THERMAL ANALYSIS OF ELECTRICAL DISCHARGE MACHINING USING QUITE ELEMENT TECHNIQUE

By

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DISSERTATION

Submitted to the Mechanical Engineering Programme
in Partial Fulfilment of the Requirements
for the Degree
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CERTIFICATION OF APPROVAL

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Approved by,

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(DrHasanFawad)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JUNE 2012

CERTIFICATION OF ORIGINALITY

This is certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and that original work contained herein have not been undertaken or done by unspecified source or person.

(Ahmad Fazuan Zainuddin)

ABSTRACT

Electrical discharge machining (EDM) is a machining option that was well-established for manufacturing purpose especially for high hardness material parts or complex in geometry that is extremely difficult to be machine by using conventional machining. This machining process alternative that required no contacts have attracted a significant amount of research interest. EDM process is based on thermoelectric energy between the electrode and work piece. A discharge of pulse occurs in a small gap between the electrode and the work piece will removes the targeted part of by the mean of melting and vaporisation. Basically, EDM can be divided into two major types, wire cutting machine and die sinking. In wire cutting EDM, the sparks is generated between a thin wire and work piece. For die sinking, the work piece which is formed by duplication of a shaped tool electrode is fully immersed in the dielectric fluid. This project paper objective is to research and develop the numerical model of the specimens by using the EDM process by including the quite element technique. The model then will be analyse in terms of hazard affected zone (HAZ), material removal rate (MRR), and the view of model of after the machining process done. The data of MRR that been obtained from the model will be compared with the data obtained from actual experiment and previous research. The methodology of this project will be preliminary data gathering, model development, thermal analysis, actual experiment and result’s validation. In the end, this project will be able to present the thermal model for single and multi-spark EDM process by using CAD / CAMS software, ANSYS.

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LIST OF ABBREVIATION

EDM	Electric discharge machine
FEM	Finite element method
ANSYS	Software’s name
CAE	Computer aided engineering
CAMS	Computer aided manufacturing system
HAZ	Heat affected zone
APDL	ANSYS parametric design language
E	Young Modulus

CHAPTER 1
PROJECT BACKGROUND

1.1 BACKGROUND OF STUDY

1.1.1 Electric Discharge Machine (EDM)

Demands of technology for the difficult-to-machine and advance materials, like high-strength and thermally resistant alloys as well as hardened steels is increasing rapidly nowadays [2]. In order to machining those materials, conventional manufacturing techniques have been replaced by more high technology techniques that can deal with them. EDM is a process that used to remove or cut metal part by the action of an electrical discharge of high density current and short duration between the tool and the work piece [3]. There are no physical contacts or cutting forces apply between the tool and the work piece. EDM has been proved very effective especially in the machining of very tough, electrically conductive materials for example the new space-age alloys and been used intensively in machining mould-steel for injection moulding and powder metallurgy [3,4]. These metals would have been difficult to machine by conventional methods, but EDM has made it relatively simple to machine regardless of the shape even the nearly impossible to shape geometry. In specific dielectric liquid, the EDM machine applies high voltage on the cathode and anode across a thin gap [4]. The electric field causes the breakdown of the dielectric thus an electrical arc is generated between the anode and cathode [4]. This arc gives the point of the spark on the surface of the work piece a very high temperature and cause the material to melting and vaporizing. Simultaneously the dielectric between the electrodes was vaporized rapidly, get rid of the chips, and return to the initial state [4].

1.1.2 Finite Element Method (FEM)

The fast growing technology and economy raises pressure in production engineering field to require optimisation of existing production processes. The finite element method (FEM) is an appropriate and best tool to get the necessary knowledge of these processes [5]. Generally there are two types of analysis that currently used in industry: 2-D modeling, and 3-D modeling. 2-D modeling preserves simplicity and the analysis can be run on a relatively normal computer, the result tends to yield less accurate. However 3-D modeling advantage is it can produces more accurate results but it can be run on the fastest computers effectively only. For this project model, author choose to use 2-D modeling for purpose of simplicity.

1.2 PROBLEM STATEMENT

1.2.1 Problem Identification

The hasty growing in manufacturing fields has lead to the increasing demand of the people toward the research relating to the machining process like EDM. The research is important in order to get the data and improve any weakness in the machining process. Nowadays people come up with the FEM software such as ANSYS to do research and experiment instead of carry out physical experiment that more time and money consuming. The software allows the user to create the model in 2D and 3D and carried out the analysis such as thermal and stress analysis. There are people that have carried out the research to define the thermal analysis for the single spark before such as HasanFawad and JunaidWazir [6]. The scope of the project is restricted only for single spark only. There is a research that has been done by previous student that is thermal analysis and stress analysis of single and multisparks. The scope of the research did not take into account the material remove after the spark applied. This research is an extensive research that been carry out prior to the previous student research. The scope of this project is wider as its cover both single spark and multispark as well as include the quite element technique that represents the material been removed. So, this research is a continuing research by redo the project and includes the quite element technique. The result collected from this research will be compared to the previous research as well as data from the actual EDM experiment.

1.2.2 Significant of the Project

This research will focus on the thermal analysis of single and multispark for EDM process by including also the quite element technique. The analysis will be carried out by using ANSYS software. The expected details that will be collected by the end of the project are material removal rate (MRR), the thermal distribution of the model in form of contour chart, the graph of model temperature against and also the view of crater structure of the model after the spark been applied. The data collected from this research are able to provide reference for the researcher in the future in order to achieve their respective objective. The methodology and time line of the project also was arranged in proper documentation thus provide the future researcher better view to plan their research.

1.3 OBJECTIVE OF STUDY

- Development of numerical heat transfer model of single and multispark EDM for determination of heat affected zone (HAZ) and material removal rate (MRR) by including the quite element technique.
- Compare heat affected zone (HAZ) and crater shape of the model with and without quite element technique.
- Perform the physical experiment and gather the relating data by using EDM machine.

1.4 SCOPE OF STUDY

- FEA analysis of the die sinking process applying single and multispark to steel by modifying few parameters and compare the heat distribution and material removal rate for each of those.
- Inclusion of quite element technique in the previous EDM model for better prediction of crater shape and HAZ.
- Comparison of the result of material removal rate with the actual die sinking process, and also other experiments done earlier.

1.5 RELEVANCE OF THE PROJECT

The scope of the project is covering the development of the single and multispark of EDM structure by using quite element technique. Most of the methods use in the project is related to the ANSYS programming task. The programming work done can be easily detected if any error or mistakes happen in the program command. The experimental values of MRR are able to be calculated by using the developed model only by performing few numbers of experiments [7]. Apart from that, the CAE gives us the advantages in minimizing the physical experiment and prototype. The data generated and analyse by the software is accurate and consistent. The result that be generated is consistent and reliable and still in acceptable error ranges [7].

1.6 FEASIBILITY OF THE PROJECT WITHIN TIMEFRAME AND SCOPE

The expected achievements for this project for the FYP 1 period are:

- Data gathering and review of topic related.
- Development of the program for single and multisparks by including the quite element technique.

For the time period of FYP 2, the programming model been expected to be fully develop. The data validation will be carried out between the result collected and the others previous research project result. The comparison between the data gain from FEM and the physical lab experiment will be carried out as well. The aspect of data will be focusing on the following details:

- Heat Affected Zone (HAZ)
- Material Removal Rate (MRR)
- The view of the crater structure.

The project planning is feasible with the time frame have been given and the scope of the project also stay within the range of achievable.

CHAPTER 2
LITERATURE REVIEW

2.1 HISTORY OF DEVELOPMENT OF ELECTRICAL DISCHARGE MACHINING (EDM) TECHNOLOGY.

The beginning of electrical discharge machining (EDM) dates back to 1770 when English scientist Joseph Priestly discovered the erosive effect of electrical discharges. Attempts were made for the first time to machine diamonds and metals by using electrical discharges during 1930s. Erosion generated by intermittent arc discharges that occur in air between the electrode and work piece which connected to a DC power supply. The process was not very accurate respect to overheating of the machining area and can be defined as “arc machining” rather than “spark machining” [4].

Pioneering work on EDM was carried out in 1943 during World War II by two Russian scientists, B.R. and N.I Lazarenko at the Moscow University. The destructive effect of an electrical discharge was channelized and a controlled process for machining materials was created. In 1950s the RC (resistance –capacitance) relaxation circuit was introduced, which provided the first consistent dependable control of pulse times as well as a simple servo control circuit to automatically find and hold a given gap between the electrode (tool) and the work piece. In the 1950s and later, the RC circuit was broadly be used and served as the successful model in EDM technology [4].

In the 1980s with the initiation of Computer Numerical Control (CNC) in EDM that brought advancement in efficiency improvement of the machining operation. Respect to continuous process improvement, modern EDM machine have become so stable and can be operated round the clock under monitoring by an adaptive control system [4].

2.2 EDM PROCESS PARAMETERS

2.2.1 Discharge voltage

Discharge voltage in EDM is related to the break down strength of the electric and spark gap. Before current can flow, the open gap voltage widen until an ionization path created through the dielectric. As the current gap flow, voltage will drops and stabilize at the working gap level. The preset voltage will determine the width of the spark gap between the work piece and leading edge of the electrode.

2.2.2 Peak Current

Peak current is the amount of power used in EDM, measured in units of amperage, and is the most important machining parameter in EDM. The current increases until it reaches a preset level during every on-time pulse, which called as the peak current. In both die sinking and wire-EDM application, the highest amount of amperage is determines by the surface area of the cut. Use higher currents will improve MRR, but at the cost of surface finish and tool wear [4].

2.2.3 Pulse duration and pulse interval

Every cycle has an on-time and off-time that is expected in units of microsecond. All the work is done during on-time so the duration of these pulses and the number of cycles per second are very important. Material removal is directly proportional to the amount of energy being applied during the on-time. This energy is controlled by the length of the on-time and peak amperage. Pulse on-time is commonly referred to as pulse duration and pulse off-time is called pulse interval. The pulse duration get longer, more work piece material will be melted away. The crater resulted will be wider and deeper than a crater produced by a shorter pulse duration [4].

2.2.4 Pulse waveform

The pulse shape is normally rectangular, but generators with other pulse shapes have also been developed. Using a generator which can produce trapezoidal pulses, Bruyn (1968) succeeded in reducing relative tool wear to very low values. Other types of generators introduce an initial pulse of high voltage but low current and a few microseconds duration, before the main pulse, which facilitates ignition [4].

2.2.5 Polarity

The polarity of an electrode can be either positive or negative. The current passing through the gap will causes high temperatures that causing material evaporation at both electrode spots. The plasma channel is composed of ion and electron flows. As the electron processes show quicker reaction, the anode material is worn out in major. This effect causes minimum wear to the tool electrodes and becomes of importance under finishing operations with shorter on-times [4].

2.2.6 Electrode gap

The tool servo-mechanism is importance in the determination of working efficiency in EDM, and function to control responsively the working gap to the set value. Most of electro-mechanical and electro-hydraulic systems are used, and usually designed to respond to average gap voltage. The reaction speed supposes to be high in order to respond to open gap conditions or short circuits. Gap width cannot be measure directly, but can be inferred from the average gap voltage [4].

2.2.7 Type of dielectric flushing

Basic properties required for a dielectric in EDM are high dielectric strength and quick recovery after breakdown, effective quenching and flushing ability. Type of dielectric and the method of its flushing will affect MRR. Dielectric fluids mostly are hydrocarbon compounds or water. The dielectric fluids are flushed through the spark gap to remove gaseous and solid debris during machining as well as to maintain the dielectric temperature well below its flash point [4].

2.3 FINITE ELEMENT METHOD (FEM)

2.3.1 APPLICATION OF FEM

ANSYS is a finite element method (FEM) analysis code which is very popular in the engineering field because of its functionality. ANSYS software allows engineers to construct computer models of structures, machine components or systems; apply operating loads and other design criteria; and study physical responses, such as stress levels, temperature distributions, pressure, etc. [9]. It permits an evaluation of a design without having to create and distinguish multiple prototypes in testing. The ANSYS program can create do the modelling and simulation works for any items in our everyday life such as computer, stand-fan, cupboard, the simulation of machining process and others. ANSYS is much related to EDM for such a long time. Many people have done the research relating ANSYS with EDM. For EDM, Finite elements simulations are done in 3 steps with the main pieces which are modelling by FEMB, the thermal study and processing, and post-processing result of analysis by ANSYS software for results discussion. According to Ali. Moarrefzadeh [7], the finite-element techniques steps are finite elements modelling, types and properties for model different parts, the definition of material properties, parameter definition, loading, boundary and initial value definition, common interfaces definition, and control parameter definition.

2.3.2 PROJECT PARAMETERS AND ASSUMPTIONS

The initial and boundary condition of H. Fawad et al. [6] is being used for this project. The boundary conditions to simulate the conditions during EDM process which taking the work piece dimension as the radius R_w along the r-axis and the depth H_w along the z-axis. The boundary conditions used for this continuing model are being shown as follows:

Parameter(s)	Location	Value
Ambient temperature, $T_{Ambient}$	Whole domain	300K
Heat input, q(r)	0 < r <$R_c$at z=0	Gaussian distribution
Convection coefficient, h	R_c< r <R_W at z = 0 and 0 < z <$-H_w$	5.6 W/m^2K^{-1}
Temperature, T_s	Isothermal boundary condition applied at bottom surface of the work piece either at 0 < r <R_W at z = H_w	300K

Table 1: Parameter(s) and its location and value for initial and boundary condition

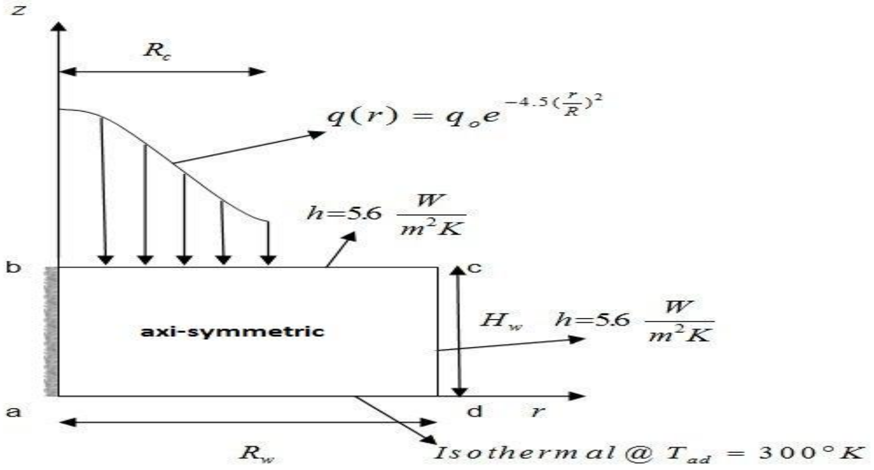

Figure 1: Boundary conditions for axis-symmetric thermal model [6]

Ikaiet al. [8],Joshi et al. [4] have developed a model of EDM spark using a semi-empirical equation for plasma radius which is relying upon discharge current and on-time. In this project model, the radius of plasma channel discharge being calculate using Eq (1) which is also known as equivalent heat input radius. The value of the radius calculate is a near to realistic approach for mesh sensitivity analysis and achieving an accurate thermal profile.

$$R_c = 2.04X10^{-3} I^{0.43} t^{0.44} \quad \textbf{(2.1)}$$

For fraction of energy transferred to cathode, Fc, value of 0.30 was chosen from the graph for energy distribution shown in figure XX by referring to M. Kunieda et al. [10]. The fraction of the energy that is transferred to the cathode (Fc), Voltage applied, and intensity of current are assume to be constant in the duration of the pulse.

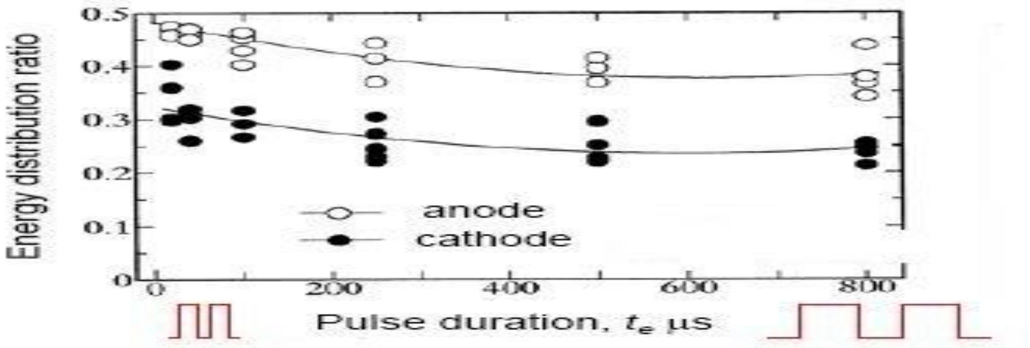

Figure 2: Relationship between energy distribution ratio and pulse duration

Most commonly used heat input model are the point source model and a Gaussian heat input model. However since Gaussian model is the most popular and accurate, it was choose to in this project model. Respect to experimental observations by Descoeudres et al. [11] and Kojima et al. [12] by using spectroscopy techniques, one of the reasons is the Gaussian is more accurate is in term of approximation of heat flux. The non-uniform temperature distributions exist within the plasma channel which resembles to Gaussian form Eq. (2) as follows:

$$Q(r) = Q_0 e^{-4.5(\frac{r}{R_c})^2} \quad \textbf{(2.2)}$$

Maximum heat flux, Q_0 was calculated using the formula given below:

$$Q_0 = \frac{4.57UIF_C}{\pi R_c^{\ 2}} \quad \textbf{(2.3)}$$

Rc is the radius of the plasma channel in µm, U is the electric potential, I the current density, Td the time of discharge and Fc the fraction of power to the cathode.

This project used the same assumption used by the previous student for his thermal analysis that made by H. Fawad et al. [6]. The assumptions that been used are as follows:

- Work piece is taken to be axis-symmetric
- The spark efficiency is assumed to be ideal (100%).
- The electric discharge voltage is maintained constant during the pulse.
- The criterion of material removal is taken to be equivalent temperature. All elements reaching this temperature are assumed to be effectively removed from the work piece for the purpose of calculation of a theoretical value of material removal rate,
- Free convection is assumed to occur at the surfaces of the work piece material
- Latent heat of melting and vaporization are considered, moreover temperature dependent material properties are also used
- The pulses are considered ideally normal with no arcing or short circuits and no ignition delays, etc.

2.3.3 QUITE ELEMENT TECHNIQUE BY ELEMENT DEATH.

Once a material is removed from a system, certain elements in the model may become "nonexistent". Quite element technique is a technique used to eliminate or remove any part of model under certain defining criterion. Death element is one of the solutions to carry out the quite element technique that available in ANSYS software. The element death options can be used to deactivate selected elements in such cases. This feature can be useful in analyzing excavation , staged constructions, sequential assembly and many other applications in which user can easily identify activated or deactivated elements by their known locations. In some circumstances, element's death status may be dependent on an ANSYS-calculated quantity, such as temperature, stress, strain, etc.

Various commands can be use to determine the value of quantities in selected elements, and to change the status of those elements accordingly [14].

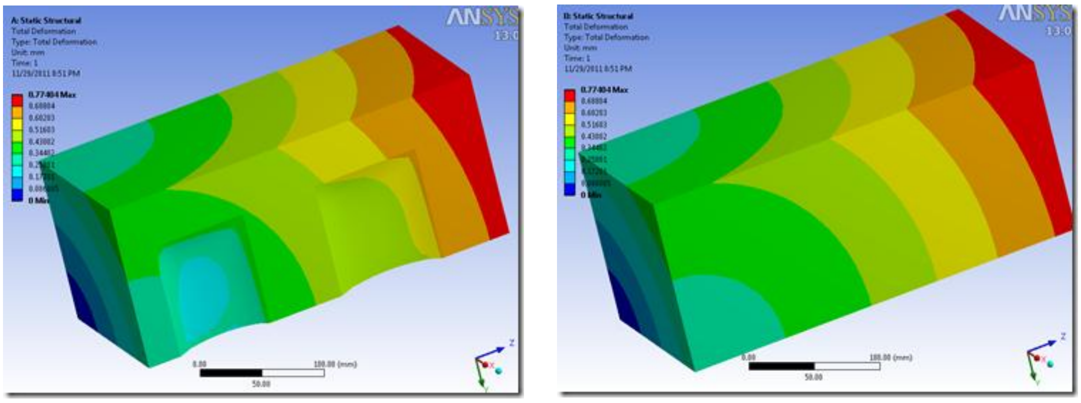

Figure 3: Comparison between model that apply quite element technique and standard model [14]

In element death effect, the ANSYS program does not actually remove "killed" elements. Instead, it deactivates them by multiplying their stiffness or conductivity, or other analogous quantity by a severe reduction factor. Element loads associated with deactivated elements are zeroed out of the load vector, however, they still appear in element-load lists. Similarly, mass, damping, specific heat, and other such effects are set to zero for deactivated elements. The mass and energy of deactivated elements are not included in the summations over the model. An element's strain is also set to zero as soon as the element is killed.

CHAPTER 3
METHODOLOGY

3.1 RESEARCH METHODOLOGY

The methods to conduct the project need to be neatly plan in order to gain the reliable result and meet the time relevancy. For this project, the methodologies are as follows:

3.1.1 Preliminary data gathering

Some of the parameters and governing equation need to be gathering to be used in the process of development of the thermo physical model. The collected must neatly be check so that it comes from the good and reliable source or reference.

3.1.2 Development of thermo physical model

After the data have been gathered then the FEA method can be used. The physical structure of the work piece needs to be created and established by using ANSYS software. The work piece has to meet all the criteria and follow the specification of data that have been gathered before. In this part of methodology the technique of quite element need to be include so that the different in view of the structure after the spark applied in the simulation is visible.

3.1.3 Thermal analysis

After the physical structure in the ANSYS has been developed the thermal analysis will be carried out. The Contour chart and other related graph need to be generated in order to collect the data of result. The focus of the data that will be collected is the heat distribution and material removal rate.

3.14 Actual experiment

The actual experiment will be carried out by using EDM die sinking machine. The material use for this experiment is mild steel and the electrode will be choose between cooper or brass depend on the availability of the material. The data from this experiment is the mass of the work piece remove which will be used to calculate the MRR.

3.1.5 Result’s validation

The data collected from part of thermal analysis will be compared to the previous project that be carried out by previous FYP. The comparison will be defined in term of the different of the heat distribution pattern, the different in material removal rate as well the method used. The data for material removal rate will go through another comparison process that is between the data gain from the simulation and the data gain from the actual physical experiment.

3.2 PROCESS FLOW OF METHODOLOGY

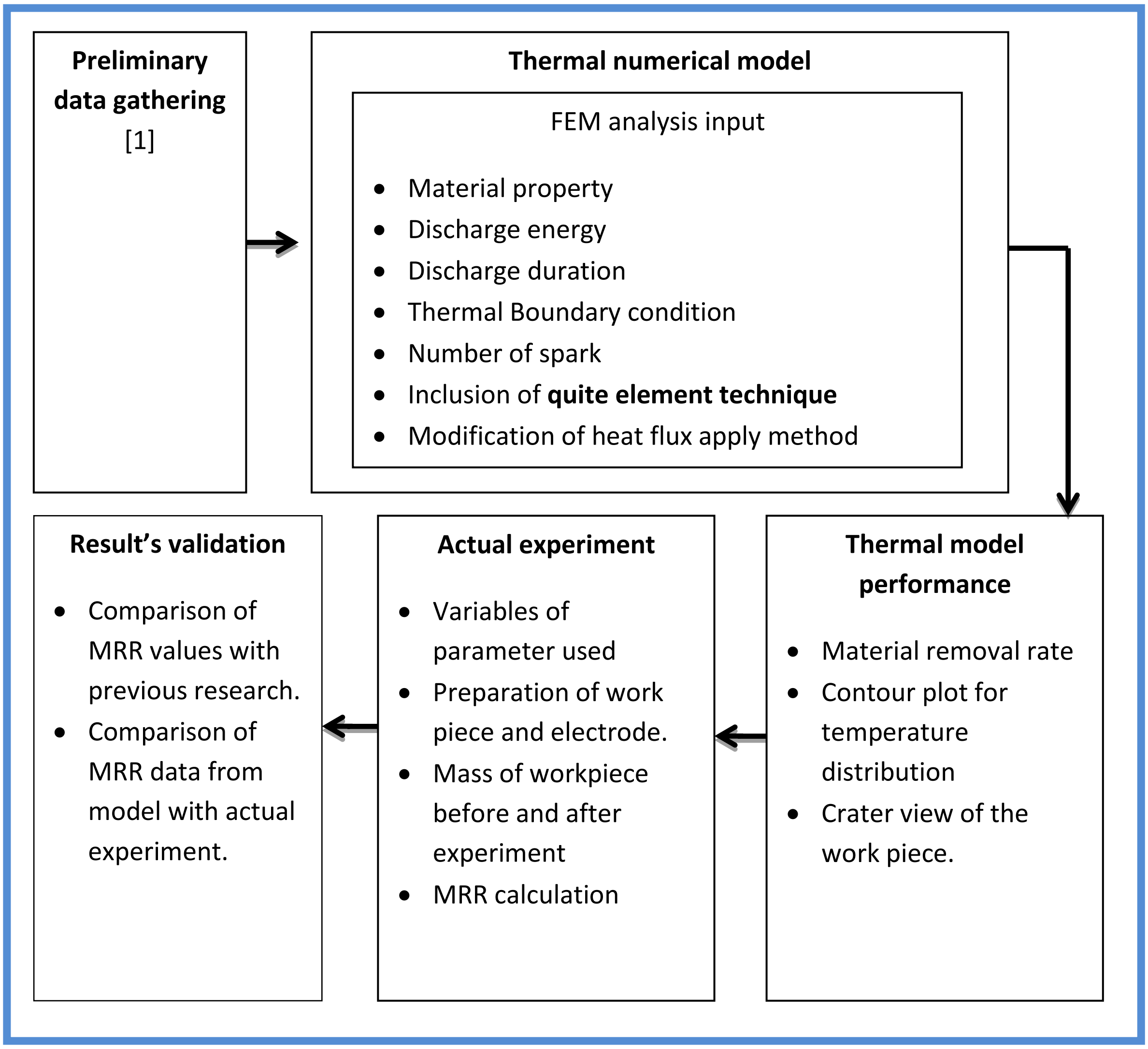

Figure 4: Integrated process model development

3.3 APPARATUS, MATERIAL, AND COMPUTER SOFTWARE REQUIRED

3.3.1Apparatus

- Die sinking machine
- Electronic balance
- Lathe machine
- Milling machine

3.3.2 Material

- Mild steel
- Brass

3.3.3 Computer software

- CAD/ CAMS ANSYS Version 11.0 software

Majority of the tasks and job scope of this project is related to the usage of CEA that is ANSYS software. The part of physical lab work will cover only small part of the project time thus the apparatus and material required listed is few in numbers.

3.4 PROJECT ACTIVITIES AND KEY MILESTONES

The timeline of the progress of the project has been set as follows. Table 1 and 2 are the Gantt charts for the FYP 1 and FYP 2 respectively.

Table 2: Project Activities and Key Milestones for FYP I

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic	🟦	🟦						MID SEM BREAK							
2	Preliminary Research Work / Literatures Review		🟦	🟦	🟦	🟦										
3	Submission of Extended Proposal						○									
4	Research on ANSYS programming.							🟦		🟦						
5	Proposal Defense									🟦	○					
6	Preliminary data gathering											🟦	🟦	🟦	🟦	
7	Submission of Interim Draft Report														○	
8	Submission of Interim Report															○

Legends:

🟦 Project Activity

Table 3 :Project Activities and Key Milestones for FYP II

No.	**Detail/ Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Executed model experiment	🟦	🟦	🟦	🟦	🟦	🟦		**M I D S E M B R E A K**								
1	FEM of thermal and analysis, compare with experimental result							🟦		🟦							
2	Submission of Progress Report									🟦 ○							
4	Compare the FEM result with Other Treatment Methods										🟦	🟦					
5	Pre-EDX												🟦 ○				
6	Submission of Draft Report													🟦 ○			
7	Submission of Dissertation (soft bound)														🟦 ○		
8	Submission of Technical Paper														🟦 ○		
9	Oral Presentation															🟦 ○	
10	Submission of Project Dissertation (Hard Bound)																🟦 ○

Legends:

🟦 Project Activity

CHAPTER 4
PRELIMINARY DATA GATHERING

In this part, the data such as parameter, equation and experiment procedure that will be used and related to the development of the thermo physical model been gathered. For the purpose of data validation and comparison at the end of this research, author used exactly the same data value as being used by previous student. The data and parameter are as follows:

4.1 PARAMETER AND ITS VALUE USED IN APDL FOR FEA OF EDM PROCESS

4.1.1 Auxiliary options part

Table 4 : Parameter(s) and its Value(s) for Auxiliary options part

No.	Parameter(s)	Value (s)
1	Wide	0.002 m
2	Height	0.006 m
3	Temperature 1	300 K
4	Temperature 2	300 K
5	Convection coefficient	5.6 W / m^2K^{-1}
6	Current	25A
7	Voltage	25A
8	Time on	0.0001 s
9	Time off	0.0001 s
10	Grid size	0.00001 m

4.1.2 Define element type, material model, areas, meshing part

No parameter needs to be list for this part.

4.1.3 Apply boundary conditions part

Table 5 : Parameter(s) and its Value(s) for Apply boundary conditions part

No.	Parameter(s)	Value (s)
1	Fraction of energy transferred to cathode	0.30

4.1.4 Solve part

Table 6 : Parameter(s) and its Value(s) for Solve part

No.	Parameter(s)	Value (s)
1	PFE (Plasma flushing efficiency)	0.75

4.1.5 The parameters for (950, 1050, 1150, 1465 degree Celsius) part

Table 7 : Parameters for (950, 1050, 1150, 1465 degree Celsius) part

No.	Parameter(s)	The values of each of the parameters is being included in notepad part entitled pipemat
1	Density	
2	Young modulus	
3	Poisson ratio	
4	Thermal conductivity	
5	Specific heat	
6	Coefficient of thermal expansion	
7	Reference temperature	
8	Yield stress	

4.1.6 Quite element technique part

For this part by using the element death the elements that be selected by specified criterion will be “quite” or remove from the model. The criterion for this die EDM process model is the melting temperature of the work piece. Any element that exceeds the defined melting temperature after spark been applied will be removed from the model.

Table 8 : Parameter(s) and its Value(s) for Solve part

No.	Parameter(s)	Value (s)
1	Melting temperature (Steel)	1750˚C

4.2 EQUATIONS USED IN APDL PROGRAM FOR FEA OF EDM PROCESS

The equation listed as follows use to calculate and generate the value that will be important for the program to solve model. Some of the equations below were taken from the research by previous student and some of them have been modify to integrate with the quite element technique.

a) RAD = (0.00204)*(Voltage)*(time on)*0.44

b) LOOP = RAD / Grid size

c) S= (3.142)*RAD*RAD

d) DISTX = L (I) – (Grid size / 2)

e) Q (I) = ((U*ID*F*4.57)/S)*(2.72) ** (-4.5*((DISTX)/(RAD))**2)

f) ACV= 3.142*(R) **2*H*(1000) **3

g) MRR=PFE*60*ACV/(F*(TON+TOFF))

CHAPTER 5
THERMAL ANALYSIS

5.1 THERMAL ANALYSIS FOR SINGLE SPARK EDM PROCESS WITH QUITE ELEMENT TECHNIQUE

For thermal analysis of single spark EDM process of this research the writer need to study and understand the APDL command of the previous student research. There is not much problem regarding this part of research as the previous research is focusing on the fundamental of the EDM process model while this research is more to improve the model to be more realistic and closer to real die sinking EDM process. After the APDL command of the previous student have been checked and there is no command that contradict to the quite element technique the writer modify the APDL command by inserting command to create the element table of all the elements. From this element table, data of the temperature of all elements can be obtained. By applying the death element command with the criterion of elements temperature that exceeding 1750 □ C the ANSYS program will select the elements and quite the selected elements. The contour plot of single spark EDM process with the quite element technique which shows the element that been quite after one spark been applied is being showed in Figure 5:

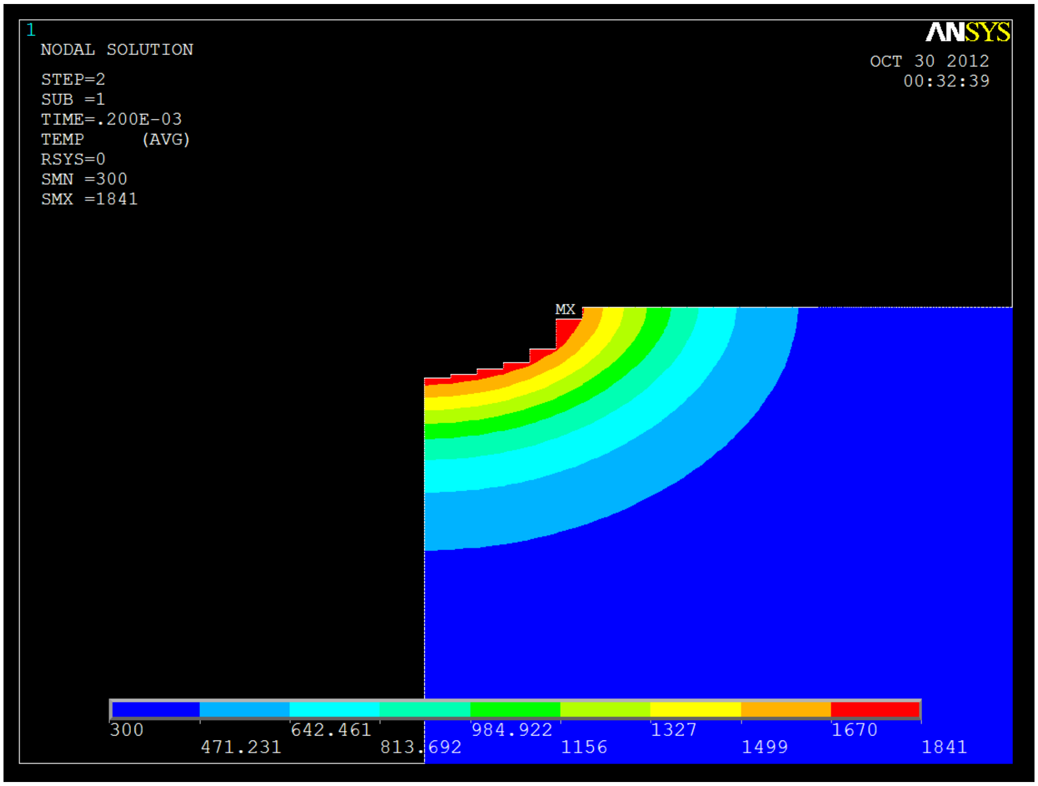

Figure 5 : Contour plot for single spark EDM process after discharge applied

The variation of color in the contour plot shows the temperature distribution at the work piece caused by the discharge. The color order of highest temperature to the lowest temperature is from red to blue area. The temperature variation can be interpret respect to the temperature scale display.

For single spark discharge, we can observe that the elements that exceeding the temperature of 1750 □ C have been removed from the work piece. The crater shape of the work piece after the material removed also can be view from the figure. The crater shape of material removed depend on the temperature distribution within the work piece which we can see from figure that more heat been distribute in horizontal direction of the work piece compared to vertical direction.

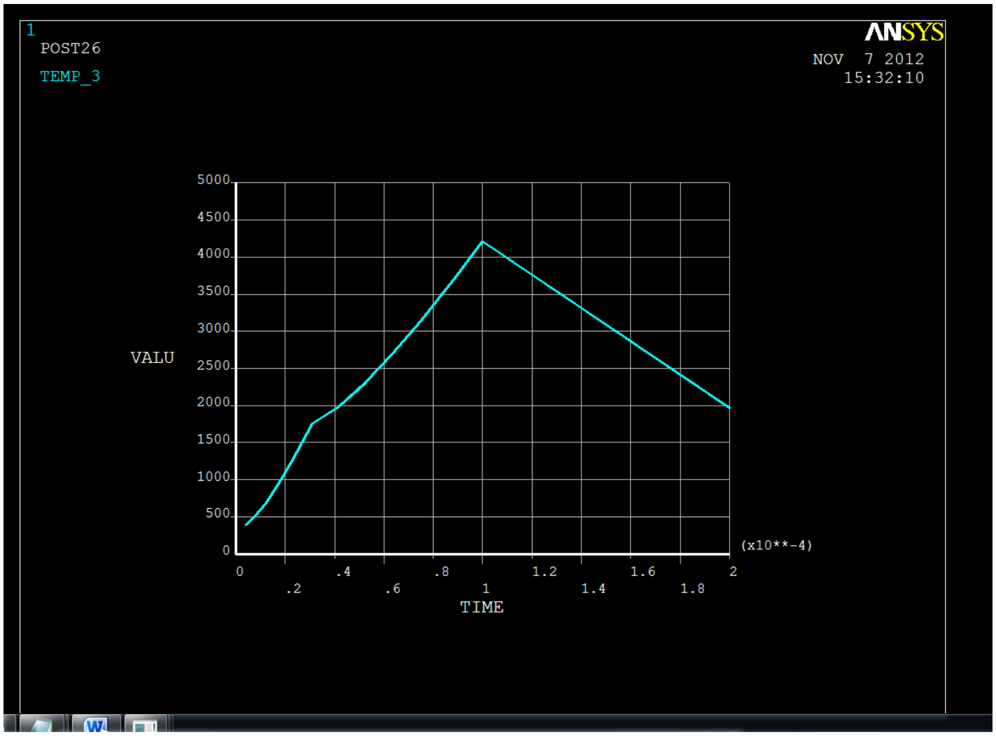

Figure 6: The graph of the temperature versus the discharging time for single spark node with maximum discharge applied to (Node number 1189)

From the analysis also another data presentation that can be establish beside from contour plot is the graph of the temperature versus discharging time for specific node. The ANSYS software cannot analyze the temperature based on the element instead it can be done by choosing the specific node. The graph is shown in Figure 6.

From this graph there are many information that we can get and thus useful for the thermal analysis. The first information is we can figure out the location of the melting point and their time for the material to reach the melting point of the material that is 1750 degree Celsius. The graph show that the temperature is constantly increase with high gradient and as it reach the melting point of the work piece the temperature continue to increase but with slightly lower gradient than the previous gradient. This is due to the steady phase during the melting of the material. The trend of the temperature also can be observe from this graph when the temperature stop increase and start to cool down at the time of 0.0001 second. The point where the temperature start decreasing is the time where the spark stops been applies to the work piece. The time of the region where temperature increasing is called Time on where else the decreasing temperature is called Time off. The total time of Time on and Time off is means for one complete cycle of a spark.

Graph generated from the command that contain quite element techniques do not affect the information as the comparison between this graph and the previous student do not show the different in information. The advantage of this modify command is the user can view more clearly the part of material that been removed after one spark applied.

5.2 THERMAL ANALYSIS FOR 25 SPARKS EDM PROCESS

To further analyze the pattern of crater shape of the work piece and MRR of the model as the machining advances, the numerical simulation is run for a finite number of multiple discharges that is 25 times. There are some modifications that need to be done to make the simulation more realistic as well as give more accurate data.

5.2.1 CHALLENGES FACED FOR THERMAL ANALYSIS OF 25 SPARK BY INCLUDING QUITE ELEMENT TECHNIQUE

1) **Difficulties in applying the command to get the data of element that will be applied with heat flux.**

In this model the material that will be removed after every spark is unpredictable as the solution of the thermal analysis is done by the program. Irregular crater surface of the model after every spark made the process of getting the element for the next spark is difficult. At first the author choose to do the loop in checking the live element start from the most top and left of the model and the checking process move to the right direction but the loop is too complicated and contain nested loop. The author then chooses to check the live element from top to bottom to get data of the elements.

5.2.2 IMPROVEMENT MADE FOR THERMAL ANALYSIS OF 25 SPARKS BY INCLUDING QUITE ELEMENT TECHNIQUE

1) Include the quite element technique

The model simulate by the previous student does not remove the material erosion after every spark have been applied. In this model the material that achieved or exceeding the defined melting temperature that is 1750 □ C been removed by using death element. This improvement makes the model more realistic and will give better data of MRR as the material that supposed to be removed have been quite down.

2) The position of the heat source changing for every spark

In this model the position of the heat source will change for every spark applied. This is totally different to the previous model which the heat flux is been applied statically at one position. This model is more realistic as in the real die sinking EDM process the electrode that generate the spark is moving approaching the work piece surface every time the spark applied.

3) The elements of heat flux be applied.

The elements that selected for heat flux to apply during the time on of the EDM machining have been modified to be more realistic. In previous student model, the element that heat flux been applied is in straight line form but for this model the elements selected is the element which is exposed to the surrounding. This was done by include some APDL command to get and store the elements number which is exposed to the surrounding in array form. The comparison of the way the heat flux applied in previous model and this model can be view in the figure 7.

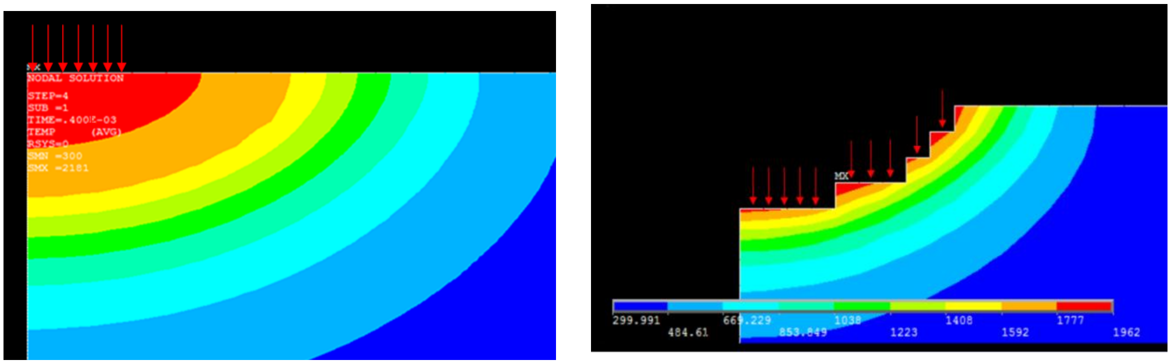

Figure 7: The comparison of way heat flux be applied in previous model and this model

4) Element table been used instead of calculating the average temperature of element from 4 node.

The previous student chooses to use formula to calculate the temperature of every element in his model. The way it done is by get the temperature of all 4 node of the element and divides by 4 to get the average temperature. The average temperature then is considered as the temperature of the element. For this model, writer chooses to use element table which is a function in ANSYS program which directly generated the temperature of the elements. Author chooses this option as it is simpler and does not affect the data produced then. The data of result will be the same even though this step was used.

5) Using the loop function to simplify the command

The loop function is a function to do a command repetitively and contain criterion to be fulfils. The previous student does not include this loop function but instead use to repeat the command until 25 times. The disadvantage of this method is the number of the spark is hard to be modified. By using the loop function the author can modify the number of spark applied just by changing some parameter in the APDL command.

5.2.3 THERMAL PROFILES AND DATA FOR EDM MACHINING OF 25 SPARKS USING QUITE ELEMENT TECHNIQUE

The APDL command that have been improved from single spark EDM simulation is run and contour plot been generated as in figured XX. As be explained before, the quite element technique use in this project that is EKILL function be performed in APDL command after every time heat flux applied to the model. The APDL command for multispark EDM machining have been run for 6 times using different parameter for each. For the purpose of data comparison, the value of parameters used that were discharge current, time on and time off were taken from the previous student data. Table 9 shows the parameter and their value that been used.

No. of data	Machining condition			
	PFE (%)	Current (A)	Pulse-on time (μs)	Pulse-on time (μs)
1	41	10	32	32
2	50	12.8	42	42
3	54	20	56	56
4	75	25	100	100
5	100	36	180	180
6	100	44	240	240

Table 9 : Data of parameter used in multispark EDM modelling

The contour plot and element plot for every data been showed in following figures. From the contour plot we can analyze the heat distribution in the model by referring to the scale of temperature provided. The element plot give better view of the element that been removed from the model.

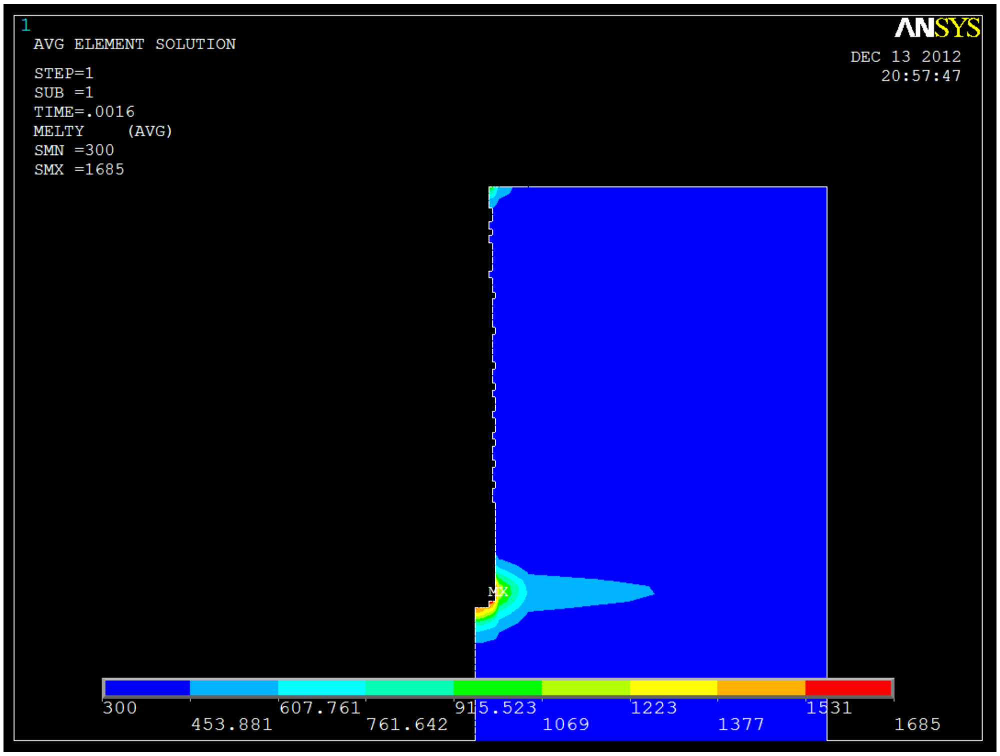

Figure 8: Contour plot for data 1 (I=10 ,Ton= 32µs, Toff= 32µs)

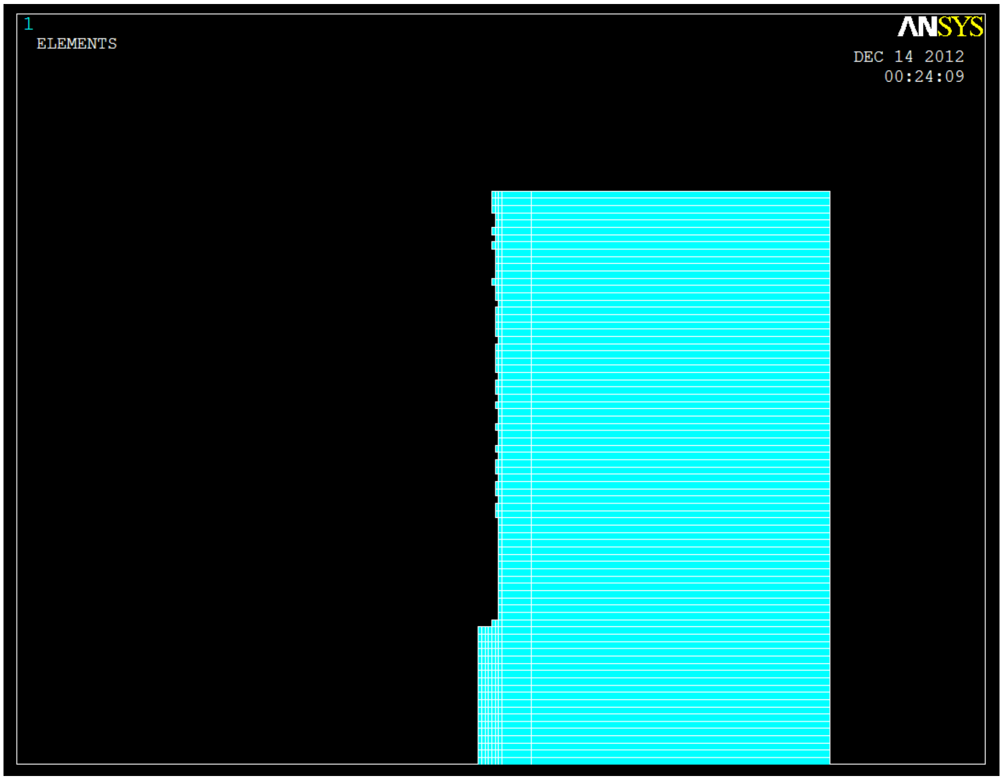

Figure 9: Element remove for data 1 (I=10 ,Ton= 32µs, Toff= 32µs)

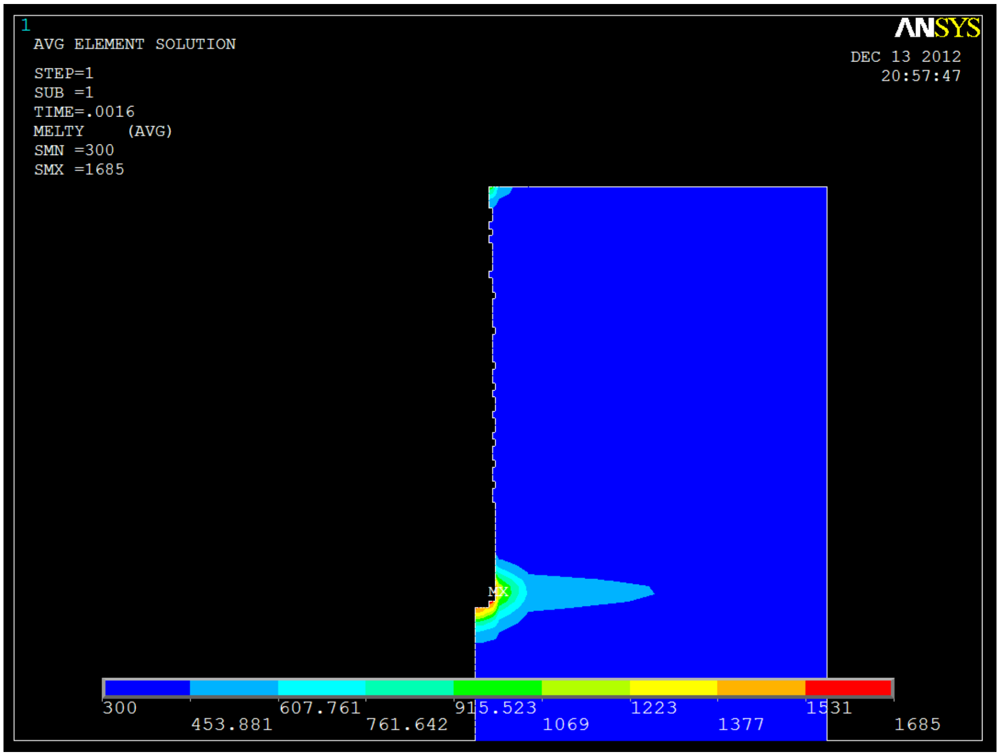

Figure 10: Contour plot for data 2 (I=12.8 ,Ton= 42µs, Toff= 42µs)

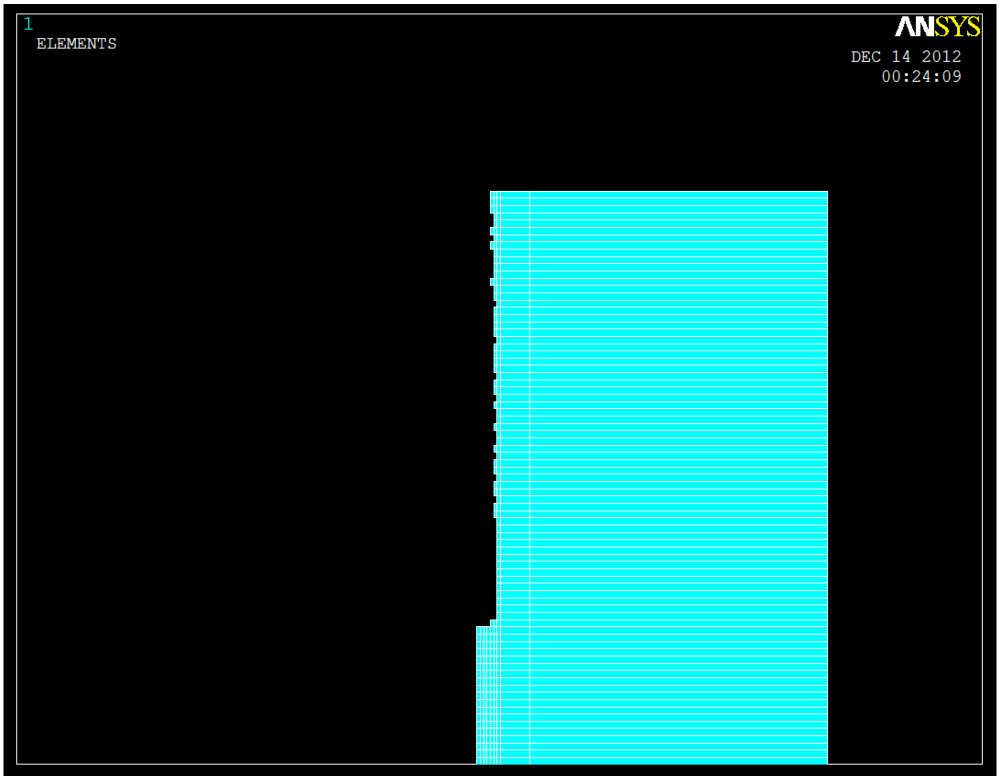

Figure 11: Element remove for data 1 (I=12.8 ,Ton= 42µs, Toff= 42µs)

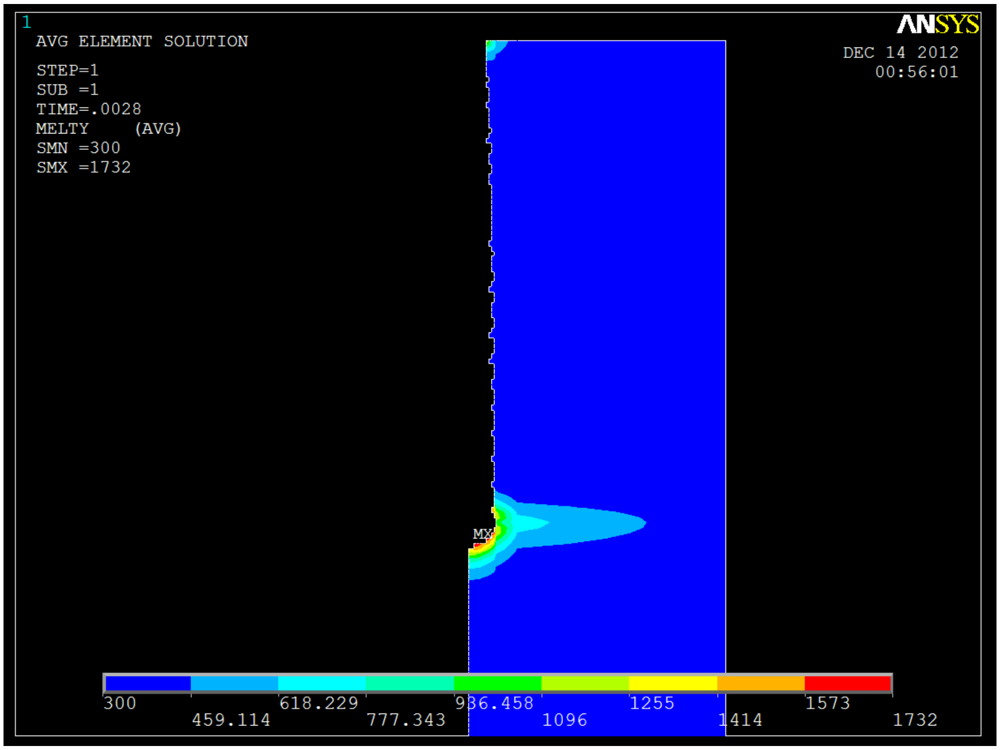

Figure 12: Element remove for data 3 (I=20 ,Ton= 56µs, Toff= 56µs)

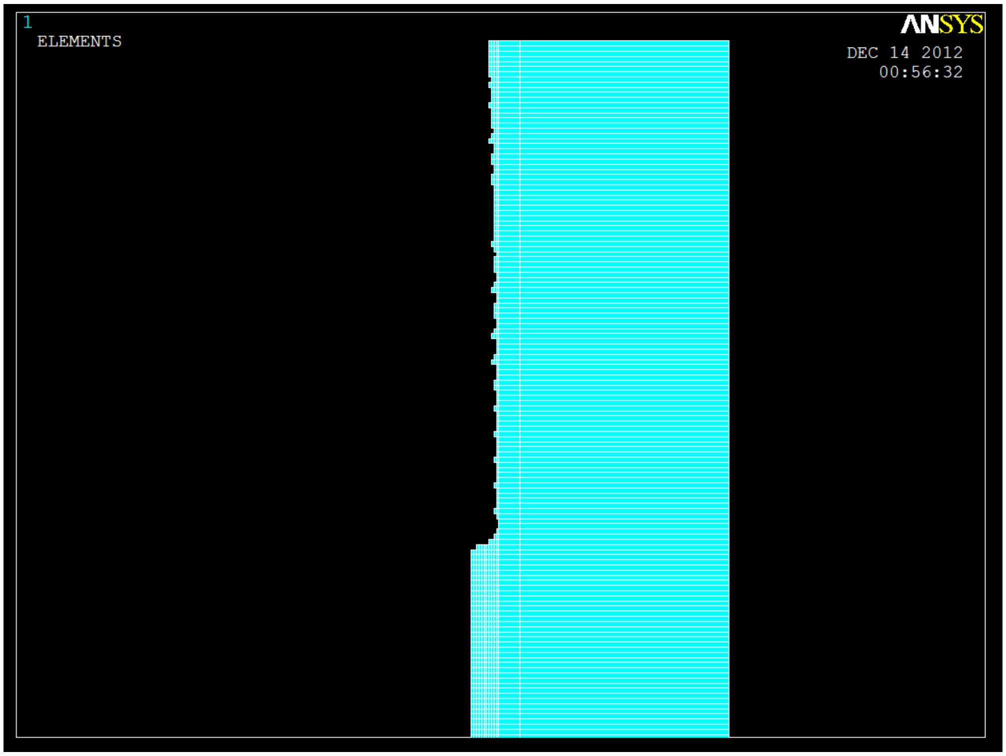

Figure 13: Element remove for data 3 (I=20 ,Ton= 56µs, Toff= 56µs)

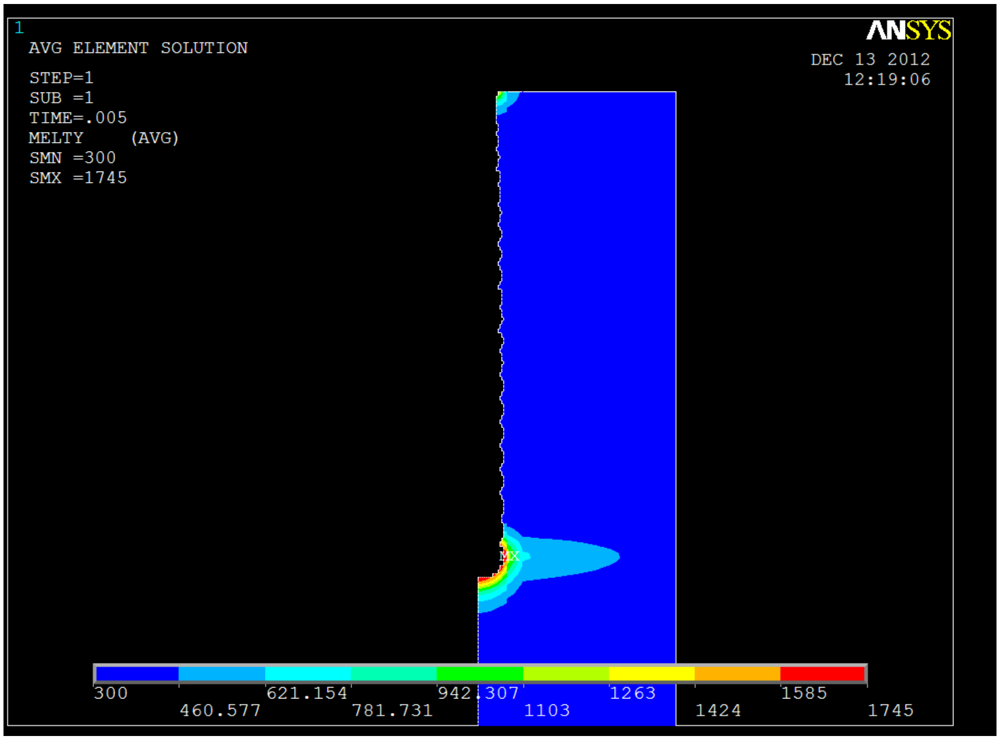

Figure 14: Element remove for data 4 (I=25 ,Ton= 100µs, Toff= 100µs)

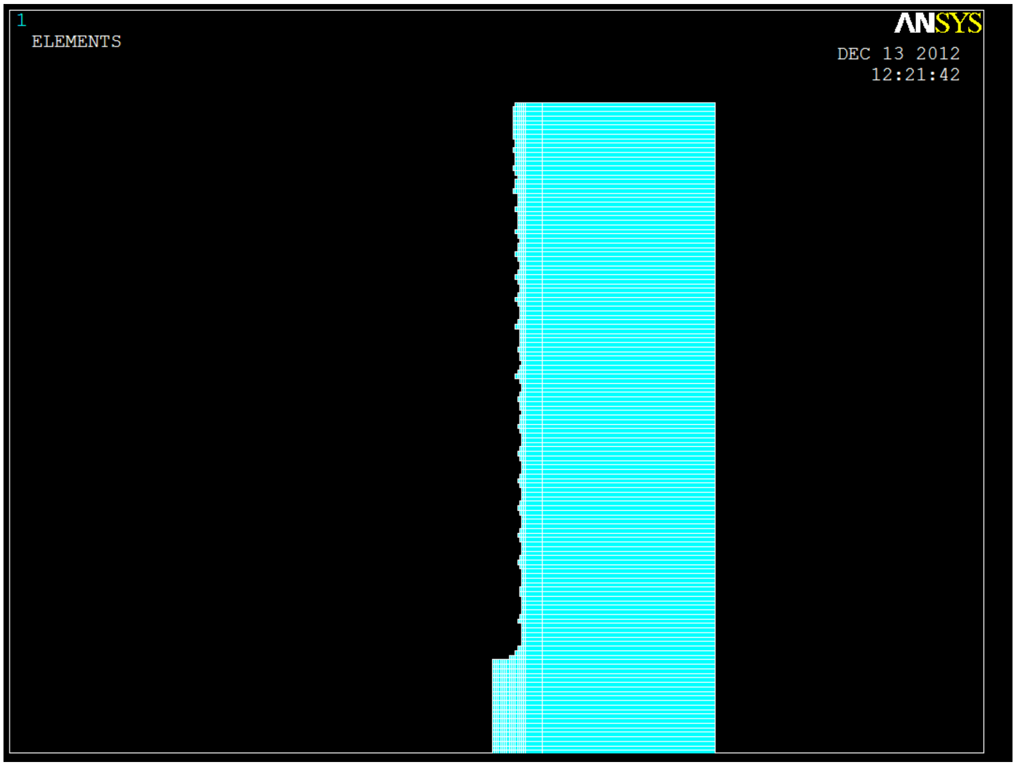

Figure 15: Element remove for data 4 (I=25 ,Ton= 100µs, Toff= 100µs)

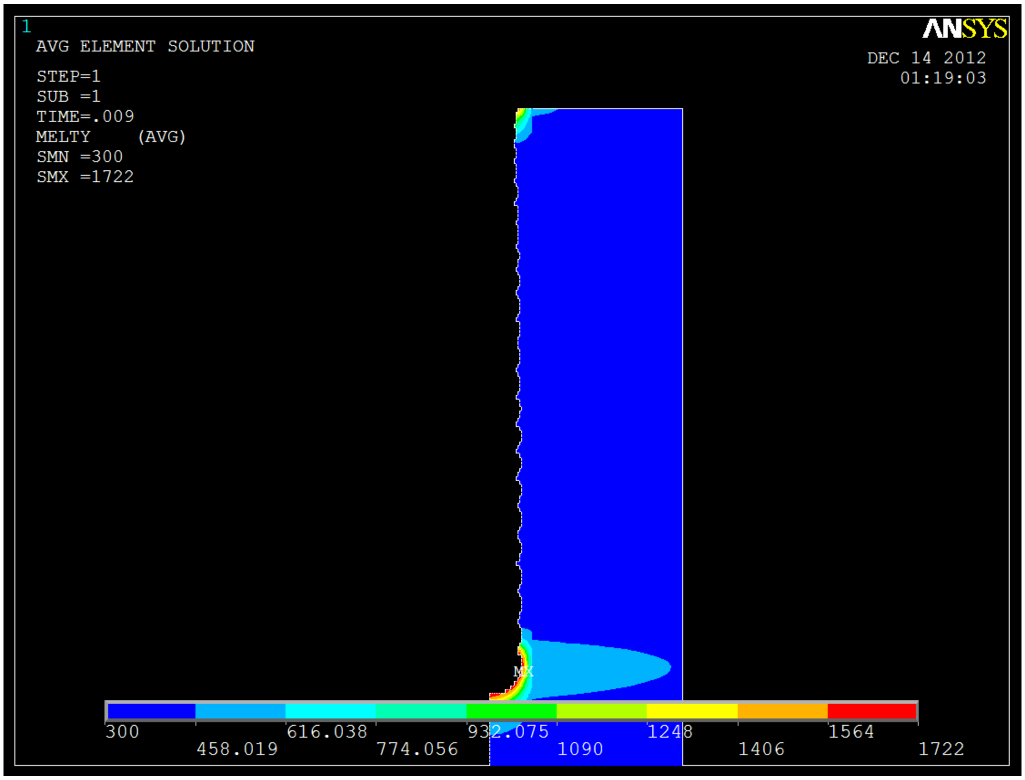

Figure 16: Element remove for data 5 (I=36 ,Ton= 180µs, Toff= 180µs)

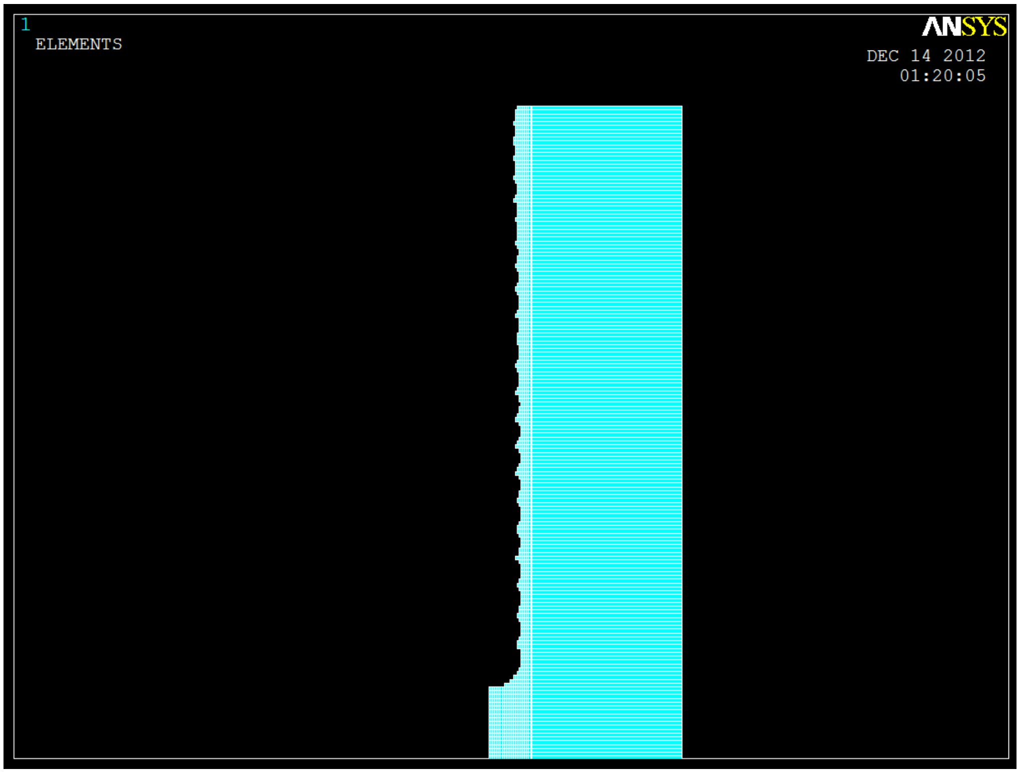

Figure 17: Element remove for data 5 (I=36 ,Ton= 180µs, Toff= 180µs)

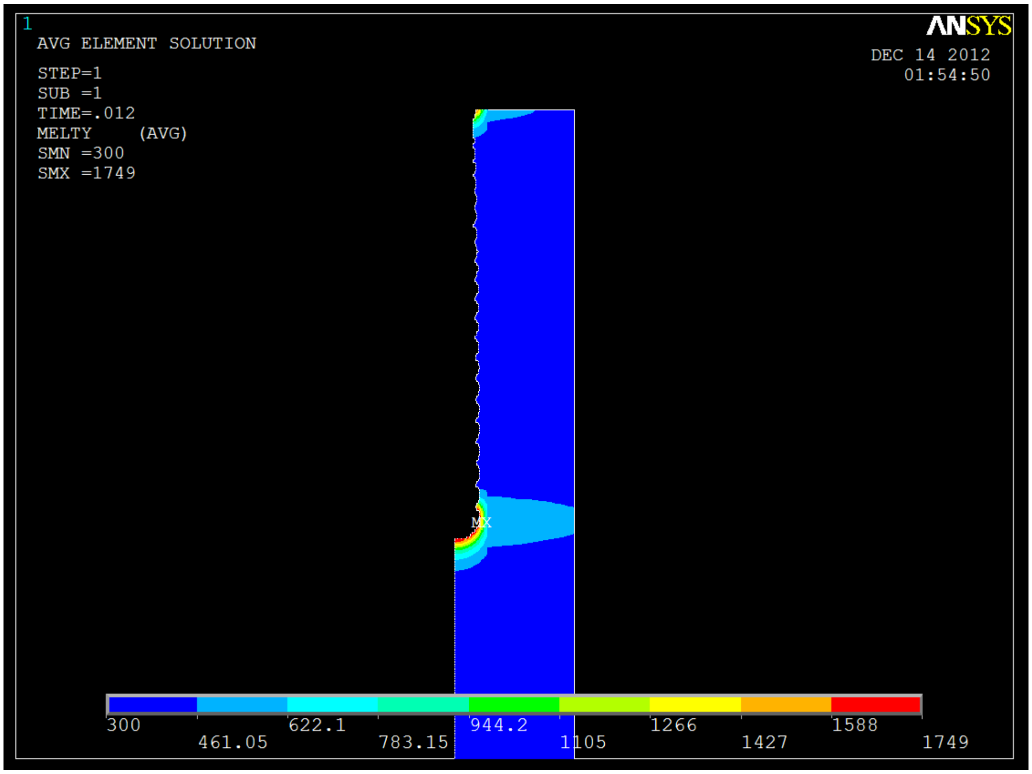

Figure 18: Element remove for data 6 (I=44 ,Ton= 240μs, Toff= 240μs)

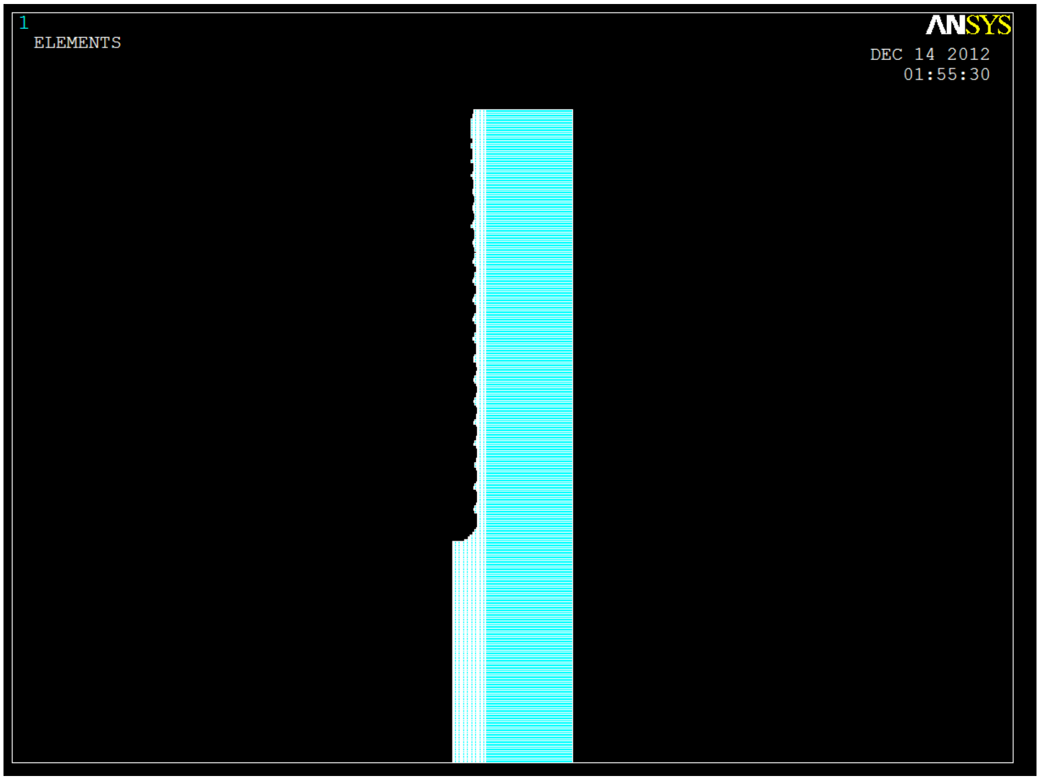

Figure 19: Element remove for data 6 (I=44 ,Ton= 240μs, Toff= 240μs)

From the numerical simulation run, the contour plot of the model after 25 sparks applied for all 6 data show heat distribution is wider as the value of the discharge current, time on and time off been increase. The number of the element affected by the heat also is higher as the controlled parameter increase. The elements with highest temperature can be observed locate at the surface of the crater part. The temperature of the element decrease as the distance from the crater increase.

It is observed that the crater penetrates into the work piece with a constant radius because the molten elements are removed from work piece model with the heat source simultaneously moved downwards after every time spark applied. The element that reach the temperature of 1750 □ C were completely be removed from the model. The heat transfer through the sides of crater is neglected because of the instantaneous and violent nature of dielectric flushing which is a matter of few microseconds and also because an axi-symmetric element PLANE55 has been used which acts as insulation in the absence of applied thermal boundary conditions.

5.2.4 DATA OF MATERIAL REMOVAL RATE FROM THERMAL ANALYSIS

The model of this EDM machining is established to study the thermal analysis of the model after the machining process. Data that collected from the simulation were the radius and height of the crater part effect from the erosion. The data are important in order to determine the MRR of the workpiece model. Table 10 below shows the data gather from this model of numerical simulation.

Table 10: Material removal rate for different machining condition of 25 sparks EDM process

Machining condition				**Results**		
PFE (%)	**Current (A)**	**Pulse-on time (µs)**	**Pulse-off time (µs)**	**Value of radius / R (mm)**	**Value of height / H (mm)**	**Material removal rate /MRR (mm^3/min)**
41	10	32	32	0.04335	1.2100	109.8158961
50	12.8	42	42	0.05886	1.4300	222.3078857
54	20	56	56	0.07470	1.9900	403.7049257
75	25	100	100	0.10848	2.4700	821.8475010
100	36	180	180	0.15103	3.0300	1447.5699730
100	44	240	240	0.18173	3.6100	1872.6582850

Equation for MRR calculation of 25 sparks

Formulas used in the command to calculate the MRR are as follows:

$$\text{Volume of material remove} = \Pi R^2 \times H \qquad \textbf{(5.1)}$$

$$\text{MRR for 25 sparks} = \frac{(\text{PFE} \times \text{Volume material remove})}{25\,(\text{Time on} + \text{Time off})} \qquad \textbf{(5.2)}$$

Volume of material removed

This model has developed to simulate the EDM machining process for multispark EDM process using quite element technique that consider the material erosion after spark been applied. The area of material been remove from this model view from side view resembles more closely to a rectangle but the volume is consider being cylindrical shape. As the machining progresses and the volume of material removed is calculate by Equation 5.1 where R is the crater radius and H is the height or horizontal length of the crater.

Table 10 shows the value of crater radius and crater height with different value of discharges current, time on and time off for this 25 sparks numerical model. Equation 5.1 shows that the value of volume of material removed is directly proportional to the value of crater radius and crater height. The volume of material removed increases linearly with the increase in discharge current, time on and time off for this multi spark models using quite element technique.

Material removal rate (MRR)

MRR is one of the most important parameter to be measure in order to define the performance of EDM machining. This project model with quite element technique shows that MRR increase constantly as the machining time progress which is evident from Table 10.

The value of material removal rate (MRR) increase linearly with the increment in discharge current, time on and time off parameters. The lowest value of MRR 109.8158961 mm^3/min was get from data 1 where the discharge current used was 10 A, plasma flushing efficiency was 0.41, time on and time off were 32 microsecond respectively. The MRR (mm^3/min) is estimated using the same equation as derived earlier, Equation 5.2. The plasma flushing efficiency (PFE) factor which is the ratio of actual volume of material removed to the total volume of the predicted molten material has been used to be the same as the value used by previous student for data comparison purpose.

CHAPTER 6
ACTUAL EXPERIMENT TO FIND MRR

6.1 MATERIAL AND APPARATUS

6.1.1 MATERIAL

1. Cylindrical mild steel

- Dimension : diameter 0.32 m, height 0.3 m
- The number of cylindrical mild steel prepared is 6.
- Purpose: Work piece for experiment.

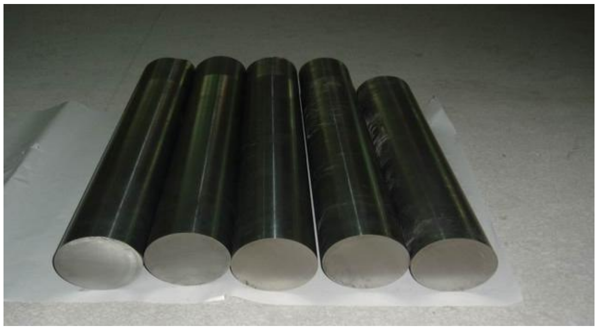

Figure 20: Cylindrical rod mild steel before being cut off to appropriate dimensions

2. Brass cylinder

- Dimension : diameter 0.013m, length 0.05m
- The number of cylindrical brass prepared is 6.
- Purpose: Electrode

Figure 21: Cylindrical brass material after been cut to appropriate dimension

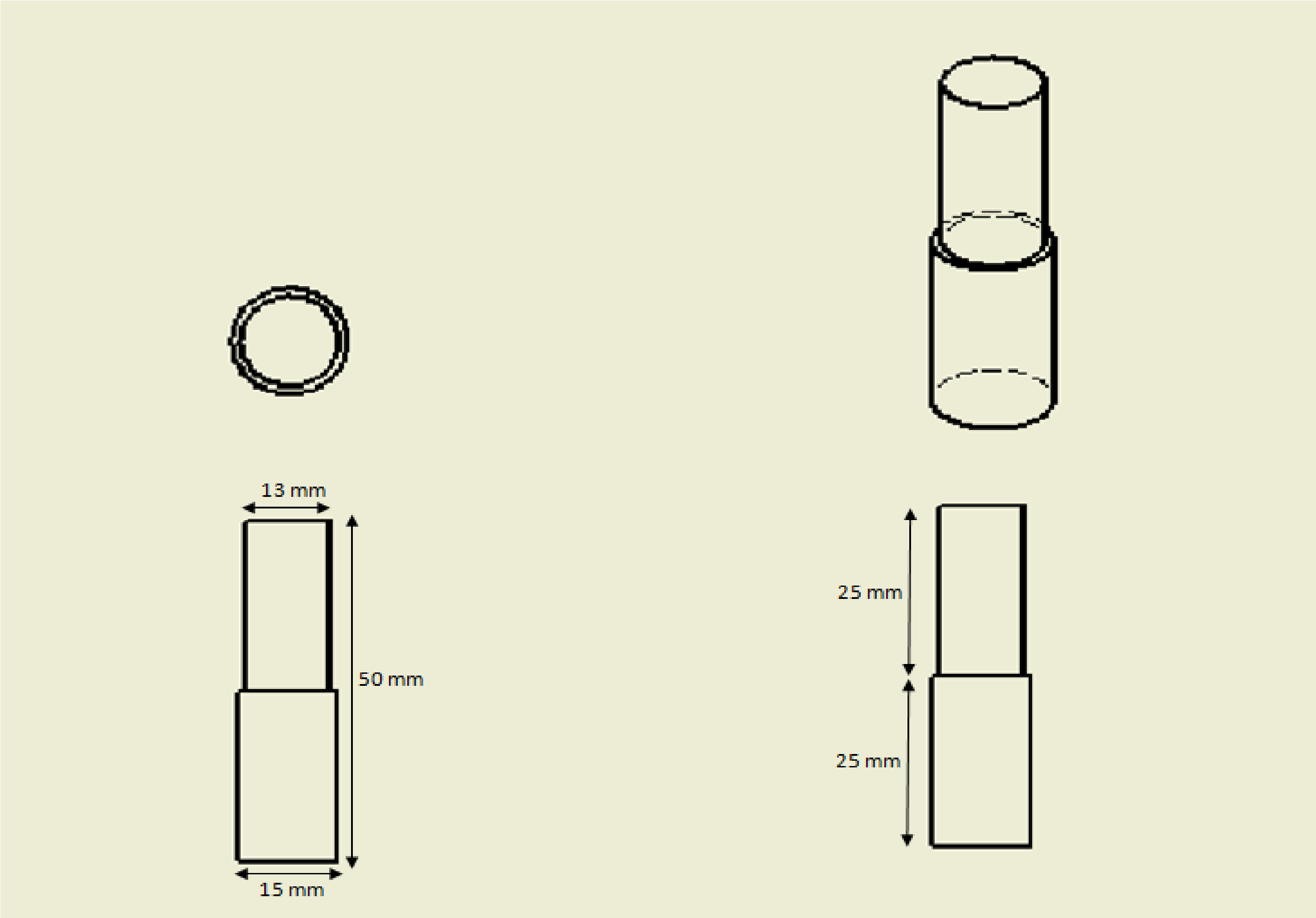

Figure 22: Technical drawing of the electrode (unit in mm)

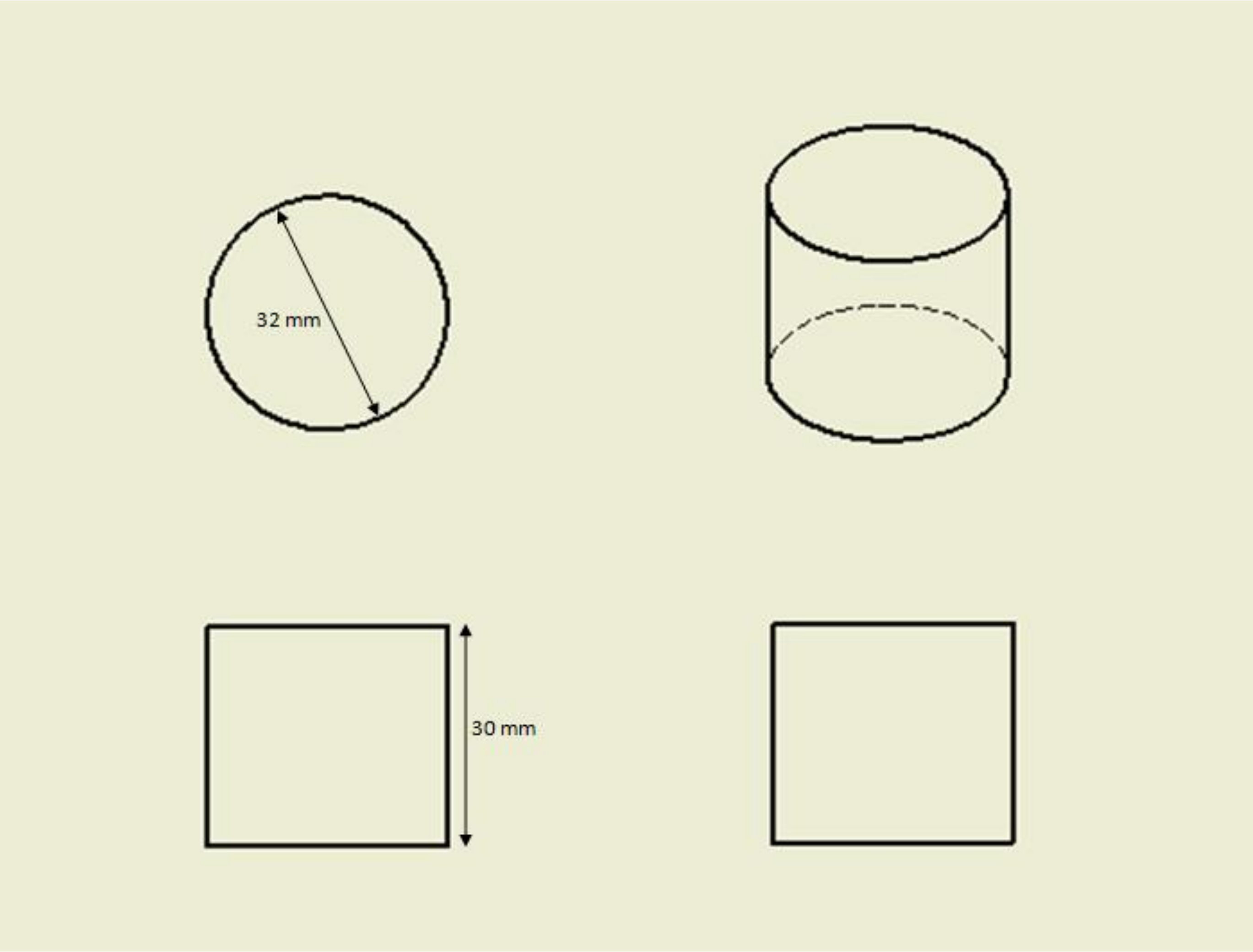

Figure 23: Technical drawing of the machined work piece (unit in mm)

6.1.2 APPARATUS

1. EDM Die sinking machine

Figure 24: EDM die sinking machine used for actual experiment

Specification :

Model	Sodick AQ55L (Sinker EDM)
Machine dimension	69"L X 101"D X 114"T
Machine strokes (X x Y x Z)	21.6" x 15.8" x 13.8"
Dielectric fluid	FUCHS EDM Fluid , RATAK FEL model
Type of flushing	Flushing nozzle
Flushing pressure	0.04 MPa
Voltage	Value of voltage depend on the current defined

Table 11 : Specification of EDM machine used for actual experiment

2. Electronic balance

Figure 25: Electronic balance used for actual experiment

Purpose: To determine the work pieces weight before and after the experiment.

6.2 PROCEDURE FOR ACTUAL EXPERIMENT

1. The initial mass of the all 6 work piece is being taken using the electronic balance.
2. The work piece is placed properly on die sinking machine and clamped.
3. The machining electrode that ready to be used is placed and clamped to the machine. Use different electrode for different work piece.
4. The die sinking machine is being set up by entering the 3 parameters that we will be control. The first data of parameter used for the first machining process is 10A for current, time on is 32×10^{-6} seconds and time off used is 32×10^{-6} seconds.
5. The machining process is being started and machining time for the process to complete is taken.
6. The final mass of the work piece is taken using the same electronic balance
7. The above procedure is repeated for other 5 data. The parameters value can be refer from the table.
8. The data is being inserted in the table as shown in the next part of the report.
9. The result for the experiment is being compared with the result FEM model

6.3 RESULTS AND DATA GATHERING FOR ACTUAL EXPERIMENT

6.3.1 Data of MRR for 25 sparks

Work piece no.	Mass before (gram)	Mass after (gram)	Mass remove (gram)	Double mass remove (gram)	Volume remove (mm^3)
1	187.9880	187.9814	0.0066	0.0132	1.6794
2	190.4630	190.4485	0.0145	0.0290	3.6896
3	190.3180	190.2834	0.0346	0.0692	8.8041
4	187.7000	187.6524	0.0476	0.0952	12.1120
5	188.6480	188.5539	0.0941	0.1882	23.9440
6	190.2400	190.1147	0.1253	0.2506	31.8830

Table 12: Data of work piece volume removed in actual experiment

Work piece no.	Current (A)	Pulse-on time (µs)	Pulse-off time (µs)	Machining duration (sec)	MRR (mm^3/min)
1	10	32	32	120	1.1196e-6
2	12.8	42	42	120	3.2284e-5
3	20	56	56	120	1.0271e-4
4	25	100	100	120	2.5233e-4
5	36	180	180	120	8.9790e-4
6	44	240	240	120	1.5941e-3

Table 13: Data of MRR for 25 sparks in actual experiment

6.3.2 Equation for calculation of MRR of 25 sparks

$$\text{No. of spark applied} = \text{Machining time} / (\text{Time on} + \text{Time off}) \quad \textbf{(6.1)}$$

$$\text{Overall MRR} = \frac{(\text{Mass before machining} - \text{Mass after machining}) / \text{Density}}{\text{Machining time}} \quad \textbf{(6.2)}$$

$$\text{MRR for 25 sparks} = (25 / \text{No. of spark applied}) \times \text{Overall MRR} \quad \textbf{(6.3)}$$

CHAPTER 7
DATA COMPARISON AND VALIDATION

7.1 Data comparison and validation

No	Machining condition				MRR for 25 sparks (mm^3/min)	MRR for 25 sparks (mm^3/min)	MRR for 25 sparks (mm^3/min)
	PFE (%)	Current (A)	Pulse-on time (µs)	Pulse-off time (µs)	FEA model by previous student	FEA model of this project	Experimental value of this project
1	41	10	32	32	38.8180236	109.8158961	1.1196e-6
2	50	12.8	42	42	53.2912434	222.3078857	3.2284e-5
3	54	20	56	56	90.810826	403.7049257	1.0271e-4
4	75	25	100	100	125.8913458	821.8475010	2.5233e-4
5	100	36	180	180	202.312992	1447.5699730	8.9790e-4
6	100	44	240	240	227.872464	1872.6582850	1.5941e-3

Table 14: Data comparison between the project and previous research

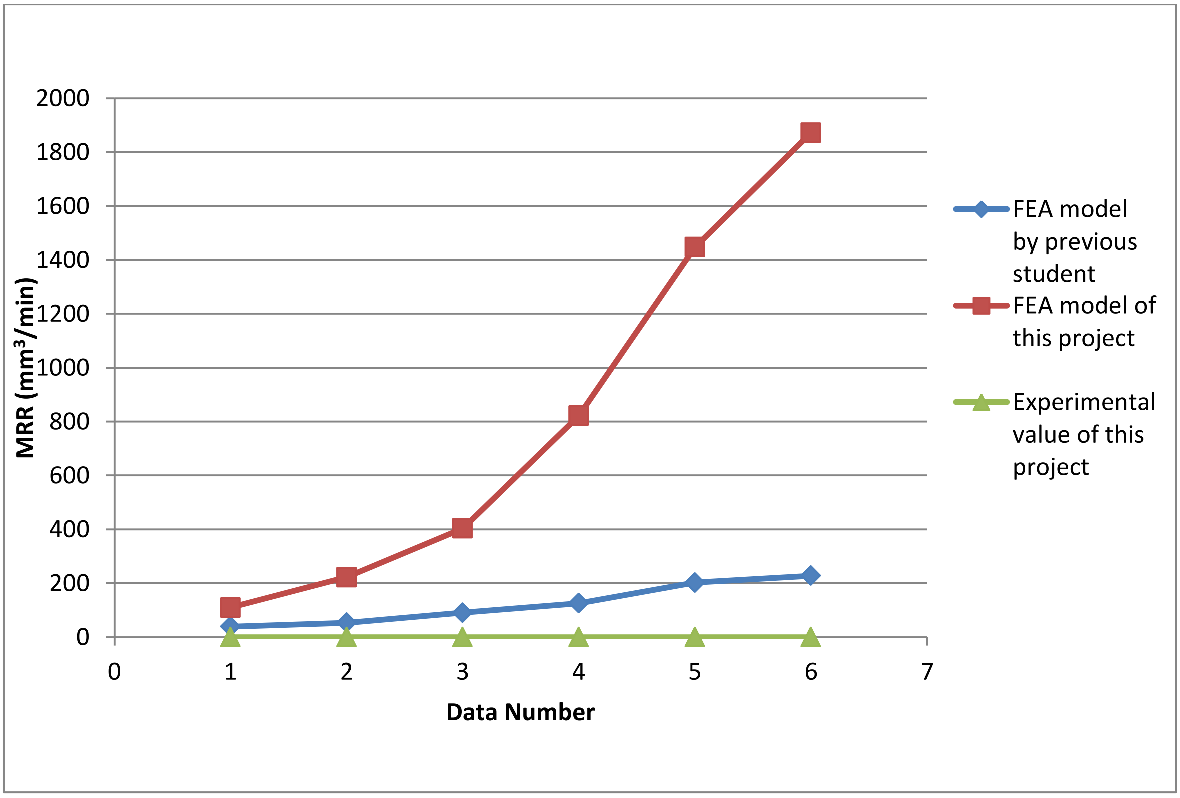

Figure 26: Comparison between the graph of MRR

The references that the author choose to compare the value of the data of for this project model of thermal analysis data for 25 sparks EDM process is the data of from previous student model and the data from actual experiment. From the graph of MRR data in Figure 26, the plot line of this model data is higher compare to the plot line of the previous student model. For data 1 that used current 10A, pulse on-time 42 microseconds and pulse off-time 42 microseconds the MRR value of this model and previous student shows large different where the MRR of this project model is 109.8158961 mm^3/min while previous model is 38.8180236 mm^3/min. As the value of discharge current, pulse on-time and pulse off-time be increase that is in data 2 till data 6 the value of MRR of this project model increase drastically compare to MRR data of the previous model. All the parameters used for both model are the same.

The value of MRR by this model is much greater than the previous model. The reason for the different of MRR are because of the heat source been moved after very spark applied. The inclusion of quite element technique which removes the material that considers to be melt by the heat flux give more realistic model of the machining process. The quite element technique used in this model is actually deactivates the specified element which however remains in the model but contributes a near zero conductivity value to the overall matrix. The previous model whose does not include quite element technique have lower value of MRR due to the heat that source from the spark need to pass through more element where as in this project model the element that supposed to be melt have been removed thus provided space for the heat flux to be applied directly on the remaining element. The second reason of the large different in the MRR value is due to the assumption made for the shape of the crater volume. This project model uses the assumption of rectangular shape which produces cylindrical volume whereas the previous student model uses the assumption of triangular shape for the calculation of the MRR which shows in equation 7.1 below:

$$ACV = (1/3)\, \Pi R^2 \times H \qquad \textbf{(7.1)}$$

From the graph plotted our model MRR value is much higher compare to the previous model which has been predicted.

To validate the most accurate value of MRR, both data from this project model and the previous model should be compare with the result of MRR obtained from the actual experiment. The experiment was carried out by using EDM die sinking machine and the material for the work piece is mild steel. From Table 14, we can observe that the value of MRR obtained from the actual experiment is too small compare to both FEA model. The data supposed to be within the range of data generated by either one of the FEA model. From the data obtained, author concluded that the data cannot be use to validate the most accurate data.

Possibilities of errors that lead to false data obtained are:

1. Wrong technique during electrode setting.

   During the machine setup the position of the electrode tip supposed to be set to fully face the work piece but due to misunderstanding of experiment concept, the author set only half of the electrode tip to face the work piece. The value of the result have been double in chapter 6 but still the result is too low to be compare with the result obtained from the FEA modeling.

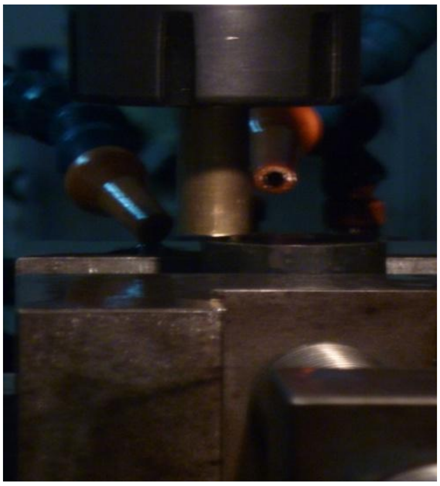

Figure 27: Electrode position during actual experiment

2. Ambient factor.

   The environment condition may affect the data obtained during the experiment, the room temperature during should be control to be in the range of room temperature. The ambient temperature that too low may affect the heat transfer from the spark to the work piece during machining.

7.2 Conclusion

A die sinking EDM single and multispark model with quite element technique have been developed which resemble more realistic process of real phenomenon of material removal occurring during the EDM process. Graph of MRR with respect to different data of discharge current, pulse time on and pulse time off have been plotted to study the trends of the process.

From the analysis, the result show that the increasing value of deep and radius when discharge current, pulse time on and pulse time off were increased. These FEA model should be validated by comparing the results with the result from actual experiment using the same process conditions but unfortunately the actual result seems to be invalid. The result from this project model be compared with the previous model.

In overall, the result of this project was expected in the beginning of the project where the MRR should be higher by inclusion of quite element technique compare to thermal analysis without quite element technique. In the future, the recommended work for future researcher is to reconfirm the data obtained from this project.

7.3 Recommendation for future works

The following aspects are recommended for future work on thermal analysis of EDM using quite element technique:

1. The thermal model developed from this project can further be used to carry out extensive studies on the EDM process to obtain optimal process conditions.

2. The area where the heat flux be applied are only on top surface of the element. The side surface of the element was neglected. Thus, further improvement in the development of more advance and realistic can be done by considering the side area of the element to be applied with heat flux.

3. The actual experiment can be reconduct by future reseacher to acquire the best data of MRR of the actual experiment and reconfirm the data of this research.

4. The high temperature gradients that generated at the gap during Electrical Discharge Machining (EDM) result in large localized thermal stresses in a small heat-affected zone. These thermal stresses can lead to micro-cracks, decrease in strength and fatigue life and possibly catastrophic failure [6]. Further thermal stress analysis can be conduct to analys this effect.

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