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Assessment of Wire Offset While Machining EN-24 on WEDM

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Abstract

Wire offset is the dimensional shift that is experienced while machining a job on Wire-EDM machine. This modeling of wire offset during machining of EN-24 (EN is Euro Norm) was performed implementing Response Surface Methodology (RSM). Factors under consideration are peak current, on duration and off duration of pulse. Scanning Electron Microscopy was later performed for measurement of dimensional shift experienced under various machining conditions. The difference of programmed width and actual width obtained revealed the wire offset of the machined specimen. The tests revealed that Wire-EDM (Wire-Electro Discharge Machine) variables and Wire Offset can be modelled using Quadratic equations. ANOVA (Analysis of Variance) depicted that quadratic term of peak current is crucial parameter for Wire offset trailed by off duration. Keeping medium level of electrical parameters will lead to lower wire offset. Further model validation was performed and the residual error for Wire Offset was found to be 2.43% which suggest the competence of the present model.

1. Introduction

EN-24 (low carbon steel) is majorly utilized to make gears and shafts for power transmission purpose, heavy-duty shafts, axles, gears, studs, bolts, collets, sprockets, pinions, spindles, couplings, pins, engine connecting rods, parts of conveyor and other structural parts etc. It possesses high toughness, wear resistance and is known for capability to accomplish higher strengths when heat treated. It also possesses better fatigue strength and is atmospheric corrosion resistant. Due to these properties, the complex contours are difficult to cut using conventional processes. One of the machines used for cutting complex contours on EN-24 is spark erosion Wire-EDM. Wire-EDM is the non-conventional machining process that involves the phenomenon of removing the material by spark erosion. The sparks are produced by the thin wire while maintaining a spark gap between the wire and the workpiece. To enhance the cutting conditions, the dielectric medium is used. During wire electric discharge machining, a dimensional shift to the programmed size is observed and the required size of the job is sometimes not achieved. This result due to the excess of material removed by the sparks striking the work surface. This dimensional shift can be optimized using a correct set of electrical and non-electrical factors of Wire-EDM.

Pradeep Singh et al [1] during their investigation on Wire-EDM found that when the wire feed is increased, the dimensional shift decreases. Furthermore, the dimensional shift initially increases and then it gets decreased when the levels of off time are increased. With increasing voltage, the dimensional shift decreases. Moreover, it was found that the crucial parameter among all electrical parameters for dimensional shift is the servo voltage followed by off duration.

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Nomenclature	
WEDM	Wire -Electro Discharge Machine
EN	Euro Norm
SEM	Scanning electron Microscopy
RSM	Response Surface Methodology
ANOVA	Analysis of Variance
MRR	Material Removal Rate
SMSS	Sequential Model Sum of Square
DOF	Degree of Freedom
PI	Prediction Interval
CI	Confidence Interval

Pankaj Patidar et al [2] worked on optimizing surface roughness and cutting speed by varying the on duration, off duration and wire feed. Liao et al [3] conducted experiments on SKD 11 steel to establish a model that could relate the outcomes like rate of material removal, roughness of machined surface and kerf width with different electrical parameters. They later determined the optimal factor for WEDM process. Scott et al [4] worked to develop a mathematical model for predicting the rate of material removal and finish of machined surface during WEDM of D2 tool steel. The results revealed that no optimum combination of parameter was obtained. Lin and Lin [5] used Grey Relation Analysis in order to develop an approach to optimize the parameters of WEDM for different performance measures.

In another investigation carried by Saini [6] on Titanium alloy concluded that small pulse duration dominates the rate of material removal when brass wire is used. When the pulse duration and pulse width is increased, the material removal is more. This is due to increase in discharge energy resulting due to increase in pulse duration and pulse width. Kuldeep Ojha et al [7] elucidated that major research work has been performed to optimize rate of material removal, wear of the tool and finish of surface. Their research presented the ways to improve the rate of material removal and the mechanism to remove material. Kruth et al [8] carried out investigation and concluded that the ultimate tensile stress and degree of penetration reduces as the finish runs are increased. Sometimes, residual stresses are perceived during roughing cut. The pessimistic impact of leftover stress is eliminated following the roughing cut. This may result in crucial deformation of the job resulting in poor surface finish.

Amitesh Goswami et al [9] during their research on WEDM while machining Nimonic-80A alloy reported the rate of removed material and roughness of machining with surface morphology. Their investigation used Taguchi's approach for designing the experiments. The results concluded that the rate of material removed and roughness get increased with increase in on duration and decreases with increase in off duration. Further, in another research conducted by Venkatesh et al. [10] on Wire-EDM with on duration, off duration and wire feed as parameters for achieving better rate of material removal and minimum roughness on SS 304. Their investigation shows the optimum cutting conditions for rate of metal removal and roughness. They also concluded that on duration was major influencing parameter for both MRR and finish of machining. The off duration and wire feed are less influencing in contrast to on duration.

Rupesh Chalisgaonkar et al [11] conducted investigation on pure Titanium while machining on Wire-EDM while on duration, off duration, current, feed, voltage and offset are considered as electrical parameters to investigated rate of material removal, finish of surface and electrode consumption. They further developed a mathematical to forecast the rate of material removal. The report depicts satisfying results for the developed model. Ashok Kumar Srivastava et al [12] made use of on duration, off duration, wire feed, gap voltage to assess the wire offset during Wire-EDM. They developed a mathematical model to evaluate machinability using RSM approach. They reported that the mathematical model contemplates the influence of different machining factors.

Amitesh Goswami et al [13] in their investigation performed trim cut following roughing machining so as to eliminate the deposited rougher layer post operation because of re-solidified molten removed material. They employed Taguchi's approach to plan the experiments. Later they also performed ANOVA to evaluate the comparative influence of different parameters. They concluded that trim cut produces better surface finish in contrast to rough cut. For the literature survey, the aim of this research is assessing and modeling the Wire Offset experienced during Wire-EDM of EN-24 with bass wire electrode. The experiments are designed based upon the response surface methodology.

2. Experimental Procedure

Wire-EDM of Electronica make and Ezeecut model was used to perform the experiments on EN-24. Kerosene was used as dielectric fluid while 0.25 mm diameter brass wire was used as electrode. The experiments were designed using RSM with rotatable central composite design (CCD). A total of twenty trials were designed using current (Ip), on duration o (Ton) and off duration (Toff) as electrical factors in order to estimate the Wire Offset induced while machining. Table 1 and table 2 depicts the physical properties and composition of EN-24. The Wire Offset

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was estimated using linear measuring tool of Scanning Electron Microscopy. Setting of WEDM is illustrated in Figure 1. Wire offset results from the pull created by sparks during machining, which bends the wire and causes a slight displacement. The deviation causes a dimensional shift in the produced profile as a result of this force. The perpendicular distance between the anticipated cut path and the actual job profile is known as dimensional shift (DS). The Wire offset for initial cut is what this is called. For rough cutting, the wire offset is equal to DS. Figure 2 depicts the dimensional.

$$Dimensional\ Shift = \frac{(Programmed\ Width - Actual\ Job\ Width)}{2} \quad (1)$$

Table 1 *Properties of EN-24*

Density (grams/cc)	Melting Temperature (°C)	Yield Strength (M-Pa)	Modulus of Elasticity (GPa)	Poisson's Ratio	Brinell Hardness
7.85	1427	470	196	0.3	217

Table 2 *EN-24 Chemical Compositions by weight*

Material	Fe	Ni	Mn	Cr	C	Si	Mo
% Composition	95.7	1.83	0.87	0.72	0.41	0.28	0.21

Fig. 1 *Setting of WEDM for EN-24*

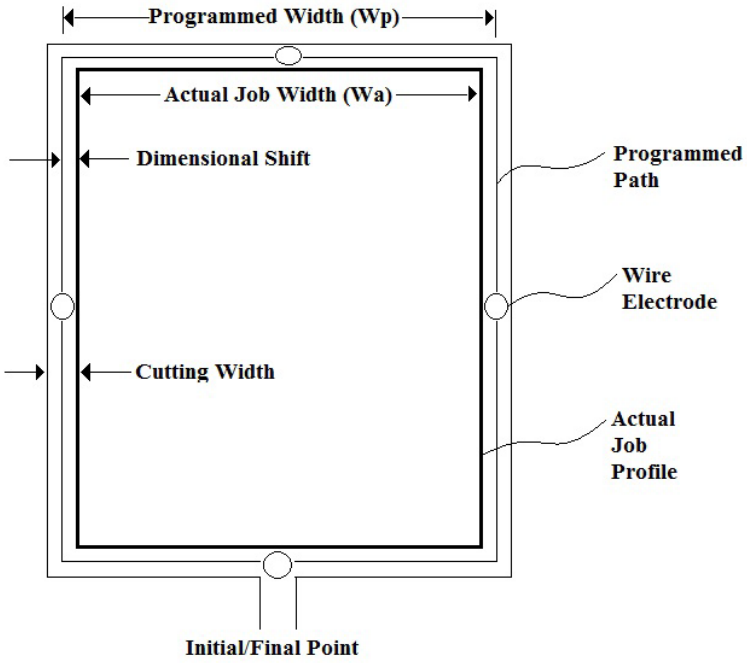

Fig. 2 *Illustration of wire offset in wire EDM*

Table 3 *Wire experiment description for wire offset*

Experiment No.	Current (A)	On Duration (µsec)	Off Duration (µsec)	Machined Size (mm)	Programmed Size (mm)	Wire Offset (mm)
1	2	5	3	4.776	5	0.112
2	6	5	3	4.71	5	0.145
3	2	15	3	4.8204	5	0.0898
4	6	15	3	4.778	5	0.111
5	2	5	9	4.8204	5	0.0898
6	6	5	9	4.788	5	0.106
7	2	15	9	4.905	5	0.0475
8	6	15	9	4.877	5	0.0615
9	2	10	6	4.897	5	0.0515
10	6	10	6	4.741	5	0.1295
11	4	5	6	4.897	5	0.0515
12	4	15	6	4.874	5	0.063
13	4	10	3	4.874	5	0.063
14	4	10	9	4.958	5	0.021
15	4	10	6	4.909	5	0.0455
16	4	10	6	4.930	5	0.035
17	4	10	6	4.926	5	0.037
18	4	10	6	4.918	5	0.041
19	4	10	6	4.916	5	0.042
20	4	10	6	4.924	5	0.038

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3. Experimental Results

3.1 Wire Offset

The Response Surface Model statistic investigation was performed to determine appropriate polynomial equation so as to represent relation between the Wire-EDM process variables and Wire Offset for present set of experiments. The formal solution used for this purpose is Sequential Model Sum of Squares (SMSS) and Lack of fit tests that were conducted using Design Expert 11.0 software. These tests highlighted that the relation between the Wire-EDM variables and Wire Offset could be modeled utilizing Quadratic equations. The following table 4 and 5 shows the SMSS and lack of fit tests respectively. To evaluate the significance of Wire-EDM process variables on Wire Offset, ANOVA for Quadratic model was used which is depicted in table 6 below. Analysis of Variance revealed that F-value of model is 10.11, which implies that the present model is significant. The chances of occurrence of this f-value because of noise is only 0.01% and the model data is within 95% confidence interval. The model terms having p-value less than 0.05 are significant. current (A), on duration (B), off duration (C) and quadratic term of peak current (A^2) are found as significant model terms. However, other parameters are insignificant for wire offset as p-value greater than the 0.10 specifies that the model term is insignificant.

All the three chosen electrical parameters possess great influence on wire offset. Among them quadratic term of peak current is the most dominating factor (p-value= 0.0006) followed by pulse off duration (p-value = 0.0026) and peak current (p-value = 0.0076). Our experiments are in line with previous results for peak current and pulse off duration as they are significant parameter for wire offset. The lack of fit F-value of 31.59 suggested that it is significant corresponding to pure error. Such value of lack of fit occurring due to noise has a chance of 0.09%.

Figure 3 illustrates the main effect plot for Wire Offset. The plot elucidates that the Wire Offset initially decreases with all electrical parameters and further it tends to increase. Higher dimensional shift is observed at higher extent of current and lower extent of on and off durations. The plot elucidates that the Wire Offset is minimum at 4A peak current, 10µsec on duration 6µsec off duration.

The surface plot for the Quadratic response model of Wire Offset is depicted in figure 4(a). The parameters under consideration are current and on duration, as they are crucial parameters for Wire-Offset identified by analysis of variance. The surface plot elucidates that major influencing factor is peak current for Wire Offset and higher Wire Offset is observed at higher peak current region. A medium current and on duration must be set to achieve lower wire offset. The curve plot depicts the presence of quadratic term in the model.

Table 4 *Lack of fit test for wire offset*

Source	Sum of Square	DOF	Mean Square	F Value	P Value	
Linear	0.0158	11	0.0014	98.27	<0.0001	
2FI	0.0155	8	0.0019	133.29	<0.0001	
Quadratic	0.0023	5	0.0005	31.59	0.0009	Suggested
Cubic	0.0001	1	0.0001	6.67	0.0493	Aliased
Pure Error	0.0001	5	0.0000			

Table 5. *SMSS for Wire Offset*

Source	Sum of Square	DOF	Mean Square	F Value	P Value	
Mean vs Total	0.0953	1	0.0953			
Linear vs Mean	0.0082	3	0.0027	2.75	0.0767	
2FI vs Linear	0.0002	3	0.0001	0.0593	0.9803	
Quadratic vs 2FI	0.0132	3	0.0044	18.58	0.0002	Suggested
Cubic vs Quadratic	0.0022	4	0.0006	19.45	0.0014	Aliased
Residual	0.0002	6	0.0000			
Total	0.1193	20	0.0060			

Table 6 *ANOVA for wire offset*

Source	Sum of Square	DOF	Mean Square	F Value	P Value	
Model	0.0216	9	0.0024	10.11	0.0006	significant
A-Current	0.0026	1	0.0026	11.10	0.0076	
B-On Duration	0.0017	1	0.0017	7.28	0.0224	
C-Off Duration	0.0038	1	0.0038	16.01	0.0025	
AB	0.0000	1	0.0000	0.1031	0.7547	
AC	0.0001	1	0.0001	0.3031	0.594	
BC	0.0001	1	0.0001	0.4928	0.4987	
A2	0.0056	1	0.0056	23.78	0.0006	
B2	0.0004	1	0.0004	1.69	0.2231	
C2	0.0000	1	0.0000	0.1169	0.7395	
Residual	0.0024	10	0.0002			
Lack of fit	0.0023	5	0.0005	31.59	0.0009	significant
Pure Error	0.0001	5	0.0000			
Cor Total	0.024	19				

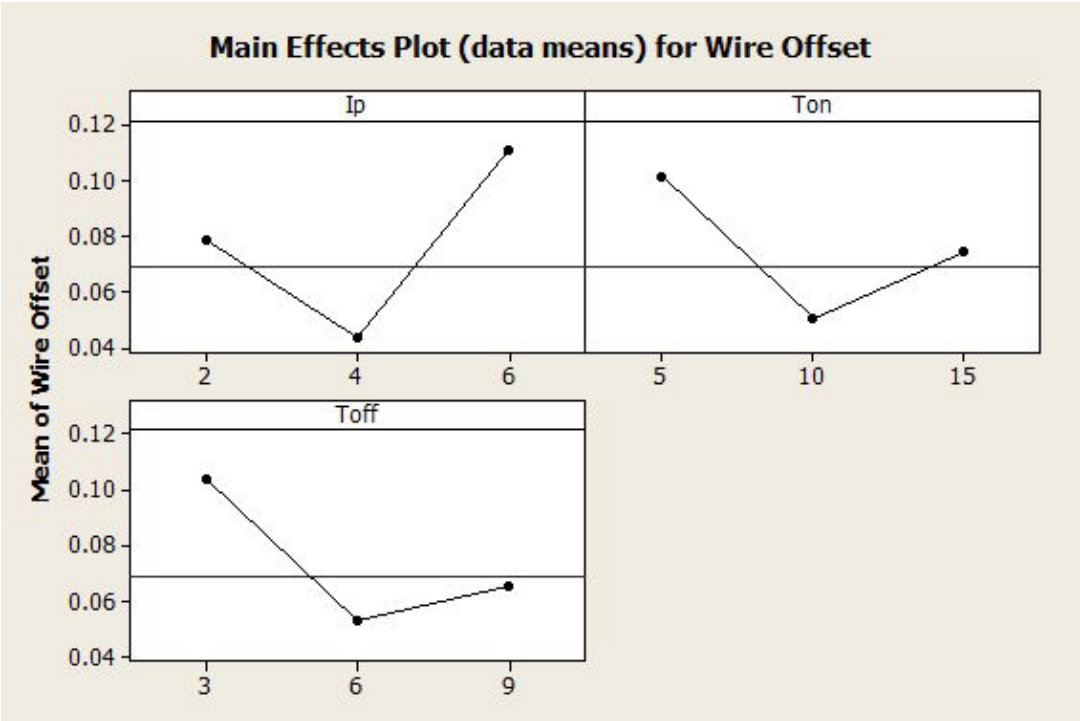

Fig. 3 *Main effect plot for wire offset*

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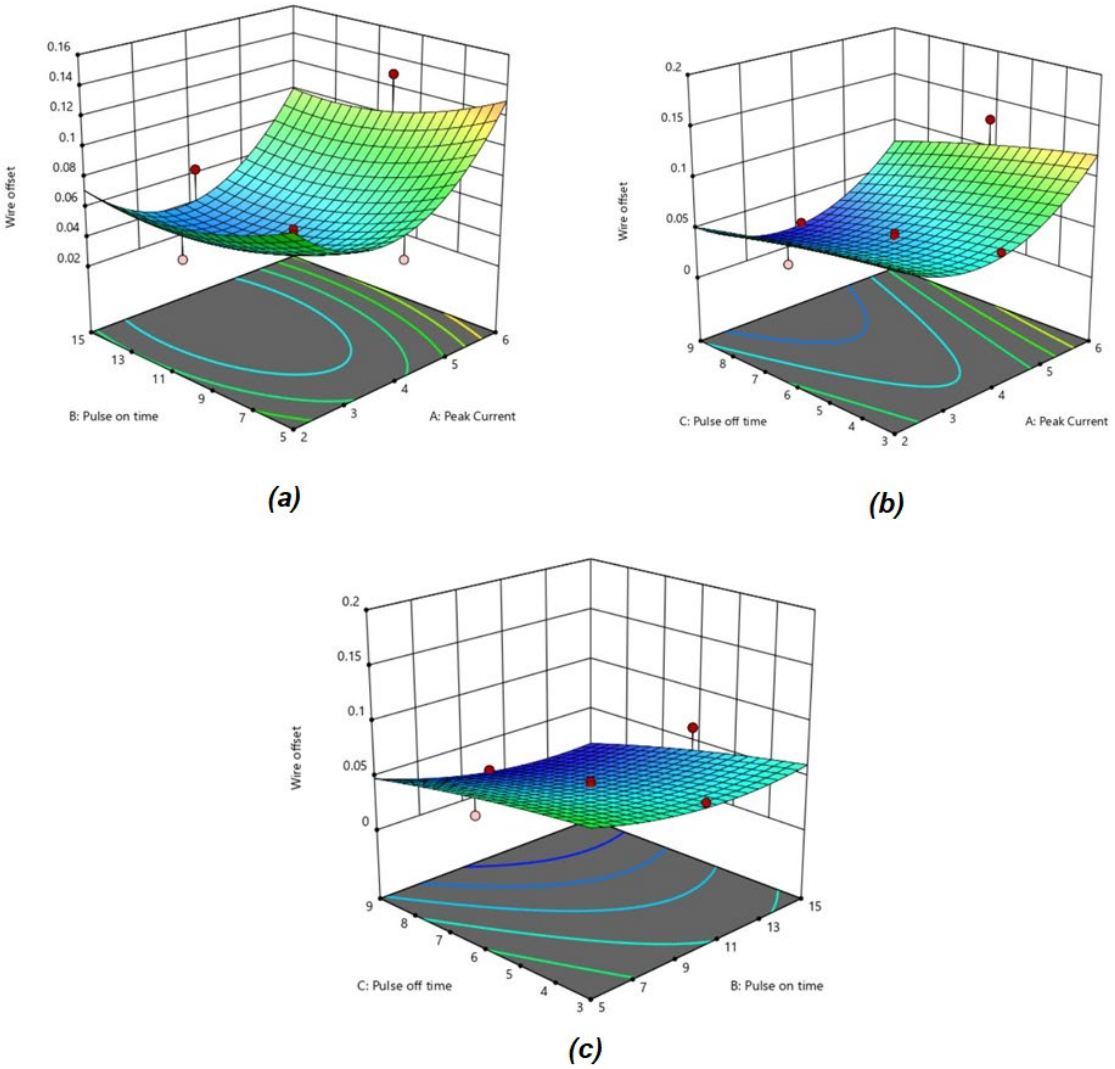

Fig. 4 *Response Surface plot for Wire Offset (a) Between current and on duration; (b) Between current and off duration; (c) Between on duration and off duration*

The surface plot for the Quadratic response model of Wire Offset is depicted in figure 4(b). The parameters under consideration are current and off duration, as they are crucial parameters for Wire-Offset identified by analysis of variance. The surface plot elucidates that major influencing factor is Pulse off time for Wire Offset and lower Wire Offset is observed at higher pulse off duration region. A medium current and pulse on duration must be set for achieving lower wire offset. The curve plot depicts the presence of quadratic term in the model. The surface plot for the Quadratic response model of Wire Offset is depicted in figure 4(c). The parameters under consideration are on duration and off duration, as they are crucial parameters for Wire-Offset identified by analysis of variance. A higher pulse on duration and off duration must be set to achieve lower wire offset. The curve plot depicts the presence of quadratic term in the model. Figure 5 below illustrates scanning electron microscopy (SEM) depictions of the machined samples. Figure 5(a) represents sample 1 and figure 5(b) represents sample 14. Linear measuring tool of SEM was utilized to assess the wire offset post cutting.

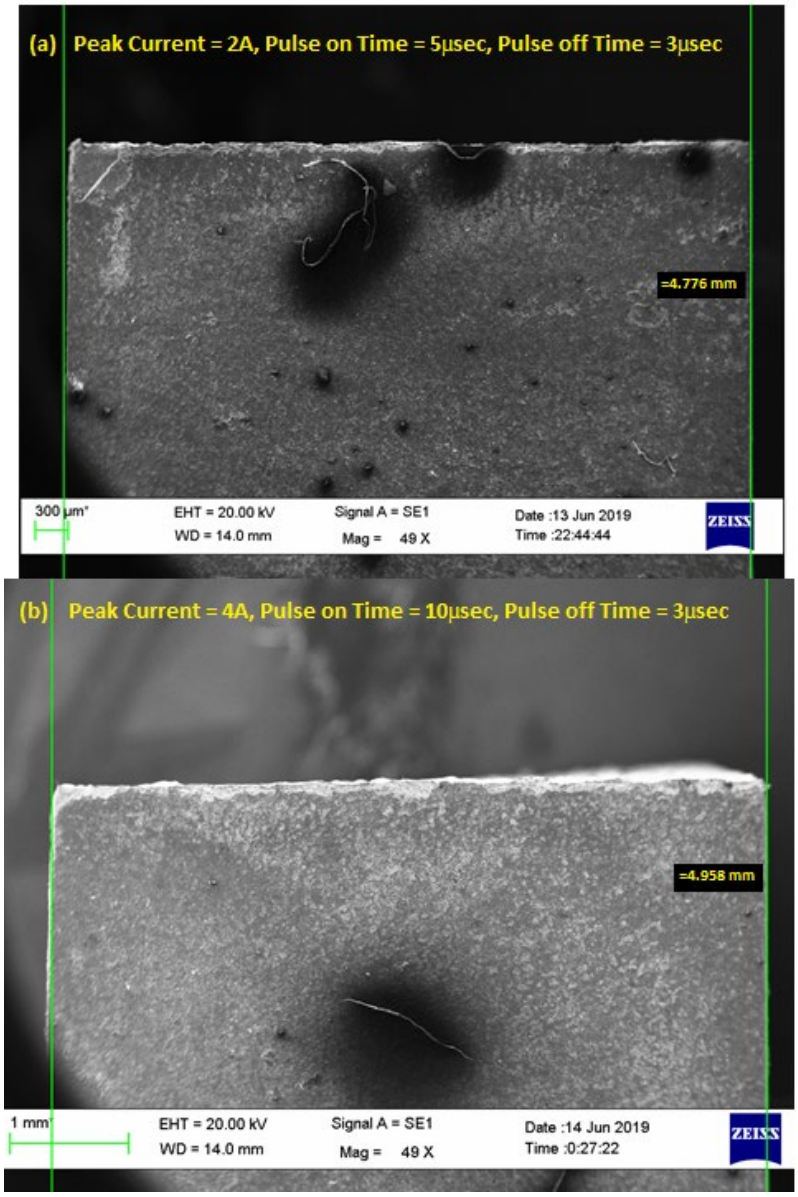

Fig. 5 *SEM micrographs depicting wire offset of sample 1 (a) and sample 14 (b)*

3.2 Model Validation

All tables should be numbered with Arabic numerals. Every table should have a caption. Headings should be placed above tables. Only horizontal lines should be used within a table, to distinguish the column headings from the body of the table, and immediately above and below the table. Tables must be embedded into the text and not supplied separately. Below is an example which the authors may find useful.

The model is validated up in order to estimate whether the evolved response surface model can forecast wire offset behavior successfully or not. This is done through point prediction ability of Design Expert and process parameters were selected for validation run. Design expert calculates the predicted value of wire offset based on the developed algorithm accompanied by their 95% prediction interval value. The validation run value and the predicted value are compared by residual error for determining the validity of the model. As the validating level fall within 95% prediction interval and residual error is lower than 5%, model is interpreted as justifiable and precise. Table 7 presents the result of validations with the set of machine variables. The residual errors are below 2.43% and 4.76% which specifies that the existing model is adequate for forecasting the wire offset under 95% confidence interval and the residual error corresponding to forecasted value is below 5%.

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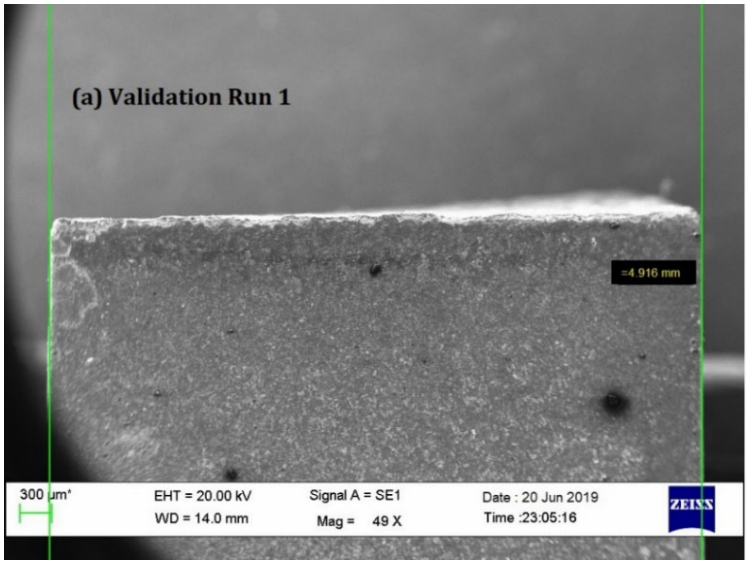
Table 7 *Validation run for wire offset*

S.No	Input Parameters			Prediction	Prediction Interval		Validation	Residual Error%
	Peak Current (A)	Pulse on time (µs)	Pulse off time (µs)	Wire Offset	95% PI low	95% PI high	Wire Offset	
1	4	10	6	0.042	0.0301156	0.0537262	0.041	2.43%
2	4	10	6	0.042	0.0301156	0.0537262	0.040	4.76%



(a)

(b)

Fig. 6 *SEM images for validation of wire offset of (a) Validation run 1; (b) Validation run 2*

4. Conclusions

The present modeling of Wire Offset while roughening cut of EN-24 was performed on Wire-EDM using RSM CCD with current, on duration and off duration. Scanning Electron Microscopy was carried out to assess the value of wire offset for each specimen. The tests revealed that Wire-EDM variables and Wire Offset can be modelled using Quadratic equations. ANOVA depicted that all the three chosen electrical parameters possess great influence on

wire offset. Among them quadratic term of peak current is the most dominating factor (p-value= 0.0006) trailed by off duration (p-value = 0.0026) and peak current (p-value = 0.0076). The results were found to be in line with previous results for peak current and off duration as both are significant parameter for wire offset. The range of wire offset lies between 0.021 mm and 0.145 mm. Higher dimensional shift is observed at higher level of peak current and lower level of on and off durations. Wire Offset is minimum at 4A peak current, 10µsec on duration 6µsec off duration. The validation run for Wire Offset found that the residual errors are below 2.43% and 4.76% which specifies that the existing model is adequate for forecasting the wire offset under 95% CI. Further studies on various materials can be conducted in order to assess and analyze the wire offset induced during wire electro-discharge machining.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors conform contribution to the paper as follows:
study concept and design: *Dr. Syed Asghar Husain Rizvi;* ***data collection:*** *Durgesh Verma;* ***analysis and interpretation of results:*** *Dr. Syed Asghar Husain Rizvi, Durgesh Verma, Unni Kisan;* ***draft manuscript preparation:*** *Dr. Syed Asghar Husain Rizvi, Unni Kisan. All authors reviewed the results and approved the final version of the manuscript*

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