International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 1 Issue 6, August - 2012

A Design And Development Of An Intelligent Information System For Electric Discharge Machine

M.Venkata Naveen*, K.L.N. Murthy[#], T.S.S.R.Krishna[$].
** Final M-Tech, Godavari Institute of Technology & Engineering,RJY-533294,*
[#] *Assoc.prof, Godavari Institute of Technology & Engineering*
[$] *Asst.prof, WestGodavari Institute of Science & Engineering*

Abstract

The electrical discharge machining (EDM) process has been extensively used in machining hard, high-strength and temperature-resistant materials. The material is removed rapidly and repeatedly by spark dischargers across gap between the tool and the work piece. In EDM, it is important to select machining parameters for achieving optimal machining performance. Usually, the desired machining parameters are determined based on experience or on handbook values. However, this does not ensure that the selected machining parameters result in optimal or near optimal machining performance for that particular electrical discharge machine and environment. The important output parameters of the process are the material removal rate (MRR) and surface roughness (Ra). And the input parameters are peak current (I), pulse on-time (T-ON) and pulse off-time (T-OFF).In this thesis, Analysis of variance (ANOVA) technique was used to find out how various parameters affecting the surface roughness and material removal rate. Results from the analysis show that peak current and pulse-off time are significant variables to the surface roughness. The surface roughness of the test specimen increases when these two parameters increase. And peak current, pulse-on time and pulse-off time are significant variables for material removal rate. The material removal rate of the test specimen increases when peak current increase and decrease when pulse-on time and pulse-off time increase. Finally for the prediction and optimal selection of process parameters in small deep hole drilling EDM a mathematical model was developed using regression analysis to formulate the input parameters to the output parameters. The developed model was validated with a set of experimental data, and the verified experimentally, and the amounts of relative errors where calculated. The errors are all in acceptable ranges, which, again, confirm the feasibility and effectiveness of the adopted approach.

1.Introduction

1.1 Manufacturing

The word "manufacturing" is derived from the Latin word "manu *facture*" which means made by hand. It is a process of making a raw material into a finished product. The term may refer to a range of human activity, from handicraft to high tech, but is most commonly applied to industrial production, in which raw materials are transformed into finished goods on a large scale. Modern manufacturing includes all intermediate processes required for the production and integration of a product's components. Machining has a special status in the whole spectrum of manufacturing process.

1.2 Machining

Machining one of the most important material removal methods is a collection of material-working processes in which power-driven machine tools, such as lathes, milling machines, and drill presses, are used with a sharp cutting tool to mechanically cut the material to achieve the desired geometry. Machining is a part of the manufacture of almost all metal products, and it is common for other materials, such as wood and plastic, to be machined.

The three principal machining processes are classified as turning, drilling and milling. Other operations falling into miscellaneous categories include shaping, planing, boring, broaching and sawing.

- Turning operations are operations that rotate the workpiece as the primary method of moving metal against the cutting tool. Lathes are the principal machine tool used in turning.
- Milling operations are operations in which the cutting tool rotates to bring cutting edges to bear against the workpiece. Milling machines are the principal machine tool used in milling.
- Drilling operations are operations in which holes are produced or refined by bringing a rotating cutter with cutting edges at the lower extremity into contact with the workpiece. Drilling operations are done primarily in drill presses but sometimes on lathes or mills.
- Miscellaneous operations are operations that strictly speaking may not be machining operations in that they may not be chip producing operations but these operations are performed at a typical machine tool.

Burnishing is an example of a miscellaneous operation. Burnishing produces no chips but can be performed at a lathe, mill, or drill press. In manufacturing it is probable that more holes are produced than any other shape and a large proportion of these are made by drilling. Drilling is very important process. Although drilling appears to be a relatively simple process, it is really a complex process due to large aspect ratio, tool materials.

1.3 Drilling

Drilling is one of the most fundamental machining technologies and is moving toward high precision / high speed applications for productivity enhancement. Drilling processes is divided into either "short-hole" drilling, which is most common, or "deep hole" drilling. A short hole is defined as a hole with a small ratio of depth to diameter. Typically that would include holes up to 1.2" (30mm) having a depth of no more than 5 or 6 times that diameter. For holes greater than 1.2" (30mm) in diameter, short holes are those on more than 2.5 times hole diameter. Short holes are usually drilled in one motion. Drilling deeper with conventional drills requires repeated withdrawal of the drill to clear the chips from the drill's flutes. This repeated withdrawal of the drill is called "pecking." Deep hole drilling is more difficult, mainly in keeping the hole straight, and requires special drills, guides, equipment, and methods. Many techniques are available for making small holes like Electric discharge machining (EDM), Electron beam machining (EBM), laser beam machining (LBM) etc. These processes are very affective when compared to traditional machining process for aspect ratio greater than 10.

1.4 Hole Making Process

1.4.1 Conventional methods

The most common type of hole making process in conventional method is drilling. It is usually done with the help of twist drill .The surface finish, dimensional accuracy and tolerance is poor for high-end materials and it is tough to machine. Drilling cannot be provided smooth surface finish and geometrical accuracies, and close tolerances. For that we need to go for reaming and broaching. To increase the dimension of existing hole we need to go for boring by single point bore tool. However torsional rigidity of shank poses difficulties in making deep holes using twist drill or boring tools. Gun drilling was developed towards the end of eighteenth century for drilling straight true holes in long gun barrels. Trepanning is another hole making operation where an angular groove is produced leaving a solid cylindrical core in the center. Trepanning is feasible only for deep holes, which have diameter greater than 160 times the diameter.

1.4.2 Non-conventional methods

Not too long ago, a hole the size of a human hair (about 0.003 inch in diameter) was about the smallest hole that could be made using conventional machine tools on a production basis. Today, advances in the fields of medical devices, communications, optics, electronics, computers and others have created a need for holes that are straighter, more accurate, better defined-and in many cases much smaller in diameter than a human hair.

Today, that need is being met by not-so-new but little-known non-conventional hole-making techniques. These techniques not only have prompted the development of machine tools designed with small hole making in mind, but they also have produced specialized contract shops that, by serving the trend toward miniaturization, are on the leading edge of new-product development. However the aspect ratio demand is often larger than 10 which can't be met easily by above methods. EDM, ECM, EBM can be successfully employed for deep hole drilling. The performance of these available non-conventional machining can be evolved in terms of type of workpiece material (conductive/non-conductive), shape of hole (circular, slot, geometric, irregular), size of the hole, aspect ratio, surface integrity, production rate and cost of machining.

Electric Discharge Machining (EDM) is a nontraditional method of removing material by a series of rapidly recurring electric arcing discharges between an electrode (the cutting tool) and the workpiece, in the presence of an energetic electric field. The EDM cutting tool is guided along the desired path very close to the work but it does not touch the piece. Consecutive sparks produce a series of micro-craters on the work piece and remove material along the cutting path by melting and vaporization. The particles are washed away by the continuously flushing dielectric fluid. It is also important to note that a similar micro-crater is formed on the surface of the electrode, the debris from which must also be flushed away. These micro-craters result in the gradual erosion of the electrode, many times necessitating several different electrodes of varying tolerances to be used, or, in the case of wire EDM machining, constant replacement of the wire by feeding from a spool.

Electro Chemical Machining (ECM) is a method of removing metal by an electrochemical process. ECM is similar in concept to Electrical discharge machining in that a high current is passed between an electrode and the part, through an electrolyte; however, in ECM there is no tool wear. The ECM cutting tool is guided along the desired path very close to the work but it does not touch the piece. Unlike EDM however, no sparks are created. The workpiece is eroded away in the reverse process to electroplating. Very high metal removal rates are possible with ECM, along with no thermal or mechanical stresses being transferred to the part, and mirror surface finishes are possible.

Electron Beam Machining (EBM) is a thermal process that uses beam of high energy electrons focused on workpiece to melt and vaporize metal. This process requires a vacuum chamber and magnetic coils for transfer of the beam on o workpiece without any detection. The main advantage of this method is the aspect ratio of hole up to 100 can be obtained.

1.5 Electric discharge machining (EDM)

1.5.1 EDM Principle

The EDM process was improved by two Russian scientists, Dr. B.R. Lazarenko and Dr. N.I. Lazarenko in 1943.Electrical discharge machining (or EDM) is a machining method primarily used for hard metals or those that would be impossible to machine with traditional techniques. One critical limitation, however, is that EDM only works with materials that are electrically conductive. EDM can cut small or odd-shaped angles, intricate contours or cavities in pre-hardened steel without the need for heat treatment to soften and re-harden them as well as exotic metals such as titanium, hastelloy, kovar, Inconel and carbide.

Sometimes referred to as spark machining or spark eroding, EDM is a nontraditional method of removing material by a series of rapidly recurring electric arcing discharges between an electrode (the cutting tool) and the workpiece, in the presence of an energetic electric field. The EDM cutting tool is guided along the desired path very close to the work but it does not touch the piece. Consecutive sparks produce a series of micro-craters on the work piece and remove material along the cutting path by melting and vaporization. The particles are washed away by the continuously flushing dielectric fluid. It is also important to note that a similar micro-crater is formed on the surface of the electrode, the debris from which must also be flushed away. These microcraters result in the gradual erosion of the electrode, many times necessitating several different electrodes of varying tolerances to be used, or, in the case of wire EDM machining, constant replacement of the wire by feeding from a spool. The Fig.1.1 shows the schematic diagram of EDM machine.

There are two main types of EDM machines:
a. Conventional EDM (also called Sinker EDM and Ram EDM)
b. Wire EDM

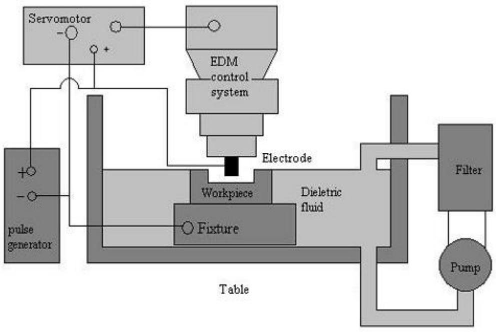

Fig. 1.1 Schematic diagram of EDM machine.

Some of the advantages of EDM include machining of complex shapes that would otherwise be difficult to produce with conventional cutting tools, machining of extremely hard material to very close tolerances, and machining of very small work pieces where conventional cutting tools may damage the part from excess cutting tool pressure.

1.5.2 Components of EDM

EDM machine consists of four major components which are power supply, dielectric system, tool and workpiece, and servo system.

1.5.2.1 Power supply

Power supply converts alternating current (AC) into pulsed direct current (DC) used to produce spark between tool and workpiece. Solid state rectifier is used to convert AC into DC. A fraction of DC power is used to generate a square wave signal with the help of a digital multi-vibrator oscillator. This signal triggers a bank of power transistors that act as high speed switches to control the flow of remaining DC power. It creates high power pulsed output responsible for generating sparks between electrodes. EDM power supply senses the voltage between the electrodes and then sends the relevant signals to the servo system, which maintains the desired gap between the electrodes.

Power supply should also be able to control the parameters like voltage, current, duration and frequency of a pulse, duty cycle and electrode polarity. EDM power supplies are also equipped with power protection circuit. Power is cut-off when there is short circuit between the electrodes or due to over voltage and over current.

1.5 2.2 Dielectric system

Dielectric system consists of dielectric fluid, reservoir, filters, pump, and delivery devices. Dielectric fluid is used to cause ionization, acts as an effective cooling medium and for removal of the wear particles from the gap. It should posses certain properties like
1) High dielectric strength
2) Effective cooling medium

3) High degree of fluidity
The fluids commonly used are transformers oil, paraffin oil, kerosene, lubricating oils and deionizer water.

Insulation

This requirement refers to a dielectric fluids ability to insulate until sufficient voltage is applied across the spark gap to break the dielectric strength and then to ionize, allowing a current to flow to the workpiece. A dielectric that meets this requirement is characterized by high dielectric strength which is simply the measure of maximum voltage that can be applied to a given material before ionization take place.

Cooling

This requirement refers to a dielectric fluids ability to resolidify the vaporized workpiece material in to chips and keep the work and electrode reasonably cool. Through this thermal transfer capability heat generated through the machining process is carried away by the dielectric fluid as it passes the spark gap.

Flushing

This is the most important requirement of a dielectric fluid. This choice of the flushing methods depends upon the workpiece size and geometry. The suction method is relatively better since it reduces side taper by eliminating the possibility of side arcing with the wear debris. Similarly the fluid flow through the electrode is the most convenient method.

1.5.2.3 Electrodes

The tool and workpiece are referred as electrodes in EDM. In general, electrode is used only for tool. The material to be used as tool electrode should posses desirable properties like easily machinable, low wear rate, good conductor of electricity and heat, cheap and easily available. Some of the materials used for making the tools are graphite, copper, brass, copper tungsten, cast aluminum, copper boron and silver tungsten. Copper and graphite are more commonly used. Graphite electrodes with finer grains result in lower tool wear rate, better surface finish, and higher material removal rate. But its brittleness is an undesirable characteristic because of which it is prone to breakage.

The tool wear is usually quantified by 'wear ratio'. Wear ratio is the ratio of volume of tool material removed to the workpiece material worn out during the same period. Depending up on the tool and work piece materials, machining conditions, and type of operation, the wear ratio may vary in the range of 0.05:1 to 100:1.

1.5.2.4 Servo system

In EDM process, during machining the gap between tool and workpiece has a critical importance. As the workpiece is machined this gap tends to increase. For optimum machining efficiency this gap must be kept constant. This task is done by servo mechanism which controls the movement of electrode. This servo mechanism can either be electro mechanical or hydraulic. In the electro mechanical system the electrode is moved by a rack and pinion arrangement which is driven through reduction gearing from a D.C servo motor. As the gap between the tool and workpiece increases, the voltage across the gap drops. This voltage drop is automatically measured and a feed back is given to the servo control which sends a signal to the servo motor which operates the electrode downward until the gap reaches its critical value again.

1.5.3 Process parameters

The selection of EDM process parameters is important in determining the accuracy and surface finish obtained for a particular application. Parameters are manually selected on most of EDM systems, although some recently available systems use CNC units or programmable controllers to adjust and match parameters for various applications. The important process parameters are current, pulse on time, electrode rotation, voltage and flushing pressure.

1.5.3.1 Current

As current is increased, each individual spark removes a larger crater of metal from the workpiece. The amount of material removed and the surface finish produced isdependent upon the current in the spark, therefore it will depend on the crater depth, which is directly proportional to the current. However, decreasing the current in the spark and increasing its frequency improves surface finish in view of small crater size, but at the same time material removal rate can be maintained by increasing the frequency.

1.5.3.2 Pulse on time

Pulse On time is defined as the duration for which the electrons are discharged from the capacitor. It is always measured in microseconds. All the work is done during On time. The spark gap is bridged, current is generated and the work is accomplished. The longer the spark is sustained more is the material removal. Consequently the resulting craters will be broader and deeper; therefore the surface finish will be rougher. Obviously with shorter duration of sparks the surface finish will be better. With a positively charged work piece the spark leaves the tool and strikes the work piece resulting in the machining. Except during roughing all the sparks that leave the tool result in a microscopic removal of particles of the surface. More sparks produce much more wear, hence this process behaves quite opposite to normal processes in which the tool wears more during finishing than roughing.

1.5.3.3 Pulse off time

While most of the machining takes place during On time of the pulse, the off time during which the pulse rests and the re-ionization of the die-electric takes place, can effect the speed of the operation in a large way. More is the off time greater will be the machining time. But this is an integral part of the EDM process and must exist. The Off time also governs the stability of the process. An insufficient off time can lead to erratic cycling and retraction of the advancing servo, slowing down the operation cycle.

1.5.3.4 Voltage

The voltage used is usually a DC power source of 40 to 400 volts. Voltage determines the width of the spark gap between the leading edge of the electrode and the workpiece. High voltage settings increases the gap and hence the flushing and machining.

1.5.3.5 Electrode rotation

Electrode rotating drives consists of a precision spindle, a drive mechanism and a speed control. Most spindles are designed with built-in-seals to effect flushing through the electrode. The relative motion between the electrode and the workpiece circulates dielectric oil through the gap impressing flushing and increasing cutting speed. In addition to the increase in cutting speed, the surface quality produced is superior to that obtained using a stationary electrode.

1.5.4 Responses parameters

All the responses such as Material Removal Rate (MRR), Surface Roughness (Ra), Electrode Wear Ratio (EWR) and Linear Material Removal Rate (MRR_l) were characterized by the following formulas

1.5.4.1 Material Removal Rate (MRR)

The material removal rate (MRR) in machining operations is the volume of material/metal that is removed per unit time in mm3/min

$$\text{Material Removal Rate} = \frac{\text{volume of material removed from part}}{\text{time of machining}}$$

1.5.4.2 Electrode Wear Ratio (EWR)

During the EDM drilling operation along with the material erosion the tool also wear along the length. The weight loss of the electrode with respect to the weight loss of the work is called Electrode Wear ratio. Mathematically EWR is given as follows:

$$\text{Electrode Wear Ratio (EWR)} = \frac{\text{Electrode Wear Weight (EWW)}}{\text{Work Removal Weight (WRW)}} \text{x100}$$

The difference in the initial weight of the workpiece and the weight of the work after machining gives the Work Removal Weight.

Work Removal Weight (WRW) = (Weight before machining – Weight after machining)

1.5.4.3 Surface roughness (Ra)

Surface roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth.
Surface roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Surface roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion.

1.6 Analysis of Variance

Analysis of variance, or ANOVA, is a powerful statistical technique that involves partitioning the observed variance into different components to conduct various significance tests. This article discusses the application of ANOVA to a data set that contains one independent variable and explains how ANOVA can be used to examine whether a linear relationship exists between a dependent variable and an independent variable.

Analysis of Variance Identity

The total variability of the observed data (*i.e.* the total sum of squares, SS_T) can be written using the portion of the variability explained by the model, SS_R, and the portion unexplained by the model, SS_E, as:

$$SS_T = SS_E + SS_R$$

$$\sum_{i=1}^{n} (y_i - \tilde{y})^2 = \sum_{i=1}^{n} (\hat{y}_i - \tilde{y})^2 + \sum_{i=1}^{n} (y_i - \hat{y}_i)^2$$

The above equation is referred to as the *analysis of variance identity*.

Where SS_T = Total sum of squares due to residual error

SS_R = Sum of square due to regression
SS_E = sum of squares due to residual error
y_i = observation taken under factor level i
$\tilde{y}$= average of observations
$\hat{y}_i$ = estimate of the corresponding observation

1.7 Regression analysis

Regression analysis includes any techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. It involves finding the best straight line relationship to explain how the variation in an outcome (or dependent) variable, Y, depends on the variation in a predictor (or independent or explanatory) variable, X. Once the relationship has been estimated we will be able to use the equation:

$$Y = b0+b1X$$

In many situations the outcome will depend on more than one explanatory variable. This leads to multiple regression, in which the dependent variable is predicted by a linear combination of the possible explanatory variables.

$$Y = b0+b1X1+b2X2\ldots\ldots\ldots\ldots..$$

Where the values b0, b1, b2… are called the regression coefficients.

1.8 Objectives

Objectives of this project is to find out how various process parameters are affecting the output parameters and create a model using regression analysis for an EDM deep hole drilling process for a particular set of input variables, the set of input variables used are discharge current, pulse-on time, and pulse-off time and the output variables are material removal rate (MRR) and surface roughness (Ra)

The objectives include:

1. To analyze the effect of various input parameters on the out parameters
2. To develop empirical models for Metal Removal Rate (MRR) and Surface Roughness (Ra).
3. To validate the mathematical model.

1.9 Problem Statement:

For any machining process higher machining rate, better surface finish is desirable for better performance. The material removal rate (MRR), and surface roughness (Ra) are the machining performance criteria often applied to evaluate the machining effects in each stage. Many process parameters that can be varied in the different machining stages of EDM deep hole drilling process greatly affect the machining performances. Consequently, it becomes important to select properly the process parameter set for different machining stages in order to promote efficiency. Usually, the desired process parameters are determined based on experience or hand book values. However, it is undoubtedly a challenge to ensure that the selected process parameters result in optimal or near optimal machining performance for that particular electrical discharge machine and environment.

2. Experimental setup & procedure

2.1 Design of experiments

Design of experiments (DOE) is a powerful statistical technique introduced by R.A.Fisher in England in 1920" s to study the effect of multiple variables simultaneously. Design of experiment (DOE) is widely used in research and development, where a large proportion of the resources go towards solving optimization problems. The key to minimizing optimization costs is to conduct as few experiments as possible. Design of experiments involves designing a set of ten to twenty experiments in which all relevant factors are varied systematically. When the results of these experiments are analyzed, they help to identify optimal conditions, the factors that most influence the results, and those that do not, as well as details such as the existence of interactions and synergies between factors.

Building a design means, carefully choosing a small number of experiments that are to be performed under controlled conditions. There are four interrelated steps in building a design:

1. Define an objective to the investigation, e.g. better understand or sort out important variables or find optimum.
2. Define the variables that will be controlled during the experiment (design variables), and their levels or ranges of variation.
3. Define the variables that will be measured to describe the outcome of the experimental runs (response variables), and examine their precision.
4. Among the available standard designs, choose the one that is compatible with the objective, number of design variables and precision of experiments, and has a reasonable cost.

Standard designs are well-known classes of experimental designs. They can be generated automatically as soon as you have decided on the objective, the number and nature of design variables, the nature of responses and the number of experimental runs you can afford. Generating such a design will provide you with a list of all experiments you must perform, to gather enough information for you purpose. The technique of defining and investigating all possible conditions in an experiment involving multiple factors is known as design of experiments.

For full factorial design,
No. of possible designs = (no. of levels) ^ (no. of factors)

It is not desirable to conduct all experiments as there will be a lot of wastage as several trials is not useful in determining the results. So we go for fractional factorial design of taguchi methodology in which the trials are greatly reduced.

2.2 Taguchi Method

Taguchi method is a powerful problem solving technique for improving process performance, yield and productivity. In taguchi methodology best result is achieved by optimization of control factors using Design of Experiment.Taguchi created some techniques based on DOE such as signal-to-noise ratio, orthogonal arrays, and robust designs. Mostly orthogonal array technique is used to reduce the complexity and the number of experimental runs involved in solving a problem with full factorial design.

An orthogonal array produces a design matrix whose columns are all mutually orthogonal. Orthogonal array is identified by the letter L followed by a subscript indicating number of rows in the array. L9 orthogonal array contains 9 rows. The maximum number of columns in the orthogonal array depends on the number of levels on the experimental design variables. Each array will contain one less number of column than the number of rows. For example an L32 orthogonal array contain maximum of 31 columns.

2.3 Experimentation

The experiments were conducted using an Electronica Electric discharge machine series C425. The work piece material used for conducting experiment is **Stainless Steel 17-4 PH** and the electrode of copper tube.

2.3.1 Stainless Steel 17-4 PH

Stainless Steel 17-4 PH One of the most widely used precipitation hardening grades in the business. While soft and ductile in the solution annealed condition, it is capable of high properties with a single precipitation or aging treatment. Characterized by good corrosion resistance, high harness, toughness and strength. Commonly used in both aircraft and gas turbines, nuclear reactor, paper mill, oil field, and chemical process components.

Table 2.1: Composition of Stainless Steel 17-4 PH

	Weight %
C	0.07 max
Si	1 max
Mn	0.04 max
P	0.04 max
S	0.03 max
Cr	15 - 17.5
Ni	3 – 5
Cu	3 – 5
Nb	0.15-0.45
Mo	0.50max
Fe	Balance

2.3.2 Properties of Copper electrode

The desirable properties of the copper is good electrical conductivity, good thermal conductivity, corrosion resistance and easy to machine. Because of its good electrical and thermal conductivity, it allows the electrons to flow freely from tool to the work piece.

2.3.3 Experimental setup

The experiment for EDD and AEDD were conducted using an Electronica C425 Die sinking machine. Design of experiment was done according to taguchi method. For three factors and three levels L27 orthogonal array was selected with two repetitions. The voltage of DC source kept constant as 40 V.

The electrode was fed downwards with the help of servo mechanism. Special rotary head was designed and fabricated in order to provide rotary motion to the electrode. Spark erosion oil 450 is used as dielectric fluid. It has the conductivity of 0.43 seibals. The viscosity of oil is 2.3 at 40ºC and the dielectric strength is 12kVmin. The dielectric pressure is kept constant at a pressure of 2 Kgf/cm². The dielectric fluid is flushed through the pump. Fixture setup is used to fix the work piece which was Stainless Steel 17-4 PH. Electrode used in EDD is a bare copper electrode. Fig 2.2 and 2.3 shows the work piece and electrode respectively.

Fig 2.1 EDM Machine

Fig 2.2 Work piece **Fig 2.3BareElectrode**

2.3.4 Experimental plan

The L27 orthogonal array of taguchi methodology was used with peak current, pulse on-time, pulse off-time as three input or operating parameters. A circular workpiece of 50mm diameter and 7.5mm thick is used.

S.No.	A	B	C		S.No.	A	B	C
1.	1	1	1		**15.**	2	2	3
2.	1	1	2		**16.**	2	3	1
3.	1	1	3		**17.**	2	3	2
4.	1	2	1		**18.**	2	3	3
5.	1	2	2		**19.**	3	1	1
6.	1	2	3		**20.**	3	1	2
7.	1	3	1		**21.**	3	1	3
8.	1	3	2		**22.**	3	2	1
9.	1	3	3		**23.**	3	2	2
10.	2	1	1		**24.**	3	2	3
11.	2	1	2		**25.**	3	3	1
12.	2	1	3		**26.**	3	3	2
13.	2	2	1		**27.**	3	3	3
14.	2	2	2					

Table 2.2: Process Parameters

Work condition	Description
Work piece	Stainless Steel 17-4 PH
Electrode	Copper 3 mm diameter
Dielectric fluid Kerosene	Spark Erosion oil 450
Peak current	6, 12, 18A
Pulse on time	40, 60, 80 μs
Pulse off time	3, 6, 9 μs
Gap voltage	40v
Flushing pressure	2 Kgf/cm^2
Total no. of runs	27

Table 2.3: Levels of input parameters

S.NO.	Factors	Units	Levels		
			1	2	3
1	Current	Amps	6	12	18
2	T-ON	µ sec	40	60	80
3	T-OFF	µ sec	3	6	9

2.3.5 Experimental procedure

The L27 orthogonal array was used for design of experiment . The SS-304 work piece of diameter 50 mm and thickness 7.5 mm was used. The electrode used was copper tube of diameter 3 mm. Both surfaces of workpiece are made smooth, flat and parallel to each other. Collet chuck of 3 mm diameter was used to hold the electrode. Rubber washer was used to ensure there is no leakage around electrode. Using AUTOPOS, the top surface of workpiece was made origin point of vertical axis. All the operating parameters except current are adjusted to experimental values. Dielectric tank was filled with dielectric liquid and the flushing pressure was adjusted to 2 Kgf/cm². Spark was applied and when electrode is nearer to workpiece surface, current was applied. Machining time for each experiment was calculated using a stopwatch. Each experiment was repeated twice in order to improve the robustness of experiment.

Table 2.4: Experimental results for EDM

Exp No	Current (Amps)	T-ON	T-OFF	Ra(µm)			MRR(mm³/min)		
				Ra_1	Ra_2	Ra_{avg}	MRR_1	MRR_2	MRR_{avg}
1	6	40	3	4.6	4.63	4.62	18.62	19.92	19.27
2	6	40	6	4.75	4.71	4.73	16.69	15.39	16.04
3	6	40	9	4.82	4.84	4.83	13.96	14.49	14.22
4	6	60	3	4.17	4.22	4.20	11.53	12.16	11.85
5	6	60	6	4.43	4.48	4.46	10.56	10.87	10.72
6	6	60	9	4.81	4.73	4.77	9.59	9.09	9.34
7	6	80	3	4.47	4.52	4.50	7.02	7.33	7.18
8	6	80	6	4.62	4.65	4.64	5.63	5.88	5.75
9	6	80	9	5.38	5.43	5.41	4.31	4.84	4.57
10	12	40	3	4.85	4.79	4.82	25.18	24.38	24.78
11	12	40	6	5.42	5.34	5.38	20.58	19.45	20.01
12	12	40	9	5.97	5.85	5.91	17.38	16.58	16.98
13	12	60	3	4.98	5.03	5.01	15.92	16.84	16.38
14	12	60	6	5.5	5.36	5.43	14.49	13.80	14.14
15	12	60	9	6.41	6.35	6.38	13.17	12.42	12.80
16	12	80	3	4.7	4.67	4.69	11.65	11.01	11.33
17	12	80	6	5.12	5.01	5.07	9.45	8.80	9.12
18	12	80	9	6.42	6.33	6.38	7.40	6.59	7.00
19	18	40	3	6.34	6.24	6.29	32.51	29.90	31.21
20	18	40	6	6.94	6.81	6.88	20.23	19.59	19.91
21	18	40	9	7.24	7.09	7.17	17.52	16.00	16.76
22	18	60	3	7.6	7.65	7.63	16.11	16.63	16.37

23	18	60	6	7.77	7.69	7.73	12.95	12.75	12.85
24	18	60	9	7.93	7.86	7.90	10.53	10.35	10.44
25	18	80	3	7.48	7.54	7.51	14.05	15.52	14.79
26	18	80	6	7.52	7.56	7.54	13.00	13.11	13.06
27	18	80	9	7.79	7.97	7.88	8.54	10.11	9.33

3.ANALYSIS

3.1 ANOVA Technique

- The analysis in this project has been done using the ANOVA technique. The ANOVA procedure performs *analysis of variance* (ANOVA) for balanced data from a wide variety of experimental designs.
- In analysis of variance, a continuous response variable, known as a *dependent variable*, is measured under experimental conditions identified by classification variables, known as *independent variables.*
- The variation in the response is assumed to be due to effects in the classification, with random error accounting for the remaining variation.
- The ANOVA procedure is designed to handle balanced data (that is, data with equal numbers of observations for every combination of the classification factors)
- The ANOVA procedure is explained and the model calculation is discussed which is given as follows:

3.1.1 Model Calculation of ANOVA for Surface Roughness

A model calculation for determining the percentage contribution of one cutting parameter on surface roughness is being presented here. In the first step, the overall mean was calculated which was the average of the surface roughness measured during the trials.

- Overall mean (m) 1 / 27 (∑ ή i) = 1 / 27 X (157.76) = 5.842
- Grand total sum of squares (G T)= ∑ ήi ² = 962.42
- Sum of squares due to mean(S S) = Number of experiments X m²= 921.78
- Total sum of squares= (G T – S S) = 40.64
- sum of squares due to Current = 3[(A_1 -m)²+(A_2 -m)²+(A_3-m)²] = 11.6853

Where A_1 is the average surface roughness value observed when the first level of Current was used for machining. Similarly A_2 and $A_3$are the average surface roughness value observed when the second and third level of cutting speed was used for machining. The sum of squares due to each of the remaining TWO factors are calculated using similar relationships and found to be 0.2129, 1.0366 for the factors Pulse on time Pulse off time respectively.

- Degree of freedom for the error = (Degree of freedom for the total sum of squares) – (sum of degrees of freedom for various factors) = 26 – 6= 20
- Mean Squares = (Sum of squares due to each factor)/(Degrees of freedom for each factor)
- Variance ratio = (Mean squares due to the factor) / (Mean squares error)
- Percentage of contribution = (Sum of squares for each factor x 100) / (Total sum of squares) = (11.6853 X 100) / (12.9348) = 90.34% for current

3.1.2 ANOVA for Surface Roughness:

S. No	Factors	Degree of freedom	Sum of squares	Mean squares	Variance	% contribution
1	Current(Amps)	2	11.685	5.8426	4.2178	90.34
2	T-ON(µ sec)	2	0.2129	0.1063	0.0767	1.645
3	T-OFF(µ sec)	2	1.0366	0.5183	0.3741	8.014
4	Total	6	12.934	-	-	-
5	Error	20	27.705	1.3852		

From the ANOVA it was observe that current is having more influence on the surface roughness and Pulse off time (T-OFF) is also having some influence on the surface roughness but small when compare to current. The variation of these parameters is represented graphically as follows

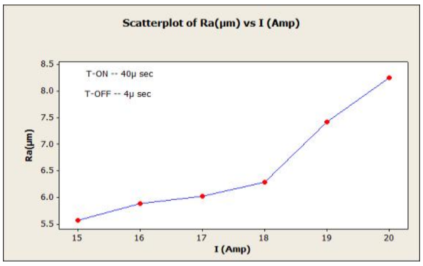

Fig 3.1 Scatter Plot of Surface Roughness Vs Current

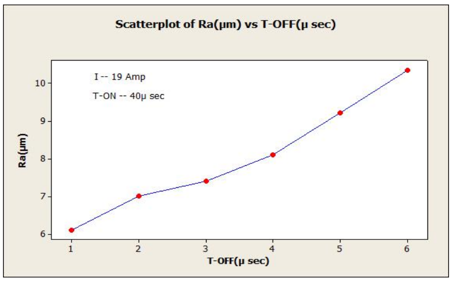

Fig 3.2 Scatter Plot of Surface Roughness Vs Pulse off time

3.1.2 ANOVA for Material Removal Rate:

S. No	Factors	Degree of freedom	Sum of squares	Mean squares	Variance	% contribution
1	Current	2	41.641	20.820	0.661	15.27
2	T-ON)	2	180.572	90.286	2.868	66.25
3	T-OFF	2	50.320	25.160	0.799	18.46
4	Total	6	272.533	-	-	-
5	Error	20	629.412	31.470		

From the ANOVA it was observe that Pulse on time (T-ON) is having more influence on the material removal rate. Pulse off time (T-OFF) and current are also having some considerable influence on the material removal rate. The variation of these parameters is represented graphically as follows.

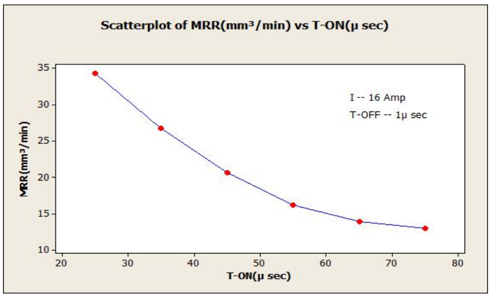

Figure 3.3 Scatter Plot of Material Removal Rate Vs Pulse on time

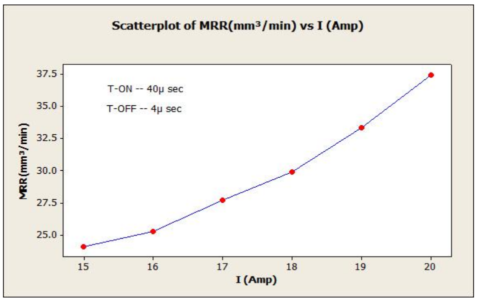

Figure 3.4 Scatter Plot of Material Removal Rate Vs Current

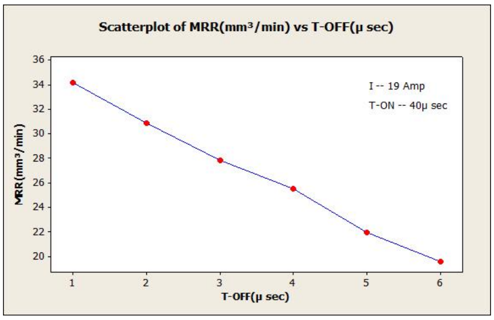

Figure 3.5 Scatter Plot of Material Removal Rate Vs Pulse off time

3.2 3-D Surface Plots:

- The 3D surface plots are generated in order to show the variation of the output parameter based on the two input parameters.
- These graphs give an idea how the output parameters are varying with different combinations of input parameters.
- All the possible combinations has been tried to show the variation of the parameters.
- MINITAB software is used for generating these graphs.

3.2.1 Variation of Surface Roughness:

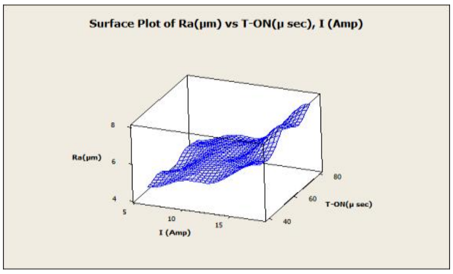

Fig 3.6 Surface Plot of Surface Roughness Vs Pulse on time Vs Current

From the **Fig. 3.6**, as the current increases surface roughness increases. As the pulse on time increases there is slight increment in the surface roughness.

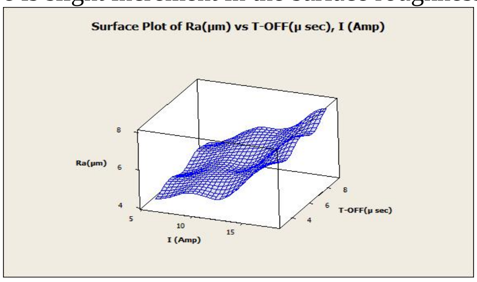

Fig 3.7 Surface Plot of Surface Roughness Vs Pulse off time Vs Current

From the **Fig. 3.7**, as the current increases surface roughness increases. As the pulse off time increases there is increase in the surface roughness.

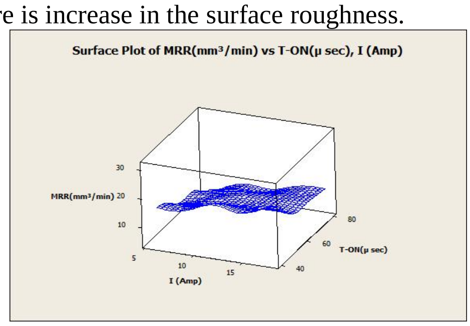

Figure 3.8 Surface Plot of material removal rate Vs Pulse on time Vs Current

From the **Fig. 3.8**, as the current increases material removal rate increases. As the pulse on time increases there is decrease in the material removal rate.

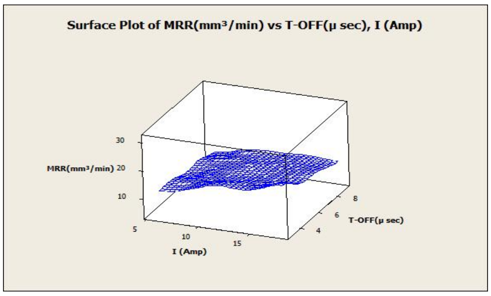

Figure 3.9 Surface Plot of material removal rate Vs Pulse off time Vs Current

From the **Fig. 3.9**, as the current increases material removal rate increases. As the pulse off time increases there is decrease in the material removal rate.

4.RESULTS AND DISCUSSION

The final results that are obtained are the mathematical models obtained using the MINITAB software and the generalized software program using the PHP software. PHP: Hypertext Preprocessor is a widely used, general-purpose scripting language that was originally designed for web development to produce dynamic web pages.

4.1 Mathematical Models:

The mathematical models that are generated are:

Ra = 1.82 + 0.226 I + 0.00826 T-ON + 0.136 T-OFF ------ (4.1)

MRR = 30.8 + 0.424 I - 0.270 T-ON - 0.957 T-OFF ------ (4.2)

Where,

R_a = Surface Roughness
MRR = Material Removal Rate
I = Current
T-ON = Pulse on time
T-OFF = Pulse off time

Using this mathematical model a generalized software program is generated in the PHP software. These models are obtained using the **Regression Analysis** concept in the MINITAB software.

4.2 Software Program:

A generalized program is generated in the PHP software which gives the values of the output parameters for the given values of the input parameters. The instructions of that program are given as follows:

4.2.1 PHP Program:

- Select any one of the orthogonal array:(L27 or L18 or L9 or L8)
- Select Input Parameters and output Parameters needed
- Enter 3 Levels of Input
- Enter R_a and MRR values
- Calculate the Predicted values and percentage error
- Enter input parameters I , T-ON and T-OFF
- Get the R_a and MRR

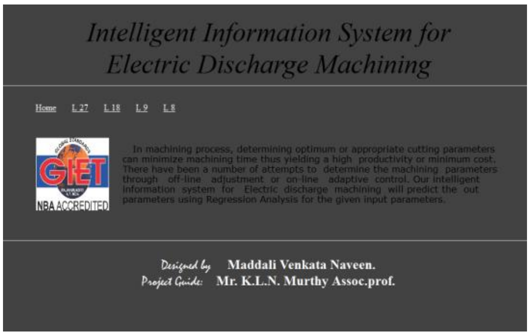

Fig 4.1 Homepage for intelligent information system for EDM

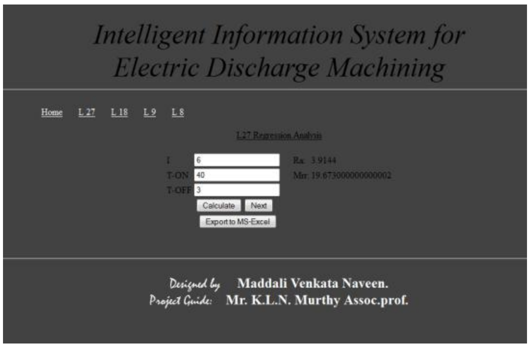

Fig 4.2 Input Parameters Screen Shot

4.3 Validation of Software:

The software program is tested by taking some trial values from the data collection and the respective results are obtained.

Table 4.1 Comparison of Regression modal value and Experimental model on Ra

S.No	Current (Amps)	T-ON	T-OFF	Ra (μm)	Predicted Ra (μm)	Ra Error %
1	6	40	6	4.73	4.32	8.62
2	6	60	3	4.20	4.08	2.87
3	12	40	9	5.91	6.09	-2.98
4	12	80	9	6.38	6.42	-0.58
5	18	60	3	7.63	6.79	10.99
6	18	80	9	7.88	7.77	1.36

Table 4.2 Comparison of Regression modal value and Experimental model on MRR.

S.No	Current (Amps)	T-ON (μ sec)	T-OFF (μ sec)	MRR (mm³/min)	Predicted MRR (mm³/min))	MRR Error %

1	6	40	3	19.27	19.67	-2.09
2	6	60	6	10.72	11.4	-6.36
3	12	40	9	16.98	16.47	2.97
4	12	80	3	11.33	11.42	-0.77
5	18	40	9	16.76	19.02	-13.48
6	18	80	3	14.79	13.96	5.61

The above trial values are taken from the data collected previously and these values are used to check the software program which was generated in the PHP software and results are obtained for the same input values of the trials taken previously from the data collection and are tested in the PHP software for the program generated and the outputs and percentage error are obtained as given in the above table.

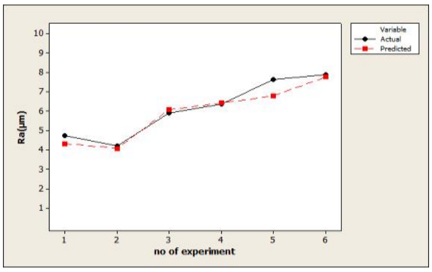

Fig 4.3 comparison between actual and predicted values on R_a.

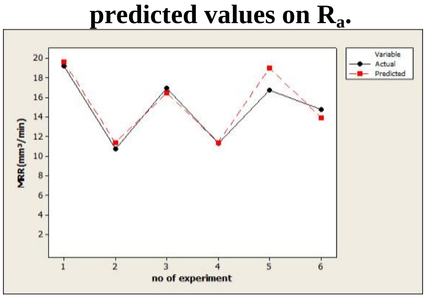

Fig 4.4 comparison between actual and predicted values on MRR

The developed model was validated. The errors are all in acceptable ranges, which, again, confirm the feasibility and effectiveness of the adopted approach.

5.CONCLUSION

Influence of EDM machining variables on material removal rate (MRR) and surface roughness (R_a) for Stainless Steel 17-4 PH investigated in this paper. The machining variables included peak current, pulse-on time and pulse-off time. The variables affecting the surface roughness were identified using ANOVA technique. Result shows that peak current and pulse-off time are significant variables for the surface roughness. The surface roughness of the test specimen increases when these two parameters increase. And peak current, pulse-on time and pulse-off time are significant variables for material removal rate. The material removal rate of the test specimen increases when current increase and decrease peak when pulse-on time and pulse-off time increase. A mathematical model was developed using regression analysis to formulate the input parameters to the output parameters.

Then an Intelligent Information System for Electric Discharge Machining was developed. Based on the results obtained for the generated software program which is modeled based on the mathematical models generated the following conclusions are drawn:

- The software program is a simple program and is in user friendly format.
- The results that are shown above clearly explain that predicted values are almost near to the original values and so the program is reliable.
- This program gives the predicted values which are not supposed to be considered as authorized values for the machining. This will give only the approximate idea of the values that will come if the experimentation is done with the input values which user gives.

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