OPTIMIZATION OF ELECTRICAL DISCHARGE MACHINE ON MILD STEEL AISI 1020 BY USING GREY RELATIONAL ANALYSIS

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I certify that the project entitled "*Optimization of Electrical Discharge Machine on Mild Steel AISI 1020 by Using Grey Relational Analysis*" is written by *Abdul Rahim b Asas* . 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 with Manufacturing Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Dedicated to my family

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In the name of Allah, the Most Gracious and Most Compassionate

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ABSTRACT

This report deals with machining workpiece mild steel AISI 1020 using electrical discharge machining (EDM). The objective of this thesis is to optimize the surface roughness (SR), electrode wear ratio (EWR) and material removal rate (MRR) by using grey relational analysis (GRA) with orthogonal array (OA) and to discuss on the significant result by using analysis of variance (ANOVA). The machining of mild steel AISI 1020 steel workpiece was perform using the EDM machine AQ55L (ATC) and the analysis done using equation for GRA and STATISTICA software for ANOVA. In this study, the machining parameters, namely workpiece polarity, pulse off time, pulse on time, peak current, servo voltage and dielectric fluid are optimized. A grey relational grade obtained from the grey relational analysis is used to solve the EDM process with the multiple performance characteristics. Optimal machining parameters can then be determined by the grey relational grade as the performance index. Based from the result, the most significant parameter that effect the MRR, EWR and SR was the peak current while significant parameter was workpiece polarity. Experimental results have shown that machining performance in the EDM process can be improved effectively through this approach.

ABSTRAK

Laporan ini membincangkan proses pemesinan keluli kerja AISI 1020 menggunakan proses pemesinan nyahcas elektrik (EDM). Objektif tesis ini adalah untuk mengoptimumkan kekasaran permukaan (SR), nisbah kehausan elektrod (EWR), dan kadar penyingkiran (MRR) dengan menggunakan analisis hubungan kelabu (GRA) dengan susunan orthogonal (OA) dan membincangkan keputusan yang signifikan menggunakan analisis perbezaan (ANOVA). Kerja pemesinan keluli kerja AISI 1020 dilakukan menggunakan mesin AQ55L (ATC) dan analisis menggunakan persamaan bagi GRA dan perisian STATISTICA untuk ANOVA. Dalam kajian ini, parameter memesin iaitu kekutuban keluli kerja, pulse off time, pulse on time, arus puncak, servo voltan dan bendalir dielektrik yang dioptimumkan. Gred hubungan kelabu didapati daripada analisis hubungan kelabu digunakan untuk menyelesaikan pelbagai proses ciri-ciri prestasi. Parameter memesin optimum boleh ditentukan dengan gred hubungan kelabu sebagai indeks prestasi. Daripada keputusan, parameter paling signifikan yang member kesan kepada MRR, EWR and SR adalah arus puncak manakala signifikan parameter adalah kekutuban keluli kerja. Keputusan eksperimen telah menunjukkan bahawa prestasi memesin boleh ditingkatkan dengan efektif melalui kaedah ini.

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t_i	Pulse On-time
t_o	Pulse Off-time
µs	The duration of time machining
µΩ	Electrical resistivity
s	second
W_b	Weight of workpiece material before machining (g)
W_a	Weight of workpiece material after machining (g)
A	Ampere
µm	Micrometer
x_{ij}	Normalized value
x_i^0	Ideal value
ζ	Distinguishing coefficient
γ_m	Total mean of the Grey relational grade
γ_i	Mean of the Grey relational grade at optimal level
q	Number of the machining parameters

LIST OF ABBREVIATIONS

EDM	Electrical Discharge Machining
MRR	Material Removal Rate
EWR	Electrode Wear Ratio
V	Voltage
I	Current
AISI	American Iron and Steel Institute
SME	Society of Manufacturing Engineering
GRA	Grey Relational Analysis
OA	Orthogonal Array
DOE	Design of Experiment
EWW	Weight of Electrode Use
WRW	Weight of Workpiece Used
ANOVA	Analysis of Variance
GRG	Grey Relational Grade
GRC	Grey Relational Coefficient
MS	Mean Square
D.O.F	Degree of Freedom
SS	Sum of Square
F	Fisher Test

CHAPTER 1

INTRODUCTION

1.0 Introduction

Electrical discharge machining (EDM) is a non-traditional manufacturing process based on removing material from a part by means of a series of recurring electrical discharges between a tool called electrode and the part in the presence of a dielectric fluid (Lin et al., 2002). This technique has been widely used in modern metal-working industry because of its ability to cut fully hardened steels especially in the die making industry. One critical limitation, however, is that EDM only works with materials that are electrically conductive.

The machine used in this study is a AQ55L (ATC) EDM and the workpiece material used is a mild steel with AISI 1020 grade. The important output parameters of the process are the material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR). Wu.H.H (1996) stated that Grey Relational Analysis (GRA) is a method that used to get the desired information based on the relation with incomplete information. GRA require only a limited amount of data to estimate behavior of unknown systems. By using this method, we can determine and find the suitable parameter to optimize the electrical discharge machine on mild steel workpiece. This project is to investigate the optimum parameter required for MRR, EWR and SR by using GRA.

1.2 Important of research

The important of doing this research are:

i) Improve the quality surface finish of the cut metal.
ii) Improve efficiency of production process.
iii) Minimize the cost of production process.
iv) Enhance the production rate.

1.3 Objective

The objectives of the study are to:

i) Optimize the surface roughness (SR), electrode wear ratio (EWR) and material removal rate (MRR) by using GRA with Orthogonal Array (OA).
ii) Discuss on the significant result by using analysis of variance (ANOVA).

1.4 Problem statement

During the machining process, wear will occur on the electrode. This will affect the machining efficiency and cost. Other than that, crack also will occur due to the workpiece material condition. Mild steel AISI 1020 is a soft material, thus the proper machining is required to avoid the crack.

Other than that, the optimum parameter is also problems occur in this project. The optimum parameter can affect and meanwhile optimize the EDM process.

1.5 Project Scopes

This project will focus on machining parameter and the method used to optimize MRR, EWR and SR. The parameters that would be studied in this project are:

i) Peak current
ii) Pulse off duration
iii) Pulse on duration
iv) Polarity
v) Dielectric pressure
vi) Servo voltage

This project also focuses on the methods used which are GRA, OA and ANOVA in order to obtain the data. All of the methods that used in this project were aimed to evaluate the best and optimum parameter stated above. SR, EWR and MRR could simultaneously satisfy requirements of both quality and as well as productivity with special emphasis on reduction of electrode wear that ensures increase in tool life. The optimal setting ensured minimization of SR and EWR, while maximize MRR.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discuss on some literatures about EDM process, parameters and methods involved in this project. A literature review is a body of text that aims to review the critical points of current knowledge and studies related to the project.

2.2 Electrical discharge machine (EDM)

The origin of electrical discharge machining (EDM) dates back to 1770 when English scientist Joseph Priestly discovered the erosive effect of electrical discharges. During the 1930s, attempts were made for the first time to machine metals and diamonds with electrical discharges. Erosion was caused by intermittent arc discharges occurring in air between the tool electrode and workpiece connected to a DC power supply. These processes were not very precise due to overheating of the machining area and may be defined as “arc machining” rather than “spark machining” (Ho and Newman, 2003).

EDM is an electro-thermal non-traditional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark. EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. EDM can be used to machine difficult geometries in small batches or even on job-shop basis.

This machining process is continually finding further applications in the metal machining industry. It is being used extensively in the plastics industry to produce cavities of almost any shape in metal moulds. Although, the application of EDM is limited to the machining of electrically conductive workpiece materials, the process has the capability of cutting these materials regardless of their hardness or toughness. The use of EDM in the production of forming tools to produce plastics mouldings, die castings, forging dies and many more have been firmly established in recent years.

Development of the process has produced significant refinements in operating technique, productivity and accuracy, while widening the versatility of the process. EDM continues to grow, therefore, as a major production tool in most tool making companies, machining with equal ease hardened or annealed steel. While machining using EDM, there are several important parameters that would affect the machining. The important output parameters of the process are the material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (RS) (S.H.Lee et al., 1999).

Optimization of the EDM process is concerned with maximizing MRR while minimizing EWR, and also producing the optimum SR so that the finish should be as smooth as possible. There are two main types of EDMs; the Die-sinking and the wire-cut. But in this project, EDM used is Die-sinking. Each are used to produce very small and accurate parts as well as large item. The largest single use of EDM is in die making. Materials worked with EDM include hardened and heat-treated steels, carbide, polycrystalline diamond, titanium, hot and cold rolled steels, copper, brass, and high temperature alloys. However, any material to be machined with the EDM process must be conductive (SME, 2009).

The benefits of EDM include:

i) EDM is a non-contact process that generates no cutting forces, permitting the production of small and fragile pieces.

ii) EDM machines with built-in process knowledge allow the production of intricate parts with minimum operator intervention.

iii) Burr-free edges are produced.

2.3 Die-sinking EDM machine

Die-sinking EDM machines are also known as ram or vertical EDMs. The equipment used to perform the experiments was a die-sinking EDM machine of type AQ55L (ATC). Also, a jet flushing system in order to assure the adequate flushing of the EDM process debris from the gap zone was employed. The dielectric fluid used for the EDM machine was kerosene. Figure 1 show the schematic diagram of basic EDM system.

Die-sinking EDM have four sub-systems that are:

i) DC power supply to provide the electrical discharges, with controls for voltage, current, duration, duty cycle, frequency, and polarity.

ii) Dielectric system to introduce fluid into the voltage area/discharge zone and flush away work and electrode debris, this fluid is usually a hydrocarbon or silicone based oil.

iii) Consumable electrode.

iv) Servo system to control infeed of the electrode and provide gap maintenance.

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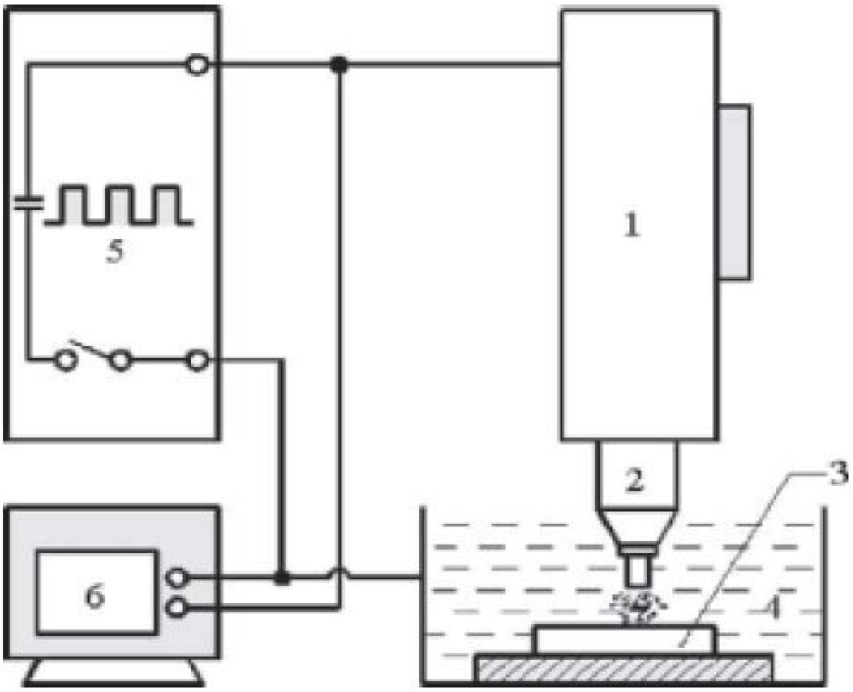

Figure 1: Schematic diagram of basic EDM System (1-servo, 2-electrode, 3-workpiece, 4-dielectric fluid, 5-pulse generator, 6-oscilloscope).

Source: H.S.Payal et al. (2008).

2.3.1 Principles of Die-sinking EDM

The workpiece is mounted on the table of the machine tool and the electrode is attached to the ram of the machine. A DC servo unit or hydraulic cylinder moves the ram (and electrode) in a vertical motion and maintains proper position of the electrode in relation to the workpiece. The positioning is controlled automatically and with extreme accuracy by the servo system and power supply. During normal operation the electrode never touches the workpiece, but is separated by a small spark gap. During operation, the ram moves the electrode toward the workpiece until the space between them is such that the voltage in the gap can ionize the dielectric fluid and allow an electrical discharge (spark) to pass from the electrode to the workpiece.

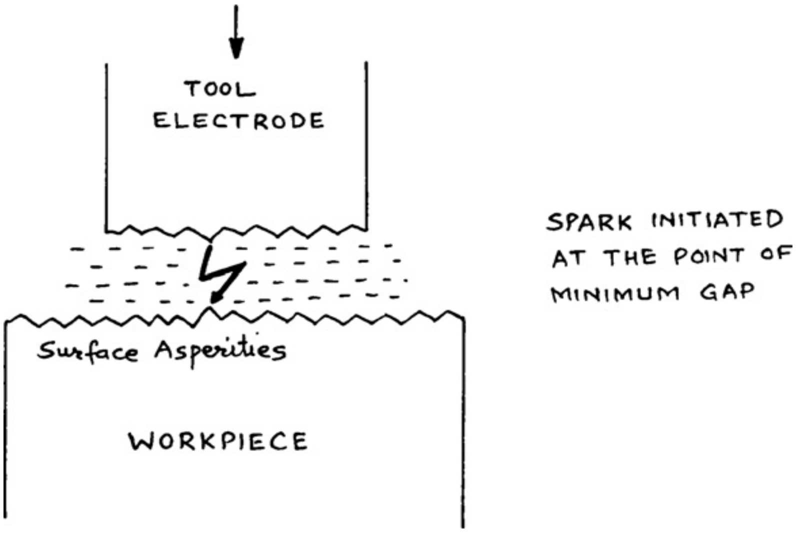

Figure 2: Spark initiation in EDM process

Source: S.Kumar et al. (2008).

From Figure 2, spark is initiated at the point of smallest inter-electrode gap by a high voltage, overcoming the dielectric breakdown strength of the small gap. As the workpiece is spark-eroded, the tool has to be advanced through the dielectric towards it. A servo system, which compares the gap voltage with a reference value, is employed to ensure that the electrode moves at a proper rate to maintain the right spark gap, and to retract the electrode if short-circuiting occurs. The RC circuit did not give good material removal rate (MRR), and higher MRR was possible only by sacrificing surface finish. The spark discharge (arc) always travels the shortest distance across the narrowest gap to the nearest or highest point on the workpiece (S.Kumar et al., 2008).

The mechanical characteristics of workpiece and electrode are not a concern because the electrical energy is converted into thermal energy causing the melting of material. EDMing process allows the machining of hard materials and more complex shapes which cannot be processed by other conventional methods.

The EDMing process is normally applied to mould and die making. Compared to conventional machining method, the material removal rate of this machining remains rather low.

In EDMing process, the material of both electrode and workpiece are melted and due to these erosions, the size of the sparking gap tends to increase (Figure 3). In order to maintain a stable spark, this gap must be controlled by an automatic adaptive system. This can be done by adjusting the motor speed during EDMing process to keep the spark gap constant (Altpeter F. and Tricarico C., 2001).

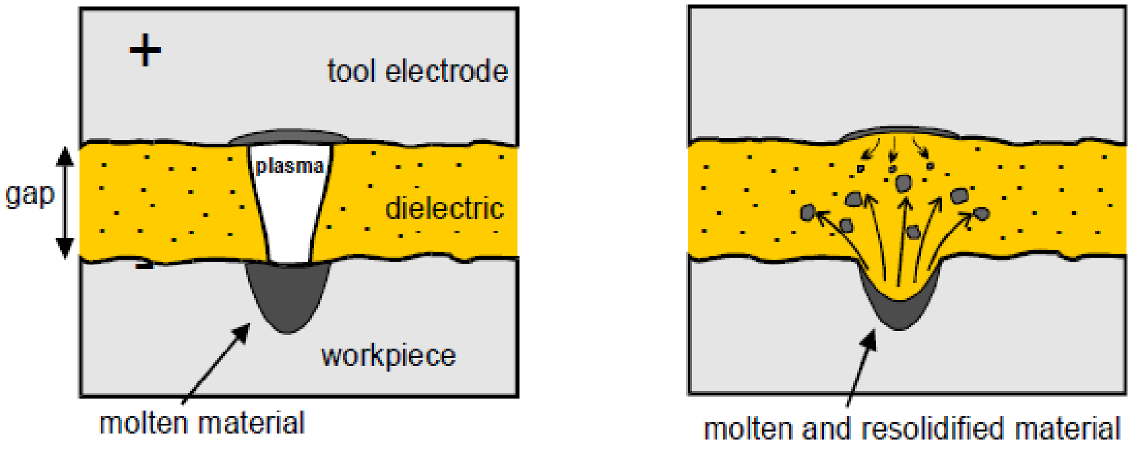

Figure 3: Spark gap and material removal due to one pulse in EDMing process.

Source: Altpeter F. and Tricarico C. (2001).

2.3.2 Dielectric Fluid

Kuneida et al. (2005) stated that for EDM, the dielectric serves to concentrate the discharge energy into a channel of very small cross-sectional area. It also cools the two electrodes, and flushes away the products of machining from the gap. The electrical resistance of the dielectric influences the dis-charge energy and the time of spark initiation. Dielectric fluid acts as an electrical insulator to help control the spark discharges. As thermal processing is required to be carried out in absence of oxygen so that the process can be controlled and oxidation avoided.

Oxidation often leads to poor surface conductivity (electrical) of the workpiece hindering further machining. Hence, dielectric fluid should provide an oxygen free machining environment. Moreover, during sparking it should be thermally resistant as well.

Ali Ozgedik et al. (2005) described that the use of kerosene as a dielectric liquid is very common in the published research. Distilled water, water solutions of sugar, glycol, glycerin and polyethylene glycol are also used as dielectric fluids. The use of kerosene gives a higher workpiece removal rate with increasing current compared with the other dielectrics. EWR increases with increasing current for kerosene while it decreases with the other dielectrics. Kerosene dielectric gives lower relative tool wear values compared with the other dielectrics for a low to medium range of current.

The functions of the dielectric fluid are to:

i) Act as an insulator between the tool and the workpiece.
ii) Act as coolant.
iii) Act as a flushing medium for the removal of the chips.

2.3.3 The servo system

A servo system, which compares the gap voltage with a reference value, is employed to ensure that the electrode moves at a proper rate to maintain the right spark gap, and to retract the electrode if short circuiting occurs. The RC circuit did not give good MRR and higher MRR was possible only by sacrificing surface finish. The servo system is commanded by signals from the gap voltage sensor system in the power supply and controls the infeed of the electrode or workpiece to precisely match the rate of material removal. If the gap voltage sensor system determines that a piece of electrically conductive material has bridged the gap between the electrode and workpiece, the servo system will react by reversing direction until the dielectric fluid flushes the gap clear. When the gap is clear, the infeed resumes and cutting continues (G.F. Benedict., 1987).

The selection of the dielectric-flushing technique has a direct effect on the function of the servo system. If the flushing technique being used inefficient in removing the process by-products from the cutting gap, the servo system may have to spend most of the time reversing to clear the cutting gap. This result is extremely long cycle. However if the flushing technique being used effectively removes the by-products, the servo system will spend almost no time retracting, resulting in much faster cycles (G.F.Benedict., 1987).

2.4 Material Removal Rate (MRR)

Maximum of MRR is an important indicator of the efficiency and cost effectiveness of the EDM process, however increasing MRR is not always desirable for all applications since this may sacrify the surface integrity of the workpiece. A rough surface finish is the outcome of fast removal rates.

The material removal rate, MRR, in EDM is calculated by the following formula:

$$MRR = \frac{\mathrm{Wb} - \mathrm{Wa}}{\mathrm{T}} \qquad (1)$$

where:
W_b = weight of workpiece material before machining (g)
W_a = weight of workpiece material after machining (g)
T = machining times (min)

2.5 Electrode Wear Ratio (EWR)

In EDM, the tool wear problem is very critical since the tool shape degeneration directly affects the final shape of the die cavity. The EDM operations, performed using tools designed and produced by considering the geometric tool wear characteristics, reduce the machining errors to minimum level and result in parts of higher quality and lower cost (Ali Ozgedik et al., 2005).

The following equation is used to determine the EW value:

$$EWR = \frac{\mathrm{EWW}}{\mathrm{WRW}} \times 100\% \qquad (2)$$

where:
EWW = weight of electrode used (g)
WRW = weight of workpiece used (g)

S.Singh et al. (2004) investigated the EDM characteristics of hardened tool steel using copper, copper tungsten, brass and aluminium electrode materials. Their investigations indicate that the output parameters (material removal rate, diameteral overcut, electrode wear and surface roughness) of EDM increase with increase in pulsed current and the best machining rate are achieved with copper and aluminium electrodes. They reported that copper have minimal wear and aluminium have considerable high wear with increase in the current.

2.6 Surface Roughness (SR)

The surface produced by EDM process consists of a large number of craters that are formed from the discharge energy. The quality of surface mainly depends upon the energy per spark. The SR of the machined workpiece is measure using Perthometer surface roughness measuring machine. Due to the variability of surface finish data, multiple measurements were taken of each surface evaluated so that averages could be calculated (S.H.Tomadi et al., 2009).

2.7 EDM process parameters

There are several parameters requirement should be consider in this EDM process such as servo voltage, peak current, pulse on duration, pulse off duration, workpiece polarity and dielectric pressure.

2.7.1 Servo voltage

Servo voltage in EDM is related to the spark gap and breakdown strength of the dielectric. Before current can flow, the open gap voltage increases until it has created an ionization path through the dielectric. Once the current starts to flow, voltage drops and stabilizes at the working gap level. The preset voltage determines the width of the spark gap between the leading edge of the electrode and workpiece (Kansal et al., 2005).

Range of voltage that available in EDM equipment is in between 40 to 400 DC. Higher voltage settings increase the gap, which improves the flushing conditions and helps to stabilize the cut. MRR, tool wear rate (TWR) and surface roughness increases, by increasing open circuit voltage, because electric field strength increases (Kansal et al., 2005).

2.7.2 Peak current

This is the amount of power used in discharge machining, measured in units of amperage, and is the most important machining parameter in EDM. During each on-time pulse, the current increases until it reaches a preset level, which is expressed as the peak current. In both die-sinking and wire-EDM applications, the maximum amount of amperage is governed by the surface area of the cut. Higher amperage is used in roughing operations and in cavities or details with large surface areas (Ho and Newman, 2003).

Higher currents will improve MRR, but at the cost of surface finish and tool wear. This is all more important in EDM because the machined cavity is a replica of tool electrode and excessive wear will hamper the accuracy of machining. New improved electrode materials, especially graphite, can work on high currents without much damage (Ho and Newman, 2003).

2.7.3 Pulse on and off duration

Each cycle has an on-time and off-time that is expressed in units of microseconds. Since all the work is done during on-time, the duration of these pulses and the number of cycles per second (frequency) are important. Metal removal is directly proportional to the amount of energy applied during the on-time (Singh et al., 2005).

Increasing pulse duration of the spark has the effect of increasing the removal rate, increasing the surface roughness, and decreasing the electrode wear. The values of pulse duration available with currently available EDM machines range from a few microsecond to several milliseconds.

(i) On-time (pulse time or t_i):

The duration of time (µs) the current is allowed to flow per-cycle. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is really controlled by the peak current and the length of the on-time.

(ii) Off-time (pause time or t_o):

It is the duration of time (µs) between the sparks. This time allows the molten material to solidify and to be wash out of the arc gap. This parametric to affect the speed and the stability of the cut. Thus, if the off time is to short, it will cause sparks to be unstable (P.Janmanee et al., 2010).

2.7.4 Workpiece Polarity

Lee S.H et al. (2001) stated in their study that the negative polarity of the tool (− polarity) gives a lower EWR than that of + polarity in the range of low to medium discharge current values. At high current settings, the polarity has no significant effect on EWR. A slight decrease relative tool wear is observed with increasing current in − polarity. In the case of + polarity, relative tool wear decreases significantly with increasing current. Relative tool wear does not vary significantly with current at high settings of current for both polarities.

It is very important to pay attention to the recommended polarity of various electrode-work piece combinations. The wrong polarity can have significant implications on speed, wear, and stability. It is best to consult the specific power supply technology documentation for polarity recommendations. General polarity guidelines are listed in Table 1.

Table 1: General polarity guidelines

Electrode Material	**Polarity**
Graphite on Steel: general purpose and low wear	Electrode Positive
Graphite on Steel: high speed and 20% wear	Electrode Negative
Graphite on Copper	Electrode Negative
Copper on Steel	Electrode Positive
Copper Tungsten on Steel	Electrode Positive
Copper Tungsten on Carbide	Electrode Negative

Source: Roger K.(2008).

2.7.5 Dielectric Pressure

Cogun C et al. (2002) write in their study that relative tool wear increases rapidly when the flushing pressure is increased beginning from the static condition. Increasing dielectric pressure at high-pressure settings does not result in a significant increase in relative tool wear. The increase in dielectric pressure at low-pressure settings results in a significant increase in relative tool wear, whereas the increase in pressure at high dielectric pressure settings insignificantly affects relative tool wear.

2.8 Grey Relational Analysis (GRA)

C.L.Chang et al. (2003) describe that the proposition of grey theory occurring in the 1990 to 1999 time period resulted in the uses of Grey theory to each field, and the development is still going on. The major advantage of Grey theory is that it can handle both incomplete information and unclear problems very precisely. It serves as an analysis tool especially in cases when there is no enough data.

J.L. Lin et al. (2001) had shown that, from his study that the use of the orthogonal array (OA) with the GRA can greatly simplify the optimization procedure for determining the optimal machining parameters with the multiple performance characteristics in the EDM process. As a result, the method developed in this study is very suitable for practical use in a machine shop, factory and laboratory.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will describe about the overall process of methodology in this project from beginning until end of the project. There are four main processes that start with experimental, collecting the data, result analysis and confirmation test. All the processes will be described in this chapter by following the chart. During this part, every information and data will be gathered together and concluded according to the objectives and scope of the project.

The method are basically refers to the design of experiment (DOE) methodology and the procedure. The DOE is not a simple step process since it require many procedure and steps to follow. Actually, a series which must follow certain sequence for the experiment to yield an improve understanding of the outcome or product.

3.2 Flow Chart

Flow chart is an important method in order to make sure the project can be done on time. Based from the flow chart, the project started with the literature review on the project. Research was made through journals, webs, books and other related sources.

The design of experiment is conducted after all the information about the project is gathered. The required parameters need to be defined as a design factor. The experiment start after workpiece, electrode and machine setup was prepared. Then, collect the data and analyze it based on the constructed table attached in the appendices.

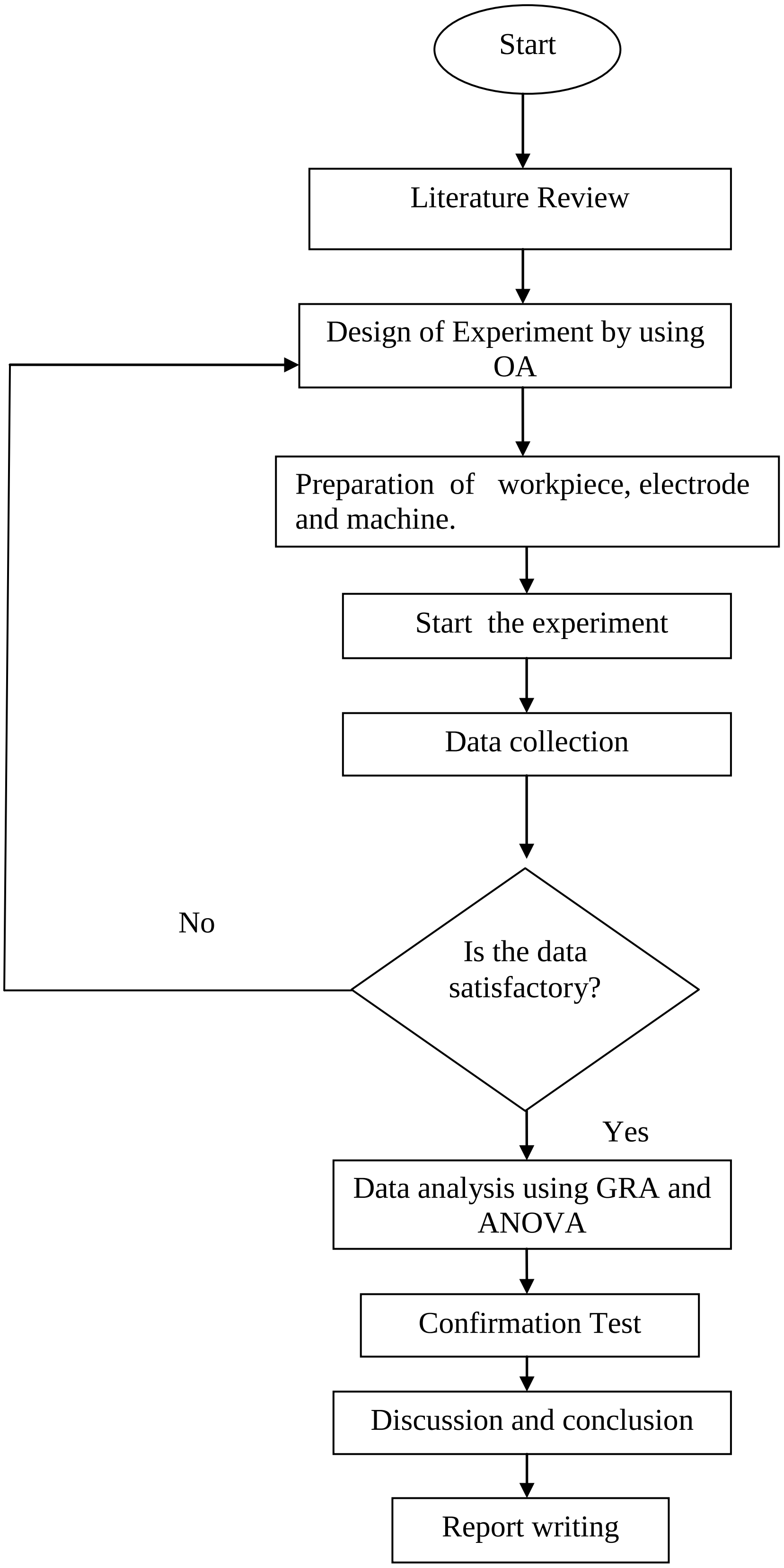

Figure 4: Flow chart that outlines the steps undertaken.

3.3 Experimental Setup

3.3.1 Workpiece material

The workpiece used in this project is mild steel AISI 1020 which is a conductive material. This material also is a cheaper material compare to others while the properties make it suitable for this project. The estimated size of the workpiece is 2.5 x 2.5 x 2 cm. Table 2 shown the properties.

Table 2: Mild Steel AISI 1020 properties.

Work Materials	
Chemical composition	
Mild steel	C:0.14%–0.2%, Fe: 98.81–99.26%, Mn: 0.6%–0.9%, P: 0.04%, S: 0.05%
Density (kg/m^3)	7.7 – 8.03
Hardness (HB)	111
Modulus of elasticity (Gpa)	200
Thermal expansion (20 ^{o}C)	11.9*10^{-6} ^{o}C^{-1}
Specific heat capacity (J/(kg*K))	486
Thermal conductivity (W/(m*K))	51.9

Source: P.J.Blau et al. (2003).

3.3.2 Electrode material

The electrode material used in this experiment is copper. The estimated size of the electrode used is 1.5 cm in diameter and 3.5 cm in length. The properties of the copper are listed in Table 3.

Table 3: Copper Properties

Electrode material properties	
Material	
Composition	
Density (g/cm^3)	8.904
Melting point (^{0}C)	1083
Electrical resistivity (μΩ cm)	9
Hardness	HB 100

Source: S.H.Lee et al. (1999).

3.3.3 Machine Tool

The machine used in this study is a AQ55L (ATC) Die-sinking EDM. The picture of the Die-sinking EDM is shown in Figure 5.

Figure 5: AQ55L (ATC) Die-sinking EDM.

3.4 Design of experiment

In identifying the effect of machining parameters in EDM, the Design of Experiment (DOE) is use so that the possible. The application of DOE requires careful planning and expert analysis of results. In the grey relational analysis, the experimental results of electrode wear ratio, material removal rate and surface roughness are first normalized in the range between zero and one, which is also called the grey relational generating. Next, the grey relational coefficient is calculated from the normalized experimental results to express the relationship between the desired and actual experimental results. Then, the grey relational grade is computed by averaging the grey relational coefficient corresponding to each performance characteristic (J.L. Lin et al., 2001).

The overall evaluation of the multiple performance characteristics is based on the grey relational grade. As a result, optimization of the complicated multiple performance characteristics can be converted into optimization of a single grey relational grade. Optimal level of the process parameters is the level with the highest grey relational grade. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With the grey relational analysis and statistical analysis of variance, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the process parameter design (J.L. Lin et al., 2001).

3.4.1 Design factors selected

There are a large number of factors to consider within the EDM process, but in this work the level of the pulse off time, pulse on duration, peak current, workpiece polarity, servo voltage and dielectric flushing pressure have only been taken into account as design factors. The reason why these six factors have been selected as design factors is that they are the most widespread and used amongst EDM researchers. Besides that, the level of experimentation in this project is three which are low, medium and high.

Table 4: Machining parameters and their respective levels

Factors	Description	Level 1	Level 2	Level 3	Units
A	Workpiece Polarity	+	-		Positive (+) Negative (-)
B	Pulse off time	300	400	500	(s)
C	Pulse on time	100	200	300	(s)
D	Peak Current	12	24	36	(*A*)
E	Servo Voltage	20	30	40	(V)
F	Dielectric flushing Pressure	0.05	0.10	0.15	Bar

3.4.2 Experimental Design

Table 4 shows the machining parameters and their respective levels based on literature reviews conducted. Six factors are selected with a combination of four electrical parameters and two non-electrical parameters. All the parameters were selected for the control factors because they affected MRR, EWR and SR analysis. The values at level were referred from the manual of EDM.

Based on OA method of DOE, an L_{18} (2^1 x 3^5) orthogonal arrays table with 18 rows (number of experiments), was selected for the experimentation (Nicolo Belavendram, 2005). Experimental layout of L_{18} orthogonal array is shown in Appendix B1.

L_{18} (2^1 x 3^5) orthogonal array has a special property where two degree of freedom are taken up between a 2-level and 3-level factor. In general, the experimenter should seek the smallest orthogonal array for an experiment.

The use of the orthogonal array with the grey relational analysis to optimize the process includes the following steps (J.L. Lin et al., 2001):

1. Select the appropriate orthogonal array and assign the process parameters to the orthogonal array.
2. Conduct the experiments based on the arrangement of the orthogonal array.
3. Normalized the experimental results of electrode wear ratio, material removal rate and surface roughness.
4. Perform the grey relational generating and calculate the grey relational coefficient.
5. Calculate the grey relational grade by averaging the grey relational coefficient.
6. Analyze the experimental results using the grey relational grade and statistical analysis of variance.
7. Select the optimal levels of process parameters.
8. Verify the optimal process parameters through the confirmation experiment.

The normalized experimental results for MRR which observes the higher the value, the better performance criteria. Meanwhile, EWR and SR observe the lower-the-better performance criteria. Larger normalized results correspond to the better performance and the best normalized result should be equal to 1.The normalized values are ranged between zero and one. The larger values yield better performance and the ideal value should be equal to one (M.A.Azmir et al., 2008).

Next, the Grey relational coefficient is calculated to express the relationship between the ideal and actual normalized experimental results. The grey relational grades are calculated by averaging GRCs for each performance characteristic. The higher the GRG represents that the experimental result is closer to the ideally normalized value (M.A.Azmir et al, 2008).

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3.5 Analysis of Variance (ANOVA)

The purpose of the analysis of variance (ANOVA) is to investigate which machining parameters significantly affect the performance characteristic. In this study, STATISTICA software was used to construct ANOVA table.

3.6 Confirmation Test

The confirmation tests were conducted by selecting the optimum combinations of machining factors. These confirmation tests were used to predict and verify the improvement in the quality characteristics for machining of mild steel AISI 1020 with respect to the chosen initial parameters setting.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter aim to explain the analysis of the project. This analysis will show the effect of the workpiece polarity, pulse off time, pulse on time, peak current, servo voltage and dielectric flushing pressure. The analysis had done using grey relational analysis (GRA). Full result of the experiment and analysis will show in this chapter.

4.2 Orthogonal array experiment

To select an appropriate orthogonal array for experiments, the total degrees of freedom need to be recognized. The degrees of freedom are defined as the number of comparisons between machining parameters that need to be made to determine which level is better to conduct. In this study, an L18 orthogonal array is used because it has 17 degrees of freedom greater than 11 degrees of freedom in the selected machining parameters.

This array has eight columns and 18 rows and it can handle one two-level machining parameter parameter and seven three-level machining parameters at most. Each machining parameter is assigned to a column and 18 machining parameter combinations are required. Therefore, only 18 experiments are needed to study the entire machining parameter space using the L18 orthogonal array. The experimental result is shown in Table 5.

Table 5: Results of surface waviness in L_{18} OA

Exp	A	B	C	D	E	F	Average values for		
							MRR (g/min)	EWR (%)	SR (µm)
1	+	300	100	12	20	0.15	0.021556	7.76	4.4265
2	+	300	200	24	30	0.10	0.043221	6.78	4.7819
3	+	300	300	36	40	0.05	0.172650	6.23	6.5713
4	+	400	200	24	40	0.15	0.107373	1.10	9.8460
5	+	400	100	36	30	0.05	0.115643	1.04	9.5718
6	+	400	300	12	20	0.10	0.100864	2.31	8.7652
7	+	500	300	36	40	0.10	0.224465	1.79	13.2150
8	+	500	100	12	30	0.15	0.011303	21.91	4.2545
9	+	500	200	24	20	0.05	0.102453	5.43	4.9874
10	-	300	100	12	30	0.10	0.018586	14.66	5.0680
11	-	300	200	24	40	0.05	0.186544	7.01	4.8546
12	-	300	300	36	20	0.15	0.346334	4.27	10.4565
13	-	400	200	36	30	0.10	0.123861	1.30	10.0256
14	-	400	100	24	40	0.05	0.066014	4.96	6.9225
15	-	400	300	12	20	0.15	0.020745	3.03	5.3462
16	-	500	300	12	20	0.15	0.023676	1.87	5.7130
17	-	500	100	24	40	0.05	0.088763	3.45	5.8791
18	-	500	200	36	30	0.10	0.197663	6.16	6.0850

4.3 Grey relational analysis for the experimental results

In the grey relational analysis, data preprocessing is first performed in order to normalize the raw data for analysis.MRR is the bigger-the-better performance criteria while EWR and SR are the lower-the-better performance response. If the target value of the original sequence is “the-bigger-the-better”, it can be calculated as follows:

$$x_{ij} = \frac{y_{ij} - \min\limits_{i} y_{ij}}{\max\limits_{i} y_{ij} - \min\limits_{i} y_{ij}} \tag{3}$$

where y_{ij} is the i th experimental results in the j th experiment.

Meanwhile, for target value which are "the-lower-the-better", then the original sequence is normalized as follows:

$$x_{ij} = \frac{\min_i y_{ij} - y_{ij}}{\max_i y_{ij} - \min_i y_{ij}} \tag{4}$$

Table 6 shows the normalized results for MRR, EWR and SR.

Table 6: Normalized results

Exp	Normalized Values		
	MRR	EWR	SR
1	0.9693	0.6780	0.9808
2	0.9047	0.7249	0.9411
3	0.5184	0.7513	0.7414
4	0.7132	0.9971	0.3759
5	0.6885	1.0000	0.4065
6	0.7326	0.9391	0.4966
7	0.3637	0.9640	0.0000
8	1.0000	0.0000	1.0000
9	0.7279	0.7896	0.9182
10	0.9782	0.3473	0.9092
11	0.4769	0.7139	0.9330
12	0.0000	0.8452	0.3078
13	0.6640	0.9875	0.3559
14	0.8366	0.8121	0.7022
15	0.9718	0.9046	0.8782
16	0.9630	0.9602	0.8372
17	0.7687	0.8845	0.8187
18	0.4437	0.7546	0.7957

Next, the Grey relational coefficient is calculated to express the relationship between the ideal and actual normalized experimental results. The grey relational coefficient can be calculated as shown in Equation 5.

$$\xi_{ij} = \frac{\min_i \min_j \left| x_i^o - x_{ij} \right| + \zeta \max_i \max_j \left| x_i^o - x_{ij} \right|}{\left| x_i^o - x_{ij} \right| + \zeta \max_i \max_j \left| x_i^o - x_{ij} \right|} \tag{5}$$

where x_i^0 is the ideal normalized result for the i th performance characteristics. The calculation for the deviation sequences shown in Appendix B2. ζ is the distinguishing coefficient which is set between zero and one and in this study it was set to $\zeta = 0.9$.

Then, the grey relational grade that is computed by averaging the grey relational coefficient corresponding to each performance characteristic. The overall evaluation of the multiple performance characteristics is based on the grey relational grade. Table 7 shows grey relational coefficient, GRCs and grey relational grade, GRGs.

Table 7: GRCs and GRGs

Exp	Grey Relational Coefficients			Grey Relational Grade
	MRR	EWR	SR	
1	0.9670	0.7365	0.9192	0.8742
2	0.9042	0.7658	0.9385	0.8695
3	0.6514	0.7835	0.7768	0.7372
4	0.7583	0.9967	0.5905	0.7818
5	0.7428	1.0000	0.6026	0.7818
6	0.7709	0.9366	0.6412	0.7829
7	0.5858	0.9615	0.4736	0.6736
8	1.0000	0.4736	1.0000	0.8245
9	0.7678	0.8105	0.9167	0.8316
10	0.9763	0.5796	0.9083	0.8214
11	0.6324	0.7587	0.9307	0.7739
12	0.4736	0.8532	0.5653	0.6307
13	0.7282	0.9863	0.5828	0.7657
14	0.8463	0.8273	0.7514	0.8083
15	0.9696	0.9042	0.8807	0.9181
16	0.9605	0.9576	0.8468	0.9216
17	0.7955	0.8863	0.8323	0.8380
18	0.6180	0.7857	0.8149	0.7395

The higher grey relational grade represents that the corresponding experimental result is closer to the ideally normalized value. Experiment 16 has the best multiple performance characteristics among 18 experiments because it has the highest grey relational grade shown in Table 7.Optimization of the complicated multiple performance characteristics can be converted into optimization of a single grey relational grade.

The response table was constructing here to calculate the average grey relational grade for each cutting parameter level. It is done by sorting the grey relational grades corresponding to levels of the cutting parameter in each column of the orthogonal array, and taking the average of the same level.

For example, the mean of the grey relational grade for the workpiece polarity at levels 1 and 2 can be calculated by averaging the grey relational grade for the experiments 1 to 9 and 10 to 18, respectively (Table 7). Using the same method, calculations are performed for each cutting parameter level and the response table is constructed as shown in Table 8.

Table 8: Response table for the grey relational grade

Symbol	Parameter	Grey Relational Grade			Max-Min
		Level 1	Level 2	Level 3	
A	Polarity	0.7953	0.8019	-	0.0066
B	Pulse off time	0.7845	0.8064	0.8048	0.0219
C	Pulse on time	0.8247	0.7936	0.7774	0.0473
D	Peak Current	0.7214	0.8571	0. 8172	0.1357
E	Servo voltage	0.8265	0.8004	0.7688	0.0577
F	Dielectric flushing pressure	0.7951	0.7754	0.8251	0.0497
Total Mean Value of the Grey Relational Grade= 0.7984					

Meanwhile, the total mean of the grey relational grade for the 18 experiments is also calculated and listed in Table 8. Figure 6 shows the grey relational grade graph. Basically, the larger the grey relational grade, the better is the performance characteristics. However, the relativity among the machining parameters for the multiple performance characteristics still needs to be known so that the optimal combinations of the machining parameter levels can be determined more accurately.

Based on Table 8,the optimal machining parameter setting is A2B2C1D2E1F3 or maintaining polarity at level 2 (workpiece (-)), pulse off duration at level 2 (400 µs), pulse on duration at level 1 (100 µs), peak current at level 2 (24 A), servo voltage at level 1(20 V) and dielectric flushing pressure at level 3 (0.15 Bar).

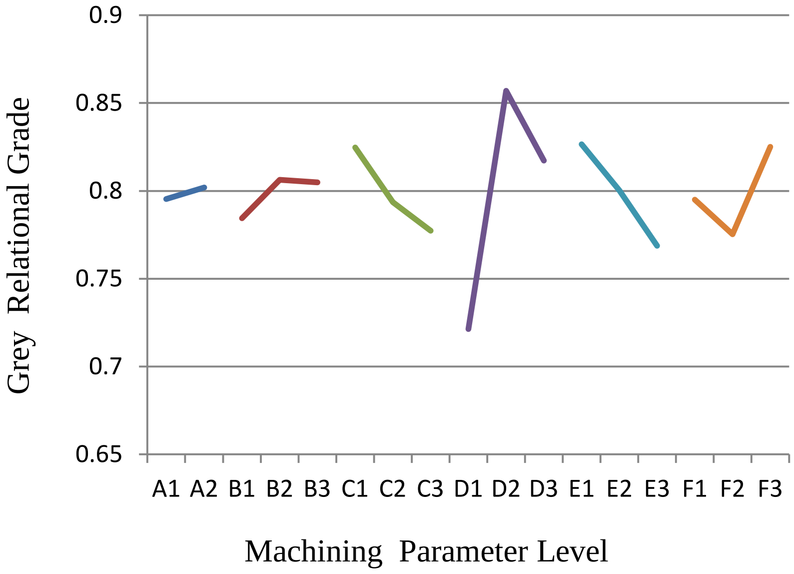

Figure 6: Grey relational grade plot.

4.4 Analysis of Variance (ANOVA)

The purpose of the analysis of variance (ANOVA) is to investigate which machining parameters significantly affect the performance characteristic. Using STATISTICA software, the ANOVA is performed and the results of ANOVA for Grey relational grade values with multiple performance characteristics are shown in Table 9. The percentage contribution by each of the machining parameter can be used to evaluate the importance of the machining parameter change on the performance characteristic.

Meanwhile, the Fisher's *F* test can also be used to determine which machining parameters have a significant effect on the performance characteristic. Usually, when *F* is large, it shows that the change of the machining parameter has a significant effect on the performance characteristic. Results in Table 9 shows that the peak current is the most significant parameter with 50.60% contribution for affecting the multi-response characteristics and the *F* value larger than others.

Table 9: Results of the analysis of variance

Symbol	Parameter	D.O.F	SS	MS	*F*	Contribution (%)
A	Polarity	1	0.005205	0.005205	1.130293	6.33
B	Pulse off time	2	0.001794	0.000897	0.194824	2.18
C	Pulse on time	2	0.001350	0.000675	0.146521	1.64
D	Peak Current	2	0.041586	0.020793	4.514895	50.60
E	Servo voltage	2	0.004410	0.002205	0.478823	5.39
F	Flushing pressure	2	0.000201	0.000100	0.021715	0.24
	Error	6	0.027632	0.004605		33.62
	Total	17	0.082178			

4.5 Confirmation Test

Once the optimal level of the machining parameters is selected, the final step is to predict and verify the improvement of the performance characteristic for machining mild steel AISI 1020 using the optimal level of the machining parameters. The estimated grey relational grade $\gamma^{\wedge}$ using the optimal level of the machining parameters can be calculated as shown in Equation 6:

$$\gamma^{\wedge} = \gamma_m + \sum_{i=1}^{q}(\gamma_i - \gamma_m) \tag{6}$$

where γ_m is the total mean of the Grey relational grade, γ_i is the mean of the Grey relational grade at optimal level and q is the number of the machining parameters.

Table 10 shows the result of the confirmation experiment using their respective optimal cutting parameters.MRR increased 0.0207 g/min, EWR is greatly reduced from 4.82% to 2.72% and SR is improved from 8.4271 to 4.3207 μm. The improvement in grey relational grade is 0.1261. It is clearly shown that the multiple performance characteristics in the EDM process are greatly improved through this study.

Table 10: Result of the confirmation experiment

	Initial cutting parameters	Optimal cutting parameters	
		Predicted	Experimental
Setting level	A2B2C2D2E2F2	A2B2C1D2E1F3	
MRR (g/min)	0.0947		0.1154
EWR (%)	4.82		2.72
SR (μm)	8.4271		4.3207
GRG	0.7582	0.8236	0.8843
Improvement of GRG = 0.1261			

4.6 Most Significant Factor- Peak Current

Peak current is the amount of power used in discharge machining, measured in units of amperage, and is the most important machining parameter in EDM. During each on-time pulse, the current increases until it reaches a preset level, which is expressed as the peak current. Based on the result, the most significant factor was peak current. Referring to the Table 4, experiment 6 and 7 for example, peak current used in experiment 6 was 12(A) while for experiment 7 was 36 (A). We can see that the MRR in experiment 7 higher than experiment 6 but it affects the EWR and SR.

The higher the material removal rate in the EDM process, the better is the machining performance. However increasing MRR is not always desirable for all applications since this may scarify the surface integrity of the workpiece. Other than that, higher current will shorten the machining time but it also will produce rough surface. Thus, optimum peak current are required in order to maximize MRR while minimize EWR and SR.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

The use of the orthogonal array with grey relational analysis to optimize the edm process with the multiple performance characteristics of the material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR) has been reported in this paper. In this study, it is shown that the performance characteristics of the edm process are improved by using the method proposed in this study.

5.2 Conclusion

The main conclusions that can be found from this research are as follows:

i) The optimization of multiple performance can convert into optimization of a single performance characteristic called the grey relational grade.
ii) Peak current are most significant factor that affect material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR) since the parameter bring major effect to MRR, EWR and SR.
iii) Increasing the peak current, pulse-on time and servo voltage increase the rate of MRR while reduce EWR and SR.
iv) ANOVA is useful in determining which parameters significantly affect the performance characteristic.

5.3 Recommendations

i) Comparison which method gives more accurate mathematical model between Grey Relational Analysis (GRA), Taguchi method and response surface method (RSM) in term of MRR , EWR and SR result.

ii) There were various software that can be used in designing experiment such as MINITAB, STATISTICA and so on rather than construct it manually. This will reduce time and increase the efficiency in doing the project.

iii) Vary the material of workpiece in machining because different material will give different machining parameter.

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APPENDIX A1

Gant Chart for Final Year Project 1

TASK	WEEK													
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Identify Title	■													
Literature review		■	■	■	■	■	■	■	■	■	■			
Introduction, Define Problem Statement, Project Objective, Project scopes			■	■	■									
Methodology, Plan the experiment, Design the experiment				■	■	■	■	■	■	■	■	■		
Proposal Writing				■	■	■	■	■	■	■	■			
Preparation for Presentation												■	■	
PSM 1 Presentation														■
TASK	WEEK													

APPENDIX A2

Gant Chart for Final Year Project 2

TASK	WEEK														
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
Literature Study	■	■													
Running Experiment			■	■	■	■	■	■	■						
Collect the data					■	■	■	■	■						
Analysis of data							■	■	■	■	■				
Report Writing		■	■	■	■	■	■	■	■	■	■	■			
Prepare Presentation													■	■	
PSM 2 Presentation															■
Report Submission														■	■

APPENDIX B1

Experimental layout of L_{18} orthogonal array

Surface waviness in L_{18} OA

Exp	*A*	*B*	*C*	*D*	*E*	*F*	Average values for		
							MRR (g/min)	EWR (%)	SR (µm)
1	+								
2	+								
3	+								
4	+								
5	+								
6	+								
7	+								
8	+								
9	+								
10	-								
11	-								
12	-								
13	-								
14	-								
15	-								
16	-								
17	-								
18	-								

APPENDIX B2

CALCULATION FOR DEVIATION SEQUENCES | $x_i^0 - x_{ij}$ | IN EQUATION 5

Deviation Sequences	MRR	EWR	SR
No. 1, i=1	0.0307	0.3220	0.0192
No. 2, i=2	0.0953	0.2751	0.0589
No. 3, i=3	0.4816	0.2487	0.2586
No. 4, i=4	0.2868	0.0029	0.6241
No. 5, i=5	0.3115	0	0.5935
No. 6, i=6	0.2674	0.0609	0.5034
No. 7, i=7	0.6363	0.0360	1
No. 8, i=8	0	1	0
No. 9, i=9	0.2721	0.2104	0.0818
No. 10, i=10	0.0218	0.6527	0.0908
No. 11, i=11	0.5231	0.2861	0.067
No. 12, i=12	1	0.1548	0.6922
No. 13, i=13	0.3360	0.0125	0.6441
No. 14, i=14	0.1634	0.1879	0.2978
No. 15, i=15	0.0282	0.0954	0.1218
No. 16, i=16	0.0370	0.0398	0.1628
No. 17, i=17	0.2313	0.1155	0.1813
No. 18, i=18	0.5563	0.2454	0.2043

where $x_i^0 = 1$ is the ideal normalized result for the i th performance characteristics while x_{ij} is normalized value.