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Experimental Investigation And Analysis Of Air With Water Mist Wire Cut Electrical Discharge Machining Process Using Rsm Methodology

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Abstract- The wire electrical discharge machining (WEDM) experiments has been conducted using air and water mixture as a dielectric medium, is called environmental friendly near dry WEDM. In this technology, the dielectric fluid (Deionized water) is replaced by liquid-air to minimize the environmental impact in the machining zone and operator health. The effect of discharge current (I), Pulse width (T_{ON}), pulse interval (T_{OFF}), applied voltage (V), air pressure (P) on the material removal rate (MRR) and surface roughness (R_a) have been analyzed using central composite design method. The set of experiments are conducted using response surface design of experiments. The mathematical models are developed using regression second order analysis. The optimum MRR and Ra are predicted and mathematical model have been developed by Response surface methodology (RSM). It is observed from this study, the voltage, spark-current and pressures are the significant parameters for the output parameters.

Index Terms- Central Composite Design,Liquid-Air, MRR, Near Dry WEDM, R_a.

I. INTRODUCTION

Wire-electro discharge machining (Wire-EDM or WEDM) has become an important non-traditional machining process, widely used in the aerospace, nuclear and automotive industries, for machining difficult to machine materials (like titanium, nimonics, zirconium) etc. Wire-electro discharge machining is a process of material removal of electrically conductive materials by the thermoelectric source of energy. The material removal is controlled erosion through a series of repetitive sparks between electrodes, i.e. work piece and tool. Fig 1shows the basic features of the Wire-EDM process. The electrode is a thin wire and it is pulled through the work piece from a supply spool onto a take up mechanism. On application of a proper voltage, discharge occurs between the wire electrode and the work piece in the presence of a flood of de-ionized water of high insulation resistance. Some major advantages are Complex shapes that would otherwise be difficult to produce with conventional cutting tools, extremely hard material to very close tolerances, Very small work pieces where conventional cutting tools may damage the part from excess cutting tool pressure, There is no direct contact between tool and work piece, Therefore delicate sections and weak materials can be machined without any distortion, A good surface finish can be obtained, Very fine holes can be easily drilled the main benefit is less vibration in tool.

Wire electric discharge machining (WEDM) is one of the most popular non-traditional machining processes used for machining high hardness materials. Near Dry WEDM is a new WEDM process and it is an environment-friendly modification of the conventional (deionized water) WEDM process in which the dielectric fluid is replaced by a mixture of gas and water. Use of Deionized water as the dielectric liquid is the major cause for the environmental problems. Dielectric waste generated during the oil WEDM process is very poisonous, cannot be recycled and also harmful fumes are generated during machining. The main advantage of this near dry WEDM is low electrode wear and high work removal rate. High velocity water and gas flow through the separate nozzle into the inter-electrode gap. High velocity gas provides removal of debris and prevents excessive heating of the tool and work piece at the discharge place.

Jerzy Kozak et al [1] investigated using air compared with kerosene. Single hole copper electrode and 2-channel copper electrode are used as tool. Result shows that 2-channel copper electrode gives better result that Minimum tool wear, Maximum material removal rate and Minimal surface roughness. Albert j. Shih et al [2] conducted

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experiments using air. Process parameters are varied and studied under wet (Deionized water) and dry (Air) EDM condition. Finally Maximum MRR is achieved in dry EDM with air, Tool wear rate is reduced in dry EDM, by applying mist of deionizied water. Smoke level is reduced in dry EDM. Kunieda Masanori et al [3] used oxygen as the dielectric fluid with copper tungsten pipe was used as the tool electrode. High velocity of oxygen gas improves the material removal rate due to oxidation, removal of machining debris, cooling of tool electrode. It shows increased metal removal rate and reduced electrode wear. Tanimura et al [4] projected new EDM process using water mist, which requires no tank for the working fluid. They also pointed out that the mist-EDM/WEDM enables non-electrolytic machining even when electrically conductive water is used as the working liquid. Dry EDM has many advantages such as, extremely low tool wear ratio, higher precision, smaller heat affected zone. H.Singh et al [5] analyze the effects of various input process parameters like pulse on time, pulse off time, gap voltage, peak current , wire feed and wire tension have been investigated and impact on MRR is obtained. Finally they reported MRR increase with increase in pulse on time and peak current. MRR Decrease with increase in pulse off time and servo voltage. Wire feed and wire tension has no effect on MRR. Fabio N. Leao et al [6] using Air and Oxygen (high speed flow) as dielectric fluid, the result is MRR achieved in oxygen is high then air and it shows very low electrode wear, it does not produce any waste and not affect the health of operator. Gaseous dielectrics such as air and Oxygen can produce high MRR compares to hydrocarbon oil. Tao et al [7] used oxygen gas and copper tool combination provides high MRR in dry EDM and nitrogen gas- water mixture dielectric and graphite tool combination gives high surface finish in near dry EDM. S.K. Choudhury et al [8] studied the effect of voltage, discharge current, pulse-on time, duty factor, air pressure, spindle speed on MRR , Surface Roughness and Tool wear rate under oxygen gas and nitrogen gas-water mixture as a dielectric medium results shows the Effect on input pressure on MRR and Ra is, higher air pressure provides better performance in MRR and Ra. Effect on current on MRR and Ra is, MRR is increase with increase current. Effect of voltage and pulse on time on MRR and Ra is both increase certain limit and decreased. Nihat Tosun et al [9] find on the effect and optimization of machining parameters on the notch and material removal rate (MRR) in wire electrical discharge machining (WEDM) operations. The experimental studies were conducted under varying pulse duration, open circuit voltage, wire speed and discharge flushing pressure. The settings of machining parameters were determined by using taguchi experimental design method. Amar Patnaik et al [10] Introducing zinc coated copper as electrode tool with the process parameters of Discharge current, Pulse duration, Pulse frequency, Wire speed, Wire tension, Dielectric flow rate. By using factors, maximization of MRR and minimization of surface roughness is done in WEDM process using Taguchi method.

II.MATERIAL AND METHODS:

Experiments are conducted on 815M17 (also known as EN353 nickel chromium with density of 8800 kg/m3, 1.1/4 % nickel chromium with case hardened steel) work specimen, with molybdenum tool wire. Work piece was in the form of a rectangle plate of dimension 75*30*5mm.Tool electrode was in the form of a wire with 0.20mm diameter. Molybdenum wire is used as electrode.

The dielectric medium in the conventional WEDM machine is replaced by air with water. Experiments were performed by air with water as the dielectric medium. High-pressure air is received from an air compressor and water from separate container was supplied through the nozzle into the discharge gap. In this air is supplied up to the pressure of 7 bar.

The pressure control valve and a pressure gauge are used to maintain the constant pressure range. The air tube is attached with the upper bed of the machine, so the air tube moves with respect to the bed. Due to this movement the air is focused on the work piece.

III.EXPERIMENTAL DETAILS

Experiments are conducted on a ST CNC-E3 (MCJ) wire EDM machine it is made by Steer Corporation this machine is numerically controlled wire EDM machine in that machine Y and X axis are servo controlled in X axis the table will move at 300mm and in Y axis 250mm. All axes have an accuracy of 5µm. A near dry WEDM unit is attachment has been designed and developed to enable performing the near dry WEDM process on this machine. An arrangement of set-up is shown in fig 1 & 2. The attachment unit has been designed to fulfill the basic requirements of near dry WEDM i.e. high velocity air, water mixture flow through a nozzle. Parametric analysis has been done by

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conducting a set of experiments using air and water as the dielectric medium. Effect of the input parameters Such as gap voltage (V), pulse width (P_{ON}), pulse interval (P_{OFF}), Current (I), inlet air pressure (P) on material removal rate (MRR) and surface finish (R_a) has been studied. One separate compressor is connected to the arrangement, this compressor supplies high velocity air to the nozzle. This nozzle is fixed near to the work specimen and wire with some gap.

Fig.1. Fabricated Model

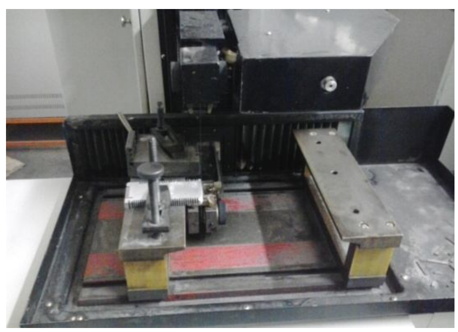

Fig.2. Pro-E Model

Parametric analysis:

To study the effect of the input parameters and the effect of their interactions with output parameters. Here two variant are change at a time. And CCD design has been conducted for analysis of parameters.

Regression analysis and model fitting:

Regression analysis of the experimental results obtained from the CCD runs has been done using the software Design Expert 8.0.7. Models with significant factor effects were obtained for MRR and R_a. But for TWR no suitable model could be obtained which had a significant effect. The regression analysis for each response is discussed below.

Here ANOVA based sequential sum of squares test was done to select the most appropriate model to be fitted. The test result is shown in Table 1. Linear, two factor interaction, quadratic and cubic models were compared to see if addition of extra terms improved the fitting as indicated by the F value in the Fischer's F test. The F values can be converted into the p value by using the F probability distribution curve. The model significance can be tested either by comparing the F value to a threshold F value or by comparing the corresponding p value to the threshold p value. The threshold p value depends on the chosen significance level which was set here to 5%. The highest order polynomial for

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which the additional terms were significant and the model was not aliased was chosen. Based on the test result, the two factor interaction model was chosen for fitting.

Table 1. Mathematical model sum of squares for MRR

Source	Sum of Squares	DF	Mean Square	F-Value	p-value Prob > F	Command
Mean vs Total	2923.463	1	2923.463	-	-	-
Linear vs Mean	554.827	5	110.965	28.105	< 0.0001	-
2FI vs Linear	33.322	10	3.332	0.806	0.6235	-
Quadratic vs 2FI	118.048	5	23.609	30.637	< 0.0001	Suggested
Cubic vs Quadratic	18.681	15	1.245	4.754	0.0029	Aliased
Residual	3.66	14	0.261	-	-	-
Total	3652.009	50	73.040	-	-	-

The regression statistics for the full two factor interaction model are shown in Table 2 the predicted R2 value and the adjusted R2 value were found to be in Close agreement Adjusted R2 is a measure of the amount of variation about the Mean which is explained by the model A value of 0.94 indicates that 94% of the Observed variation in the response can be explained by the model.

The statistics 'Adequate precision' measures the signal to noise ratio of the experiment. A value greater than 4 is preferable. A ratio of 26.213 indicates an adequate signal and the model can be used to navigate the design space. When there is a large difference in the values of predicted R2 the adjusted R2, it indicates that some non-significant terms have been included in the model and the model would improve on excluding such terms. To check if the fitting would improve on dropping some terms, a reduced two factor interaction model was fitted. Backward step-wise fitting was used for model fitting with term-dropping p value of 10%. It was found that the difference between the predicted R2 value and the adjusted R2 value decreased on dropping some of the terms. Hence the reduced two factor interaction model was chosen

Table 2. ANOVA table for response surface reduced two-factor interaction model of MRR

Source	Sum of Squares (SS)	Degrees of Freedom	Mean Square	F Value	p-value Prob > F	Test result
Model	706.198	20	35.309	45.819	< 0.0001	significant
A-V	15.0515	1	15.051	19.531	0.0001	-
C-T_{OFF}	97.973	1	97.973	127.134	< 0.0001	-
D-P	299.140	1	299.140	388.176	< 0.0001	-
E-Current	141.664	1	141.664	183.829	< 0.0001	-
AB	1.080	1	1.080	1.401	0.2461	-

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AC	0.125	1	0.125	0.163	0.6891	-
AD	4.716	1	4.716	6.120	0.0195	-
AE	0.834	1	0.834	1.083	0.3065	-
BC	0.592	1	0.592	0.768	0.3879	-
BD	2.329	1	2.329	3.022	0.0927	-
BE	0.510	1	0.510	0.662	0.4224	-
CD	3.098	1	3.098	4.020	0.0544	-
CE	0.050	1	0.050	0.0648	0.8007	-
DE	19.985	1	19.985	25.933	< 0.0001	-
A^2	16.728	1	16.728	21.707	< 0.0001	-
B^2	0.547	1	0.547	0.709	0.4064	-
C^2	21.051	1	21.051	27.316	< 0.0001	-
D^2	77.412	1	77.412	100.453	< 0.0001	-
E^2	38.062	1	38.062	49.391	< 0.0001	-
Residual SS	22.348	29	0.770	-	-	-
Lack of Fit	22.348	22	1.015	-	-	-
Pure Error	0	7	0	-	-	-
Corrected Total SS	728.546	49	-	-	-	-

The Model F-value of 45.82 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, C, D, E, AD, DE, A^2, C^2, D^2, E^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

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The final regression equation for MRR in terms of the actual parameter values is:

$$MRR= 287.36875-4.37295\times V+3.12739\times T_{ON}-3.75825\times T_{OFF}-4.27128\times P \quad 12.13811\times I\times -0.027218\times V\times T_{ON}+3.48438E-0.03\times V\times T_{OFF} \quad 0.085312\times V\times P+0.071792\times V\times I-0.022672\times T_{ON}\times T_{OFF} \quad 0.17985\times T_{ON}\times P+0.16837\times T_{ON}\times I+0.077789\times T_{OFF}\times P-0.019766\times T_{OFF}\times I\times 1.58056\times P\times I+0.027085\times V^2+0.044096 \times T_{ON}^2+0.038468\times T_{OFF}^2+1.18029 P^2+3.31049\times I^2$$

Where, MRR is in mm^3/min and Voltage in V, I in Amps, T_{ON} in µs, T_{OFF} in µs , P in kg/cm^2.

Regression analysis for R_a

ANOVA-based sequential sum of squares test was done to select the most appropriate model to be fitted. The test result is shown in Table 3. A linear model is suggested. However, the regression statistics shows that the value of adjusted R2 is low. Hence reduced models were fitted and compared as shown in Table 4. The reduced quadratic model was chosen based on the high value of adjusted R2. The "Pred R-Squared" of 0.7693 was found to be in reasonable agreement with the "Adj R-Squared" of 17.633. Also "Adeq Precision" ratio of 16.396 indicates an adequate signal and the model can be used to navigate the design space.

Table 3. Mathematical model sum of squares for R_a

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	**Comments**
Mean vs Total	254.115	1	254.115	-	-	-
Linear vs Mean	20.517	5	4.103	61.046	< 0.0001	Suggested
2FI vs Linear	0.595	10	0.059	0.857	0.5798	-
Quadratic vs 2FI	0.862	5	0.172	3.336	0.0168	Suggested
Cubic vs Quadratic	1.346	15	0.089	8.244	0.0002	Aliased
Residual	0.152	14	0.010	-	-	-
Total	277.590	50	5.551	-	-	-

The Model F-value of 21.25 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case B, C, D, E, D^2, E^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

Table 4. ANOVA table for response surface reduced two-factor interaction model of R_a

Source	**Sum of Squares (SS)**	**Degrees of Freedom**	**Mean Square**	**F Value**	**p-value Prob > F**	**Test result**
Model	21.98	20	1.10	21.25	< 0.0001	significant
A-Voltage	*0.071*	1	*0.071*	1.38	*0.2492*	-
B-T_{ON}	4.23	1	4.23	81.83	<*0.001*	-
C-T_{OFF}	3.60	1	3.60	69.70	*< 0.0001*	-

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D-Press	*12.31*	1	*12.31*	*238.04*	*< 0.0001*	-
E-Current	*0.30*	1	0.30	*5.88*	*0.0218*	-
AB	*0.027*	1	0.027	0.52	*0.4755*	-
AC	*4.753E-003*	1	*4.753E-003*	*0.092*	*0.7639*	-
AD	*0.21*	1	0.21	*3.99*	*0.0552*	-
AE	0.20	1	0.20	3.93	*0.0570*	-
BC	*1.378E-003*	1	*1.378E-003*	*0.027*	*0.8714*	-
BD	0.027	1	0.027	0.52	0.4755	
BE	*6.328E-003*	1	*6.328E-003*	0.12	*0.7290*	-
CD	0.096	1	0.096	1.85	0.1841	-
CE	*2.813E-005*	1	*2.813E-005*	*5.440E-004*	*0.9816*	-
DE	0.024	1	0.024	0.46	0.5024	-
A^2	0.027	1	0.027	0.53	0.4727	-
B^2	0.18	1	0.18	3.56	0.0693	-
C^2	0.20	1	0.20	3.89	*0.0580*	-
D^2	0.41	1	0.41	7.92	0.0087	-
E^2	0.38	1	0.38	7.44	0.0107	-
Res SS	1.50	29	0.052	-	-	-
Lack of Fit	1.50	22	*0.068*	-	-	-
Pure Error	*0.000*	7	*0.000*	-	-	-
Corrected Total SS	23.47	49	-	-	-	-

The final regression equation for R_a in terms of the actual parameter values is:

$Ra=-7.85072+0.089743\times V+0.93694\times T_{ON}+0.34217\times T_{OFF}-1.82034\times P-0.88691\times I-4.30556E-003\times V\times T_{ON}-6.77083E-004\times V\times T_{OFF}+0.017847\times V\times P+0.035417\times V\times I+1.09375E-003\times T_{ON}\times T_{OFF}+0.019375\times T_{ON}\times P-0.018750\times T_{ON}\times I+0.013672\times T_{OFF}\times P-4.68750E-004\times T_{OFF}\times I-0.054375\times P\times I-1.09590E-003\times V^2-0.025577\times T_{ON}2-3.76244E-003\times T_{OFF}2-0.085832\times P2-0.33272\times I^2$

Where, Ra is in µm and Vg in V, Id in A, Ton in µs, D is dimensionless, P in kg/cm^2

Response surface analysis

MRR Response surface

1. The response surfaces of MRR are obtained for the interface terms in the reduced two-factor interaction model. Response surface of MRR vs. voltage and pulse width is shown in Figure 4.From the figure it can be seen that MRR slightly increases with increase in pulse width. MRR is increasing with increase in voltage. MRR increases with an increase in voltage due to increase in the spark energy. And discharge gap increases with an increase in voltage. The increase in spark energy is dominated by the reduction in spark efficiency as voltage is increased. This leads to an increase in MRR as voltage is increased at high current levels.

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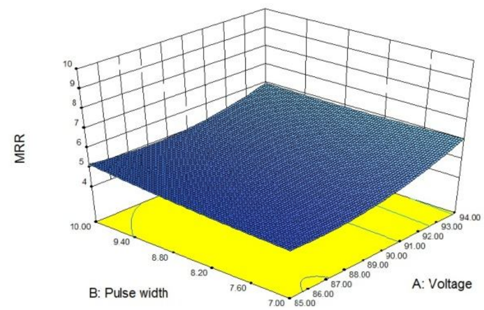


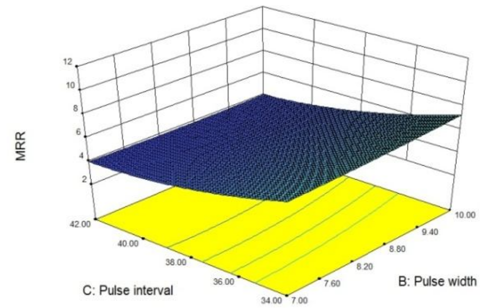
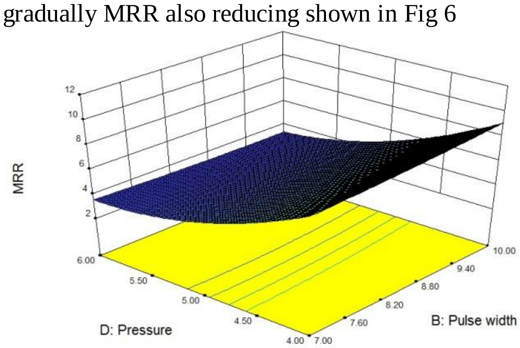


Fig 4: Response surface of MRR vs V & T_{ON} Fig 5: Response surface of MRR vs T_{OFF} & T_{ON}

MRR values gradually decreases with increase in pulse interval and MRR increases with increase in pulse width shown in Fig 5. MRR slightly increases with increase in pulse width and when the air pressure is increases gradually MRR also reducing shown in Fig 6



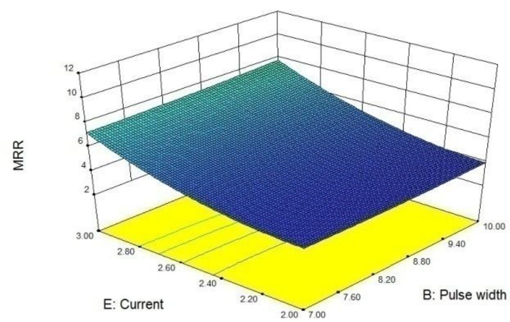
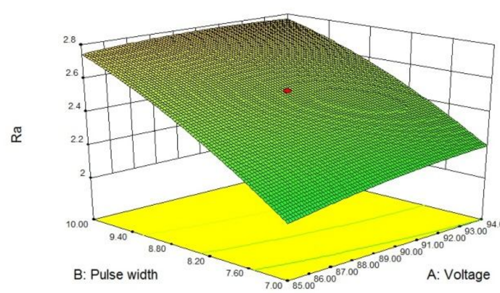


Fig 6: Response surface of MRR vs P & T_{ON} Fig 7: Response surface of MRR vs I & T_{ON}

MRR slightly increases with increase in pulse width and current increasing MRR increasing gradually shown in Fig 7

R_a Response surface

The response surfaces of R_a were obtained for the interaction terms in the reduced quadratic model. Response surface of Ra versus gap voltage and pulse width is shown in Figure 7 from the T_{ON}-V response surface it can be seen that the R_a value increasing with a decrease in the pulse width. When increase in voltage very slight change in R_a.



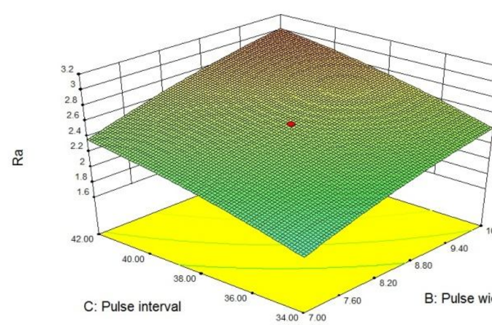


Fig 7: Response surface of Ra vs v & T_{ON} Fig 8: Response surface of Ra vs T_{OFF} &T_{ON}

R_a value increasing with a decrease in the pulse width. Increasing pulse interval R_a value also increasing shown in Fig 8.

R_a value increasing with a decrease in the pulse width and Increasing pressure R_a value decreases shown in Fig 9.

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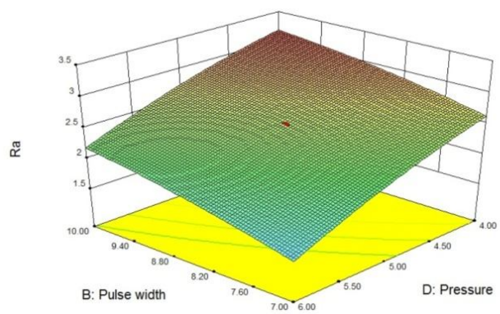

Fig 9: Response surface of Ra vs P & T_{ON}

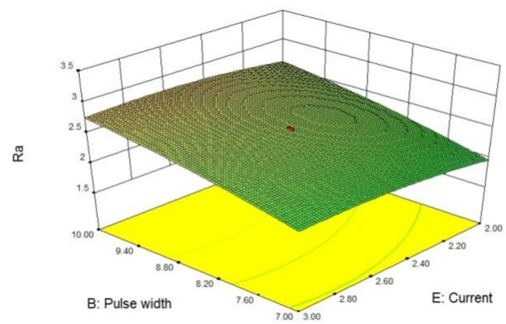

Fig10: Response surface of Ra vs I & T_{ON}

R_a value increasing with a decrease in the pulse width and. If current increases R_a value also increases at particular point then it constant shown in Fig 10.

IV.CONCLUSION

- In this article, parametric analysis of the near dry WEDM process has been done based on experimental setup. Experiments were conducted based on the Central composite design to develop empirical models of the process. Process optimization was conducted by Central composite design (RSM). Following conclusions were obtained from the result analysis.
- According to the previous experiments, wire EDM with mixture of air and water as the dielectric is possible. High velocity of air mixed with water flows in to the inter electrode gap through the nozzle. Flow of air and water particles in the inter electrode gap affects the MRR and Ra. As observed in changing the Air pressure and input parameters.
- From the designed set of experiments based on the Central Composite Design. It was found that voltage, pulse width and current are the significant factors which affect the MRR, and MRR increases with an increase in any one of the factors. While increasing other two factors, pressure and pulse interval are affects the MRR.
- The material chosen for this study was EN353 due to the growing application in the field of manufacturing aircraft components, dies and machine tool cutters.
- From the CCD experiment, all input parameters (voltage, current, pulse width, voltage, pulse interval, pressure) have significant effect on Ra. Ra values increase with increase in current, voltage, pulse width, pulse interval.

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