining(Ultrasonic Vibration ofTool) 20
2.8.2 Ultrasonic Vibration of Work Piece 21

2.9 Pulsed Powered DC Motor Supply 22

2.10 Fuzzy Logic Control in Micro EDM 25

2.11 Piezoactuator (PZT) Usage in Micro EDM 28

2.12 Problematic Areas in Micro EDM 32

2.13 Material Removal Rate (MRR) in Micro EDM 34

2.13.1 Factors in MRR 35

2.14 Volumetric Wear Ratio(VWR) 36

2.15 Factors Influencing Tool Wear 37

2.15.1Tool Material Selection 38
2.15.2Polarity 40
2.15.3 Tool Design 41

2.16 Conclusion 41

CHAPTER 3 METHODOLOGY 42

3.1 Introduction 42

3.2 Procedures 42

3.3 VWR & MRR Programming in Matlab 44

3.4 Tool Design & Analysis 46

3.5 Control Circuit Development 50

3.6 Conclusion 50

CHAPTER 4 RESULTS AND DISCUSSIONS 51

4.1 Introduction 51

4.2 Stage 1 : Control Circuit and Power Circuit 51

4.3 Stage 2: Tool Material and Design 54

4.4 Development of Micro EDM 69

4.5 Tool Wear Rate 61
4.6 Conclusion 64

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS 65

5.1 Introduction 65
5.2 Limitations 65
5.3 Conclusion 65
5.4 Recommendations and Future Prospect 66

REFERENCES 67

APPENDICES

A Tool Stress Analysis 69
B Temperature Distribution Analysis of Tool Design 1 & 2 70
C Heat Rate Analysis of Tool Design 2 72

LIST OF TABLES

Table No.	Title	Page
1.0	Material comparison	54
2.0	Parameters comparison between two different design	57
3.0	Machining parameter	60
4.0	Measurements and TWR results	62

LIST OF FIGURES

Figure No.	Title	Page
2.1	SinkEDM working principles	6
2.2	An example of sink EDM	6
2.3	Wire EDM process	7
2.4	An example of wire EDM	8
2.5	Graph of tool wear of PCD, CVDD, K10	10
2.6	Difference between conventional electrode(a) and $CuZrB_2$composite(b) after machining ANK 80 steel	11
2.7	The relation between wear percentage, material removal rate and orbit radius	12
2.8	Difference between dielectric oil (a) and mixture of powder and dielectric powders (b)	14
2.9	Relation between tool wear and pulse duration	15
2.10	Difference between oil and water as dielectric fluid	16
2.11	Relation between MRR and powder concentration	17
2.12	Relaxation type pulse generator	18
2.13	Transistor type pulse generator	18
2.14	Principal of servo feed control	19
2.15	Schematic diagram of sinker EDM combination with ultrasonic pulse generator	21
2.16	Rotary impulse generator	22
2.17	Charging-discharging circuit	23
2.18	Control circuit	24
2.19	3 input fuzzy logic control	25

2.20	Conventional EDM control loop	27
2.21	Difference between conventional EDM and fuzzy logic EDM	27
2.22	Piezoelectric process	28
2.23	Micro EDM with PZT actuator	29
2.24	Tool feed control by PZT	30
2.25	The position of PZT actuator	31
2.26	Simulation of PZT actuator	32
2.27	Problematic areas of Micro EDM	33
2.28	In Situ method	34
2.29	Parameters influencing MRR	35
2.30	Relation between MRR and flushing pressure	36
2.31	VWR parameters	37
2.32	Simulated result of tool wear	38
2.33	Temperature distribution	39
2.34	Materials comparison	39
2.35	Work piece surface micrograph due to tool different polarity	40
3.1	Project flowchart	43
3.2	MRR programming in Matlab	44
3.3	Coding for VWR	45
3.4	VWR programming output	46
3.5	Tool design 1 in SolidWorks	47
3.6	Tool design 2 in SolidWorks	48
3.7a	Tool design 1 applied load	49

3.7b Tool design 2 applied load 49
3.8 Applied temperature section of the tool in Algor 50
4.0 Simplification of control circuit 52
4.1 Control circuit simulation in ORCAD 9.1 53
4.2 Power circuit simulation in ORCAD 9.1 53
4.3 Tool design 1 analyzed as copper 54
4.4 Tool design 1 analyzed as tungsten 55
4.5 Heat rate of tool design 1as copper 56
4.6 Heat rate of tool design 1as tungsten 56
4.7 Tool design 1 with rectangular extruded machining surface 58
4.8 Tool design 2 with circles type machining surface 58
4.9 Initial planning of Micro EDM 59
4.10 Developed Micro EDM 60
4.11 Machining undergoing 61
4.12 Machined surface 62
4.13 Graph on tool wear Vs tool displacement 63
4.14 Previous study on TWR using PZT tool feed system 63
4.15 Tool under micro scope 64

LIST OF SYMBOLS

ZrB_2	Zirconium Boride
$CuZrB_2$	Composite of Cuprum Zirconium Boride
SiC	Silicon Powder
MoS_2	Moly Disulfide
mm	milimeter
°C	Celcius
K	Kelvin
mm^3	Milimeter cubic
V	Voltage
s	seconds
j	joule
W	watt

LIST OF ABBREVIATIONS

CNC	Computer Numerical Machining
CVDD	chemical vapordeposition diamond
EDM	Electrical discharge machining
Et al	And Others
EDG	Electric Discharge Grinding
K10	cemented carbide
MOSFET	metal–oxide–semiconductor field-effect transistor
OpAmp	Operational Amplifier
PWM	Pulse Width Modulator
PCD	graphitepolycrystalline diamond

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Electrical Discharge Machining or EDM is a manufacturing process in cutting complicated designs and shapes by using electrical discharge. Industries, nowadays, requires fast, precision and reliable fabricating machine such as EDM. Since the EDM is a thermal process, hard materials such as quenched steel, cemented carbide and electrically conductive ceramics can be machined. Since the tool electrodedoes not need to rotate for material removal like milling orgrinding, holes with sharp corners and irregular contourscan be machined without difficulty. EDM and Micro EDM are the same machining but have a few differences such as Micro EDM cutting tool is very small compared with conventional EDM and voltage supplied for machining for Micro EDM is much less than the normal EDM.

EDM can be divided into two types that are sinker EDM and wire EDM. Sinker EDM consist an electrode(tool) and a workpiece that are submerged in dielectric fluid. Electric power is supplied to both of these parts and when the electrode approaches the workpiece current intensity increase resulting sparks in the gap between workpiece and the electrode. The workpiece surface will start to erode due to the sparks and this is how the cutting process works in sinker EDM.

The other type of EDM is the wire EDM that uses wire as the cutting tool. The wire, usually brass, suitable in cutting plates with thickness up to 300 mm and not typically used in producing complex 3D designs. The wire is fed through the workpiece in dielectric fluid and the feeding is done from a spool that is held between upper and lower the diamond guides. Wire EDM also suitable to make punches, tools and dies from hard metal.

The latest technology in the EDM family is the electrical discharge grinding or EDG. A rotating grinding wheel, that contains no abrasives, removes material from the workpiece surface by spark discharges between the rotating grinding wheel and the workpiece. The grinding wheel is usually made of brass or graphite and this process is primarily for grinding carbide tools. Fragile parts such as honeycomb structures, surgical instrument and thin walled tubes are also produced using this technology.

1.1.1 Design Consideration For EDM

The common and general design guidelines for electrical discharge machining are as follows:

(i) Parts should be designed so that the required electrodes can be shaped properly and economically.
(ii) Deep slots and narrow openings should be avoided.
(iii) For economic production rate, the surface finish specified should not be too fine.
(iv) In order to achieve a high production rate, the bulk of material removal should be done by convectional processes (roughing out).

Source:Kalpakjian and Schmid (2007)

1.1.2 Advantages And Disadvantages Of EDM

Some of the advantages of EDM include the machining of:

(i) complex shapes that would otherwise be difficult to produce with conventional cutting tools
(ii) extremely hard material to very close tolerances
(iii) Very small work pieces where conventional cutting tools may damage the part from excess cutting tool pressure.

(iv) There is no direct contact between tool and work piece.Therefore delicate sections and weak materials can be machined without any distortions.

Some of the disadvantages of EDM include:

(i) The slow rate of material removal.
(ii) The additional time and cost used for creating electrodes for sinker EDM.
(iii) Reproducing sharp corners on the workpiece is difficult due to electrode wear.
(iv) Specific power consumption is very high.

Source: Kalpakjian and Schmid (2007)

1.2 PROBLEM STATEMENT

The machining characteristics of micro-EDM remainunclear, especially in regard to the total energy of dischargepulses and tool electrode wear, since the energy is not onlyused to machine the workpiece, but also degrades the toolelectrode. Hence, the accuracy of the components machinedby micro-EDM is also influenced by the wear of the toolelectrode.

Adhesion, short-circuiting and cavitations occur frequentlyduring machining processes in micro-EDM, making thedischarge pulses become unstable and machining time becomes excessively long.Adhesion occurs when the melted componentof the workpiece becomes attached to the toolelectrode, causing the discharge pulse to become unstableas a result of short-circuiting between the workpiece andtool electrode, and inhibiting the insulation recovery of themicro-EDM machine. Adhesion causes the machining time tolengthen because the machine table is controlled to move inthe reverse direction of the feed to maintain the gapdistance between the workpiece and tool electrode. Whenadhesion, short-circuiting, and cavitations occur, it is noteasy to accurately predict the machining time.

1.3 PROJECT OBJECTIVES

There two objectives that must be achieved in this project and that are:

(i) Develop a micro EDM with Piezoelectric Transducer(PZT) tool feed mechanism

(ii) To investigate tool wear in Piezoelectric Transducer(PZT) actuated Micro EDM

1.4 SCOPE OF PROJECT

In this project, a Micro EDM machine with Piezoelectric Transducer(PZT) to control tool feed will be developed. The scopes that are required in developing this machine are:

(i) To develop EDM control system

(ii) Tool design & analysis using Algor

(iii) Tool Wear Rate(TWR) comparison between theoretical and experiment

1.5 CONCLUSION

With the given scopes and objectives, the main idea of this project had been standardize to cope with time line and obstacles that could occur in future.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The principle of electrical discharge machining (EDM) is based on the erosion of metals by spark discharges. When two current conducting wires are allowed to touch each other an arc is produced. If we look closely at the point of contact between the two wires, we note that a small portion of metal have been eroded away, leaving a small crater.

Although this phenomenon has been known since the discovery of electricity, it was not until 1940s that a machining process based on this principle was developed. The EDM process has become one of the most important and widely used production technologies in manufacturing.

2.2 TYPES OF EDM

Generally, there are many types of EDM machine available in the market such as Electric Discharge Grinding (EDG), Wire electric Discharge Machining (WEDM) and the most common is the sinking EDM.

2.2.1 Sink EDM

The basic sink EDM system consists of a tool (electrode) and the workpiece are supplied with electricity and placed in a dielectric(electrically non conducting) fluids.

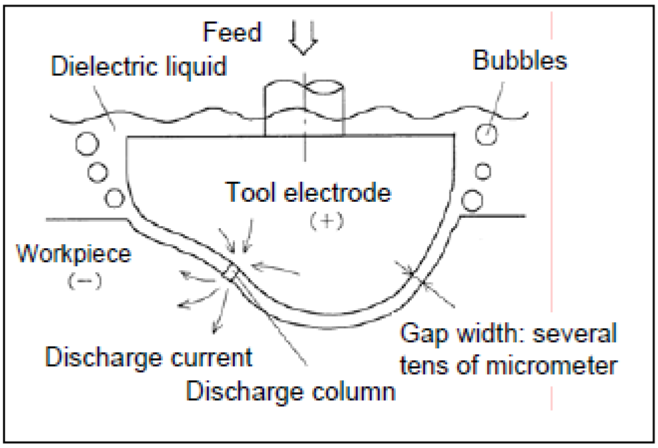


Figure 2.1: SinkEDM working principles

Source: Kunieda et al. (2007)

Based on figure 2.1, 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 workpiece 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 workpiece just like in figure 2.1, the workpiece surface erodes when the sparks created in the gap touches the workpiece surface.

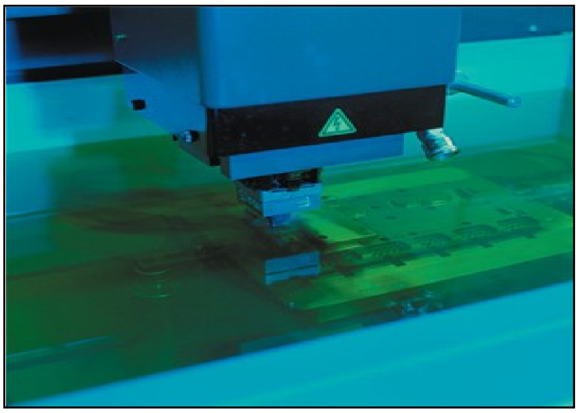


Figure 2.2: An example of sink EDM

Source: www.googleimage.com/sinkerEDM(retrieved on 26.11.2009)

The gap width must be maintained in a suitable range to avoid short circuiting. The downward feed of the tool is controlled by a servomechanism, which automatically maintains a constant gap. The ignitionof the discharge is initiated by a high voltage, overcomingthe dielectric breakdown strength of the small gap. Achannel of plasma (ionized, electrically conductive gas withhigh temperature) is formed between the electrodes anddevelops further with discharge duration. As the metalremoval per discharge is very small, discharges shouldoccur at high frequencies (103 -106 Hz). For every pulse, discharge occurs at a single location where the electrode material ejected in molten phase.

Because the process does not involve mechanical energy, the hardness, strength and toughness of the workpiece material do not necessarily influence the removal rate. The frequency of discharge or the energy per discharge, the voltage, and the current usually are varied to control the removal rate. The removal rate and surface roughness increase with increasing current density and decreasing frequency of spark.

2.2.2 Wire EDM

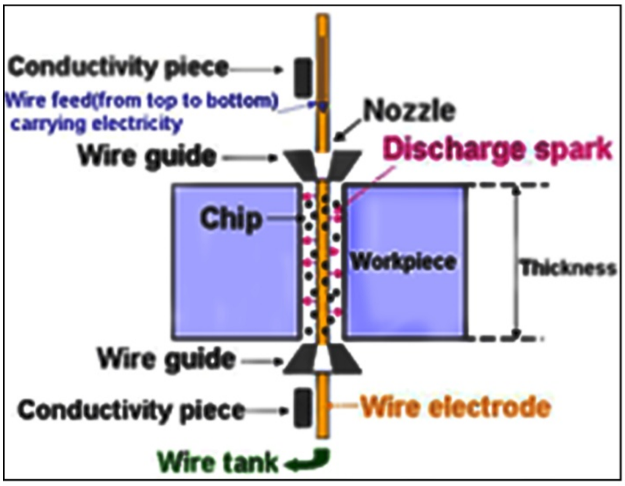


Figure 2.3: Wire EDM process

Source: www.googleimage.com/sinkerEDM(retrieved on 26.11.2009)

From figure 2.2 we learn that this machine uses wire that is usually made of brass or tungsten, as the tool in cutting the workpiece. 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 workpiece 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.

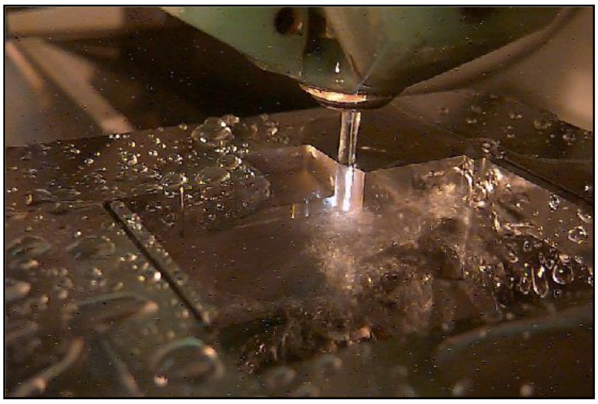


Figure 2.4: An example of wire EDM

Source: www.googleimage/WEDM(retrieved on 26/11/2009)

High technology wire EDM are equipped with following features:

(i) Computer controls for controlling the cutting path of the wire and its angle.
(ii) Multiheads for cutting two parts at the same time.
(iii) Features such as controls for preventing wire breakage.
(iv) Automatic self threading features in case of wire breakage.
(v) Programmed machining strategies to optimize the operation.

Source: Kalpakjian and Schmid (2007)

2.3 ELECTRODES

The electrodes for EDM are usually made of graphite, brass and copper. These electrodes that used as tools for the machine are basely 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 workpiece 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 J.P. et al.,(2009) for EDM processes, copper – tungsten electrodes are much more better than graphite electrode. According to them, copper – tungsten provide better surface finish and longer life than graphite electrode. Other benefits are:

(i) Speed/cost: for complex geometry, this process is faster and cheaper.
(ii) Robust electrodes that cannot be damaged easily (with graphite and even copper the electrodes can be damaged easily).
(iii) Replication of artistic hand carved objects (impossible to program) into electrodes.

Tool wear between graphitepolycrystalline diamond (PCD) cutting tool, chemical vapordeposition diamond (CVDD) cutting tool and K10 (cemented carbide) are studied. According to Davim J.P. et al.,(2009) the results are in figure 2.5

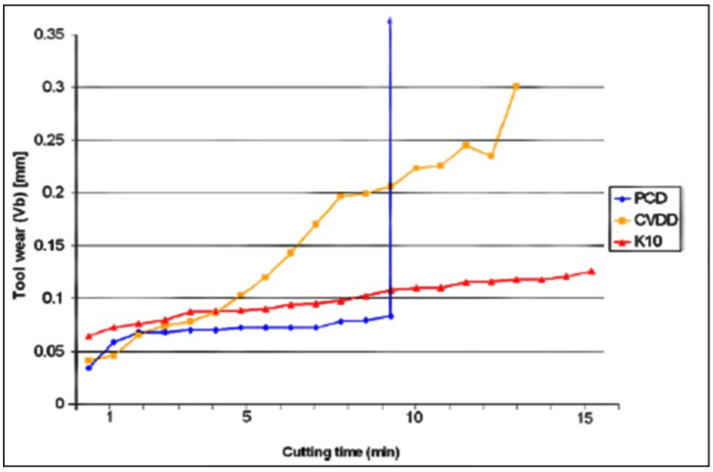


Figure 2.5: Graph of tool wear of PCD, CVDD and K10

Source: Davim J.P. et al. (2009)

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 width has to be controlled in only microns. According to Yuangang W. et al., (2009) electrodes that have been gone through composite electro deposition process have better strength than normal electrodes. This process strengthens the electrodes by depositing a layer of dispersed ceramic particles onto the electrodes surface.

Composite of ZrB_2 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 shockstability, anticorrosion, etc. It has already been used tomake critical components in aircraft and rocketsworking at high temperatures.

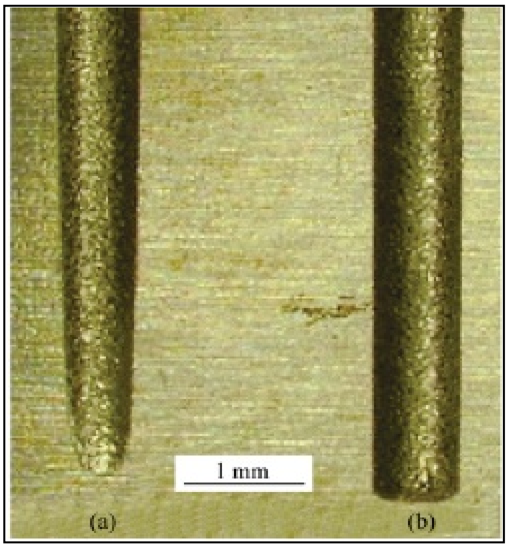


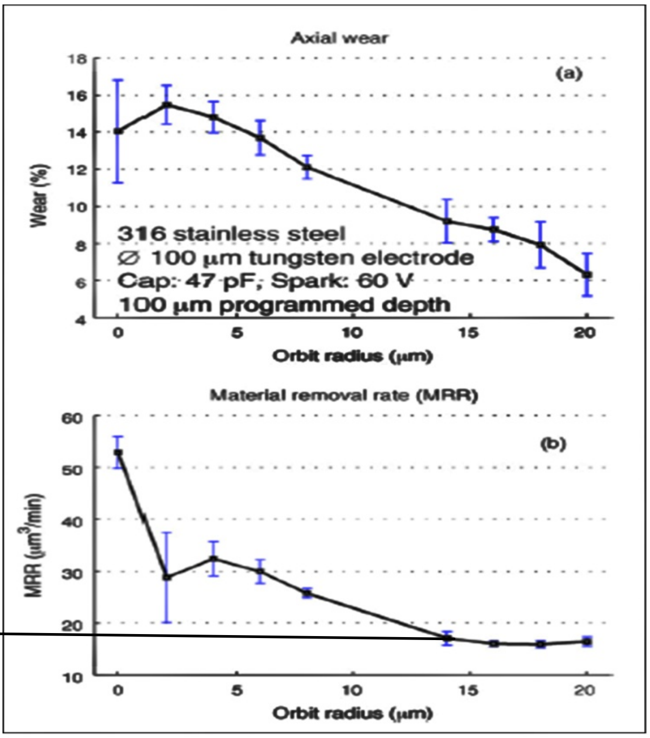
Figure 2.6: Difference between conventional electrode (a) and $CuZrB_2$composite(b) after machining ANK 80 steel

Source: Yuangang W. et al. (2009)

From figure 2.6, $CuZrB_2$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.

According to Bamberg E. et al., (2009)orbital electrode actuation is proven method in gaining high material removal rate and low wear percentage in drilling. Electrode orbiting is to actuate the electrodeon a controlled, circular trajectory. If the orbiting motionis created with a device that allows the radius to be controlledelectronically, the motion can be integrated into theEDM machine’s control system for tight process control.This motion is controlled by piezoelectric motors and actuators that machines workpiece by orbiting electrodes.

According to the journal, in drilling, orbiting electrodes perform better than non orbiting electrodes.



Material removal rate reduces when orbiting radius of electrode are bigger

Figure 2.7: The relation between wear percentage, material removal rate and orbit radius

Source: Bamberg E. et al. (2009)

Figure 2.7 proves that by 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.

2.4 DIELECTRIC FLUIDS

Dielectric fluids are electrically nonconducting 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 pure 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. The adhered carbon elements affect normal discharge, especially, the micro-slit EDM processes. Since carbon particles adhere to the electrode and work piece surface, the debris of gap is difficult to be extruded.

According to Yih-fong T.et al.,(2005) 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 added to the characteristic of surface machining remains unclear.

A study has been conducted 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.

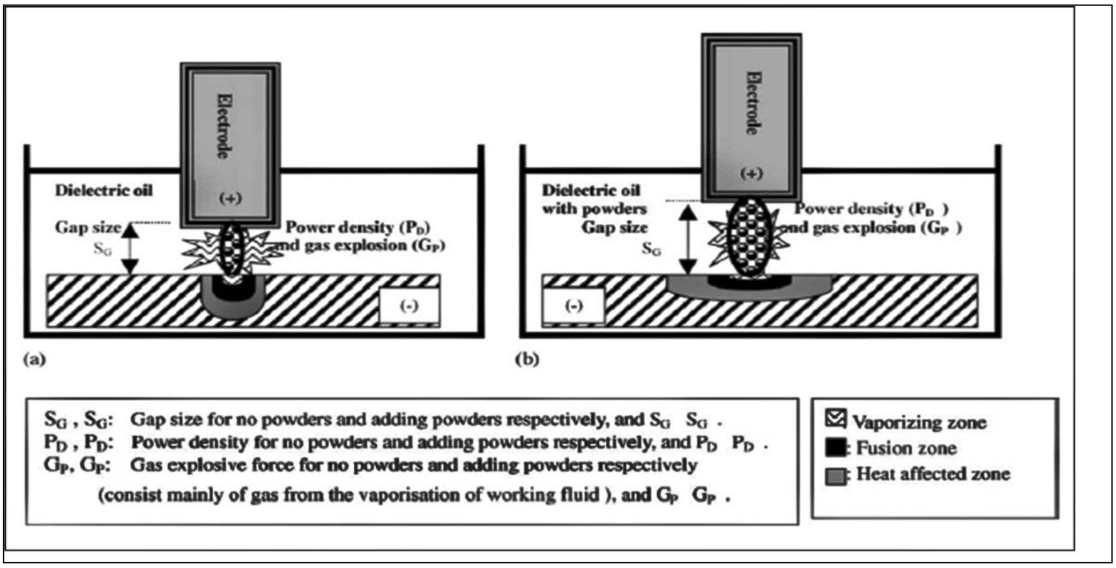


Figure 2.8: Difference between dielectric oil (a) and mixture of powder and dielectric powders (b)

Source: Han et al.(2008)

Figure 2.8 shows the difference between dielectric oil with powders noted that the additionof powders lead to an increase in gap size that subsequently resulted in a reduction in electrical discharge power densityand in gas explosive pressure for a single power pulse. Although the material removal rate is decreased but surface finish and tool life improves because sparks discharge is away from electrode.

Addictives that have smallest particle size generates best surface finish. It is due to small particles producing finecutting effects in a complementary way. Aluminum, chromium and silicon powder have been tested as powders in dielectric oil. Result shows that aluminum powder produces best surface finish but adding aluminum powder is environment pollution.

According to Han et al.,(2008)silicon powder(SiC) added into pure water produces high conductivity therefore,the gap was larger than using pure water in the EDMprocesses. Purewater and a SiC powder could disperse the dischargingenergy that refines the surface roughness effectively andalso attains a higher MRR simultaneously than that of purewater.Pure water and a SiC powder causes a larger expanding-slitand electrode wear than those of using pure water alone. However, pure water and a SiC powder attain a smalleramount of machined burr than that of using pure wateralone.This mixture does result in higher tool wear than usage of only pure water as in figure 2.9.

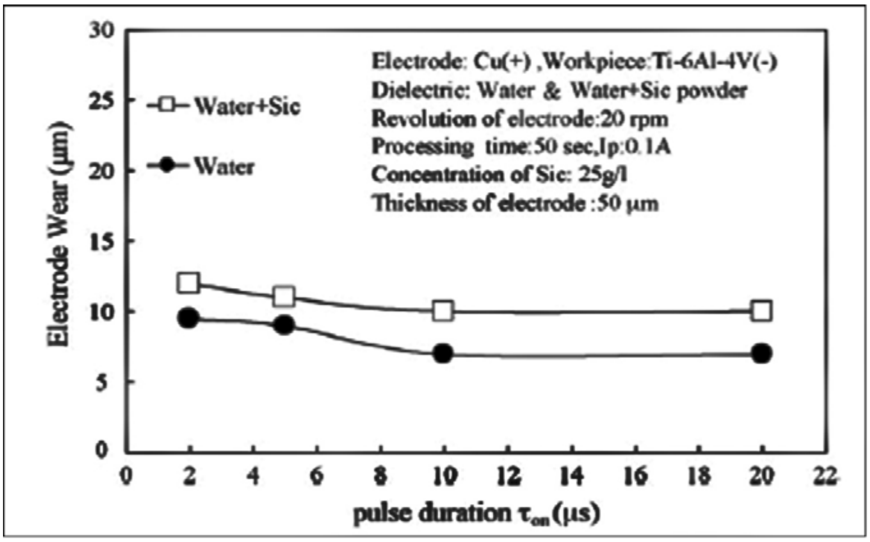


Figure 2.9: Relation between tool wear and pulse duration

Source: Han et al.(2008)

According to Leão F.N. et al.,(2004) water based dielectric fluid is the most environmental friendly machining technique. In some situation water results in better material removal rate than oils. One of the main sources of pollution in die sink electricaldischarge machining is the dielectric fluid, particularly hydrocarbonoil. At the moment, there is no total clean manufacturingprocess that could replace EDM. The use of EDMin gas (air& oxygen) could be an alternative as it does notproduce any waste and does not cause any adverse effect tohealth. However, this technique is not developed enough tobe employed efficiently. The use of water-based dielectricscan be a solution to minimize the environmental problemsin die sink EDM. The difference between this two dielectric medium can be noted in figure 2.10

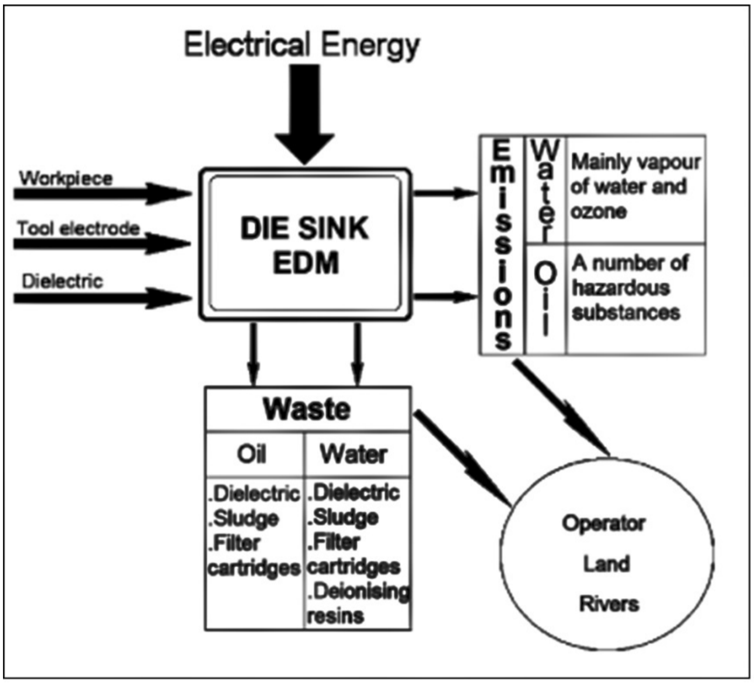


Figure 2.10: Difference between oil and water as dielectric fluid

Source: Leão F.N. et al. (2004)

According to Prihandana G.S. et al.,(2009)micro-MoS_2 powder is better than other addictives. Figure 2.11 show thehigher concentrationmicro-MoS_2, the material removal rate increases. This also accelerates the frequency of discharge and helps in improving surface finish.

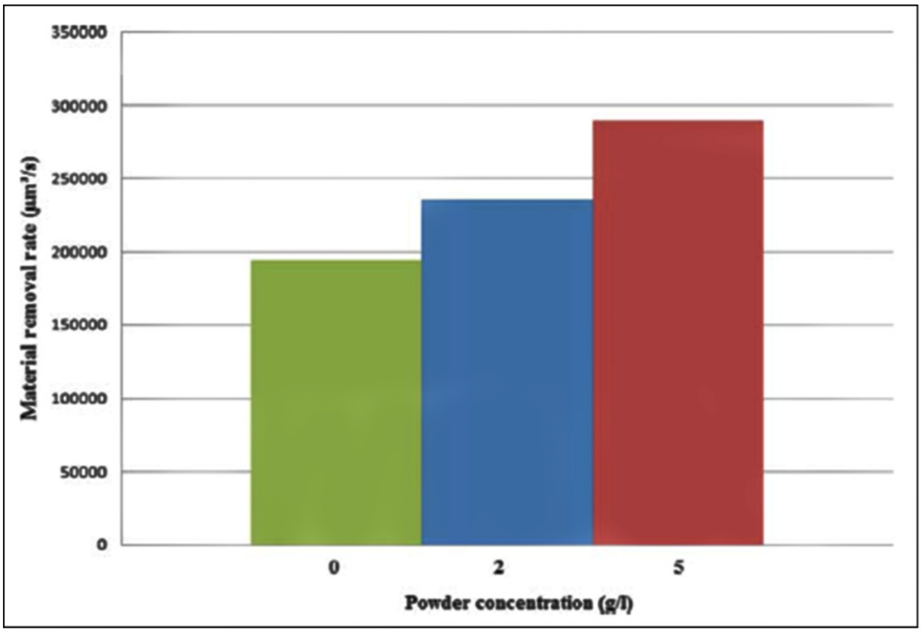


Figure 2.11: Relation between MRR and powder concentration

Source:PrihandanaG.S. et al. (2009)

Ultra sonic vibration of dielectric fluid also increases material removal rate. This is because the vibration is distributed from the bottom of the tank, thus the particles circulate around the tool and work piece. This circulation creates ease in machining, hence increasing material removal rate and reduces adhesion caused by debris that otherwise becomes attached to the work piece. In micro EDM, dielectric vibration and together with the usage of micro-MoS_2particles is the newway in machining method because this method proves that material removal rate can be increased, high lubricity of micro-MoS_2 produces better surface finish and the finishing is free from any black spot.

2.5 PULSE GENERATOR

Initially, EDM machines use relaxation type pulse generator, as shown in figure 2.12, but later improved and replaced with transistor type. The relaxation type is not good enough in supplying high peak values because current waveforms with larger peak current and longer discharge duration result in higher material removal rates.

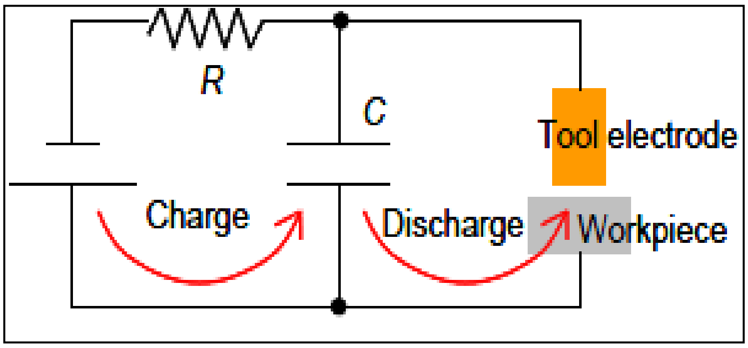


Figure 2.12: Relaxation type pulse generator

Source: Kunieda et al.(2007)

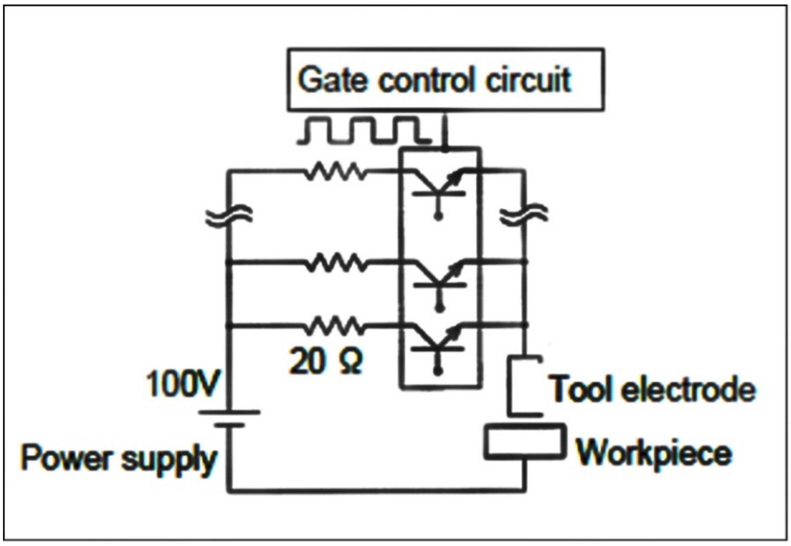


FIGURE 2.13: Transistor type pulse generator

Source: Kunieda et al. (2007)

According to figure 2.13, resistors and transistors assembled in a parallel form. When a transistor operates, voltage flows around 20 V and discharge current around 4 Ampere. Regardless of how much is the discharge current, the voltage will be steady at 20 V and this provides greater diameter of the arc column resulting in increasedelectrical conductivity of the plasma. Discharge current increase proportionally to the number of transistors switched on.

2.6 MICRO EDM

Micro EDM is an upgrade in the manufacturing field where smallest and critical product designs can be machined. Products such as micro channels, reservoirs and cantilever beams are machined using this technology. The machining process is just same with the normal EDM but the size of the tool makes the different.

In micro EDM, the gap between the tool and workpiece is only a few micron just enough to sustain the spark discharge to erode the workpiece. 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 workpiece 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.

2.7 SERVO FEED CONTROL

Servo feed control the gap width between the workpiece and the tool in a proper width.

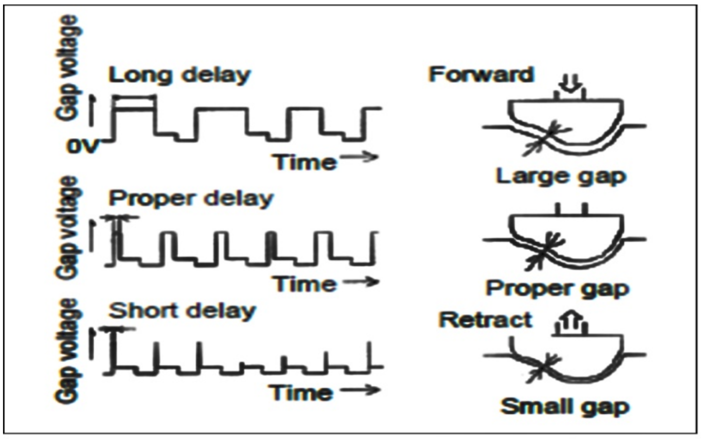


Figure 2.14: Principal of servo feed control

Source: Kunieda et al. (2007)

From figure 2.14, certain voltage delay creates different characteristic of the gap. When the gap gets larger, it causes longer ignition delays. When the measured average gap voltage is higher than the servo reference voltagepreset by the operator, the feed speed increases. On thecontrary, the feed speed decreases or the electrode isretracted when the average gap voltage is lower than theservo reference voltage, which is the case for smaller gapwidths resulting in a smaller ignition delay. This means, short circuits caused by debris can be avoided. Sometimes complicated machining that requires long and short gap voltage are only supplied with average gap voltage because to create safe working environment.

2.8 ULTRASONIC VIBRATION

Ultrasonic vibration is a boost in improving machining capability in machining different hardness of materials. The effects of ultrasonic vibration on electrode have been studied since mid 1980s. The higher efficiency gained by theemployment of ultrasonic vibration is mainly attributed tothe improvement in dielectric circulation which facilitatesthe debris removal and the creation of a large pressurechange between the electrode and the work piece, as anenhancement of molten metal ejection from the surface ofthe work piece. Zhang J.H. et al.,(1997) proposed that spark erosion using ultrasonic vibration and DC motor instead of usual pulse power supply. The pulse discharge produced by the relative motion between workpiece and tool. Hence, cost is reduced by simplify the equipment and indicated that it is easy to produce a combinedtechnology which benefits from the virtues of ultrasonicmachining and EDM.

2.8.1 Micro holes machining (ultrasonic vibration of electrode)

Various researchers found out that machining using ultrasonic vibration did produce a lot of changes especially in Material Rate Removal or MRR. Ogawa et al.,(2009) proved that the depth of micro holes machined with ultrasonic vibration produces two times deeper depth than normal EDM machining.

According toThoeT.H. et al.,(1991) the only electrode material that withstand the ultrasonic vibration machining is stainless steel whereas other material fail due to fatigue fracture and deformation. Yan B.H. et al.,(2002) proved that combining ultrasonic vibration and micro EDM produces holes with diameter variation from 2µm in microholes with diameter of 150µm and depth of 500µm. This show how accurate is ultrasonic vibration combined with micro EDM.

2.8.2 Ultrasonic vibration of Workpiece

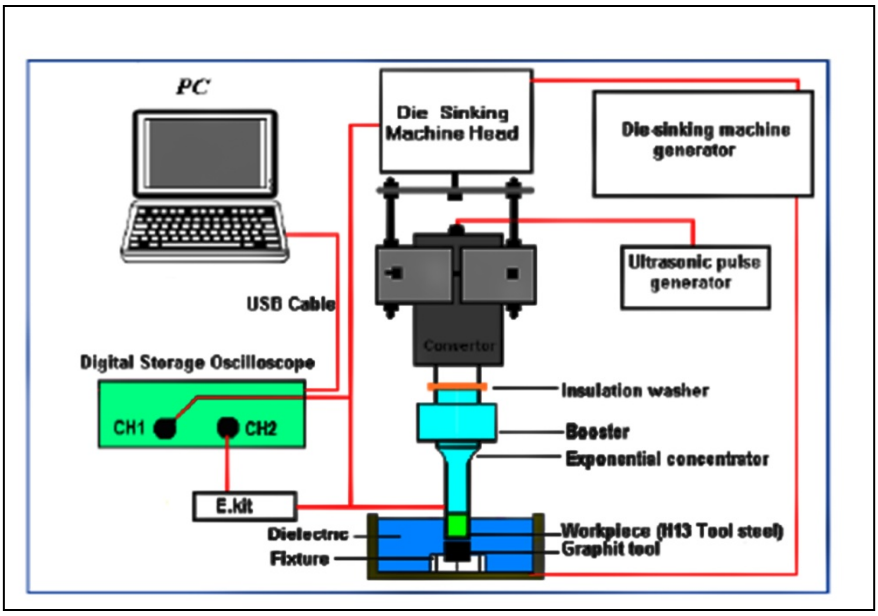


Figure 2.15: Schematic diagram of sinker EDM combination with ultrasonic pulse generator

Source:Shabgard et al.(2009)

According to Egashira K.et al.,(1999) ultrasonic vibration generator connected to work piece in many ways, one of the ways is figure 2.15, have managed to machine micro holes as small as 5µm in diameter in quartz, glass and silicon. Prihandana G.S.et al.,(2009)have studied the effect of vibrated work piece.They have shown that when the vibration was introducedon the work piece the flushing effect increased. They havefound that high amplitude combined with high frequencyincrease the MRR. Although this process creates high MRR, tool wear rate was high. To reduce the tool wear, sintered diamond tool was tested and results shows that the tool wear rate reduced but the usage of sintered diamond as tool is expensive.

2.9 PULSED POWER DC MOTOR SUPPLY

Other than relaxation and pulse generator (refer to topic 2.5), there are other types of power supply such as rotary impulse generator and hybrid generator. Rotary impulse generator, in figure 2.16, produces sinusoidal wave pattern similar to rectification. The waveform is very difficult to control and this type is seldom used.

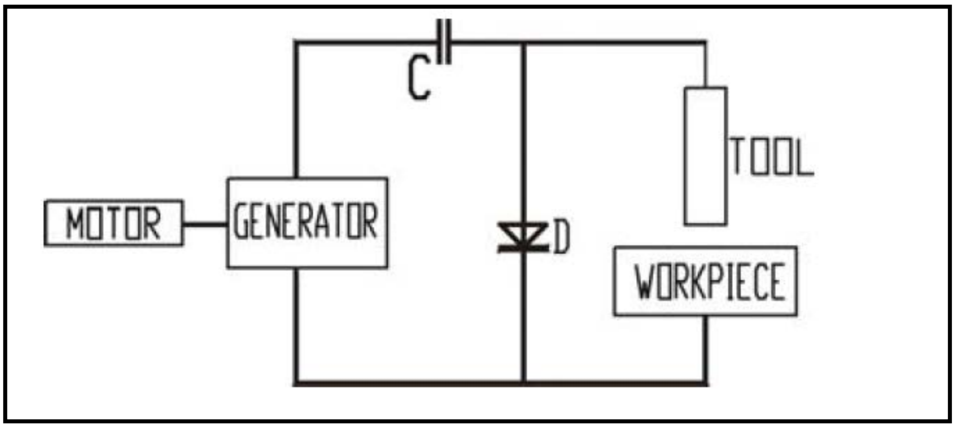


Figure 2.16: Rotary impulse generator

Source: Aditya Shah et al (2007)

In normal EDM, machining large workpiece do requires large magnitude of sparks, so when current and voltage become larger than required magnitude, uncontrolled sparks often happen. Due to large surface area, this sparks do not harm the process but helps the machining process. This uncontrolled sparks cannot be tolerated in micro EDM. There must be a system that responsible in controlling a tight number of voltage and current. In a typical micro EDM process, the voltage does not exceed 40V and the current allowed is only mili Ampere.

The pulsed power DC motor supply consist of a charging-discharging circuit, control circuit and stepper motor driver. The charging-discharging circuit is same as the pulse generator circuit but the usage of normal transistors are replaced with metal oxide semiconductor field effect transistor or MOSFET. Although normal transistors supplies pulses with the same magnitude equal to supply voltage, no discharge was observed to occur. N-channel MOSFETs were used to cause theswitching between the charging and discharging sidesof the circuit.

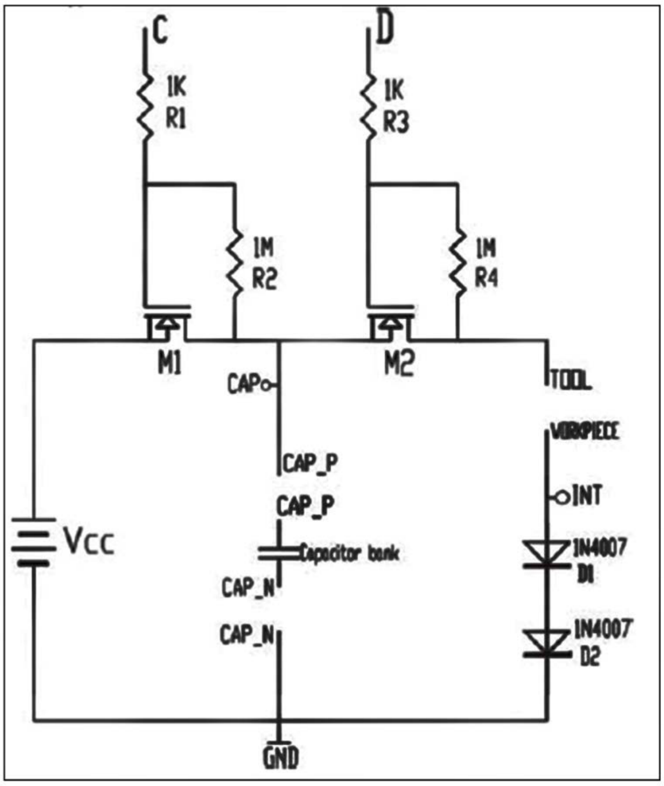


Figure 2.17: Charging-discharging circuit

Source: Aditya Shah et al (2007)

Higher value of capacitance means more current storage, hence greater current intensity of discharge. Figure 2.17 shows the circuit of charging-discharging, when the voltage flows to the MOSFETs gate, the gate will determine whether to allow charging to occur or discharge.

When discharging occur, the control circuit(figure 2.18) will determine the amount of discharge and the amount of current to recharge the capacitors, hence operational amplifiers used.

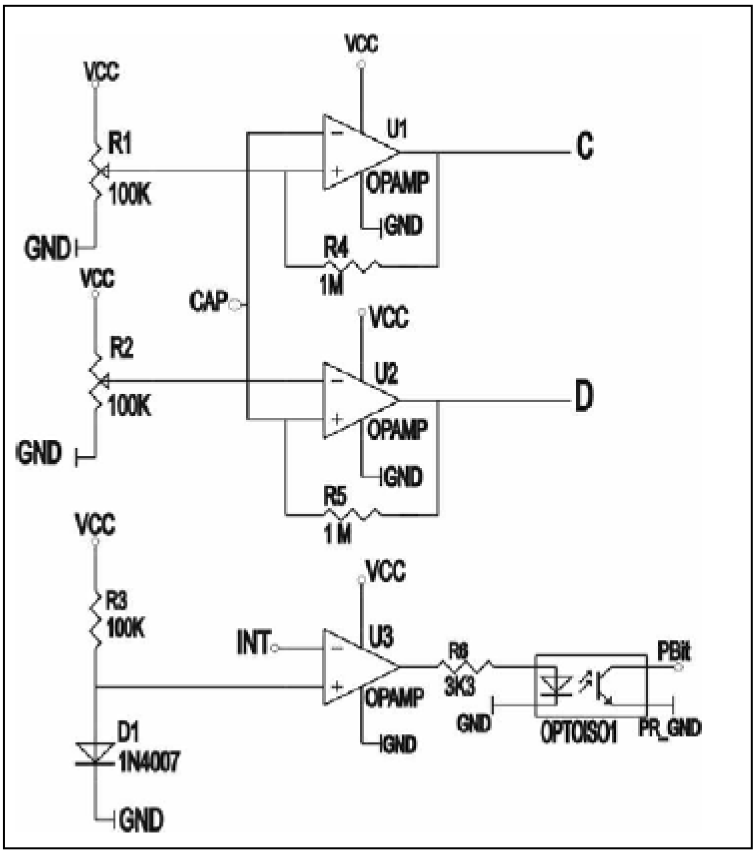


Figure 2.18: Control circuit

Source: Aditya Shah et al (2007)

When discharge occurs, due toflow of current, there is voltage drop across the diodeswhich get compared with the voltage across the onediode connected at input to comparator. As a result,there is switching between the supply voltages and thisis used to identify the spark and cause the motor to stopor reverse its direction momentarily before startingdownwards again.The above circuitprovides an easy way for maintaining the spark gap.This is because when the spark occurs the electrode ismoved up and then again down. When the materialgets eroded from the surface, the electrode automatically advances by that much amount whengoing in the downward direction towards thework piece. Thus, indirectly, it is possible to have somecontrol on the spark gap being maintained between thework piece and electrode.

2.10 FUZZY LOGIC CONTROL IN MICRO EDM

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 stabile 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.

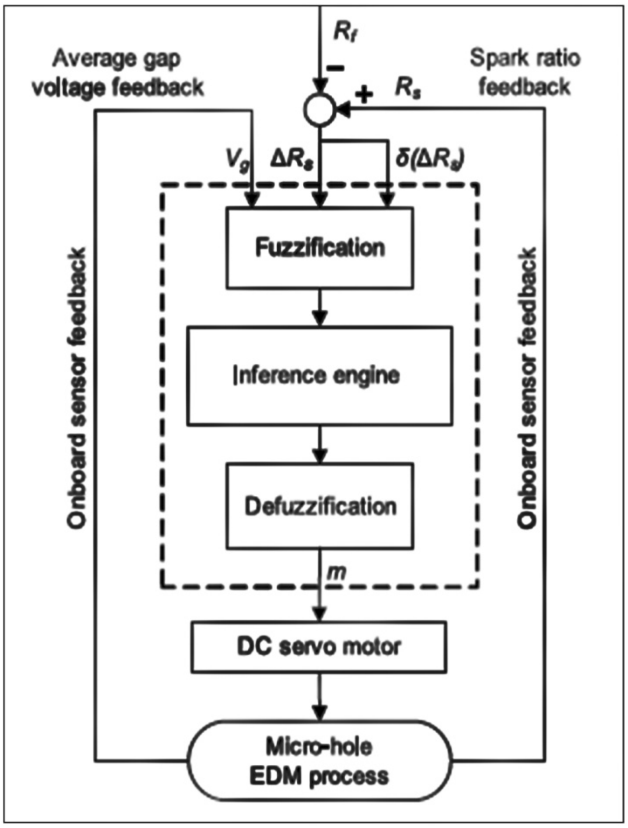


Figure 2.19: 3 input fuzzy logic control

Source: Kao et al. (2009)

1 and 2 input fuzzy logic control have been studied but the outcome is not as good as 3 input fuzzy logic control 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 logicreasoning grows significantly with the complexity of inferenceengines.

According to Kao et al., (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, ΔV_g 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 of1Vg 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 ishigher than the current electrode feed speed, then the electrodeis 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 operatingcondition, which is determined by comparing the 1Vg to a presetvalue called the breakpoint. Figure 2.19 shows the schematic diagram of a 3 input fuzzy logic controller. The value of Vg is used to identify the current EDM status, whichhas six levels: open circuit, good, fair, bad, dual state, and shortcircuit.

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 Marco et al.,(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 technologies 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 2.20

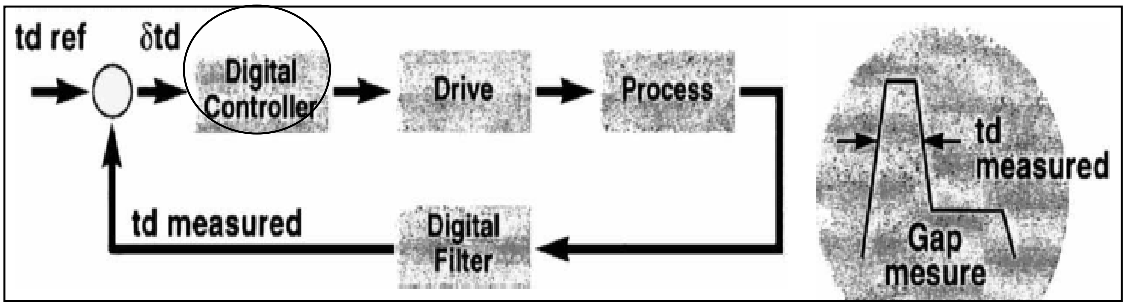


Figure 2.20: Conventional EDM control loop

Source: Kao et al. (2009)

Fuzzy logic controller works when the gap width is indirectly measured in the known wayof measuring the ignition delay time of the discharges.This ignition delay is filtered digitally and subtractedfrom a set point value .The output of the controller givesthe information to the motors to move the electrodebackward or forward in order to keep thegap width constant.

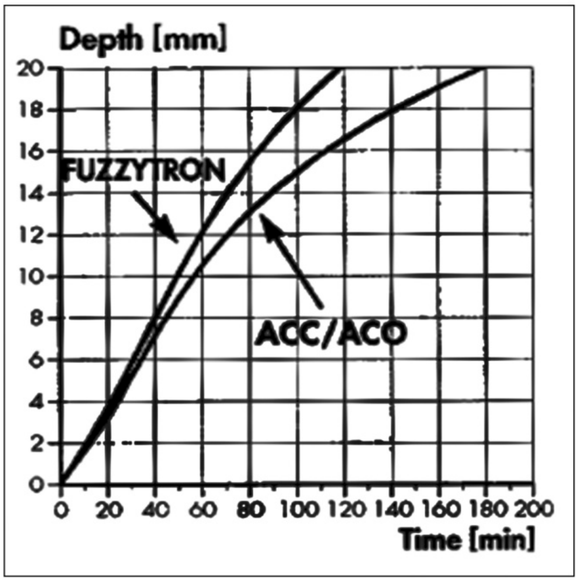


Figure 2.21: Difference between conventional EDM and fuzzy logic EDM

Source: Marco et al. (1995)

Based from figure 2.21, machining time can be saved up to 1 hour by using fuzzy logic. Although fuzzy logic helps tool wear and time to be cut down but a lot of tuning have to be done to get the perfect machining condition. The future evolution will focus on the use of neural networkstechniques joint to the adaptive fuzzy control, togive to the controller besides the self tuning capability,also a self learning feature.

2.11 PIEZOACTUATOR (PZT) USAGE IN MICRO EDM

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 and this results in changes of the material's dimensions. Figure 2.22 shows the process.

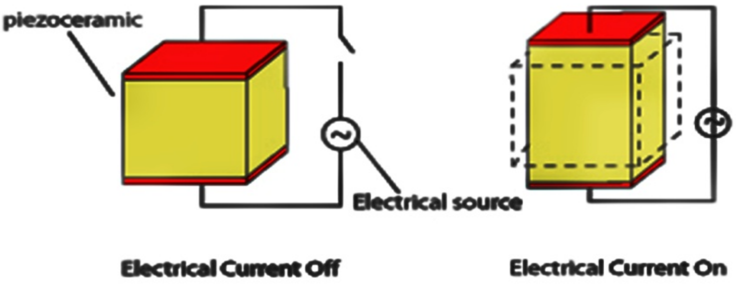


Figure 2.22: Piezoelectric process

Source:http://www.ndted.org/EducationResources/CommunityCollege/Ultrasonics/EqpmentTrans/characteristicspt.htm.(Retrieved: 11.01.2010)

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. In Piezoactuated Micro EDM process, tool wear has to be compensated continuously to reach the desired depth of machining. The required tool wear compensation is determined by the process model or based on machining experiments and the amount of tool feed is calculated before actual machining starts. During machining, the required number of pulses is counted in real time, which produces the desired spark between tool and workpiece. This data is converted into tool wear length and correction to the programmed tool wear length is made intermittently.

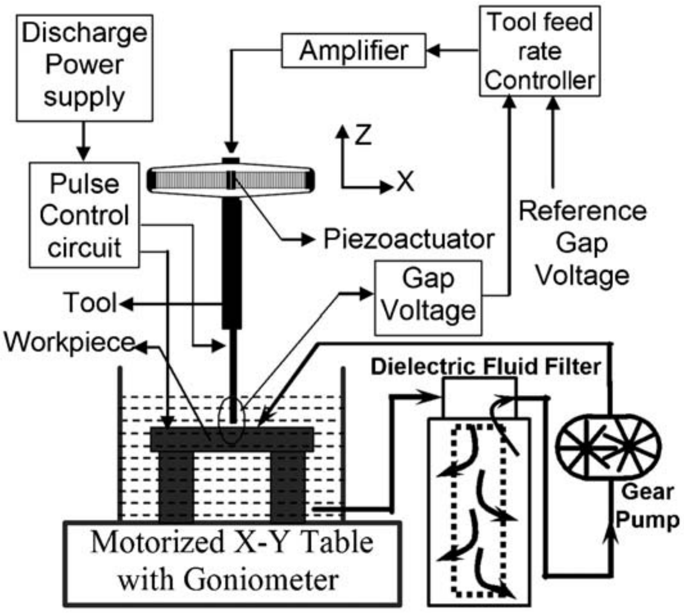


Figure 2.23: Micro EDM with PZT actuator

Source: Muralidharaet al. (2009)

Figure 2.23 shows the position and set up model for PZT actuated Micro EDM. This actuator used in controlling the feed of the tool in Z axis. The maximum displacement ofthepiezoactuatoris445 mm at150V. The PZT works with whole assembly as in figure 2.22. 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. The PZT will then move upward or downward according to the data that have been amplified form ramp controller and ramp direction. These process are shown in figure 2.24

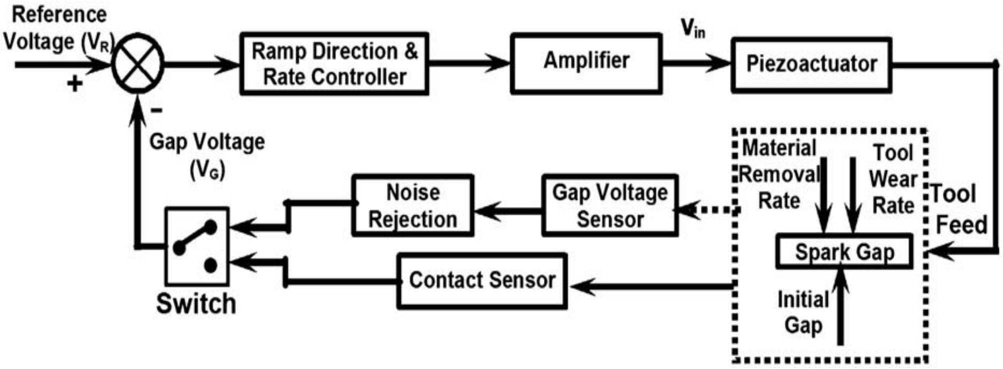


Figure 2.24: Tool feed control by PZT

Source: Muralidhara et al. (2009)

Dry Micro EDM differs from Micro EDM is only at the dielectric medium. Dry Micro EDM uses gas as dielectric medium whereas Micro EDM uses fluid. According to Masanori et al, PZT also improves in dry Micro EDM. In order to improve the frequency response, PZT is used to adjust the working gap distance.

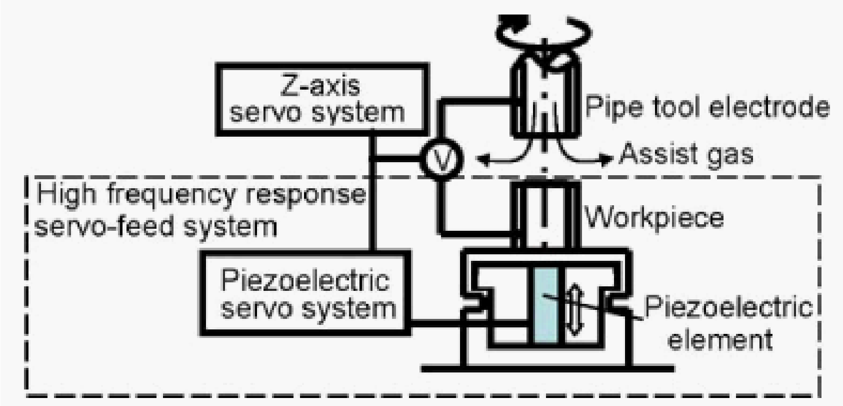


Figure 2.25: The position of PZT actuator

Source: Masanori Kunieda et al.(2004)

From figure 2.25, PZT controls the feed of the workpiece bench in Z axis rather than controlling the feed of the tool. In the discharge duration,If thelapse of time from the beginning of the discharge durationis shorter than the preset pulse duration, the simulationflow is returned to the start of the routine. Or else the gapstate is switched to the discharge interval and removal ofboth tool electrode and workpiece takes place all togetherat this moment. The removal is expressed as the wideningof the gap with a distance which is calculated by dividingthe removal volume of tool electrode or workpiece per discharge with the working area of the tool electrode orworkpiece, respectively. If short circuiting occurs during thedischarge duration, removal is not carried out. Figure 2.26 shows the example of PZT control system flow.

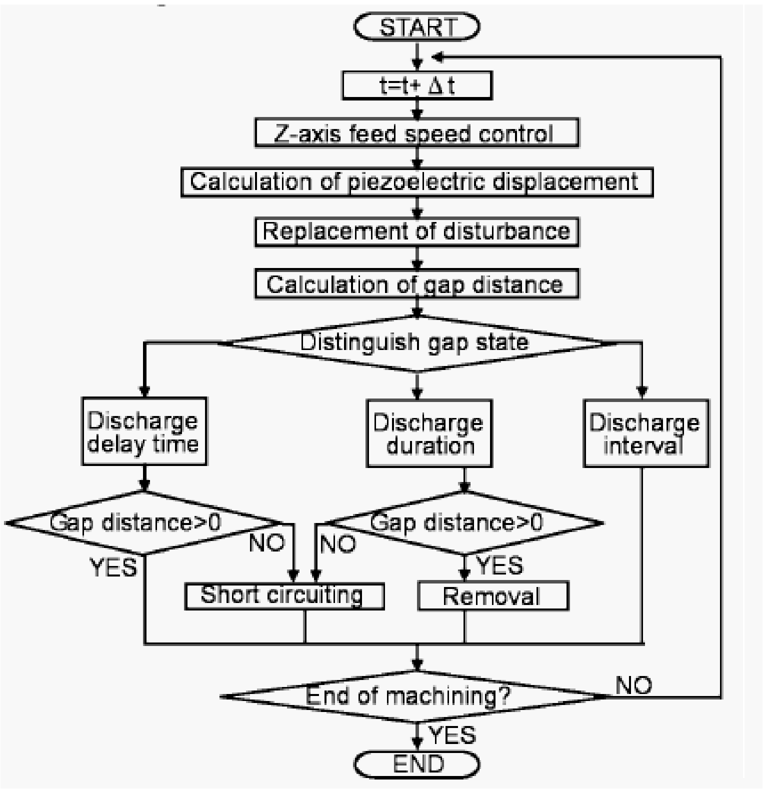


Figure 2.26: Simulation of PZT actuator

Source: Masanori Kunieda et al.(2004)

From this research, PZT stabilizes the gap control resulting in the considerable increase of the material removal rate of dry EDM. Without the PZT, the Z-axis servo control is not stable, and thus the material removal rate of dry EDM is low.

2.12 PROBLEMATIC AREAS IN MICRO EDM

Micro EDM is a modified section from conventional EDM, thus a lot of problems have arise because size of these machines are scaled down especially the size of the tool, resulting more complicated circuit and ease of short circuiting.

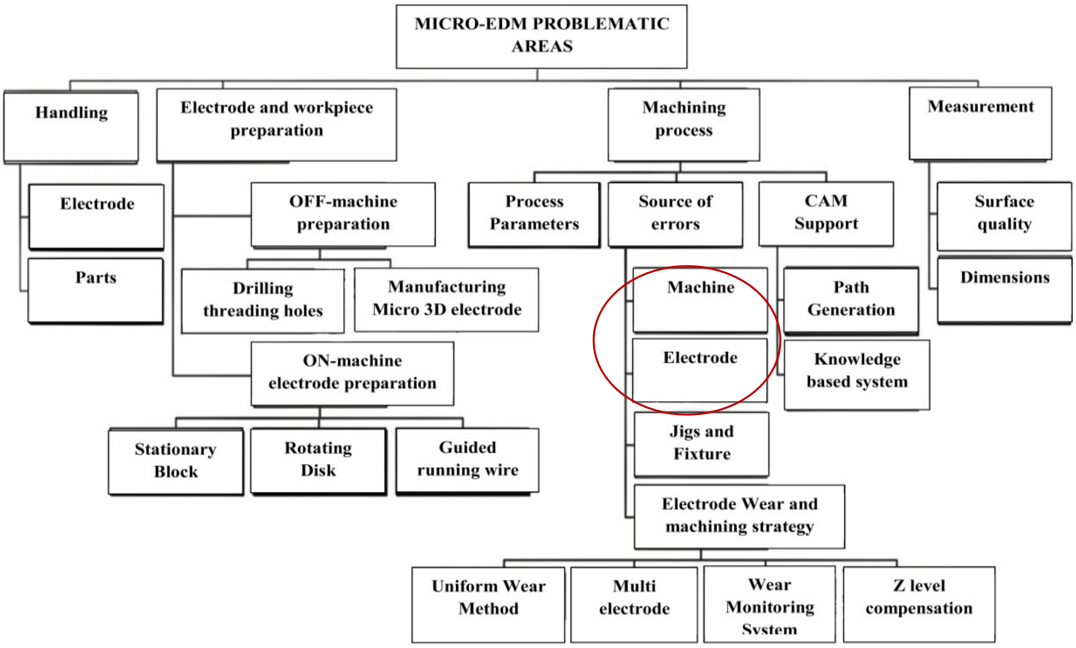


Figure 2.27: Problematic areas of Micro EDM

Source: Pham D.T et al. (2006)

Figure 2.27 shows the real mode of problematic areas in micro EDM and this report focus only in the red color circulated area. For the Micro EDM process, process planning have to be done carefully because of featured size are small and so are the machining tolerance. During process and preparation a lot of error occurred due to equipment imperfection on the one hand and the stochastic nature of the sparking process on the other. Process parameters for micro-EDM are still at the development and research stage and their effects or influences on performance measures have yet to be clarified. Due to the stochastic thermal nature of the EDM process, itis difficult to explain all of those effects influence on the process. The lack of information in this field is the main reason for the inability to develop knowledge-based systems to help the planning of micro-EDM operations.

Although CNC technology have reached an impressive level but still the usage of CAM tools in Micro EDM is lacking. One of the main reasons for the limited application of micro-EDM milling to the machining of complex 3D cavities is the difficulty of generating tool paths using existing CAM systems.

In measuring, there is no standard measuring technique in determining surface quality. Surface roughness is one of the most important aspects in micro machining. In micro EDM, Estimation of the recast layer and heat-affected zone, which affect the properties of the machined surface, requires specialized equipment because of miniature sizes of tool.

2.13 MATERIAL REMOVAL RATE (MRR) IN MICRO EDM

According to Pranthan et al.,(2008)MRR in micro EDM estimated by in situ (figure 2.28) or best known as reverse engineering method. After testing around 20 times of machining experiment and by using Minitab software, a mathematical equation has been produced:

$$\begin{aligned} MRR = {} & 0.003452 + (0.000448 \times x_1) + (0.000675 \times x_2) - (0.000308 \times x_3) \\ & - (0.000317 \times (x_1)^2) - (0.000163 \times (x_2)^2) + (0.000087 \times (x_3)^2) \\ & - 0.000121 \times (x_1 \times x_3) + 0.000362 \times (x_2 \times x_3) \end{aligned} \tag{2.1}$$

$$\begin{gathered} where, \\ x_1 = pulse\ on\ time \\ x_2 = peak\ current \\ x_3 = flushing\ pressure \end{gathered}$$

Source: Pradhan et al. (2008)

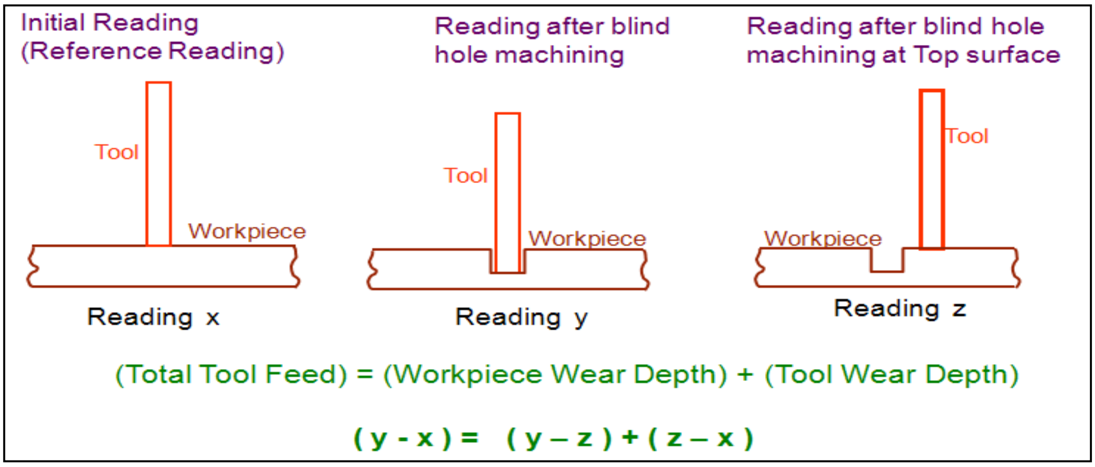


Figure 2.28: In Situ method

Source:Muralidharaet al.(2009)

By repeating 20 experiments using the method in figure 2.27, the MRR formula produced.

2.13.1 Factors in MRR

MRR are influenced by a few parameters that are the major settings in a Micro EDM machine. Figure 2.29 shows the MRR influenced by pulse on time(Ton) and peak current (Ip).

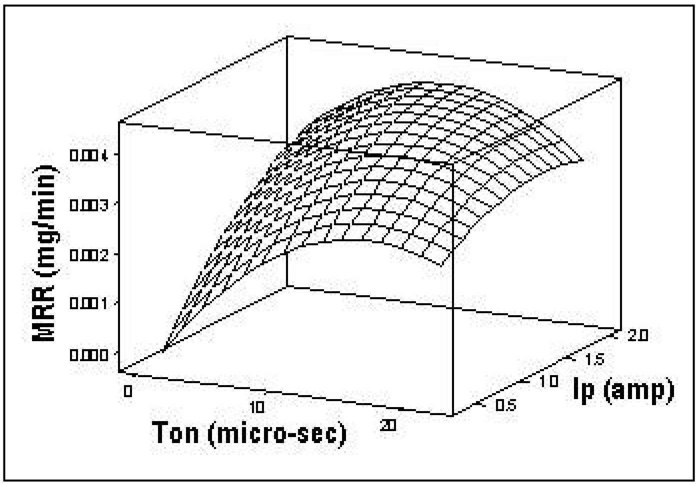


Figure2.29: Parameters influencing MRR

Source: Pradhan B. et al.(2008)

Pulse on time or Ton is the can be defined as the frequency of the current supplied to the tool for in milliseconds. The MRR seen to be increasing but decrease after 10 micro second because the frequency, although is high, but the peak current or Ip is still low. Ip is the power for every single Ton supplied. The increase of Ip does increase the MRR because without certain amount of current, the spark will be a weak spark and low MRR will occur.

Another factor that influences the MRR is the flushing pressure. Figure 2.30 shows the relation of MRR and flushing pressure.

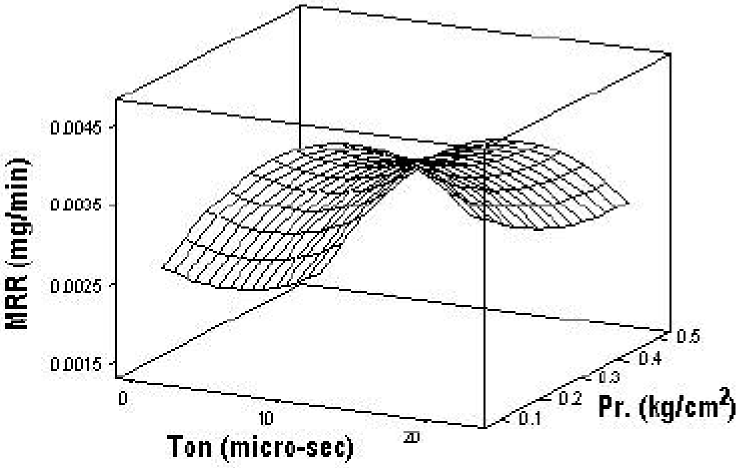


Figure 2.30: Relation between MRR and flushing pressure

Source:Pradhan B. et al.(2008)

MRR increase when flushing pressure increase because flushing prevents machined debris from being in the machining zone. If a lot of debris in the spark gap, then spark will erode the surface of debris not the surface of the work piece. Spark will just erode the surface of the debris and if the flushing pressure is high then machined debris will be flushed and this would enhance the spark to erode the work piece.

2.14 VOLUMETRIC WEAR RATIO IN MICRO EDM

According to Kunieda et al., (2007) carbon decomposition occurs happens to the electrode because the tool is positively charged and carbon particles from the hydrocarbon dielectric fluid embed to the tool. This carbon layer will protect the tool from wearing fast. The thermal properties of the tool must be high in heat conductivity. The thermal conductivity is important because when the heat flux from the spark gap is equal,higher heat conductivity results in lower temperature on theelectrode surface. Hence materials with higher heatconductivity are suitable as tool electrodes.The melting point of the tool material is also important because if the tool surface temperature is over the melting point, then tool will start to erode itself and this will make the tool wear higher.

According to Bigot S. et al.(2006) tool wear rate method that is normally calculated with the convectional EDM machine is not suitable in micro EDM. The tool wear rate is replaced by Volumetric Wear Rate(VWR) that is more suitable for Micro EDM. VWR is defined as the ratio between the eroded volume from the work piece,Vp,and the volumelost due to the wear occurring on the electrode, Ve. Measuring each of this volume would allow assessing thevolumetric wear ratio:

$$\sigma = \frac{V_e}{V_p} \tag{2.1}$$

Where,

$$V_e = \frac{\pi d_e^2}{4} \times w_e \tag{2.2}$$

$$V_p = \frac{\pi d_e^2}{4} \times w_p \tag{2.3}$$

Where,(refer to figure 2.31)

d_e=electrode diameter

d_p= diameter of eroded hole on workpiece

w_e=eroded length of tool

w_p= eroded depth

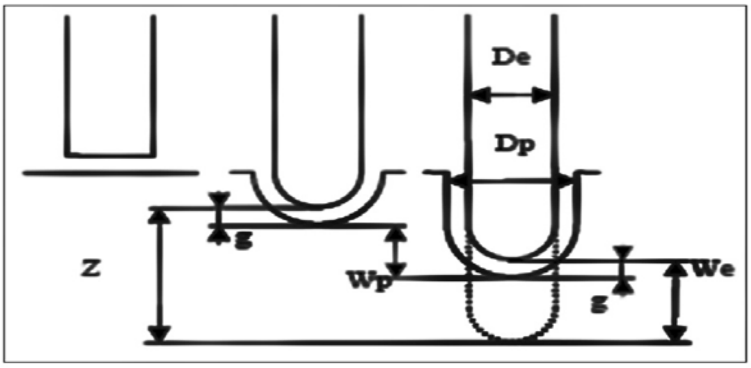
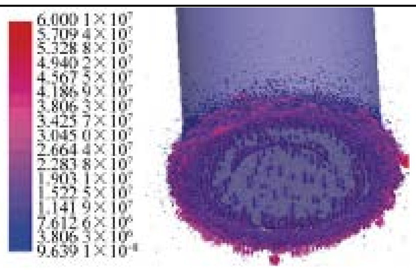


Figure 2.31: VWR parameters

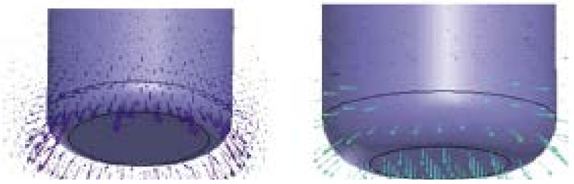
Source: Bigot S. et al. (2006)

2.15 FACTORS INFLUENCING TOOL WEAR

There a few main factors that influence the tool wear in Micro EDM. The tool material, dielectric fluid suitability, tool feed control, polarity and work piece material are the most important aspect in tool wear. Tool wear can occur in form as in Figure 2.32 shows the typical types of wear that have been simulated. There is another tool wear influence that has been studied that is the tool design. Tool design actually plays a vital part in tool wear because design can change thermal distribution and carbon deposition will be thicker if the tool has bigger surface area.



a) Initial Electrode



b) Weak loss Electrode

c) Heavy loss Electrode

Figure 2.32: Simulated result of tool wear

Source: Yuangang W. et al.(2009)

2.15.1 Tool Material Selection

The tool used must made from a material with high melting point and good thermal conductivity. High melting point material must be used because temperature in the spark gap can reach up to 6000K. From figure 2.33, temperature varies from 0 to 6000 K only at the spark gap but this depends on the amount of current and voltage supplied. If the current supplied is high, then spark ignition will be faster because of high current intensity, thus resulting in very high gap temperature. According to Eckart et al. Boron doped CVD diamond and polycrystalline diamond (PCD) are proven as resistance of tool wear compared to conventional tool such as graphite, copper and copper-tungsten composite because of high melting point and good thermal conductivity of diamond composite. Figure 2.34 shows the comparison between convectional materials and the diamond contained materials.

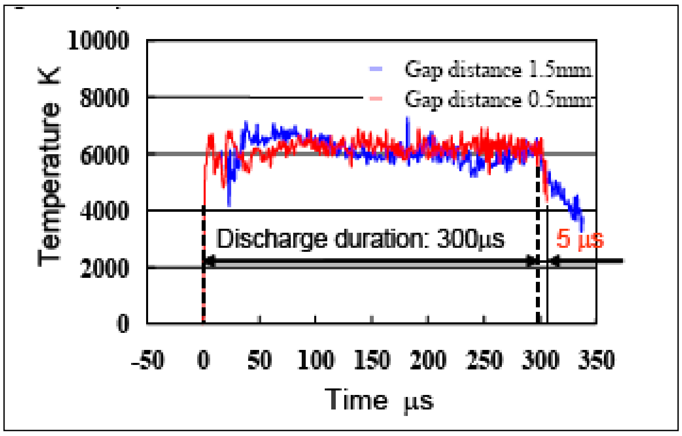


Figure 2.33: Temperature distribution

Source: Kunieda M. et al., (2007)

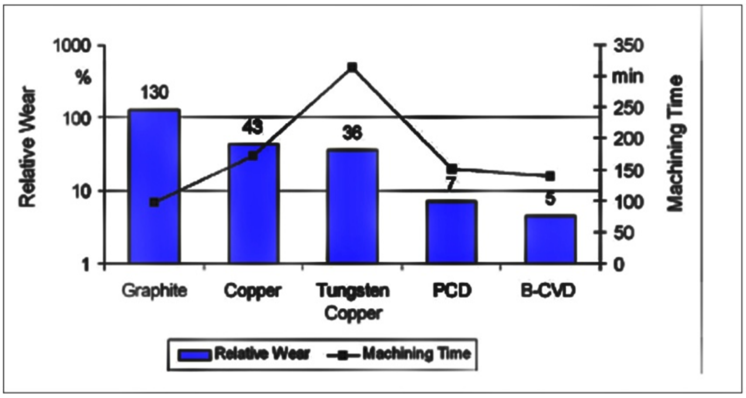


Figure 2.34: Material comparison

Source: EckartUhlmann et al.(2008)

Only certain diamond composites will result in better melting point and low tool wear.

Thermal conductivity of the tool is important as well as the material selection because higher thermal conductivity results in lower surface temperature of the tool. This helps to prevent the tool from wearing fast. If a copper electrode compared with a steel electrode, of course the steel has higher melting point but the copper electrode has better thermal conductivity. This helps the high temperature thermal distribution much better.

2.15.2 Polarity

In EDM, the tool usually positioned atpositive (anode) whereas the workpiece is negative (cathode). When hydro carbon oil such as kerosene used as the dielectric fluid, negatively charged carbon ion generated due to thermal dissociation will be decomposition at the anode surface. This layer of carbon will protect the tool surface from wear. When the carbon layer is thick, tool will be protected even in long pulse duration and high peak current. A few researchers believe that when the tool is the cathode and workpiece is anode, this improves the surface finishing of the workpiece. It is believed that the carbon layer will be created at workpiece surface and spark erosion will be mild because the carbon layer protects the workpiece from any uneven erosion. This statement does not apply to all tools. According to H.C Tsai et al.,(2003) When the tool of copper-chromium was tested on both polarity the workpiece surface result as figure 2.33

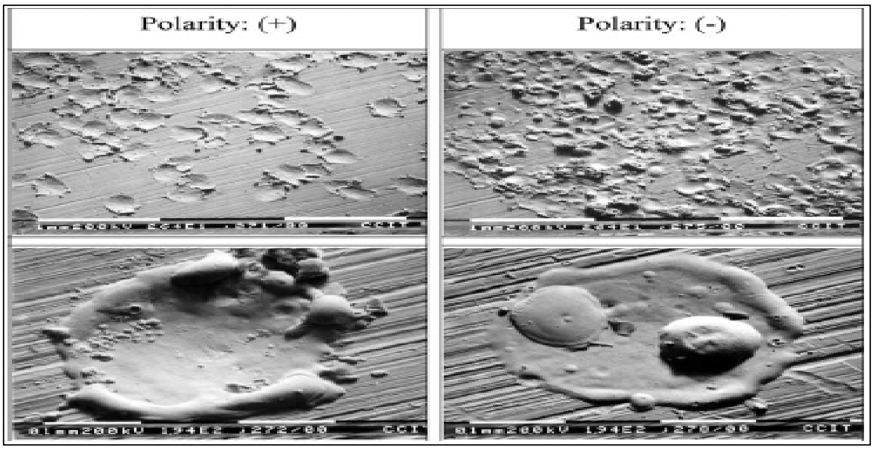


Figure 2.35: Work piece surface micrograph due to tool different polarity

Source:Tsai H.C. et al. (2003)

Based on figure 2.35, crates developed are uneven when to tool is negatively charged. The copper – chromium ions decomposed on the workpiecesurface resulting in poor material removal rate and low surface finish.

2.15.3 Tool Design

Most of Micro EDM uses cylindrical tool shape in order to produce circular holes. The main problem with cylindrical design is when the shape of the tool wears off, the holes produced would not be the same as the initial holes because burr, incomplete circle and bad surface finish would be produced. It would be a high risk to change the tool in the middle of the machining process because it is very hard to repositioned the new tool to its initial position and machining process have to be started again with new work piece. Heat flux and heat rate can be improved by redesigning the new tool. In this report there will be two proposed designs in chapter 4 with full analysis of heat flux and heat rate.

2.16 CONCLUSION

With information collected through this chapter, a Micro EDM machine with PZT tool feed system will be designed and developed. By using information collected in this chapter, new tool designs, control circuits and tool wear will be discussed thoroughly in chapter 4.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this project a flow of methodology is essential in completing the project in time. For a start the scope and the objective of this project is determined so that the flow of wok done for this project is always in time and not out of scope. Before this process is done a review on limitation and problems occurs in Micro EDM are documented. This gives the clear view of difficulties opposed in this project. These processes are represented with a flowchart in section 3.2

3.2 PROCEDURES

The procedures for this project are as illustrated is Figure 3.1.

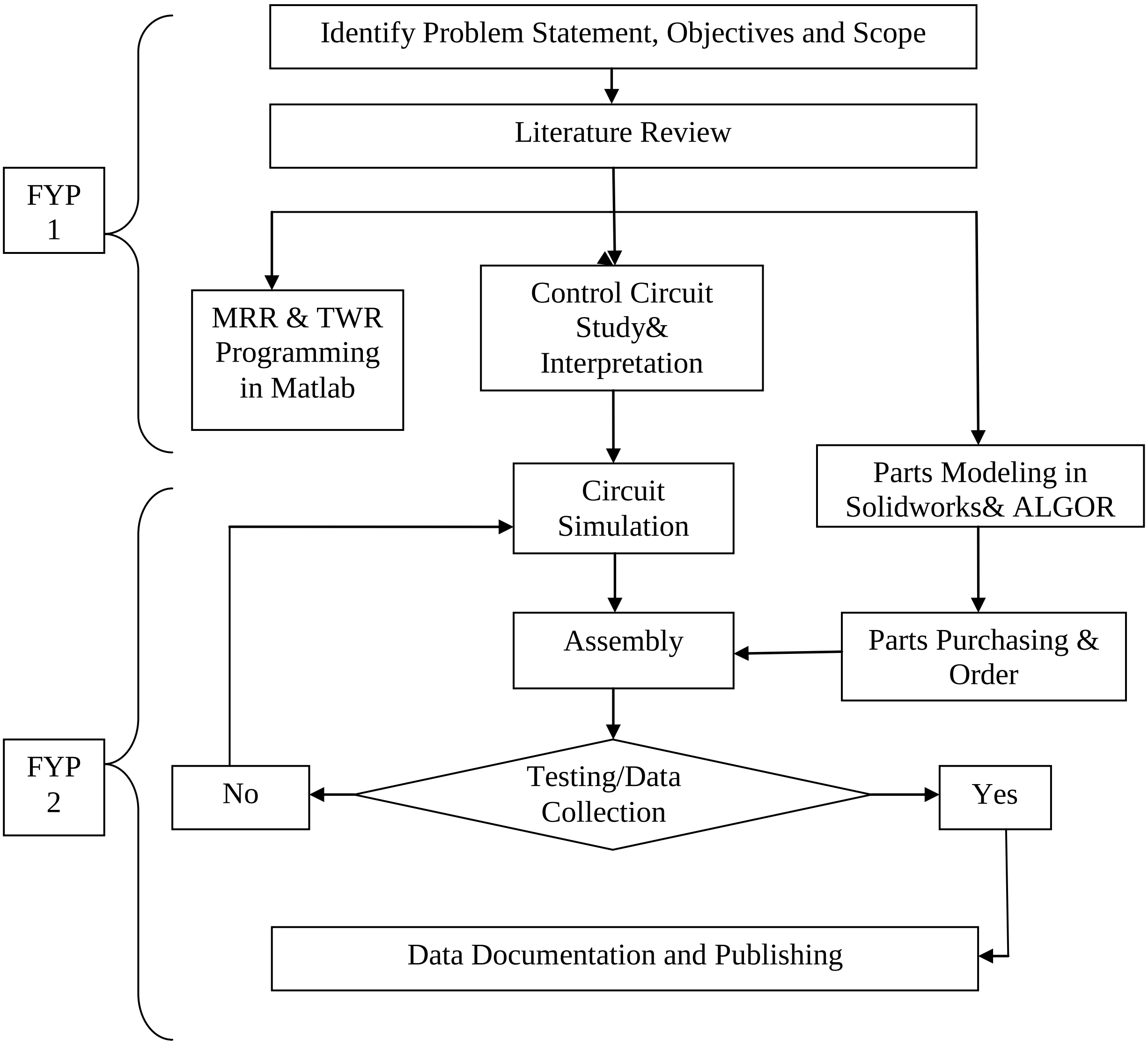


Figure 3.1: Project flowchart

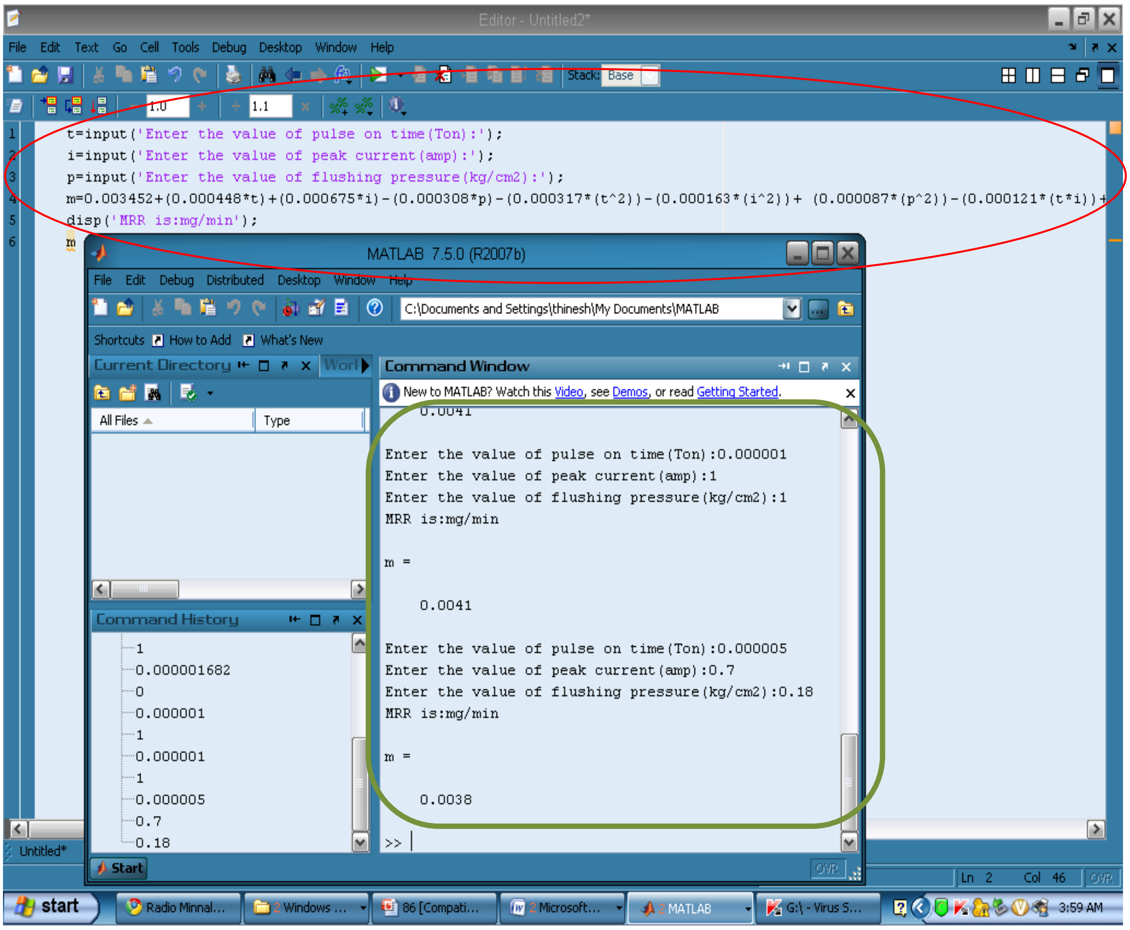
The first step of this project is to identify the project problem statement, objectives and scope to allow a proper planning and understanding of what is required within the design. The proper planning of this project is done by following Gantt Chart that is planned for Final Year Project or FYP for term 1 and 2.

MRR and TWR programming have been done using Matlab software. Control circuit study and interpretation also have been done as this is vital because this information have to be delivered to the supplier. Parts modeling and circuit simulation will be done in FYP term 2.

In FYP term 2, the circuits will be tested in Orcad software. The tool will be designed and analyzed in Algor software for thermal comparison of materials. After all analysis and simulation are done, the results are given to the supplier. The supplier will develop the machine using the data given. After development, test run of the machine will be conducted and the results of TWR will be documented for publishing purpose. If any of these test run fails, the design of the control circuit will be examined and checked again.

3.3 MRR & VWR PROGRAMMING IN MATLAB

After the process of literature review, programming for the estimation of MRR and TWR is done in Matlab Simulink software. Figure 3.2 shows the programming of MRR and figure 3.3 & 3.4 shows the VWR programming in Matlab.



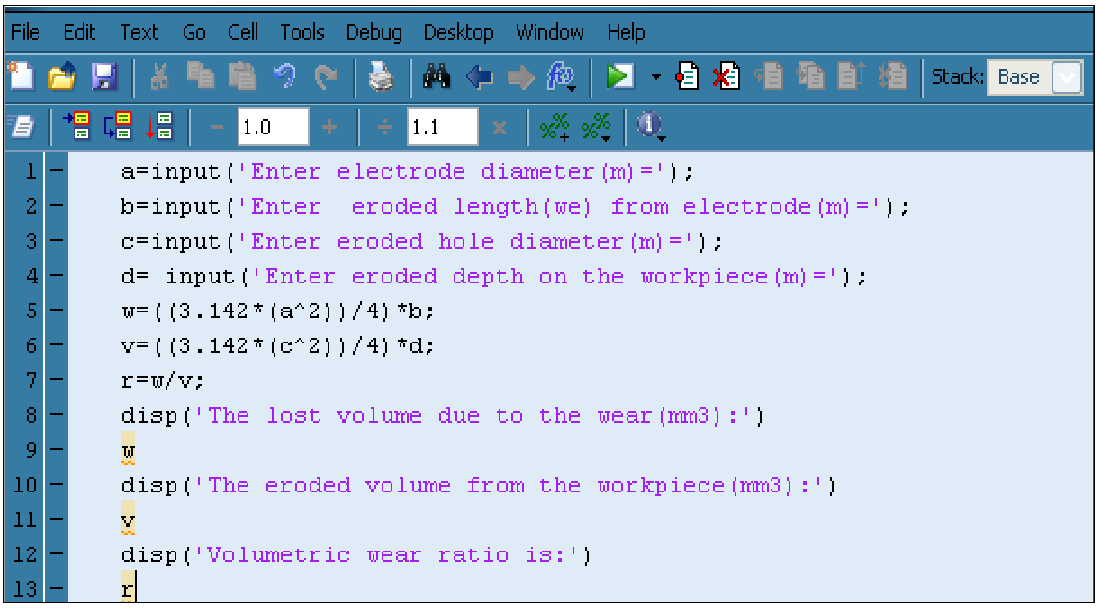
```
t=input('Enter the value of pulse on time(Ton):');
i=input('Enter the value of peak current(amp):');
p=input('Enter the value of flushing pressure(kg/cm2):');
m=0.003452+(0.000448*t)+(0.000675*i)-(0.000308*p)-(0.000317*(t^2))-(0.000163*(i^2))+ (0.000087*(p^2))-(0.000121*(t*i))+
disp('MRR is:mg/min');
m
```

```
    0.0041

Enter the value of pulse on time(Ton):0.000001
Enter the value of peak current(amp):1
Enter the value of flushing pressure(kg/cm2):1
MRR is:mg/min


m =


    0.0041

Enter the value of pulse on time(Ton):0.000005
Enter the value of peak current(amp):0.7
Enter the value of flushing pressure(kg/cm2):0.18
MRR is:mg/min


m =


    0.0038

>>
```

```
1
0.000001682
0
0.000001
1
0.000001
1
0.000005
0.7
0.18
```

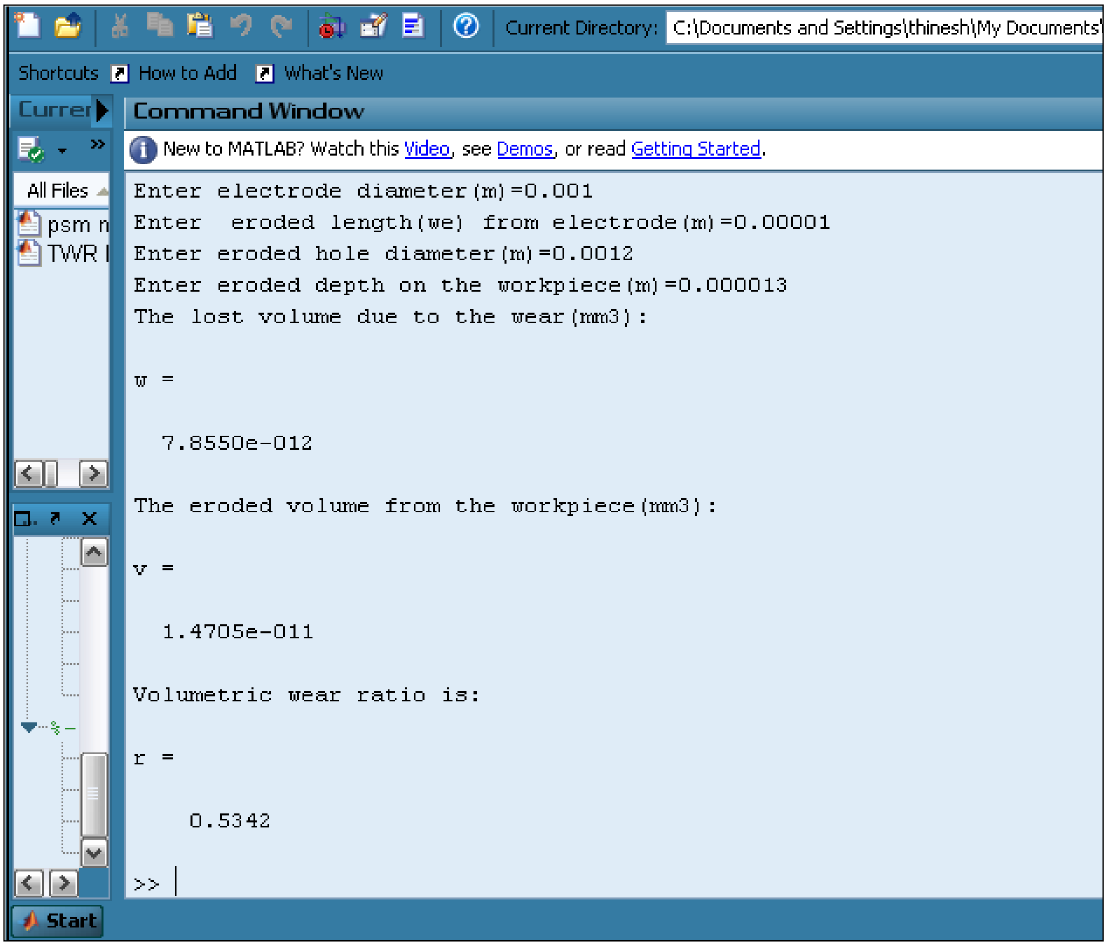
Figure 3.2: MRR programming in Matlab

From figure 3.2, the section that is inside the red oblong is the coding for the MRR whereas the output of the coding is in the light green rectangular section. The coding includes the parameters such as peak current value, flushing pressure and pulse on time. The example from figure 3.2 shows that 0.0041 mg/min is the MRR for the first example in the green section. This program is used as a estimation of MRR that should be machined in micro EDM.



```
a=input('Enter electrode diameter(m)=');
b=input('Enter  eroded length(we) from electrode(m)=');
c=input('Enter eroded hole diameter(m)=');
d= input('Enter eroded depth on the workpiece(m)=');
w=((3.142*(a^2))/4)*b;
v=((3.142*(c^2))/4)*d;
r=w/v;
disp('The lost volume due to the wear(mm3):')
w
disp('The eroded volume from the workpiece(mm3):')
v
disp('Volumetric wear ratio is:')
r
```

Figure 3.3: Coding for VWR



```
Enter electrode diameter(m)=0.001
Enter  eroded length(we) from electrode(m)=0.00001
Enter eroded hole diameter(m)=0.0012
Enter eroded depth on the workpiece(m)=0.000013
The lost volume due to the wear(mm3):

w =

  7.8550e-012

The eroded volume from the workpiece(mm3):

v =

  1.4705e-011

Volumetric wear ratio is:

r =

    0.5342

>>
```

Figure 3.4: VWR programming output

This VWR programming produces a ratio that represents the VWR. This program is used as to estimate the wear ratio of the real life micro EDM machining. From this ratio, a few modifications must be done to reduce the ratio such as changing the dielectric fluid, change the tool material and reduce the gap voltage.

3.4 TOOL DESIGN AND ANALYSIS

The design of the tool is done by using SolidWorks 2009 version and the analysis is done by using Algor. After going through sketches, only two designs are chosen for analysis. Figure 3.5 shows the first tool design whereas figure 3.6 shows the second design.

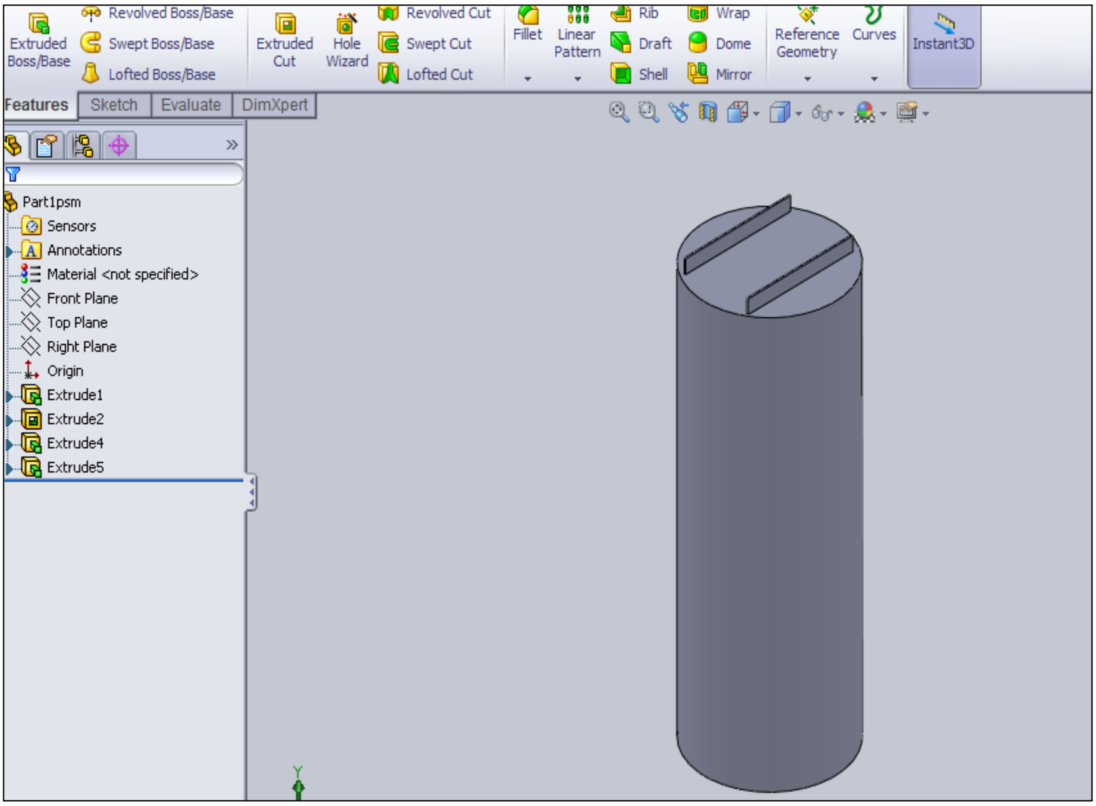


Figure 3.5: Tool design 1 in SolidWorks

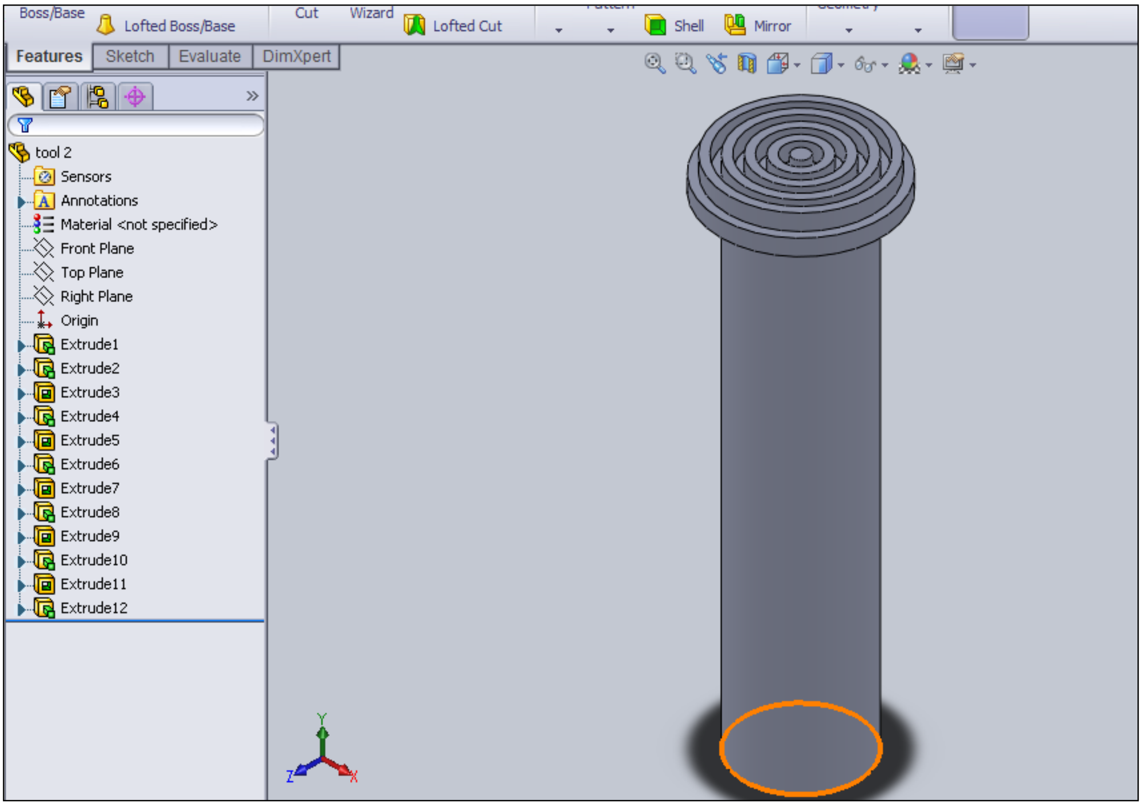


Figure 3.6: Tool design 2 in SolidWorks

After designing in SolidWorks, the designs are imported into Algor to be analyzed as two materials that are tungsten and copper. The analysis consists of the max stress and steady state heat transient. Figure 3.7a (tool design 1) and 3.7b (tool design 2) shows how the load applied whereas figure 3.8 shows the applied external temperature for both material. The red section is the where temperature 0f 1100 ^{0}C as machining temperature with 24 ^{0}C of cooling effect of dielectric fluid are distributed. In both figure 3.7a and 3.7b, the area with red nodes is the fixed because the area represents the tool holder.

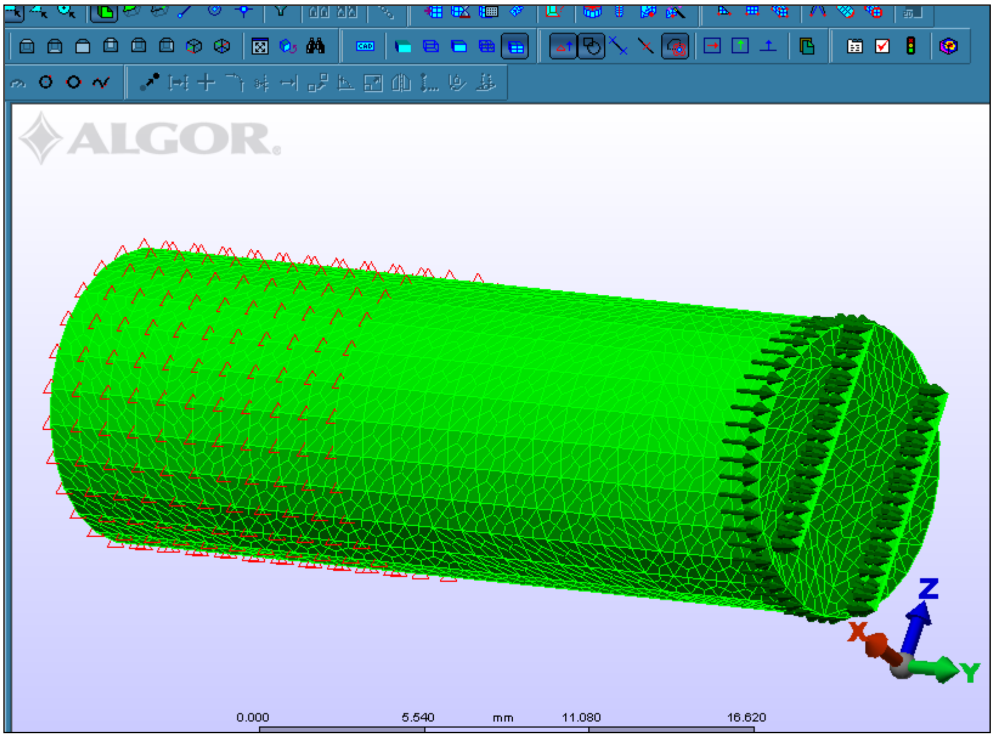


Figure 3.7a: Tool design 1 applied load

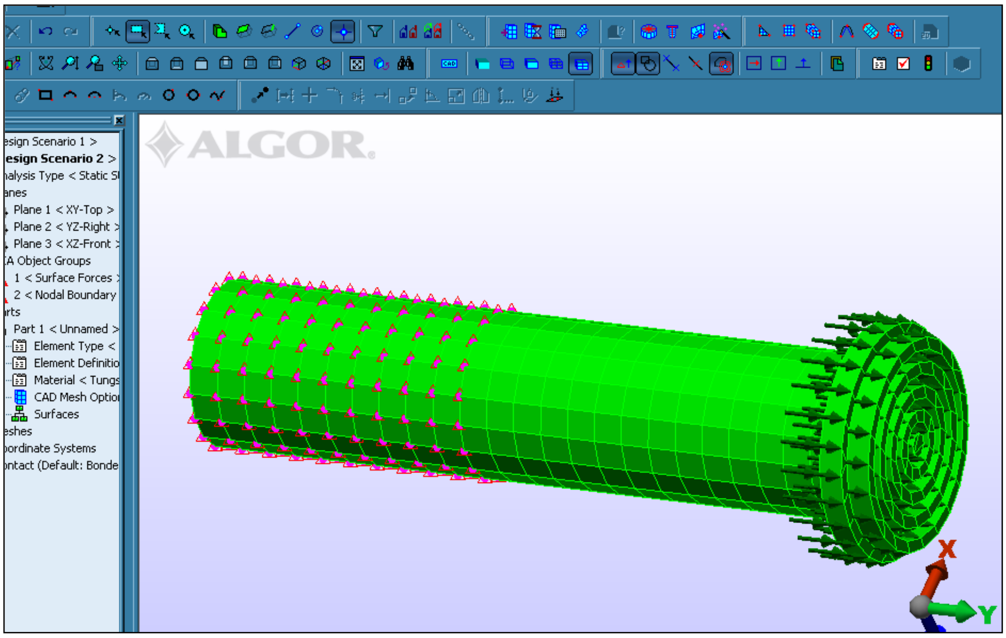


Figure 3.7b: Tool design 2 applied load

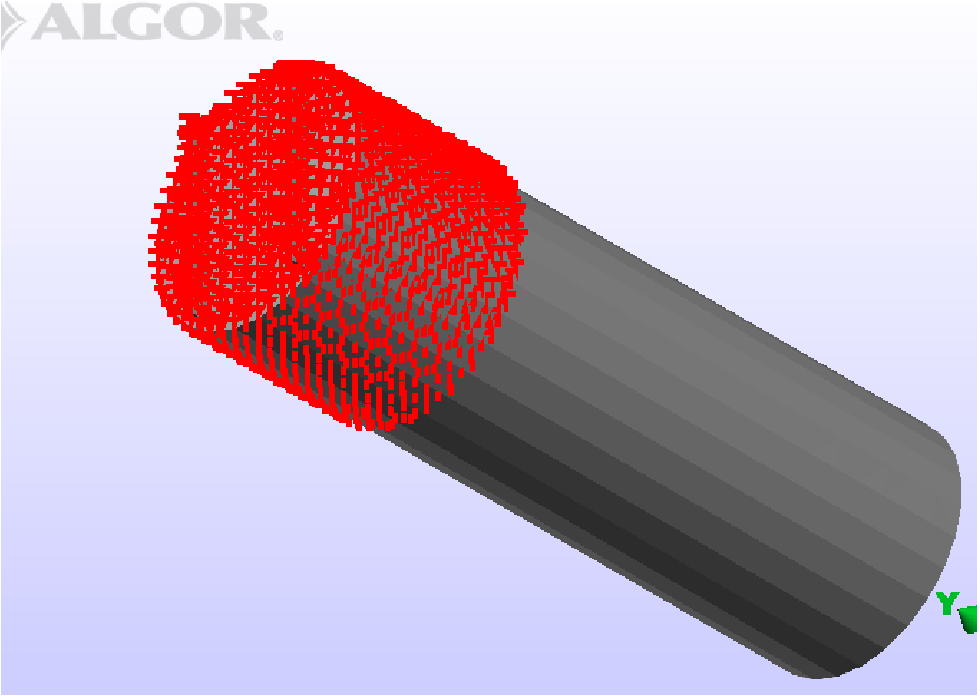


Figure 3.8: Applied temperature section of the tool in Algor

After analysis, a design is chosen to be sending for fabricating by using micro CNC machining. Analysis results and discussion are shown in the next chapter under topic 4.2

3.5 CONTROL CIRCUIT DEVELOPMENT

The control circuit is designed and tested in ORCAD software to check for any voltage leakage and circuit error. Both of these circuits were modified from normal EDM circuit to be adapted with Micro EDM. The development of the circuits are shown in chapter 4 under topic 4.2

3.6 CONCLUSION

Tool fabrication and circuit assembly were done together with the assist of the supplier.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter reveals all the simulation and experimental results in the development of the Micro EDM machine. The development of this machine consistsof three stages that are:

Stage 1: Control circuit and power circuit development
Stage 2: Tool material and design
Stage 3: Tool wear analysis

After all of these stages done, the Micro EDM machines were developed and data documentation was done.

4.2 STAGE 1: CONTROL CIRCUIT AND POWER CIRCUIT DEVELOPMENT

The control circuit consists of 3 main components usage that is a rectifier, multiplexer and a Pulse Width Modulator (PWM). Based on figure 4.0, the purpose of the rectifier is to change signal received from sensor from AC to DC signals. The negative voltage signal is only input that processed by the rectifier and the positive input processed by the Operational Amplifier (OpAmp) with the aid of multiplexer.

These signals are controlled by Metal–Oxide–Semiconductor Field-Effect Transistor (MOSFET) and these transistor gates only allow unfamiliar or unidentified signals to be processed by the rectifier. After converting the signal to DC, the signal will be send to the summing type OpAmp. At the same time positive signal from the electrode will be compared with a comparative type OpAmp by setting a reference voltage as the limit to prevent the tool from getting to near to workpiece causing high tool wear. If the signal voltage is higher than the reference voltage, the multiplexer will send a signal to the summing OpAmp to retract the PZT that is directly connected to the tool. These signals are observed by the PWD that converts the signals to the display.

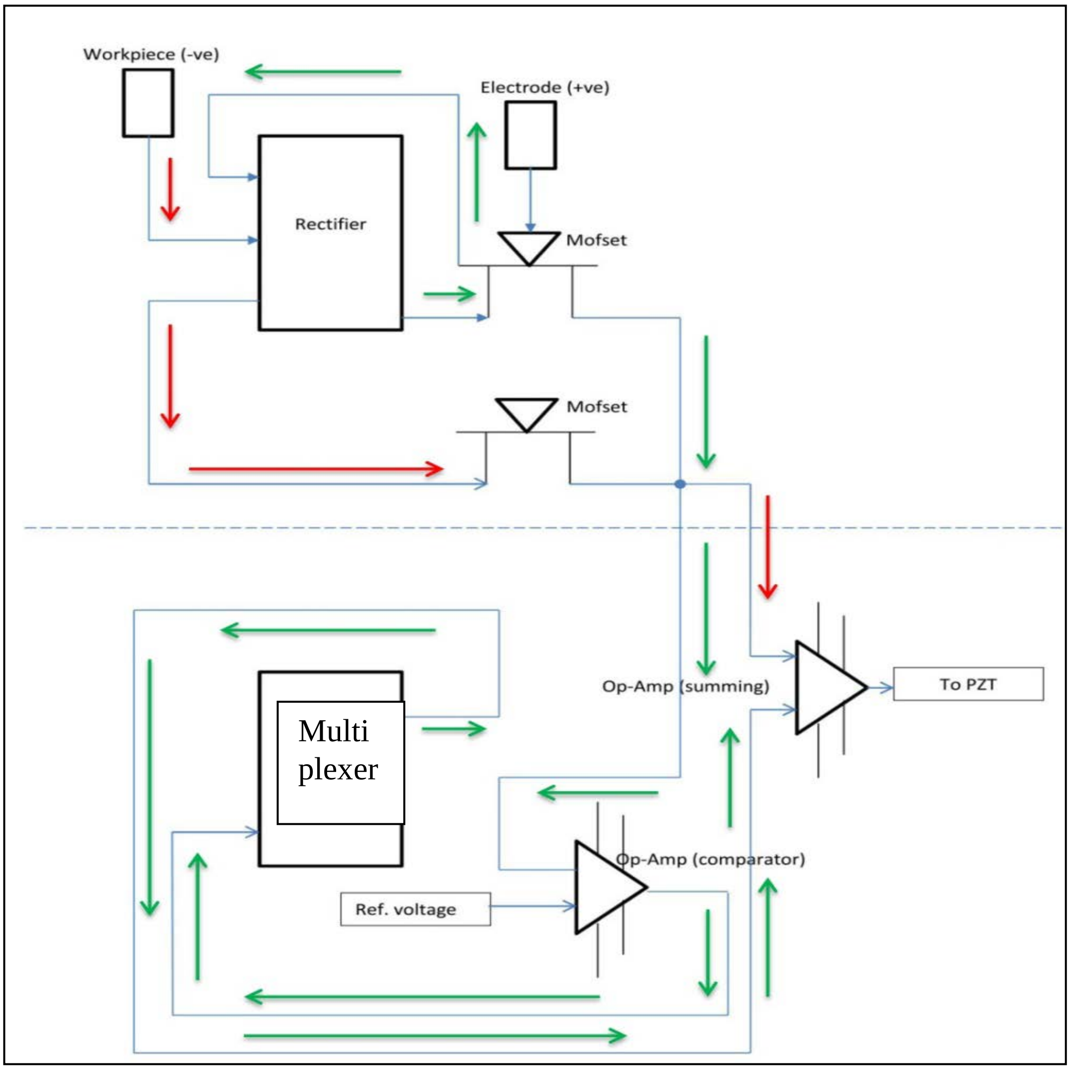


Figure 4.0: Simplification of control circuit

The control circuit and power circuit are then simulated in ORCAD v9.1 software to observe of any error. Figure 4.1 and 4.2 shows the simulation in the software. In

ORCAD software, the circuit was simulated for any voltage or current leak and circuit error.

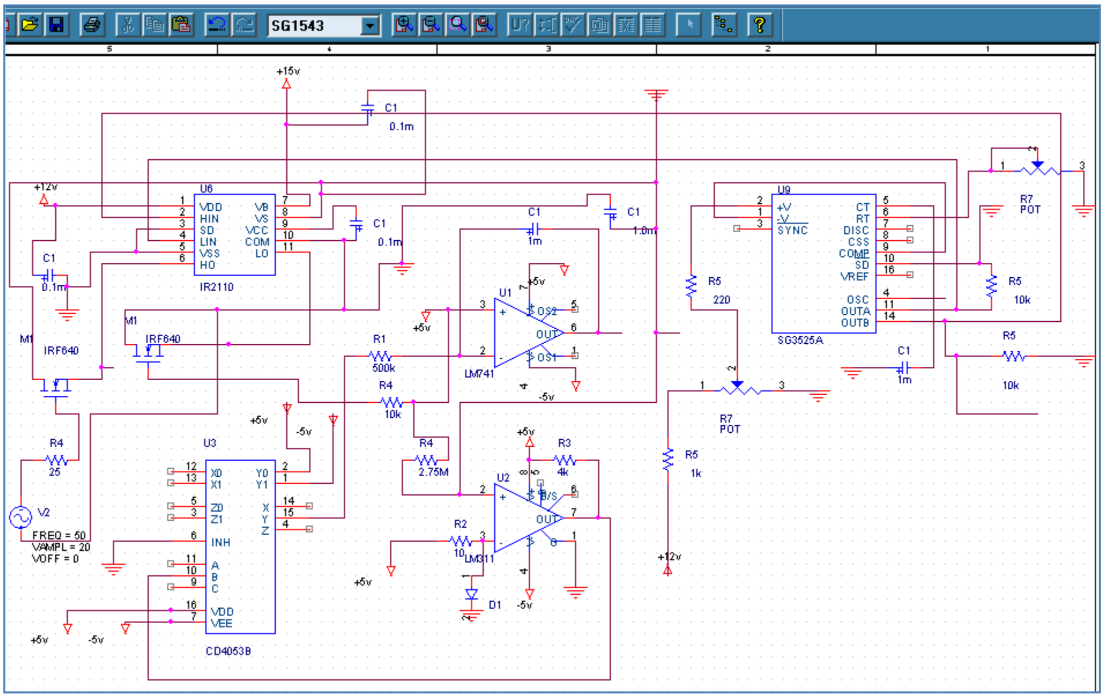


Figure 4.1: Control circuit simulation in ORCAD 9.1

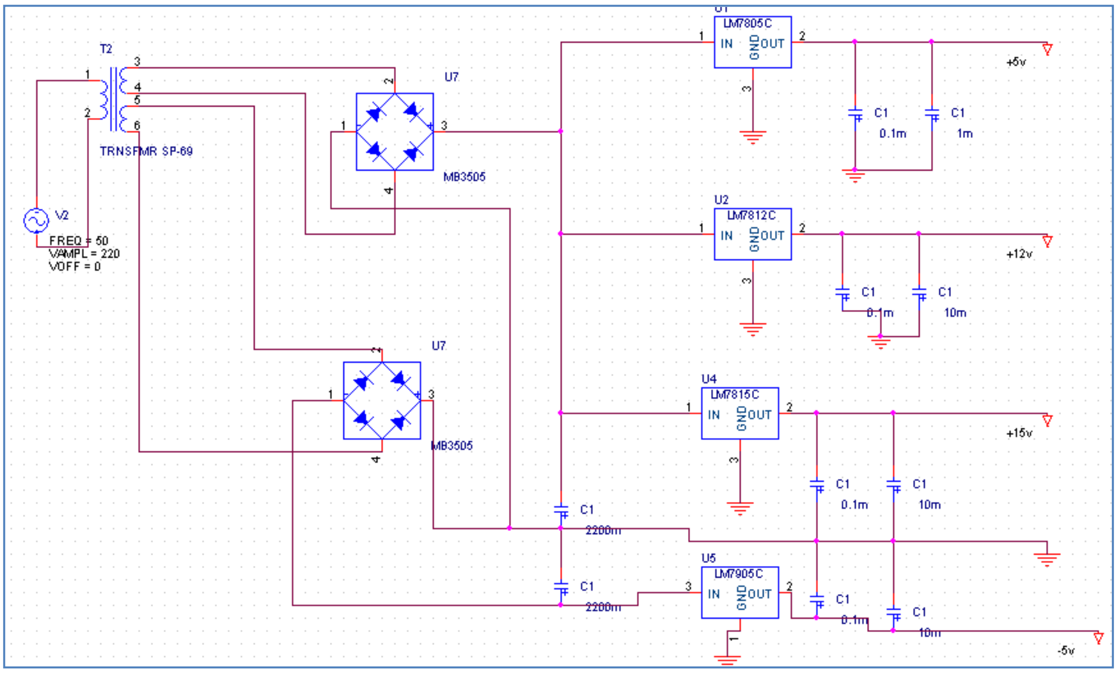


Figure 4.2: Power circuit simulation in ORCAD 9.1

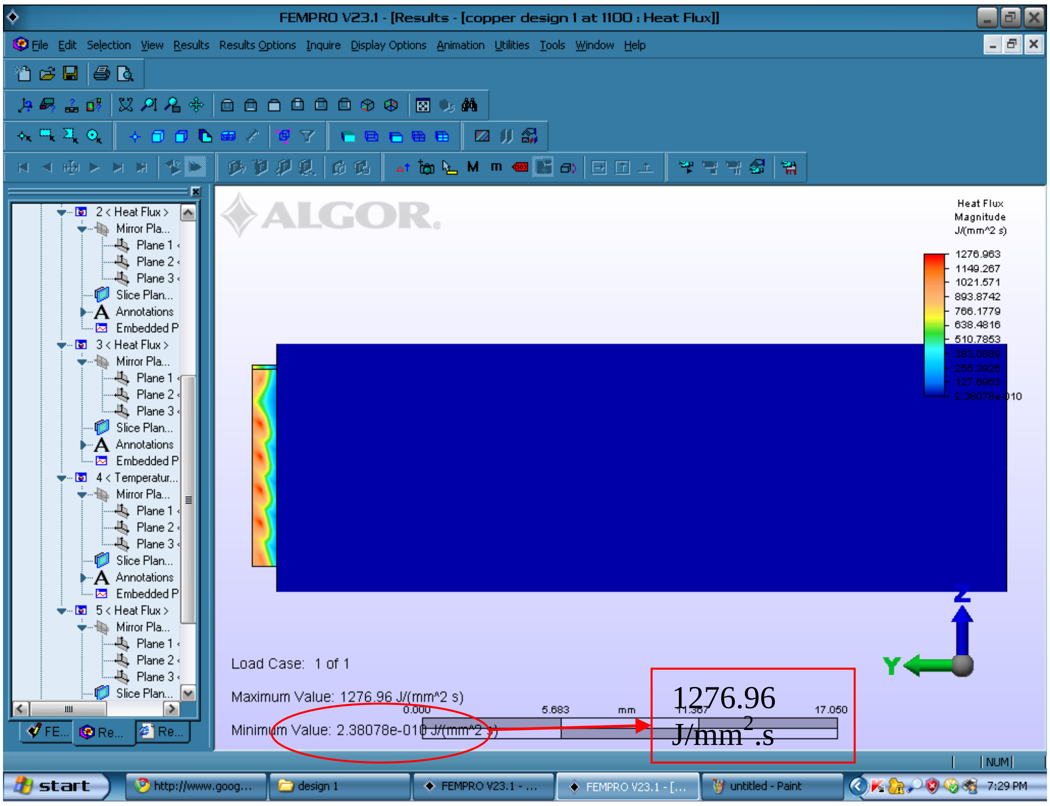
4.3 STAGE 2: TOOL MATERIAL & DESIGN

As for the tool design two materials were selected and the materials are copper and tungsten. Table 1 shows the 2 main properties of both materials.

Table 1: Material parameter comparison

PROPERTIES	COPPER	TUNGSTEN
MELTING POINT	1085 ^{0}C	3422^{0}C
THERMAL CONDUCTIVITY	410W/m·K	173W/m·K

The tool design is shown in figure 3.6 and 3.7, both of the design are analyzed in ALGOR software for maximum stress and thermal properties. Figure 4.3 and 4.4 shows the thermal heat flux results of tool design 1that are analyzed as copper and tungsten.

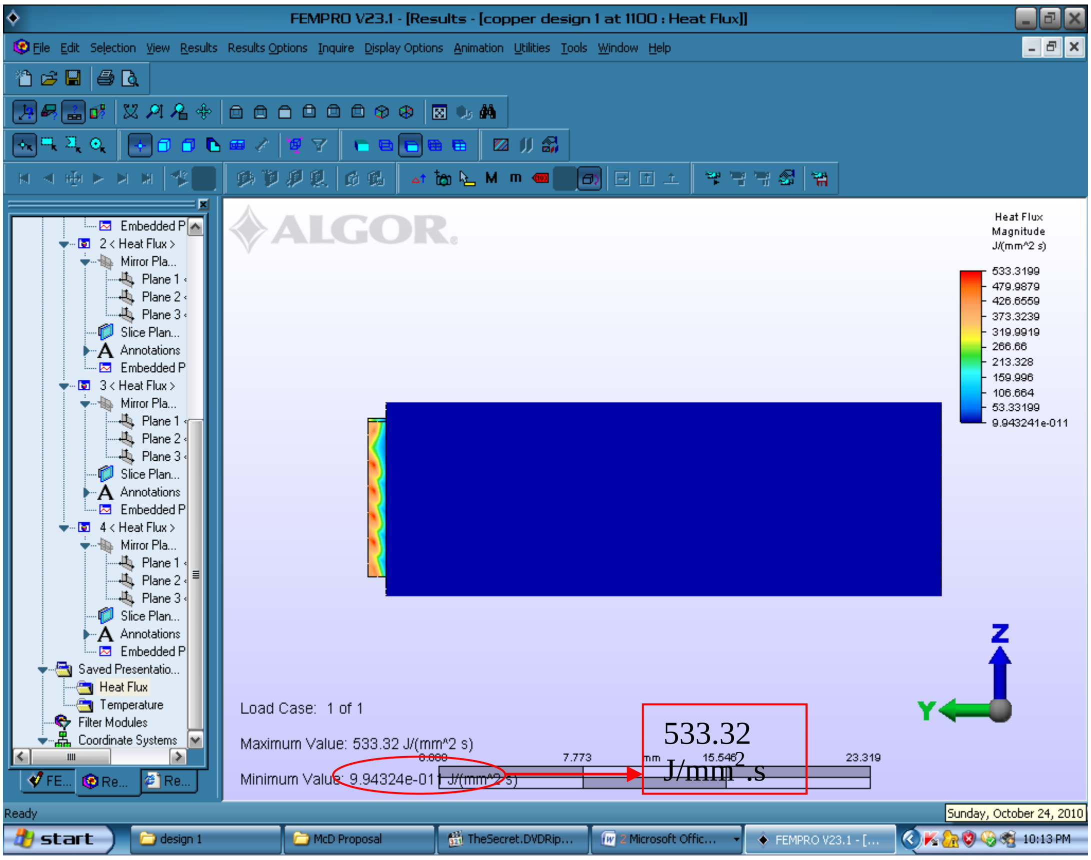


Load Case: 1 of 1

Maximum Value: 1276.96 J/(mm^2 s)

Minimum Value: 2.38078e-010 J/(mm^2 s)

Figure 4.3: Tool design 1 analyzed as copper



Load Case: 1 of 1

Maximum Value: 533.32 J/(mm^2 s)

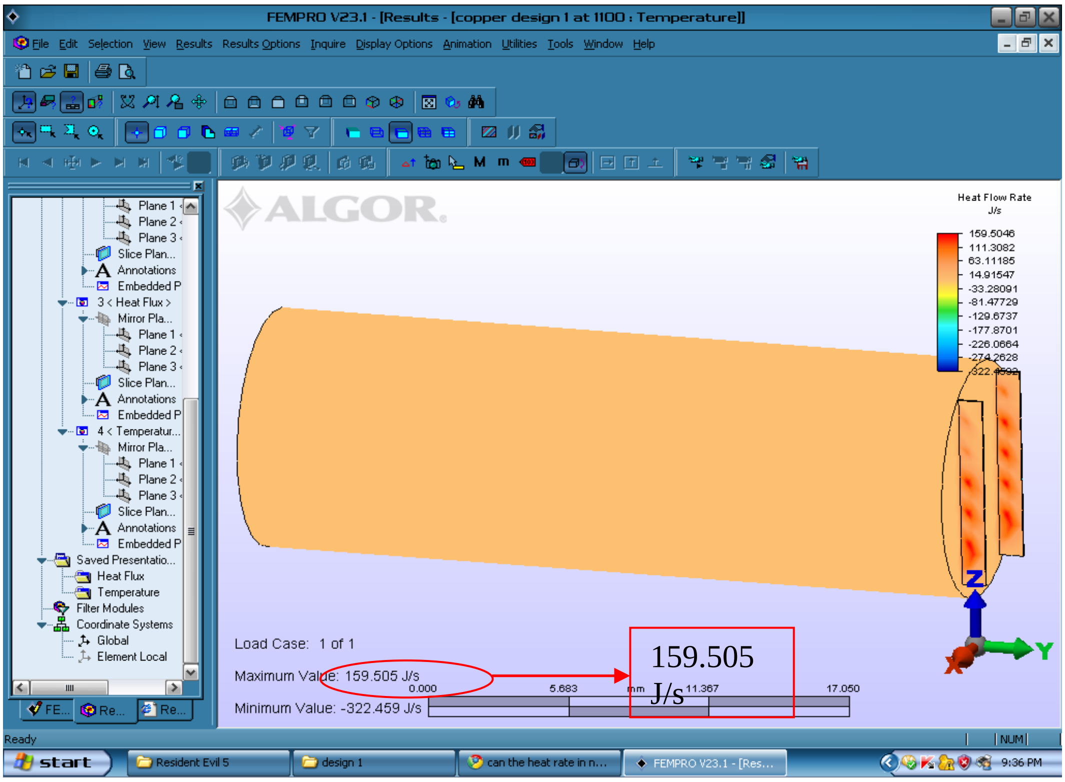
Minimum Value: 9.94324e-011 J/(mm^2 s)

533.32 J/mm^2.s

Figure 4.4: Tool design 1 analyzed as tungsten

Figure 4.3 and 4.4 shows the maximum heat flux value that can be obtained by tool design as copper and tungsten. From figure 4.3, the heat flux obtained is at1276.96 J/mm^2.s, whereas from figure 4.4 the value is 533.32 J/mm^2.s

Heat flux is the flow of energy per unit of area per unit of time. The high is the heat flux shows the high thermal conductivity ability of a material. As for Micro EDM tool, high values of heat flux means cooler surface temperature and this results slower tool wear because a large sum of energy in the form of heat transferred at a quick pace through the tool body resulting lower surface temperature than the temperature inside the tool. This is proved as figure 4.5 and 4.6 shows the heat rate of tool design 1 as copper and tungsten. Based on both of these figure, heat travels almost 160 J/s in copper whereas almost 67 J/s in tungsten. The conclusion is that copper is the best material for the tool because of its ability in high thermal conductivity than tungsten is proven.



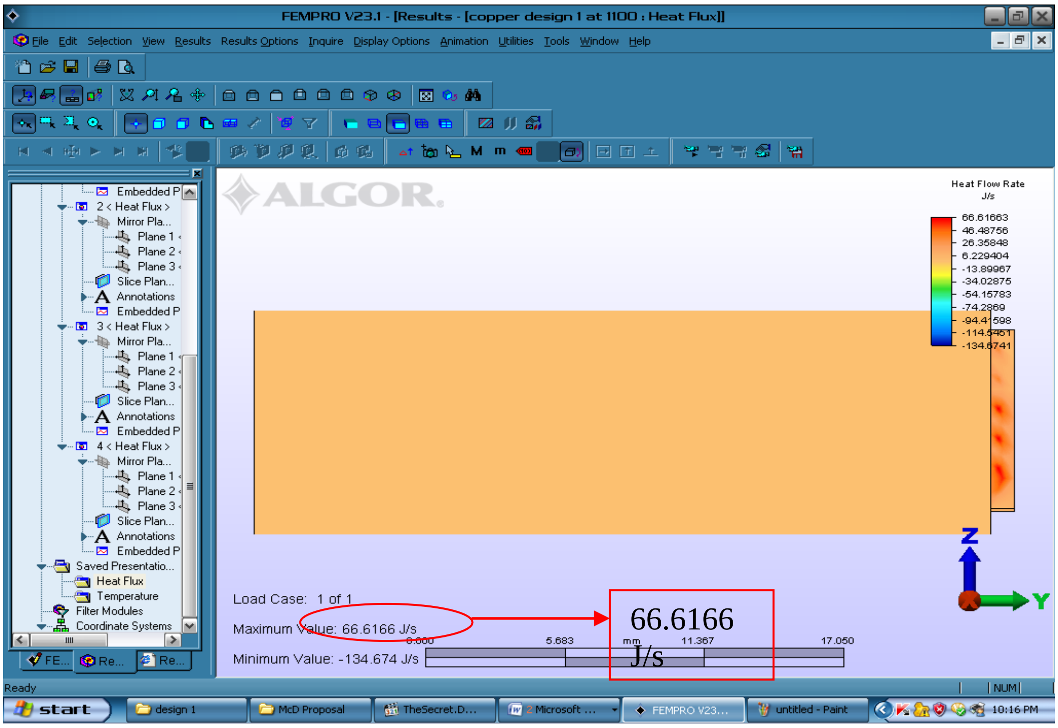
Load Case: 1 of 1

Maximum Value: 159.505 J/s

Minimum Value: -322.459 J/s

159.505 J/s

Figure 4.5: Heat rate of tool design 1as copper



Load Case: 1 of 1

Maximum Value: 66.6166 J/s

Minimum Value: -134.674 J/s

66.6166 J/s

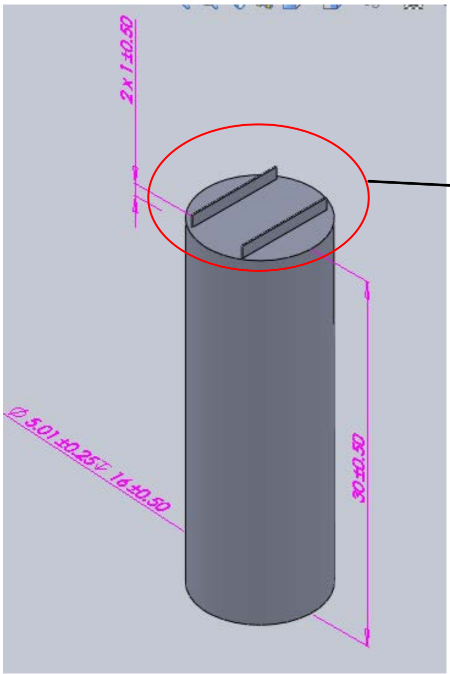
Figure 4.6: Heat rate of tool design 1as tungsten

As for design criteria, both of the designs (figure 3.6 & 3.7) were simulated in Algor as copper for heat flux and heat rate, table 2 shows the results.

Table 2: Parameters comparison between two different designs

Parameter	**Tool Design 1 (Copper)**	**Tool Design 2 (Copper)**
Heat Flux(max)	1276.96 W/mm^2	841.505 W/mm^2
Heat Rate(max)	159.505 J/s	26.241 J/s
Heat Rate/ Heat Flux = Area	0.124mm^2	0.031 mm^2

Based on table 2, tool design 1 covers more area for energy to travel than design 2. This means that thermal conductivity of design 1 is better than design 2. Design 2 has disadvantage, that is when the machining surface is eroded badly, there is no chance for the design 2 to machined again, whereas Main advantage of design 1 is when the two rectangular extruded surface are wear off, these surface are then grind off and machined to back to its initial design using Micro CNC. This process continues until the tool is too short to be machined and this is to be cost effective.



Rectangular machining surface

Figure 4.7: Tool design 1 with rectangular extruded machining surface

Circles as machining surface

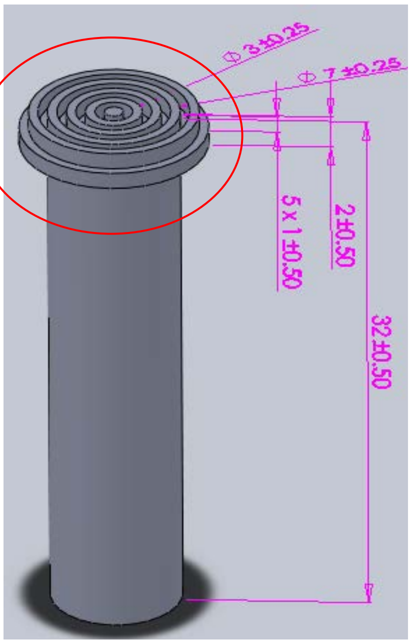


Figure 4.8: Tool design 2 with circles type machining surface

Based on figure 4.8, if the circles are eroded, the whole circles will be grinded because tool wear always happen with uneven erosion. This will lead to material waste and the design cannot be machined again unless a smaller circle shape new design is proposed.

The tool that had been chosen is tool design 1because of its ability of to conduct heat is better than design 2 and can be machined again as the design wears off in machining process.

4.4 DEVELOPMENT OF MICRO EDM

After selecting the tool design and material, the circuit and the tool design were sent to a supplier to be developed and assembled. Figure 4.9 shows the early planning of the machine.

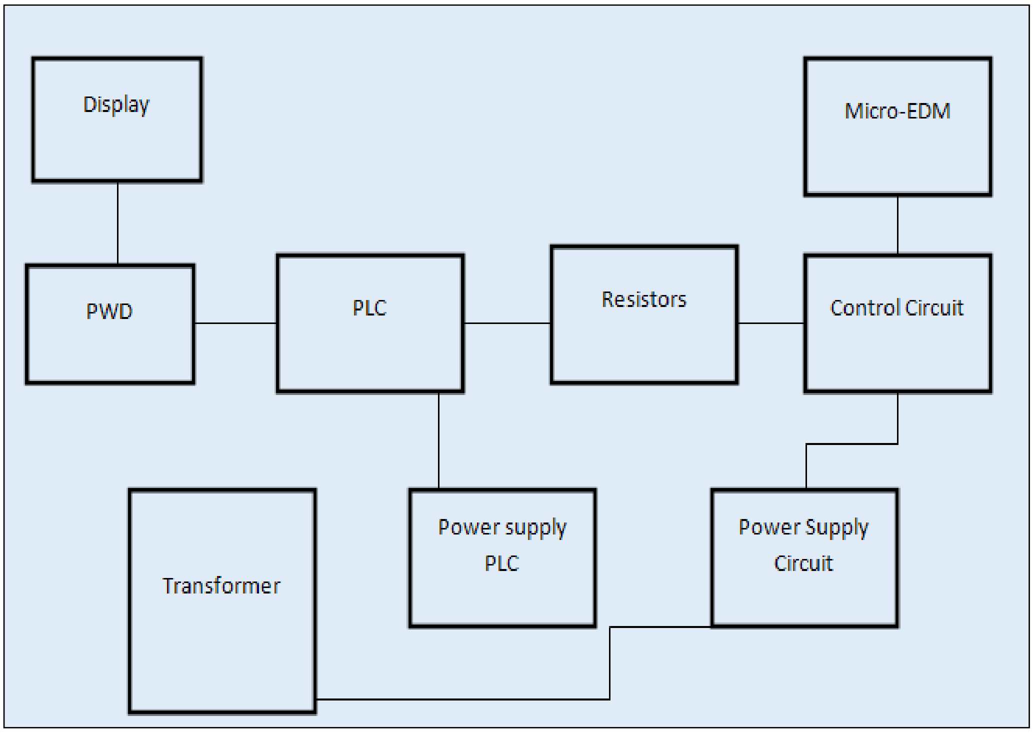


Figure 4.9: Initial planning of Micro EDM

Based on figure 4.9, the convectional EDM usually uses stepper motor to control the tool feed but for this machine development, Piezo-Actuated Transducer (PZT) is used. The developed Micro EDM is in figure 4.10

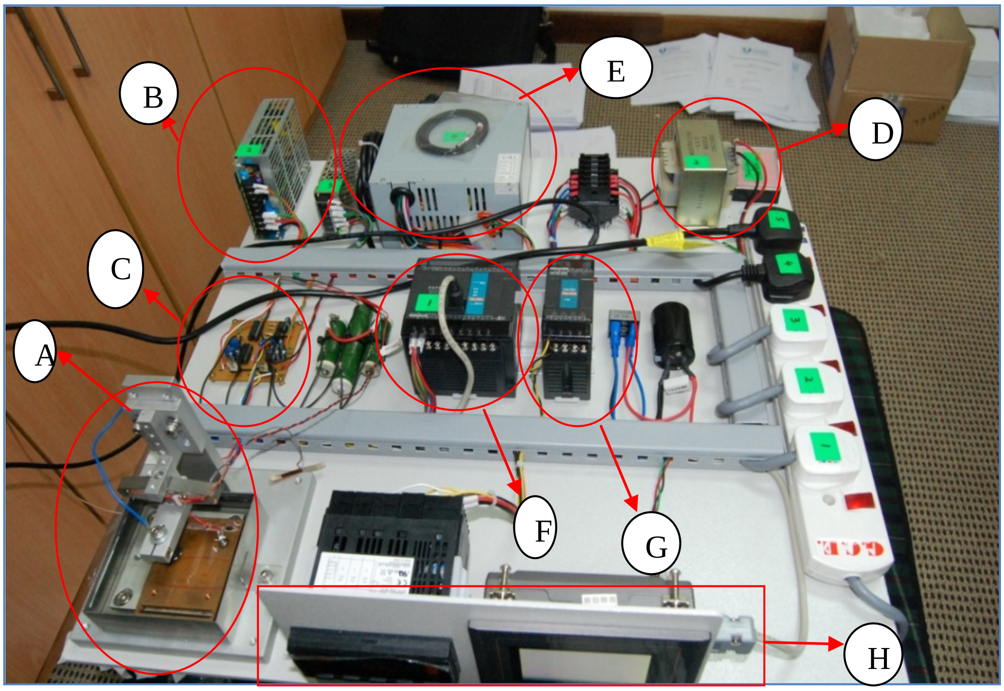


Figure 4.10: Developed Micro EDM

A - Micro EDM	E - Power supply for PLC & PWD
B – Power circuit	F - PLC
C - Control circuit	G - PWD
D – Transformer	H – Display

The Micro EDM developed as in figure 4.10, has a few parameters that have been set for the performance of the machine and the parameters are as in table 3

Table 3: Machining parameters

Parameters	Descriptions
Supplied Voltage	110 V
Gap Voltage	45- 49 V
Current	1.28 Amp
Workpiece	Copper (thickness = 5mm)
Electrode	Copper: Rectangular shape(10mm(w)x0.1mm(t)x1mm(h))
Tool Feed Control	Piezoelectric Actuator (APA 400MML)

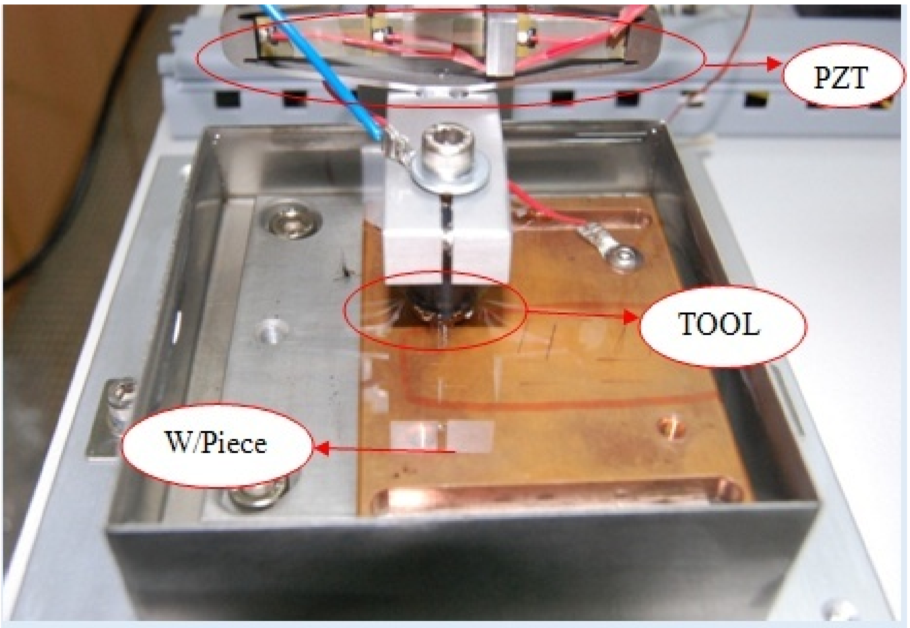


Figure 4.11: Machining undergoing

Figure 4.11 shows the machining process of Micro EDM and shows the PZT position in controlling the tool feed.

4.5 TOOL WEAR RATE (TWR)

Each experiment are done between 6 to 13 minutes, Figure 4.12 shows the machined surface after all experiment done. Tool wear calculated by measuring the tool length after every experiment. Measurements are taken 3 times also and an average will be calculated. Table 4 shows the TWR result and length measurement for 3 experiments. Below is the formula used in calculating TWR.

$$\text{TWR}\ (\text{mm}^3/\text{min}) = (\text{Volume}_{\textit{initial}} - \text{Volume}_{\textit{final}}) / \text{Machining Time} \qquad (2.4)$$

Where,

Volume*initial* = Volume of tool before each experiment

Volume*final* = Volume of tool after each experiment

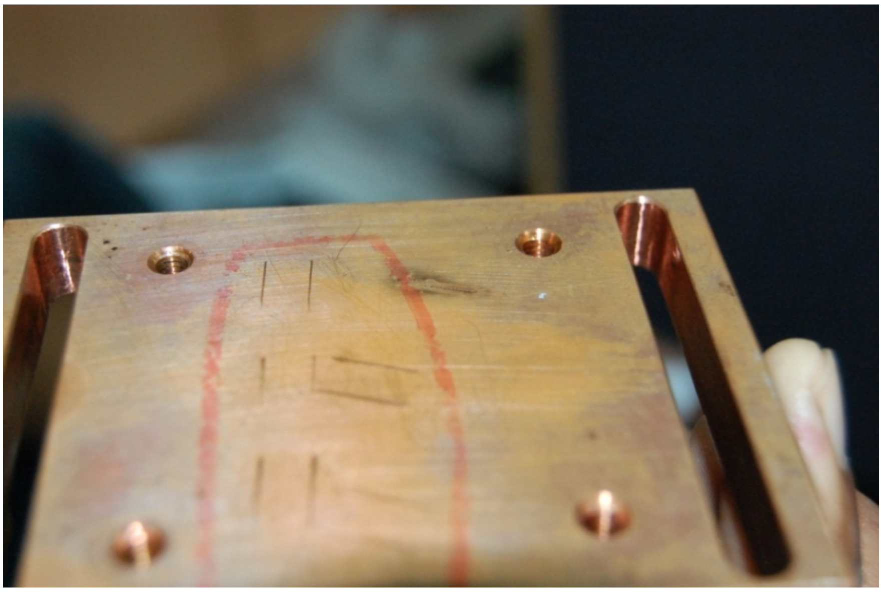


Figure 4.12: Machined surface

Table 4: Measurements and TWR result

Num ofExp	**Measured Length(mm)**	**Measured Thickness (mm)**	**Measured Width (mm)**	**Machining time (min)**	**Cum. Machining Time(min)**	**TWR (mm^3/min)**
1	1	0.1	10	13	-	Initial cond
2	0.989	0.1	10	6	19	0.000579
3	0.977	0.1	10	10	29	0.000793

Based on figure 4.15, carbon deposition can be seen all over the body of electrode and this provides better protection for the tool. There is another way in investigating tool wear that is by weighing the tool after each experiment but with carbon deposition, sometimes the tool will be heavier although it has wear off. For this experiment flushing system will be installed in future, so TWR based of tool weight will not be accurate. Based on table 4, TWR decreased in experiment 3 although machining time is longer than experiment 2 because carbon decomposition has created a layer of protection for the tool, so in experiment 3, TWR reduced.

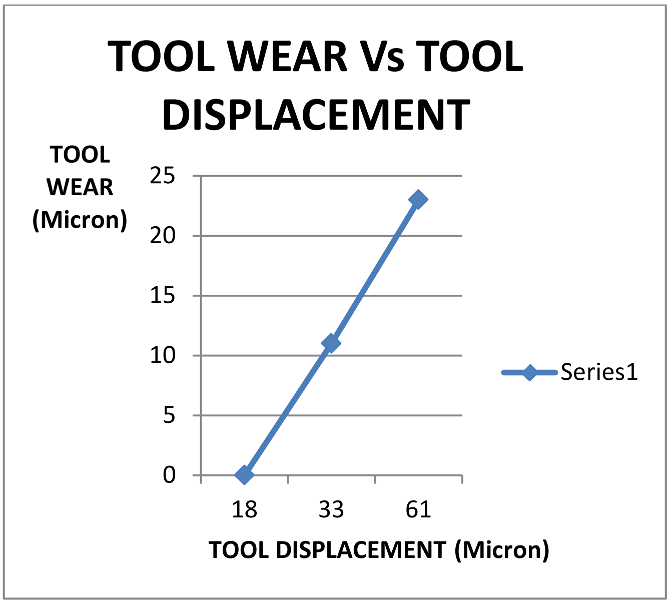


Figure 4.13: Graph on tool wear Vs tool displacement

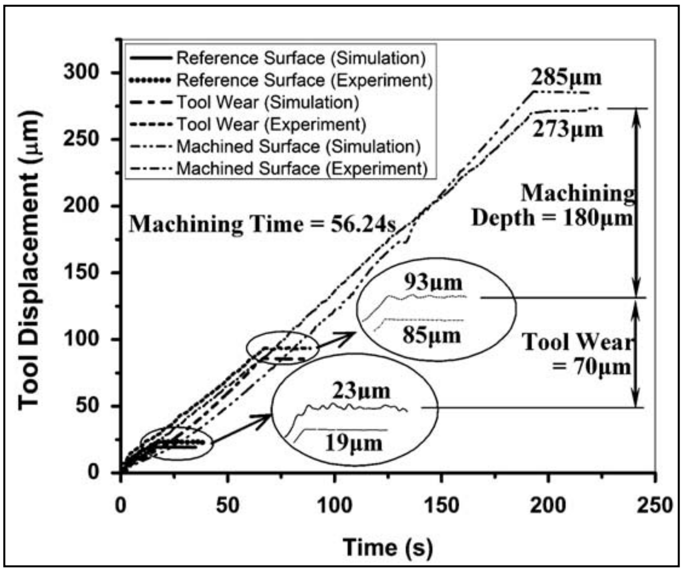


Figure 4.14: Previous study on TWR using PZT tool feed system

Source: Muralidhara et al. (2009)

According to Muralidhara et al.,(2009) figure 4.14 is the tool wear result obtained by experimental and simulation. For 180 micron of machining depth, the tool wear obtained is 70 micron. Figure 10 shows the result that for 61 micron tool displacement, only 23 micron tool wear measured. Figure 4.15 shows the tool under scope.

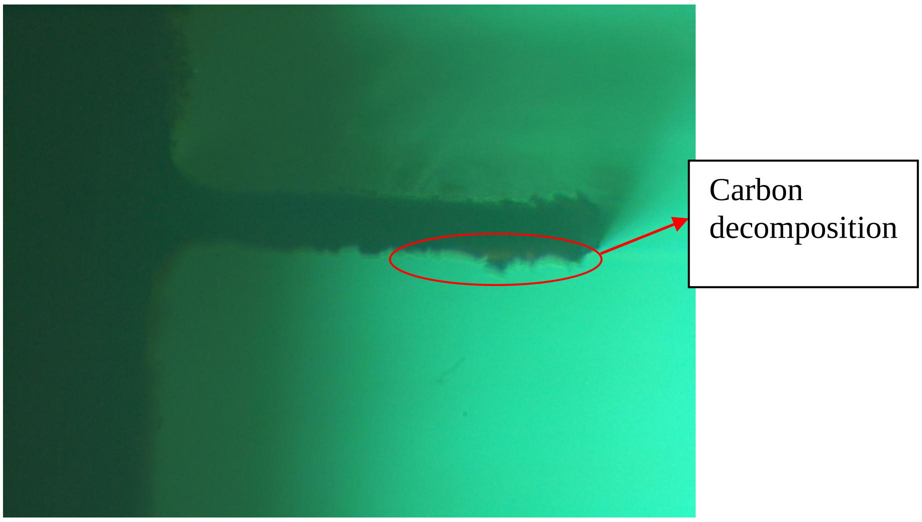


Figure 4.15: Tool under micro scope

4.6 CONCLUSION

The machine development was successful and only few test run could be made because of the cost of fabricating the tool is very high. Although only 3 experiments have been done, the resultsare better than other PZT experiments done in the past. The carbon decomposition proves to protect the tool surface from severe tool wear and the PZT system did recovers the tool from severe tool wear.

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

All the experiments were done and there are a few limitations and problems that occurred during this project. Although there were a few obstacles but the project finished early than scheduled.

5.2 LIMITATIONS

There were a few matters and problems arise that influences the result of the experiment. The measurements of the tool were taken by using a microscope owned by the faculty. This scope has been used by many users, the accuracy and precision of the scope is not 100%. There is no weekly based calibration done but only done twice per year. This type of instrument error is likely common and always researches recommended to give a margin of result accuracy. A sum of financial support was spent because of lack of facilities such as Micro CNC to machine the tool. Suppliers were given the responsibility in assembling the machine. The experience gained in this project is only on designing the machine for the suppliers but no experience gained from the assembly process of the machine.

5.3 CONCLUSION

This project was a success in pioneering Micro EDM in Malaysia. Tool wear in Micro EDM are reduced by PZT technology and the result has been proven to be in track with other PZT research. Although Nano EDM is emerging, but this a stepping stone in Micro EDM technology and hoped to be used vastly for micro machining.

5.4 RECOMMENDATION AND FUTURE PROSPECT

The Micro EDM can be improved with the combine use of orbiting tool system and PZT. With orbiting tool system the tool will orbit with a certain RPM and tool feed will be controlled by PZT tool feed system. This type of combine system machining can improve the TWR and MRR but needs a lot of expenditure to be developed. Complicated Programmable Logic Control or PLC must be developed in controlling these combined technologies Micro EDM. In future, Micro EDM will be vastly used in precision manufacturing and micro holes filters. Micro EDM must be equipped with self learning capability if to be used in mass production machining.

REFERENCES

Aditya Shah, Vishal Prajapati, Pavan Patel andAkashPandey. 2007. Development of Pulsed DC Supply For Micro EDM, *UGC National Conference on Advances in Computer Integrated Manufacturing (NCACIM)*

Yan B.H, Wang A.C., Huang C.Y., Huang F.Y. 2002 . Study of precision micro-holes in borosilicate glass using micro EDM combined with micro ultrasonic vibration machining, *International Journal of Machine Tools & Manufacture*.**42**: 1105–1111

Pham D.T., Dimov S.S., Bigot S., Ivanov A., Popov K. 2006.Micro-EDMrecent developments and research issues, Manufacturing Engineering Centre, Cardiff University, Cardiff, UK

Eberhard Bamberg and SumetHeamawatanachai.2009. Orbital electrode actuation to improve efficiency of drilling micro-holes by micro-EDM,*Journal of Materials ProcessingTtechnology*.**209**: 1826–1834

EckartUhlmann and Markus Roehner. 2008. Investigations on Reduction of Tool Electrode Wear in Micro-EDM Using Novel Electrode Materials, *CIRP Journal of Manufacturing Science and Technology,* pp. 92–96

Leão F.N., and Pashby.2004.*Journal of Materials Processing Technology*.**149**: 341–346

Prihandana G.S., Mahardika M., Hamdi M., Wong Y.S., andKimiyukiMitsui.2009.*International Journal of Machine Tools & Manufacture*.**49**:1035–1041

Han Ming Chow, Lieh-Dai Yang, Ching-Tien Lin, and Yuan-Feng Chen. 2008.*Journal of Materials Processing Technology*.**195**:160–170)

Tsai H.C, Yan B.H.,Huang F.Y. 2003. EDM Performance of Cu/Cr – based Composite Electrodes, *International Journal of Machine Tools & Manufacture*.**43**: 245–252

Zhang J.H., Lee T.C., Lau W.S., and Ai X. 1997. Spark erosion with ultrasonic frequency, *Journal of Materials Processing Technology*.**68**: 83–88

Davim J.P.,Maranhao M., Cabral G., andGracio J.2009.Performance of Cutting Tools in Machining Cu/W Alloys for Application in EDM Electrodes.*Int. Journal of Refractory Metals and Hard Materials*.**27**(4): 676–682.

Kalpakjian and Schmid. 2007.*Manufacturing Engineering and Technology*, 5th ed. page 850, Essex: Prentice

Egashira K. andMasuzawa T. 1999 .Microultrasonic machining by the application of work piece vibration, *CIRP Annals—Manufacturing Technology*.**48**:131–134

Kao C.C and Shih A.J. 2009. Design and tuning of a fuzzy logic controller for micro-hole electrical discharge machining. *Journal of Manufacturing Processes*

Marco Boccadoro and Dr. ir.Dauw D.F.1995 .About the Application of fuzzy controllers in high-performance die-sinking EDM machines,**44**:147-150

Masanori Kunieda, Tsutomu Takayal andShintaro Nakano.2004 .Improvement of Dry EDM Characteristics Using Piezoelectric Actuator,*CIRP Annals - Manufacturing Technology*.**53** : 183-186

Kunieda M., Lauwers B., Rajukar K.P., Schumacher B.M. 2007. Advancing EDM through Fundamental Insight into the Process.*CIRP Annals-Manufacturing Technology*.**54**(2): 64-87

Muralidhara ,NileshJ.Vasa and SingaperumalMakaram. 2009 . Investigations on a directly coupled piezoactuated tool feed system for micro-electro-discharge machine,*International Journal of Machine Tools & Manufacture*.**49**: 1197–1203

Mohd Abbas N., Solomon D.G., FuadBahari M.D. 2007 .A review on current research trends in electrical discharge machining(EDM).*International Journal of Machine Tools & Manufacture*.**47**: 1214–1228

Ogawa Hitoshi, NogamiTeruo and MarimotoIwao.2009 .Study of micro machining of metals by EDM with high frequency vibration, TakushimaPrefectual Industrial Technology Center, 1999–2001.

Pradhan,B. B., Kibria G. and Bhattacharyya B.2008 .Modeling of Micro-EDM Process Parameters through Response Surface Methodology, *Competitive Manufacturing - Proc. of the 2nd Intl. & 23rd AIMTDR Conf.*

Bigot S., Ivanov A., and Popov K. 2006. A study of the micro EDM electrode wear, Manufacturing Engineering Centre, Cardiff University, Cardiff, UK

Shabgard, Sadizadeh and Kakoulvand.2009 .The Effect of Ultrasonic Vibration of Workpiecein Electrical Discharge Machining ofAISIH13 Tool Steel,*World Academy of Science, Engineering and Technology*.**52**

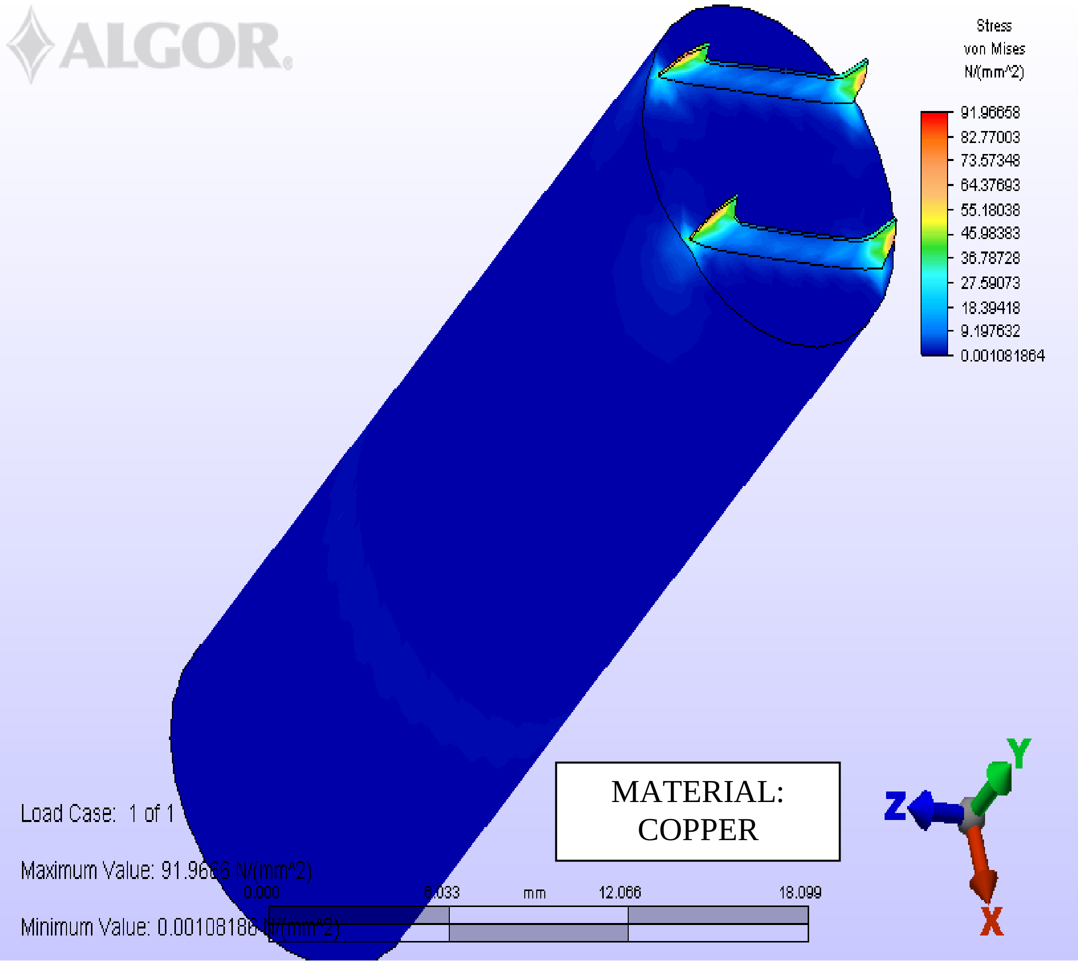
Thoe T.H., Aspinwall D.K., andKilley N. 1991 .Combined ultrasonic and electrical discharge machining of ceramic coated nickel alloy, *Journal of Materials Processing Technology*.**92–93**: 323–328

Yih-fong T., Fu-chenHow C. 2005 .Investigation into some surface characteristics of electrical dischargemachined SKD-11 using powder-suspension dielectric oil*Journal of Materials Processing Technology*.**170**: 385–391

Yuangang W., Fuling W., and Jin W. 2009.Wear-resist Electrodes for Micro-EDM.*Chinese Journal of Aeronautics*.**22**(3): 339-342

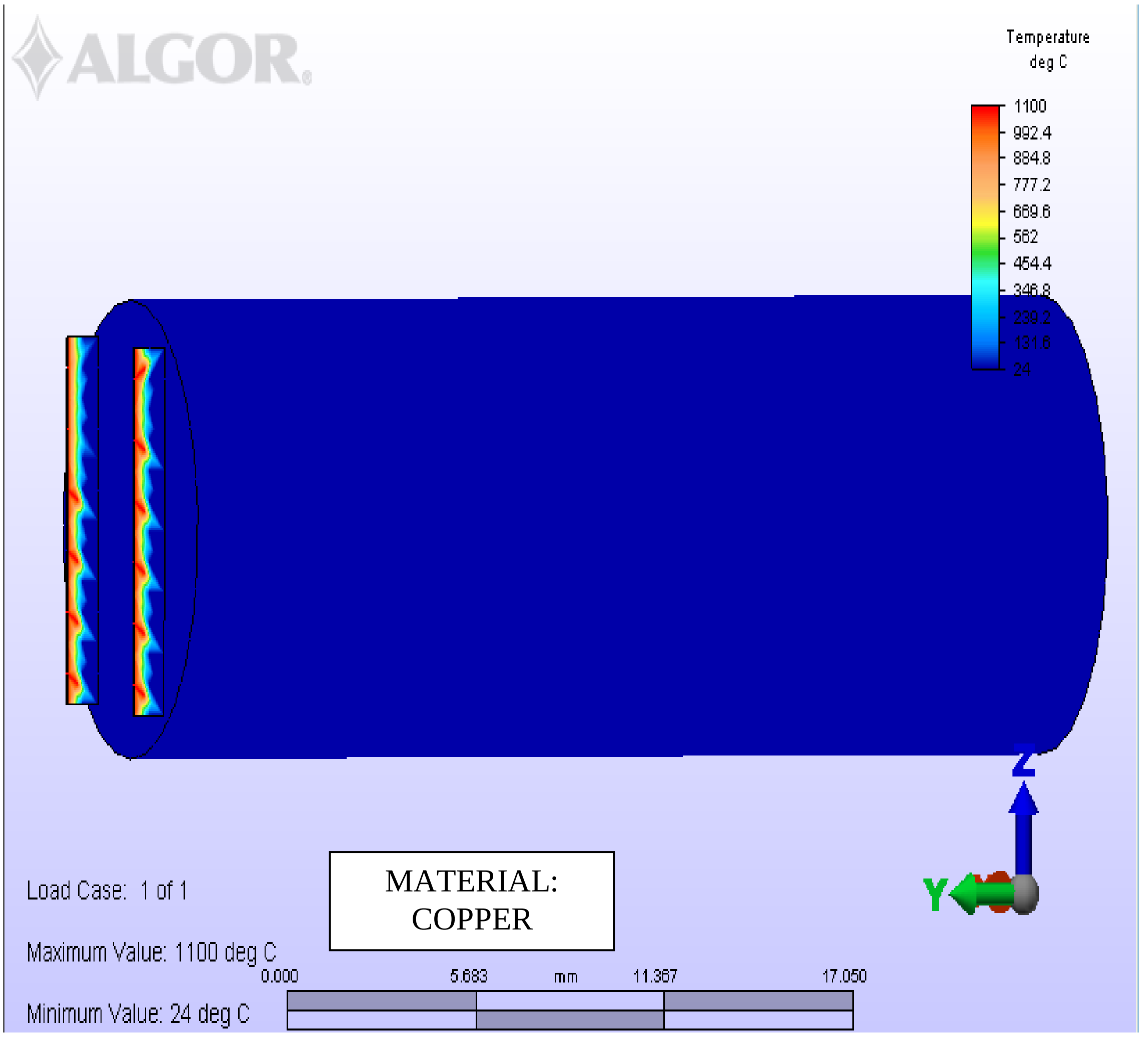
APPENDIX A

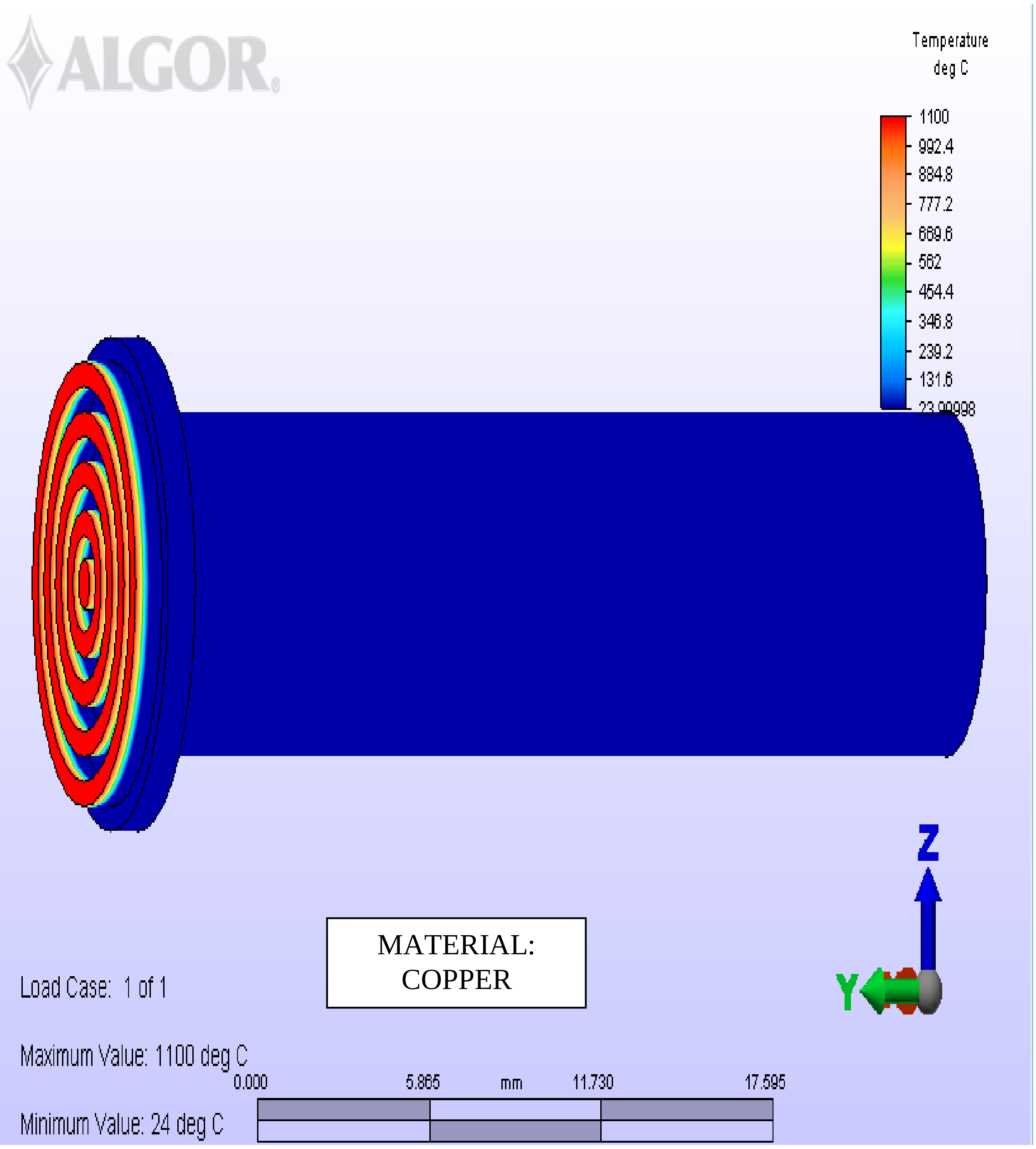
STRESS ANALYSIS OF TOOL IN ALGOR



APPENDIX B

TEMPERATURE DISTRIBUTION ANALYSIS OF TOOL DESIGN 1 & 2





MATERIAL:
COPPER

APPENDIX C

HEAT RATE ANALYSIS OF TOOL DESIGN 2