Investigation of Material Removal Rate and Surface Roughness for AISI 1015 Steel Rack Gear in Wire EDM Process

Mostafa Adel Abdullah
Production Engineering and Metallurgy Department, University of Technology/Baghdad
Email: mostafa_ad_87@yahoo.com
Safaa Kadhim Ghazi
Production Engineering and Metallurgy Department, University of Technology/Baghdad
Mustafa Mohamed
Production Engineering and Metallurgy Department, University of Technology/Baghdad

Received on:3/4/2016 & Accepted on:18/8/2016

ABSTRACT

In this work an investigation of the effects of various process parameters of Wire-EDM like Servo Feed (SF), pulse off-time (T_{OFF}), pulse on-time (T_{ON}), as inputs impact on surface roughness (Ra) and metal removal rate (MRR) as outputs on steel (AISI 1015) utilizing nine specimens. With servo feed (500, 600 and 700)mm/min, pulse-of time (10,30,50) μsec, pulse on-time (20,25,30) μsec. The characteristics of cutting variables were determined by implementing Taguchi experimental design method. The importance level of the cutting variables for metal removal rate and surface roughness is determined by implementing the analysis of variance (ANOVA).

Keywords: Taguchi, ANOVA, surface roughness, MRR.

INTRODUCTION

Non-traditional cutting operations are called advanced cutting operations since they are based in modernistic industries. These cutting operations employ different energies such as chemical, electrical, thermal, and mechanical or combination for those energies for cutting extra material. Besides, the non-conventional cutting operations do not use sharp cutters. the non-conventional machining operations are classified by distinct cutting techniques, cutting system elements and technological properties. Wire electrically discharging machining (WEDM) is a variation in electric discharging machining (EDM) that is similar to contour machining with a band saw. A continuous moving wire drives along a specified trajectory, machining the workpiece, with discharging spark acts like cutting teeth. The tighten wire is utilized only once, transferring from a take-off spool to a take-up spool while being guided to give an exact tight kerf. The horizontal moving of the work table has a numerical control to generate the cutting path. WEDM is utilized for cutting plates thickness (300 mm), and for manufacturing stripper plates, tools, punches, and extrusion dies in hard metals. It is also used for cutting the complex shapes in the electronic industries. WEDM machines at present are obtainable with CNC facilities in which the work piece tape up to ±30º is totally integrated. WEDM machines are supplied only with pulses generators, where peak current and on-time are the main parameters to control the energy of the spark.

Saurav and Mahapatra. (2010)[1] derived quadratic mathematical models representing the operation behavior of WEDM process. The experimental tests were carried out with six operation variables discharging current, wire speed, pulses duration, pulses frequency, wire tenseness and dielectric flowing rate] changed in three various levels. Metal removing rates (MRR), roughness values for the machined were inspected for each runs of the experiment. The predicted outcomes were obtained by the models have been utilized in the search for optimum variables: maximum MRR, and good surface finish.

Sadeghi, et al. (2011) [2] investigated the effecting of variables, [discharging current, open-circuit voltage, pulse interval, and servo-voltage] on the material removal rate and surface roughness of (WEDM). The pulse interval and discharging current have more influence on MRR and surface roughness than the open circuit voltage. The servo-voltage had a minimal effecting on the surface roughness and had no effect on the (MRR). The final outcomes for rough, moderate and smooth WEDM produced (3.64 %).

Abhishake Chaudhary, et al. (2013) [3] utilized responding surface method to examine the effecting of four controlling variables on the (MRR) in WEDM process. The effects of process parameters are taken two at a time on MRR. The researchers concluded that MRR increased with Pulses on time, and decreased with Pulses off time and servo voltage. While the peak current had a very small influence on the MRR, but Ton is the most influential parameter among them.

Chopde, et al. (2014) [4] investigated the effects of WEDM variables on surface finish of tool steel. Taguchi standard orthogonal system was selected for planning and carrying out the experiments. The surface roughness was considered as response for improving surface quality. The Analysis was done to calculation the optimum cutting condition combination for better (Ra). Based on ANOVA it have been noted that, the variables Ton (77.78 % contribution) is most effected parameter, Ip (11.70 % contribution) and Sv (9.18% contribution) are significant and T_{OFF} (1.32% contribution) is smaller significant on behavior measures.

Introduction to Taguchi Method:

Taguchi discovers a novel conception for the quality control method named as (Taguchi parameter design) [5]. The method stated that the quality of manufactured part must be computed by the deviation amount from the required value. He takes into consideration not only the operation mean, but also the variation magnitude or (noise) created with manipulating the inputs parameters or operation variables. The technique is focus on two major groups; a unique matrix type called orthogonal array (OA), all the columns include number of experiment depending on the level number for the control factor, in addition to (signal to noise ratio) S/N [6]. The concept (S) indicates to required amount of the outputs characteristics and concept (N) indicates for unrequired amount (standard deviations). The calculation of (*S*/*N*) is varying regard to outer functions, i.e., characteristics values. Two characteristics value “Smaller is Better (SB)” and “Larger is Better (LB)”[7].

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}(y_i^{\,2})\right] \;; \qquad i = 1,2 \ldots\ldots n \qquad \ldots\ldots..(1)$$

The formula is utilized to calculating signal to noise ratio are given by:

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{y_i^{\,2}}\right)\right] \;; \qquad i = 1,2 \ldots\ldots n \qquad \ldots..(2)$$

Where: n are the measurements of input

yi are the measurements value of output

The input parameter of nine simple are Design with using MINITAB16 program as follow:

STAT ⟶ DOE ⟶ Taguchi ⟶ Create Taguchi Design

Variance Analysis:

The experiential works tested use variance method (ANOVA) show figure out of effecting the machining variables on the surface roughness and (MRR) that depend on machining variables T_{on},T_{off} and SF while others are independent variables. (%) percent is refer to influence rate of operation variables to (Ra) and (MRR)[8].

Experimental Work:

Wire cut Electrical Discharge Machine is available in training and workshop Center University of technology. With work piece dimension (50x 20) mm and width (4) mm.with use nine semple withchage of cutting parameter use Table (5).

1. WEDM Machine:

The machine used is performed on 2- axis (ELEKTRA Wire cut Electrical Discharge Machine) type (EL PULSE 15) shown in Figure (1) and the machine specifications are shown in Table (1).

Figure (1): EL PULSE 15 Electra WED Machine being used in experimental work.

Table (1): machine specifications

Specification	Dimensions
Maximum work piece dimensions.	630 × 440 × 300 mm.
Maximum work piece weight.	500 kg.
Table travel.	400 × 320 mm.
Z-axis travel.	210 mm.
X&Y axis travel.	55 × 55 mm.
Maximum table feed rate.	180 mm/min.
Work fluid.	Distilled water.

2. Metal operator:-

The Metal operator is low Carbon steel AISI 1015 with dimensions (50x50x25) mm . The chemical composite and other properties are shown in tables (2) and (3) respective.

Table (2) : The chemical composition for AISI 1015 Carbon Steel (UNS G10150).

Element	C%	Si%	Mn%	P%	S%	Cr%	Ni%	Co%	Cu%	Fe%
Weight	0.138	0.301	0.392	0.014	0.024	0.221	0.089	0.006	0.232	Bal.
Element	**Mo**	**Al**	**Nb**	**Ti**	**V**	**W**	**Ta**	**Sn**	**Zr**	**Zn**
Weight	0.030	0.001	0.001	0.001	0.0005	0.005	0.014	0.011	0.001	0.002

Table (3): Mechanical properties of AISI 1015 Carbon Steel (UNS G10150) [9].

Property	Values
Tensile strength.	385 MPa
Yield stress.	325 MPa
Bulk modulus (typical for steel)	140 GPa
Shear modulus (typical for steel)	80.0 GPa

3. Cutting Tool:

One type of wire cut were used soft brass wire with 0.25 mm diameter and coated brass.

4. Design of Experiments:

The cutting work with total number are (nine) with (3) levels and (3) parameters as (27 test) . A paritial design was done for studying the effects of parameter on MRR and surface roughness values. The parameters were Ton, T_{OFF}, S_F. as table(4).

Table (4): Cutting conditions

No	Parameter	Symbol	Level 1	Level 2	Level 3	Units
1	Pulse on time	T_{ON}	20	25	30	µsec
2	Pulse off time	T_{OFF}	10	30	50	µsec
3	Servo feed	S_F	500	700	900	mm/min

The other factors were kept constant during machining which are:

- Current (Ip) = 12 Ampere
- Gap voltage (VP) = 1 Volt
- Water pressure (WP) = 1 Pascal
- Wire feed (WF)= 6 mm/min
- Wire tension(WT) = 6 Kg
- Servo voltage (Sv) = 25 Volt

The Table (5) shown final Experimental design for the work.

Table (5): Experimental design for the work

No	T_{on}	T_{off}	SF	Surface Roughness	MRR
1	10	20	500	1.52	2.789
2	10	40	600	1.38	2.514
3	10	50	700	1.52	3.17
4	20	20	600	2.41	10.378
5	20	40	700	1.66	6.011
6	20	50	500	1.55	4.891
7	30	20	700	2.04	12.071
8	30	40	500	1.94	7.595
9	30	50	600	2.31	7.986

5. Cutting Use WEDM:-

Figure (2) shown nine simple after cutting using of WEDM process under machining parameter.

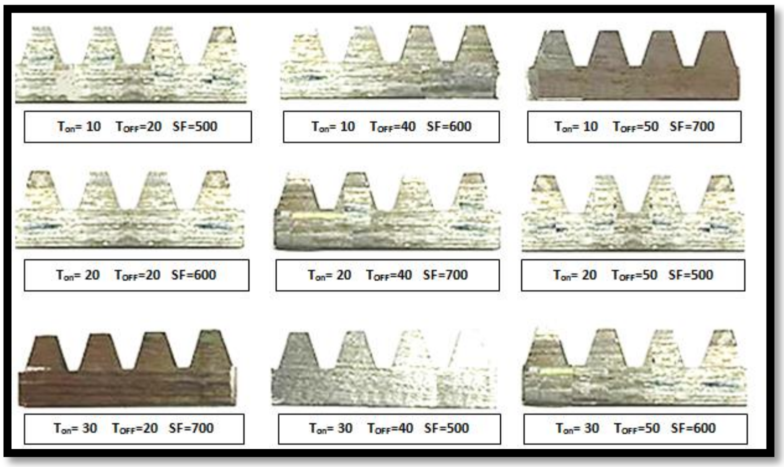

Figure (2): The nine specimens

Surface Roughness Measurement :-

The portable gauge of surface roughness Mahr Federal's is available at measurement lab / production and metallurgy engineering Department/UOT, and shown in Figure (3).

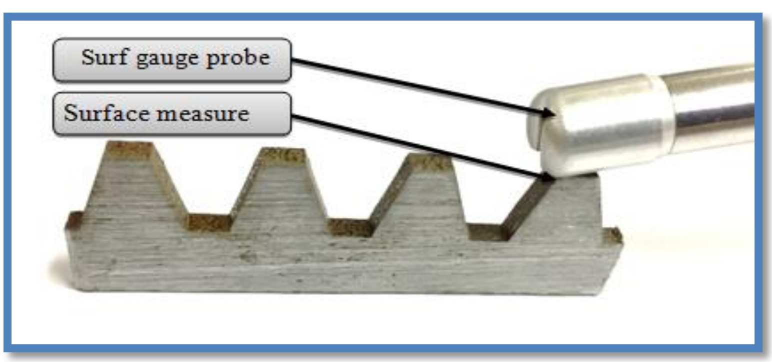

Figure (3): Pocket Surf use in the proposed work for meauser surface roughness.

MRR Measure :-

MRR Measure as follows equation:

MRR = Vc * b * h (mm³/min) ………………………….. (3)

b = d wire + 2S (m …………………………….. (4)

vc =servo speed in (mm/min)

b =width of cut in mm

h =thickness of work piece in (mm), (3 mm)

d wire = wire diameter in (mm), (0.25 mm)

S = spark gab in (mm),(0.2 mm) "

RESULTS AND DISCUSSION

1. Effecting of Pulse-on Time and Servo Feed on the MRR:

The figure (4) shows the effecting of T_{ON} and S_F on (MRR) with each value T_{OFF}. It can be seen that the raise in T_{ON} leading to raise the (MRR). Because of the large power that occur through cut and causes to large melting. Also, the raise in S_F causes to increasing MRR except when SF 700 and Ton 20 because height speed lead some error in MRR .But this increase in MRR leads to increase in Ra because of the high energy generated during machining.

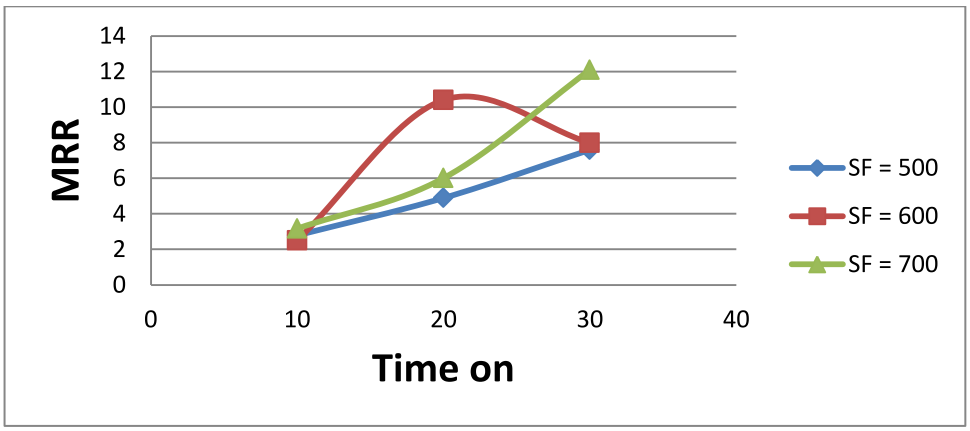

Figure (4): Effecting of Pulse-on Time and Servo Feed on the MRR

2. Effecting of Pulse-on Time and Pulse-off Time on the MRR:

Figure (5) shows the effecting of T_{ON} and T_{OFF} on MRR with each value SF. Shown the raise in T_{ON} causes to raise MRR, but the raise in T_{OFF} cause to decrease MRR. Because low melting at large value of T_{OFF} while SF has a little effect on MRR. Also, large rates of MRR can be occur at minimum level of T_{OFF}, and this minimum level of MRR give better (Ra) with measured in same parameter in Figure (8).

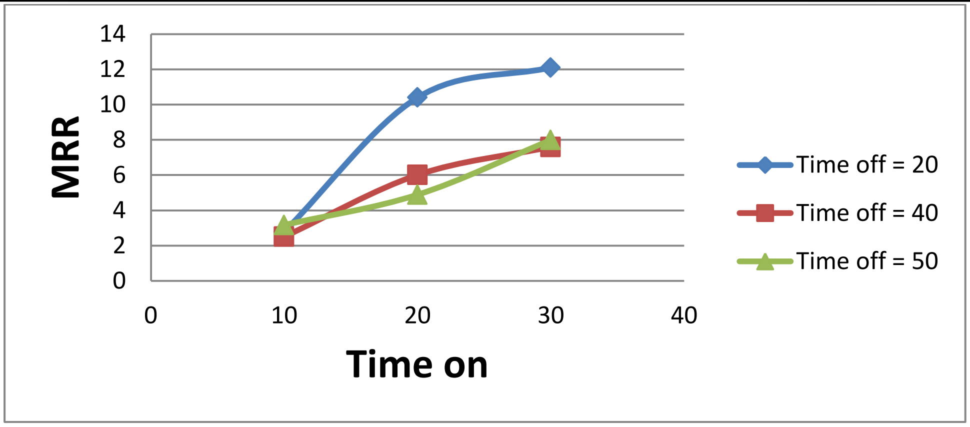

Figure (5): Effecting of Pulse-on Time and Pulse-off Time on the MRR

3. Analysis of Variance:

The outcomes are utilizing the variance (ANOVA) for determining the effects of cutting variables on the MRR as the output, T_{ON}, T_{OFF} and S_F as input.

The value(*F)* of 19.735for T_{ON} is largest than other conditions (as show in Table 6).So, the important conditions are T_{ON} (68.44%) which is about three times of the T_{OFF} (20%). The S_F has a little influence with 8%. Through analyzing, F- ratio is the mean square error ratio to residual, and its conventionally utilized to compute the importance of factors.

4. Optimum Design Conditions for MRR:

The major effecting plots are utilized for calculating the optimum design conditions for giving the optimal MRR and so that the better cutting condition utilizing (SPSS) program . Figure (6) clarify effecting of MRR with inputs process. This figure explains differences for the responding of the (3) variables, i.e. T_{ON}, T_{OFF} and SF . The optimum conditions to large (MRR) are: T_{ON} at level-3(25 µs), T_{OFF} at level-1(20 µs), and SF at level-3(700 mm/min).

Table (6): Analyses for MRR.

Source of variance	DOF	Sum of squares	Variance, V	F ratio	P (%)
Pulse on time, T_{on}	2	63.606	31.803	19.735	68.44
Pulse off time, T_{off}	2	18.624	9.312	5.778	20.04
Servo feed , **Sf**	2	7.473	3.7365	2.318	8
Error ,e	2	3.223	1.6115		3.46
Total	9	92.926			100

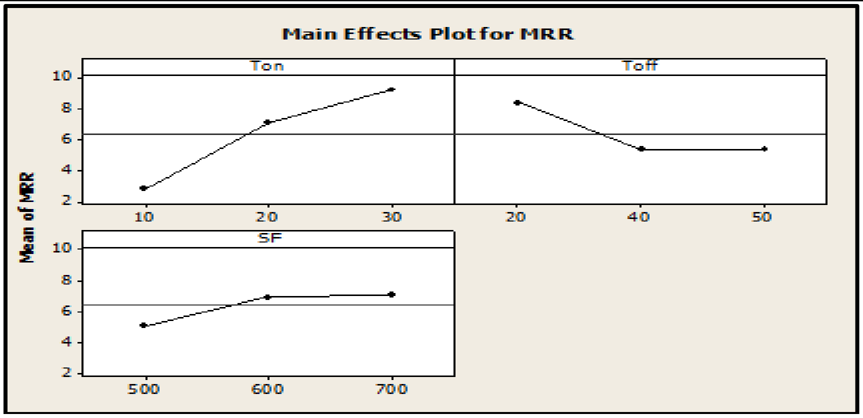

Figure (6): Mean affects plots in MRR

5. Effecting of Pulse-on Time and Pulse-off Time on (Ra):

Figure (7) shown affect of T_{ON} and S_F on (Ra) with each value T_{OFF}. That the rise in T_{ON} causes to rise in Surface roughness. Because large power occur through cutting and causes large melting of material except when SF 700 and Ton 20 because height speed lead some error in MRR. Also, the rise in S_F occur to increasing Surface roughness.

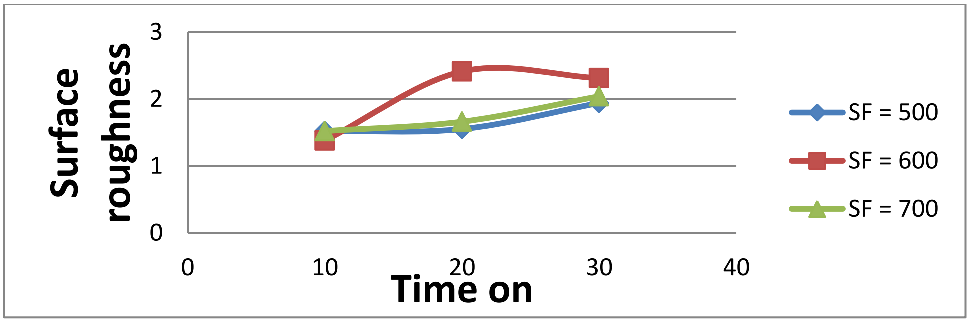

Figure (7): Effecting of Pulse-on Time and Servo Feed on the Surface roughness

6. Effect of Pulse on Time and Pulse off Time on the (Ra):

The Figure (8) shown the effecting T_{ON} and T_{OFF} on (Ra)at each value SF. the rising in T_{ON} occur to rising in Surface roughness, but the rising in T_{OFF} occur to decrease Surface roughness. Because minimum rates of melting at large values of T_{OFF} while SF has a little effect on Surface roughness. Also, from these figures, that large value of Surface roughness done at low levels of T_{OFF}.

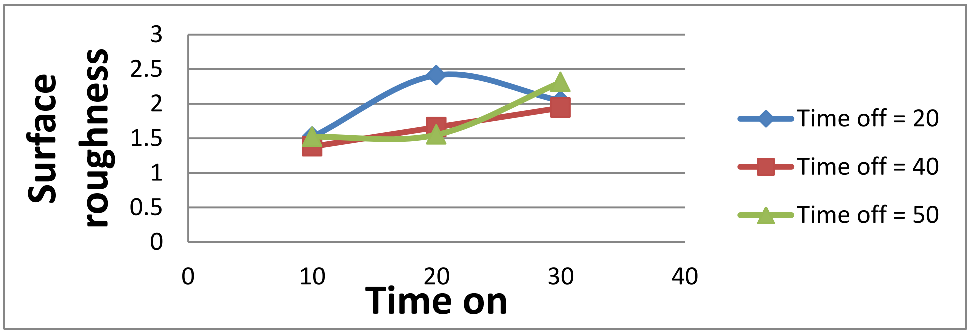

Figure (8): Effecting of Pulse on Time and Pulse off Time on the Surface roughness

7. Analysis of Variance:

The outcomes are utilizing the variance (ANOVA) for determining the effects of cutting variables on the surface roughness as the output, T_{ON}, T_{OFF} and S_F as input.

The value (*F)* of 4.708 of T_{ON} as larger compare other variables (as show Table 7). Thus, largest effective variables are T_{ON} (53%) that is about three times of T_{OFF} (14%). The S_F has a middle influence with 20%. Through analyzing, its conventionally utilized for computing the importance of factors.

8. Optimal Design Conditions for Surface roughness:

The major effecting plots are utilized for calculating the optimum design conditions for giving the optimal MRR and so that the better cutting condition utilizing (SPSS) program . Figure (9) clarify effecting of MRR with inputs process. This figure explains differences for the responding of the (3) variables, i.e. T_{ON}, T_{OFF} and SF . The optimum conditions to large (MRR) are: T_{ON} at level-3(25 µs), T_{OFF} at level-1(20 µs), and SF at level-3(700 mm/min).

Table (7): ANOVA for Ra.

Source of variance	DOF	Sum of squares ,ss	Variance, V	F ratio	P (%)
Pulse on time, T_{on}	2	0.598	0.299	4.7086	53.25
Pulse off time, T_{off}	2	0.165	0.0825	1.299	14.69
Servo feed , ***Sf***	2	0.233	0.1165	1.834	20.74
Error ,e	2	0.127	0.0635		11.3
Total	9	1.123			100

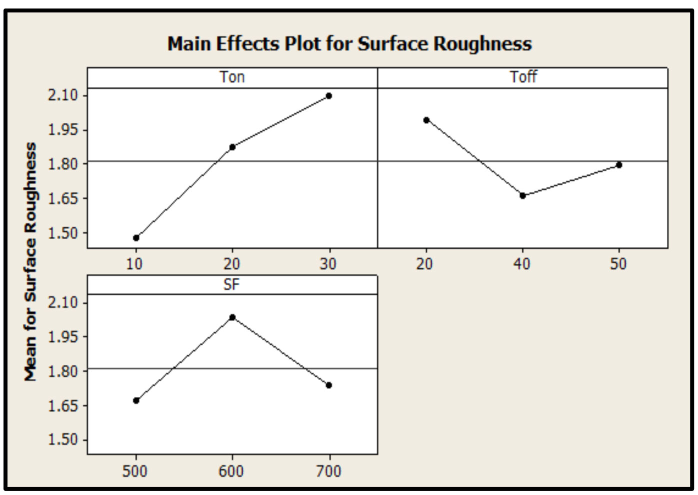

Figure (9): Mean affects for Surface roughness

CONCLUSIONS

Rack gear surfaces roughness and MRR are important produced quality and it effect by many condition. In this work study the effect of condition in operation. The result showed that increasing the SF leads to increasing the (MRR) but this increase in MRR leads to increase in Ra. Increasing the value of T_{OFF} causes to minimize MRR. Use ANOVA data, it can be observed that pulse on time (Ton) is the most influential machining variables affecting surface roughness with 53%, contribution then pulse off time (T_{OFF}) with 14% and servo feed (SF) with 20%. From ANOVA it can be found that pulse on time (Ton) is the most important cutting parameters affecting metal removal rate by 68%, contribution then pulse off time (T_{OFF}) with 20% and servo feed (SF) with 8%.

REFERENCES:

[1] Saurav Datta and Siba Sankar Mahapatra, "Modeling, simulation and parametric optimization of wire EDM process using response surface methodology coupled with grey-Taguchi technique", International Journal of Engineering, Science and Technology, Vol. 2, No. 5, pp. 166-183 ,2010.

[2] M .Sadeghi ,Hrazavi ,Aesmaeilzadeh and F.Kolahan, "Optimization of cutting conditions in WEDM process using regression modeling and tabu –search algorithm" Proceedings of the Institution of Mechanical Engineers, Part B:Journal of Engineering Manufacture, Vol. 225, No. 5, pp.1825-1834,(2011).

[3] Abhishake Chaudhary, Vijayantmaan, Bharat Singh, Chittoriya, Pardeep Gahlot, " Optimization of MRR of D-2 Steel in WEDM Process", Journal of Information, Knowledge and Research in Mechanical Engineering,Vol.2, No.3,pp.528-535,(2010).

[4] I. K. Chopde, Chandrashekhar Gogte, Dhobe Milind, "Modeling and Optimization of WEDM Parameters for Surface Finish Using Design of Experiments", International Conference on Industrial Engineering and Operations Management Bali, Indonesia, pp.1830-1839, (2014).

[5] Hongman Kim, " Statistical modeling of simulation errors and three reduction via response surface technique", Adissertation submitted to the faculty of the Virginia polytechnic institute and state university, 2001.

[6] Rahul Davis,et al" TAGUCHI METHOD AND ANOVA AN APPROACH FOR PROCESS PARAMETERS-2 ", (IJARET), Volume 4, Issue 4, pp. 01-07,May – June 2013,

[7] W.K.Hamdan, "Feasibility Development of Incremental Sheet Metal Forming Process Based on CNC Milling Machine", PhD. thesis, 2009.

[8] Shukry H. Aghdeab and Laith A. Mohammed, "Studying Parameters of EDM Based Micro-Cutting Holes Using ANOVA", Eng. &Tech. Journal, Vol.31, Part (A), No.15, 2013.

[9]Carmen Medrea-Bichtas, Gavril Negrea, and Serban Domsa "Study on mechanical properties of warm-rolled AISI 1015 carbon steel". Zeitschrift für Metallkunde: Vol. 95, No. 3, pp. 176-178. 2004.