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Experimentation and Optimization of WEDM Machining of ASSAB'88 Tool Steel

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ABSTRACT: In present days manufacturing a wide range of materials having high hardness, toughness and impact strength, good wear characteristics is required to produce different geometries and also for producing intricate shapes. After imparting the desired properties to the material, effects of the various WEDM process parameters i.e. servo reference voltage, Peak Current, Wire feed speed and wire tension on the machining quality (Material removal rate, Surface Roughness) have been evaluated to obtain the optimal sets of process parameters so that the quality of machined parts can be optimized. The Response Surface Methodology (RSM) in conjunction with central composite full factorial design has been used to investigate the effects of the WEDM process parameters and subsequently to predict sets of optimal parameters for optimum quality characteristics. In multy factor optimization of MRR 117 solutions are achieved and the optimum solution for MRR with maximum desirability of 0.683 is 0.490 mm^3/min which is obtained by taking the input parameters SRV, PC, WFS and WT as 22.5 volts, 8.571 Amp, 9 m/min and 0.9 kg respectively. In ASSAB 88 tool steel material removal rate has decreasing trend with increase in WFS and SRV whereas increasing trend with increase in wire tension.

Keywords: MRR, SR, DOE, RSM, WEDM ETC.

I. INTRODUCTION

Wire electrical discharge machining (WEDM) is extensively used in industry for machining of conductive materials when precision is of prime importance. Many advanced materials that serve as alternatives to many conventional materials, particularly when light-weight and high strength components are needed such as in the automotive, aerospace, defense and other industries.

Wire electrical discharge machining (WEDM) is a process of causing intermittent discharge between wire electrode and work piece, through a working fluid. There is relative movement of work piece and wire electrode for cutting the work piece into a desired configuration such as various types of dies, punches, machine components, metal modules etc. WEDM is a machining technique used to produce complex two- and three- dimensional shapes through difficult to machine electrical conductive metals. The performance measures in WEDM are material removal rate, surface finish and form accuracy. The main machining parameters, which affect the performance of WEDM are; pulse-on time, pulse-off time, peak current, wire speed, wire tension, type of wire, servo reference mean voltage and dielectric fluid pressure etc. Studies have been undertaken in the past in order to improve the performance characteristics, namely the cutting speed, surface roughness and wire wear ratio etc.

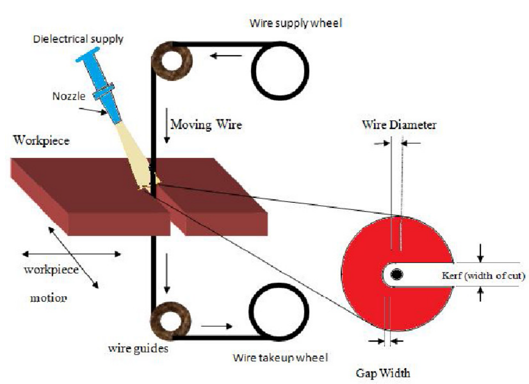


Fig. 1. Schematic of WEDM Process.

Han *et al.* [1] investigated that when pulse energy per discharge is constant, long pulses and short pulses and will produce the same surface roughness but at different material removal rates. It was also indicated that short pulse duration together with high peak value can improve surface roughness. Also reverse polarity has significant effect on surface roughness. In further investigated that increasing the wire speed, open circuit voltage, and pulse duration increases the crater depth and crater diameter, whereas increasing the dielectric fluid pressure decreases these factors. It was concluded by Liao *et al.* [2] that material removal rate and surface finish are influenced by feed and pulse rate. An EDM-wire will break when a discharge (or DC arc) introduces a flaw in the wire, which is larger than the critical flaw size necessary to produce catastrophic failure under the preload tension that has been applied. The significant factor in wire breakage is not the wire tension but the flaw created by sparks which attack the wire cross-section. A spark frequency monitoring unit was developed to detect on-line thermal load on wire [3].

Murphy and Lin [4] developed a combined structural-thermal model using energy balance approach to describe the vibration and stability characteristics of the wire EDM . High-temperature effects were also included resulting from the energy discharges. An equilibrium and eigen value analysis showed that the transport speed influenced the stability of the straight equilibrium configuration. The wire had an extended residency time in the kerf and the wire thermally buckled.

Yan *et. al.* [5] presented a feed forward neural network using a back propagation learning algorithm for the estimation of the work piece height in WEDM. The average error of work piece height estimation was 1.6 mm, and the transient response to change in work piece height was found reasonably satisfactory. The developed hierarchical adaptive control system enabled the machining stability and the machining speed to be improved by 15% compared with a commonly used gap voltage control system.

Lin *et. al.* [6] proposed a control strategy based on fuzzy logic to improve the machining accuracy. Multi-variables fuzzy logic controller was designed to determine the reduced percentage of sparking force. The objective of the total control was to improve the machining accuracy at corner parts, but still keep the cutting feed rate at fair values. As a result of experiments, machining errors of corner parts, especially in rough-cutting, could be reduced to less than 50% of those in normal machining, while the machining process time increased not more than 10% of the normal value.

Lin and Lin [7] reported a new approach for the optimization of the electrical discharge machining (EDM) process with multiple performance characteristics based on the orthogonal array with the grey relational analysis. Optimal machining parameters were determined by the grey relational grade obtained from the grey relational analysis as the performance index. The machining parameters, namely work piece polarity, pulse on time, duty factor, open discharge voltage, discharge current and dielectric fluid were optimized with considerations of multiple performance characteristics including material removal rate, surface roughness, and electrode wear ratio.

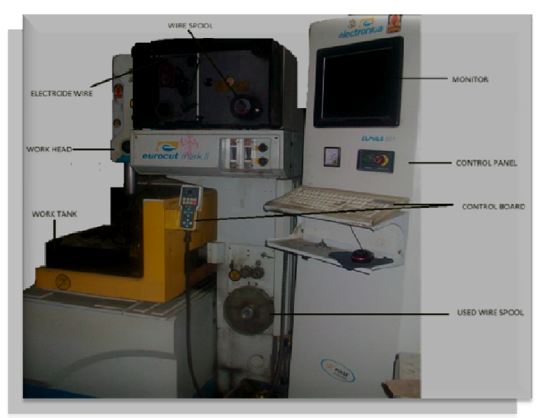
Liao *et. al.* [8] used a feed-forward neural network with back propagation algorithm to estimate the work piece height. The developed network could successfully estimate the work piece height. Based on the on-line estimated work piece height, a rule-based strategy for adaptive parameters setting was proposed to maintain a stable machining and improve the machining efficiency.

Miller et al. [9] investigated the effect of spark on-time duration and spark on-time ratio on the material removal rate (MRR) and surface integrity of four types of advanced material; porous metal foams, metal bond diamond grinding wheels, sintered Nd-Fe-B magnets and carbon– carbon bipolar plates. Regression analysis was applied to model the wire EDM MRR. Scanning electron microscopy (SEM) analysis was used to investigate effect of important EDM process parameters on surface finish. Machining the metal foams without damaging the ligaments and the diamond grinding wheel to precise shape was very difficult. Sintered Nd-Fe-B magnet material was found very brittle and easily chipped by using traditional machining methods. Carbon–carbon bipolar plate was delicate but could be machined easily by the EDM.

II. EXPERIMENTAL SET UP OF WEDM

The experiments were carried out on a wire-cut EDM machine (EUROCUT MARK-2) of Electronica Machine Tools. ASSAB 88 is a new 8% Cr-steel from Sweden. Its properties profile has been carefully balanced, and the result is a very versatile tool steel which overcomes the limitations of the 12% Cr-steel. The properties profile of ASSAB 88 is more versatile and superior to that of 12% Cr-steels. The mach inability, grind ability and harden ability are much better, and it is easier to make small repair welds. This means that ASSAB 88 is the right choice for faster tool making, better tool.

There are various process variables of WEDM affecting the machining characteristics. On the basis of literature review, the following process parameters have been selected.



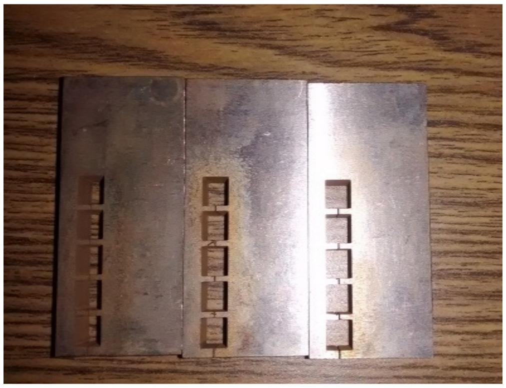


Fig. 2. Machine Set Up and Material Used.

Servo reference voltage (SV), Peak current (PC), Wire feed speed (WFS) and Wire tension (WT) and the output measures are MRR and surface roughness. For the present work RSM experimental design approach is selected. This is achieved with the help of design expert-9 software. Four factors are taken as input parameters (Control factors) and three levels of each factor are considered.

III. METHODOLOGY OF MRR AND SURFACE ROUGHNESS

The MRR is expressed as the ratio of difference of weight of the work piece before and after machining to the machining time and density of the material. The value of Material removal rate is obtained by the following equation 1.

$$MRR = \frac{W_a - W_b}{T_m.\rho} \text{------------ (1)}$$

Surface integrity or surface roughness, also known as surface texture are terms used to express the general quality of a machined surface, which is concerned with the geometric irregularities and the quality of a surface.

Table 1: Levels of Input Parameters and range.

Name	Units	Type	Changes	Low	High
Servo Reference Voltage	Volts	Factor	Easy	20	25
Peak Current	Amp	Factor	Easy	6	8
Wire Feed speed	m/min	Factor	Easy	8	10
Wire Tension	Kg	Factor	Easy	0.6	1.2

The experiments were designed and conducted by employing response surface methodology (RSM). The selection of appropriate model and the development of response surface models have been carried out by using statistical software, "Design Expert (DX-9)". The regression equations for the selected model were obtained for the response characteristics, viz., material removal rate, surface roughness. These regression equations were developed using the experimental data and were plotted to investigate the effect of process variables on various response characteristics.

Table 2: ANOVA for MRR.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	0.012	4	2.979E-003	1.16	0.3521
A-WFS	1.838E-003	1	1.838E-003	0.72	0.4057
B-SRV	7.042E-004	1	7.042E-004	0.27	0.6052
C-WT	3.038E-003	1	3.038E-003	1.18	0.2872
D-PC	6.337E-003	1	6.337E-003	2.47	0.1288
Residual	0.064	25	2.569E-003		
Lack of Fit	0.045	20	2.227E-003	0.57	0.8346
Pure Error	0.020	5	3.937E-003		
Cor Total	0.076	29			

Table 3: ANOVA for surface roughness.

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F
Model	0.000	0			
Residual	1.64	29	0.057		
Lack of Fit	1.35	24	0.056	0.98	0.5745
Pure Error	0.29	5	0.058		
Cor Total	1.64	29			

Final equation in terms of actual factors

MRR=-0.76542+0.12208* WFS-0.048500* SRV-0.098611* WT+0.26958* PC+5.75000E – 003* WFS * SRV+0.027083* WFS * WT+1.87500E – 003* WFS * PC-2.50000E – 003* SRV * WT+2.75000E – 003* SRV * PC+0.010417* WT * PC-0.016146* WFS^2-5.83333E – 004 * SRV^2-0.10995 * WT^2-0.018646 * PC^2 Eq…..2

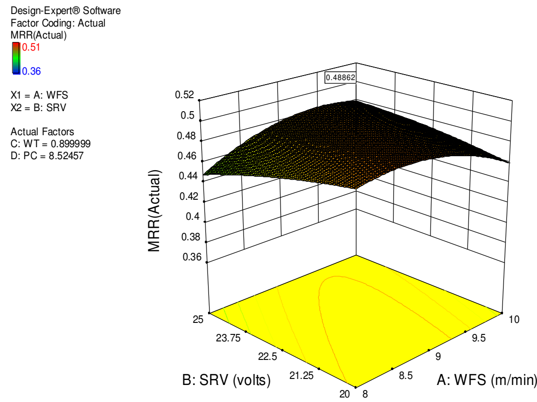
And,

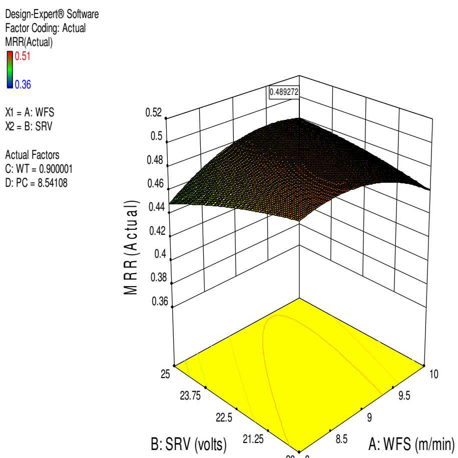
Surface Roughness = 1.10092 + 0.15917 * Servo Reference Voltage - 1.36402 * Peak Current + 0.68820 * Wire Feed speed + 1.60971 * Wire Tension

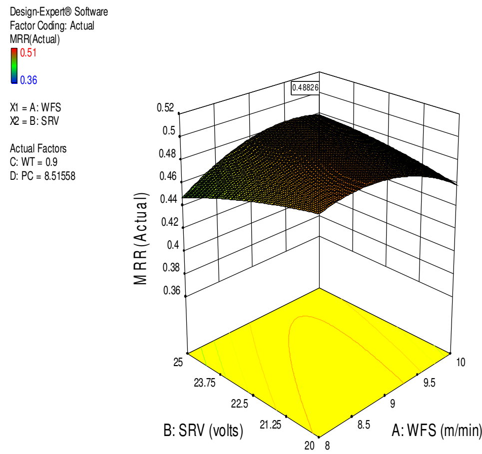
Eq…..3

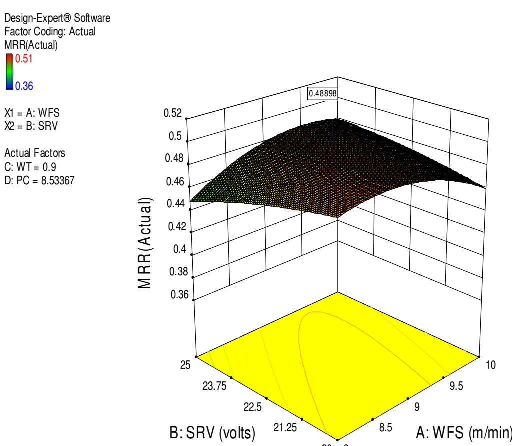
Table 4: Optimum solution of MRR.

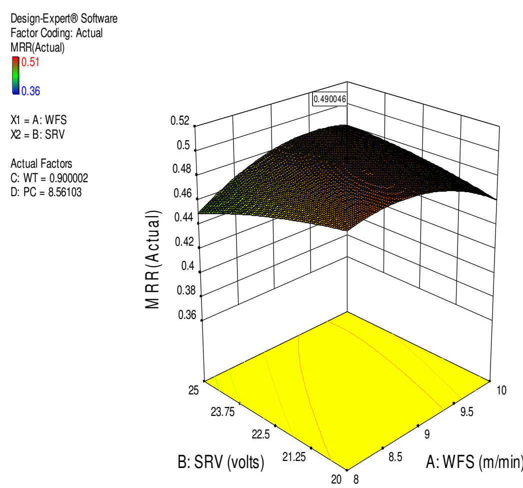
Number	WFS	SRV	WT	PC	MRR	Desirability
1	9.000	22.500	0.900	8.534	0.489	0.684
2	9.000	22.500	0.900	8.541	0.489	0.684
3	9.000	22.500	0.900	8.525	0.489	0.684
4	9.000	22.500	0.900	8.516	0.488	0.684
5	9.000	22.500	0.900	8.561	0.490	0.684
6	9.000	22.500	0.900	8.571	0.490	0.683
7	9.000	22.500	0.900	8.476	0.487	0.683

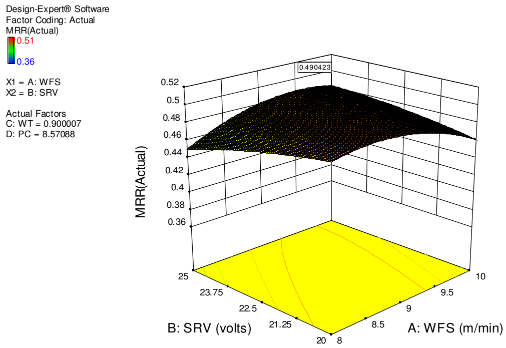












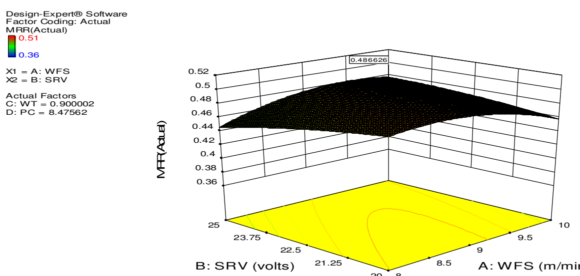
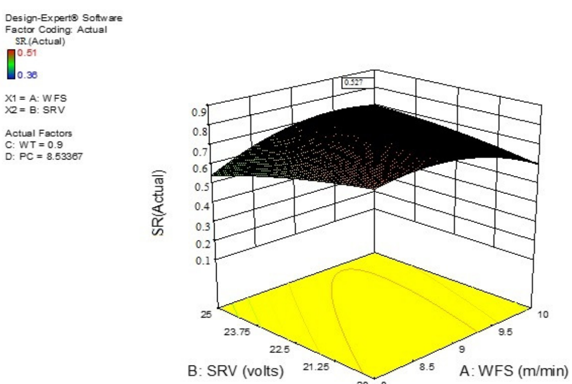


Table 5: Optimum solution of SR.

Number	WFS	SRV	WT	PC	SF(Actual)	Desirability
1	9.000	22.501	0.900	8.375	0.527	0.702



IV. CONCLUSIONS

Response surface methodology (RSM) was applied for developing the mathematical models in the form of multiple regression equations correlating the dependent parameters with the independent parameters (servo reference voltage, peak current, wire feed speed and wire tension) in WEDM machining of ASSAB 88 tool steel. Using the model equations, the response surfaces have been plotted to study the effects of process parameters on the performance measures. In multy factor optimization of MRR 117 solutions are achieved and the optimum solution for MRR with maximum desirability of 0.683 is 0.490 mm^3/min which is obtained by taking the input parameters SRV, PC, WFS and WT as 22.5 volts, 8.571 Amp, 9 m/min and 0.9 kg respectively. In ASSAB 88 tool steel material removal rate has decreasing trend with increase in WFS and SRV whereas increasing trend with increase in wire tension.

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