Journal of Mechanical Engineering and Biomechanics, Volume 2, Issue 2, Page 8-14, 2017
ISSN- 2456-219X

A parametric optimization of wire-ED turning process parameters on material removal rate of INCONEL 718

Gajanan M. Naik*, S. Narendranath*

*Department of Mechanical Engineering, NITK, Surathkal, Mangalore, India

Research Article

Article History
Received 12/07/2017
Revised 20/09/2017
Accepted 24/09/2017

Abstract

Wire electric discharge turning of INCONEL 718 has been carried out to investigate the effects of input parameters on Material Removal Rate, and also discussed the influence of input parameters on response as stated by ANOVA technique. In this research work, the machining parameters such as rotational speed, pulse on time, pulse off time, servo voltage, wire feed rate and flushing pressure were considered at different levels in Taguchi mixed type orthogonal array experiments, This has been identified the optimal level of machining parameters to maximize the material removal rate is N =250rpm, T_{on} =124μs, T_{off} =40μs, SV =18V, W_f =2m/min, P_f =1.8bar. However, the experimental results revealed that the pulse on time has most significant effect on material removal rate. DOI:https:/doi.org/10/24243/JMEB/

Keywords: Wire-EDT; MRR; ANOVA; INCONEL 718

1 Introduction

The Wire-electric discharge machining (WEDM) is an advanced and most extensively believed industrial machining process to machine hard and difficult, high strength engineering materials for precise work also it is well suited to produce intricate shapes and profiles [1]. WEDM material removal takes place by continuous erosion and thermal evaporation between the electrode and work piece, it is used to machine sheet structure, in addition to that to generate cylindrical part, the rotary spindle is added to the conventional wire-EDM process controlled by CNC system, hence this modified form of wire-EDM is recognized as wire-Electric Discharge Turning process (Wire-EDT), the ED machining has some major industrial application in dies, punches and moulds industry, finishing parts for aerospace and automotive industry, and surgical components, nuclear production of micro gas turbine blades and electronic components [2]-[4].The Fig.1,2 illustrates the idea of wire Electric Discharge Turning process. Few researchers' work has been reported in the literature to study the effect of wire EDT process parameters on MRR, surface roughness and roundness. Mohammad [5] studied the effect of process parameters on MRR using statistical analysis for AISI D3 steel. Aminollah M et al. [6] have investigated the effect of input factors on MRR, and signal to noise ratio by L18 orthogonal array and ANOVA also derived the regression equation to optimize the machining parameters. P. Matoorian et al. [7] modeled the mathematical equation between the factors and response by using ANOVA, and also examined the most effecting parameters in the process. Abimannan [8] have been reported that the material removal rate is depends on the discharge energy supplied in between the electrode and work piece gap. Jun Qu et al. [9]

*Corresponding Author : Gajanan M. Naik
Email Address: gajamnaik@gmail.com

analysed the spindle run out error to achieve maximum material removal rate, surface roughness and roundness for brass and carbide materials, while finding maximum MRR the derived cylindrical geometry equation were used. M. Parthiban et al. [10] have studied the wire electric discharge grinding spindle fabrication and run out problems, hence 35micron run out error is estimated that can be minimized by changing spindle material EN24 to EN8 and ball bearing to angular contact bearing, during inspection it shows 6 microns run out error in the spindle after assembly it is found that 8 microns run out. V. Janardhan [11] have considered the pulse train data acquisition system in order to investigate and analyse the WEDT material removal rate and to compare MRR of WEDT and WEDM, hence investigator conclude that MRR is higher in case of WEDM compare to WEDT process, and also noticed the surface roughness and roundness error of the turned component. M.J. Haddad [12] presented the effect of machining parameters of wire electric discharge turning of AISI D3 tool steel on output responses of MRR and surface roughness using Taguchi Design of Experiments and ANOVA optimization technique.

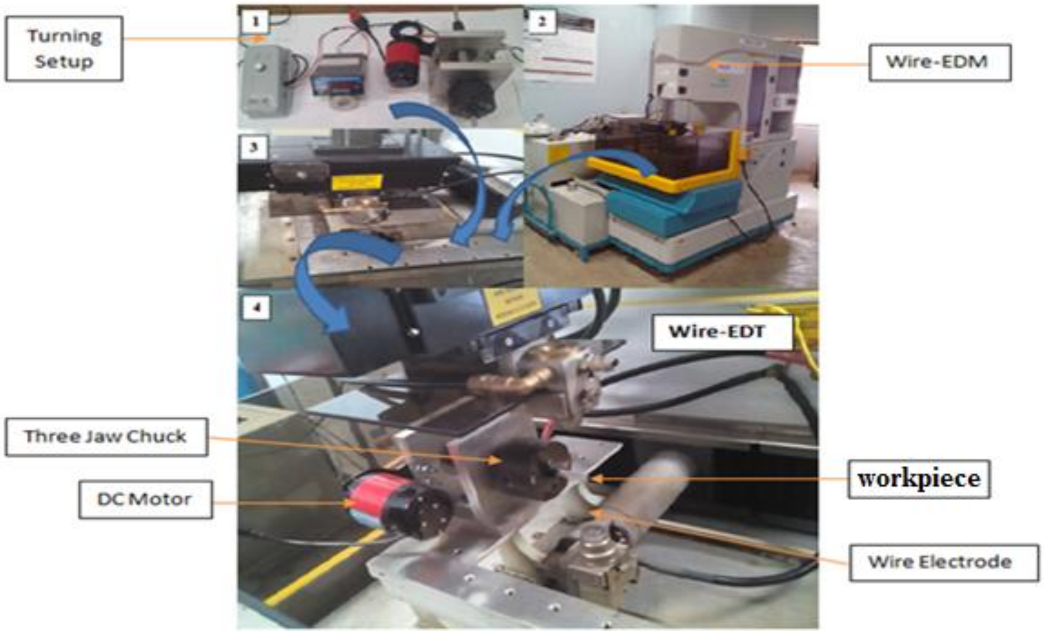

Fig 1: Wire Electric Discharge Turning

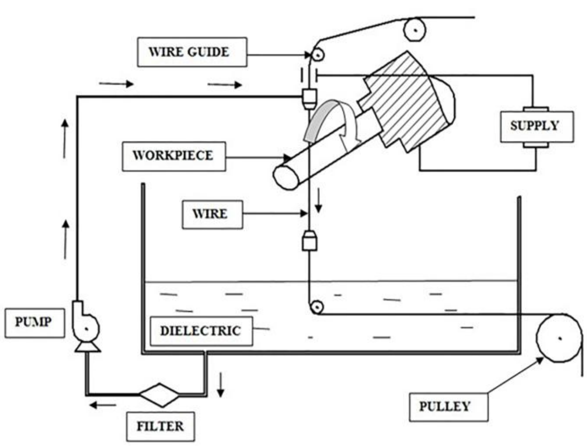

Fig 2: Illustrates the setup of Wire EDT process

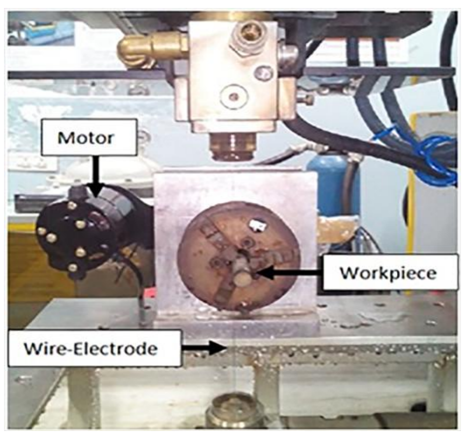

Fig 3: Illustrates the experimental set up of Wire EDT

In the present scenario, the material plays an important role in manufacturing industry as concerned with their industrial applications, such materials are hardened tool steel, die steel and super alloys etc. INCONEL718 is Austenite structure, hardened by precipitation Nickel based super alloys contains significant amount of iron, niobium, and molybdenum along with lesser amounts of aluminum and titanium, it is highly corrosion resistant and high stress temperature resistant, best plasticity in the heat treatment and it exhibits good mechanical properties, [13] and it has major application in the field of aerospace, gas turbines, rocket motors and spacecraft, nuclear reactor, pumps and tooling [14]. Because of above said properties conventional lathe turning of INCONEL 718 is difficult and yields poor surface finish and low dimensional accuracy of the machined component [18] and in connection with above applications the INCONEL 718 was chosen for experiments to investigate the machining parameters through wire electrical discharge turning process. The Taguchi's orthogonal array L18 is used to accomplish the optimization of process parameters such as pulse on time, pulse off time, wire feed rate, servo voltage, rotational speed, flushing pressure over Material Removal Rate by ANOVA optimization technique.

2 Experimental work

The ECO CUT Wire-Electric Discharge Machining Process additionally fitted with turning attachment is used during the experiments on INCONEL 718 super alloy, specimen of 10mm diameter and 50mm length are used in Taguchi's L18 array experimental design. In this current work the six parameters, namely, Rotational speed (rpm), pulse on time (T_{on}), Pulse off time (T_{off}), Servo Voltage (SV), wire feed rate (W_f), Flushing pressure (P_f) were identified and range of each parameters selected from the preliminary experiments. Each of the machining parameters are investigated to study the effects of parameters on Material Removal Rate, the MRR can be calculated by using Eq (1) [20, 26].

$$\mathrm{MRR} = \frac{W_{tb} - W_{ta}}{t\rho} \tag{1}$$

Where: W_{tb}-Weight of work-piece before machining in mg. W_{ta}-Weight of work-piece after machining in mg. t-Machining Time in min. ρ-Density of INCONEL 718.

From literature, the zinc coated brass wire electrode is an optimal choice for good performance of the setup and it is significantly removes the unwanted materials from the work-piece [15]. Henceforth the Zinc coated Brass wire has been selected as a wire electrode for the work subsequently de-ionized water is used as dielectric fluid for effective cooling and to removes debris from the machining zone. De-ionized water has low viscosity, carbon-free [16] and environment friendly [15] and also successfully exhibit high MRR compare to other dielectric fluid like kerosene [17], the experimental setup of Wire Electric Discharge Turning depicts in Fig 3.

3 Design of Experiment

The experimental method enables researchers to observe the relationship between factors affecting a process and the output response of the process by individual and interaction between them, this method helps to optimize the process parameter having less number of experimental trial with low cost and at minimum time. In design of experiment it is essential to identify the process parameters and their levels, output parameters, work material and tooling based on the application of DOE of Taguchi's orthogonal array and for robust design. While selecting orthogonal array, it should obey condition that, degree of freedom of orthogonal array is greater than or equal to degree of freedom of factors and levels. The input parameters selected for the present investigation was rotational speed in two levels and pulse on time, pulse off time, servo voltage, wire feed rate and flushing pressure in three levels and output variable considered as material removal rate or MRR. The input factors and their levels are mentioned in the Table 1.The experiments accomplished by using L18 Taguchi's orthogonal array, the experimental planed layout with response data presented in the Table 2.

Table 1 Machining parameters and their levels

Factors	Parameters	Symbol	Levels		
			1	2	3
A	Rotational speed (rpm)	N	150	**250**	-
B	Pulse on time (µs)	T_{on}	108	116	**124**

C	Pulse off time (µs)	T_{off}	24	32	40
D	Servo voltage (V)	SV	**18**	36	54
E	Wire feed rate (m/min)	W_f	**2**	4	6
F	Flushing Pressure (bar)	P_f	**1.8**	2	2.2

Table2:L18 orthogonal array with response data

Exp .No	N (rpm)	T_{on} (µs)	T_{off} (µs)	SV (V)	W_f $(\frac{m}{min})$	P_f (bar)	MRR $(\frac{mm^3}{min})$
01	150	108	24	18	2	1.8	1.2231
02	150	108	32	36	4	2.0	0.3840
03	150	108	40	54	6	2.2	0.5571
04	150	116	24	18	4	2.0	0.9426
05	150	116	32	36	6	2.2	0.6090
06	150	116	40	54	2	1.8	1.3036
07	150	124	24	36	2	2.2	1.2560
08	150	124	32	54	4	1.8	2.0321
09	150	124	40	18	6	2.0	1.9065
10	250	108	24	54	6	2.0	0.6130
11	250	108	32	18	2	2.2	0.5656
12	250	108	40	36	4	1.8	0.6279
13	250	116	24	36	6	1.8	1.6903
14	250	116	32	54	2	2.0	2.3068
15	250	116	40	18	4	2.2	2.3347
16	250	124	24	54	4	2.2	1.3065
17	250	124	32	18	6	1.8	2.3779
18	**250**	**124**	**40**	**36**	**2**	**2.0**	**3.1014**

4 Results and Discussions

4.1 Factors effecting Material removal rate

The effect of control parameters on material removal rate in machining of INCONEL 718 was studied. The response mean plot for material removal rate has shown in Fig 4 and corresponding ANOVA table for MRR is presented in Table 3. From the Fig 4 it was observed that the MRR increases with increased rotational speed, pulse on time and pulse off time, it shows MRR is directly proportional to rotational speed, pulse on time and pulse off time. This effect on MRR noticed that, by increasing pulse on time the intensity of spark increases causes high material removal rate, same effect were observed by Priyaranjan Sharma et al. (2015) **[18]** during the machining of INCONEL 706, by increasing rotational speed of the work-piece, the time needed for turning get decreases, so it leads to high MRR. By increasing pulse off time, successfully removes the debris present in the inter electrode gap at the beginning of next spark, thus it establishes stability in the machining environment hence it leads to high MRR. whereas servo voltage, wire feed rate and flushing pressure were shown inverse relationship with MRR, moreover the increasing in servo voltage leads to increase in spark gap as a result the intensity of spark get reduce. It shows low material removal rate at level 2 (Table 1) and the slight increase of MRR can be observed because of flushing phenomena at level 3 (Table 1). The higher wire feed rate led to decrease in MRR because of higher wear characteristic and adverse secondary spark condition due to the improper flushing of debris in machining zone **[18]**. The flushing pressure have been shown constant effect on MRR at Level 1,Level 2 and at Level 3 (from Table 1) MRR decreases because of high flushing pressure this attribute the fact that wire vibration led to least favourable spark in the machining zone **[18]**. Finally based on the above discussions the optimal parameter has been selected from main effects plot (Fig 4)to achieve high Material Removal Rate and factor levels are referred from Table 1, MRR is high, when rotational speed is at 250rpm (Level 2), pulse on time is at 124µs(Level 3), pulse off time is at 40 µs (Level 3), servo voltage is at 18V

(Level 1), wire feed rate at 2m/min (Level 1) and flushing pressure is at 1.8bar (Level 1). Hence optimal parametric setting of machining parameters for higher MRR is A2B3C3D1E1F1shown in Table 1.Furthermore, Analysis of Variance was adopted to check the significance of machining parameters and to identify the factors effect on response variable based on a 95% confidence interval; Table 3 presents the ANOVA outcome table for Material Removal Rate. From the Table 3 it is found that the pulse on time is only factor which shows p-value less than α level of confidence (α =0.05). Hence it is conclude that pulse on time is significant factor and it has direct influence on material removal rate among all other process parameters in Wire-EDT

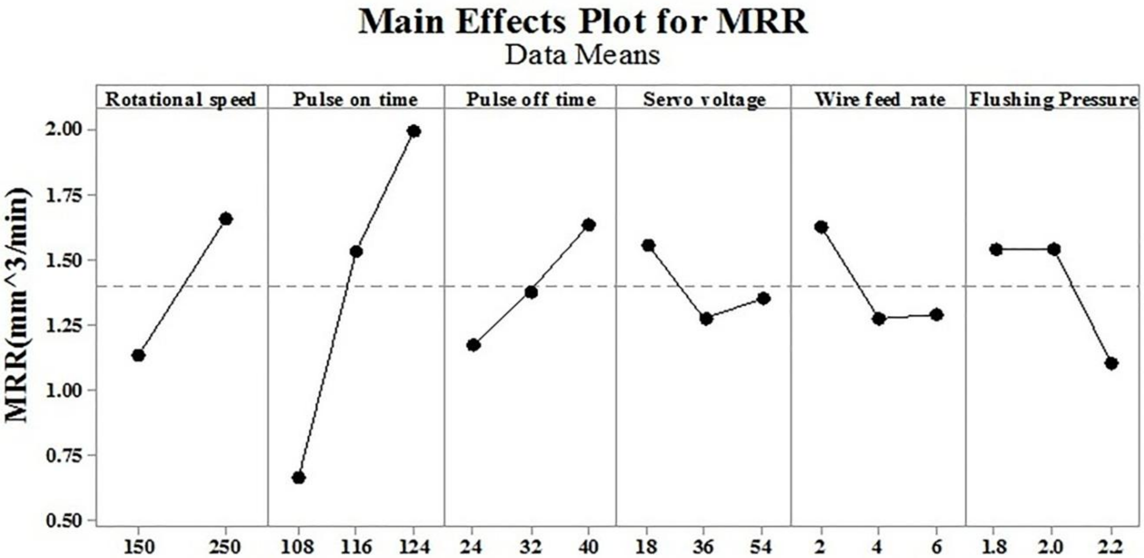

Fig 4:Effects of machining parameters on MRR

Table 3: ANOVA for Material Removal Rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Rotational Speed	1	1.2325	1.2325	1.2325	3.78	0.100
Pulse on time	2	5.5093	5.5093	2.7547	8.46	0.018
Pulse off time	2	0.6559	0.6559	0.3279	1.01	0.420
Servo voltage	2	0.2526	0.2526	0.1263	0.39	0.694
Wire feed rate	2	0.4754	0.4754	0.2377	0.73	0.520
Flushing pressure	2	0.7660	0.7660	0.3830	1.18	0.371
Residual Error	6	1.9547	1.9547	0.3258	-	-
Total	17	10.8466	-	-	-	-

4.2 Regression Model

From the experimental data, Eq (2) regression mathematical model has been developed to establish a mutual relationship between the response variable (MRR) and Wire- EDT machining parameters.

MRR= -7.53 + 0.00523 Rotational Speed + 0.0834 Pulse on time + 0.0292 Pulse off time - 0.00570 Servo voltage - 0.0834 Wire feed rate - 1.094 Flushing pressure (2)

5 Confirmation Test

From the Dr. Taguchi's experimental orthogonal array, the highest Material Removal Rate is obtained in 18th experimental setting, i.e., A2B3C3D2E1F2, is of 3.1014$\frac{mm^3}{min}$. In order to maximize the Material Removal Rate the optimal setting of machining parameters are drawn during the results and discussion section, for optimal setting parameters, the predicted Material Removal Rate has been calculated via Eq 2 and presents in Table 4. The purpose of confirmation test is to validate the predicted Material Removal Rate through experimentation, to show improvements in quality characteristics. Table 4 has presented the confirmation test results. From the Table 2 it is noticed that the MRR obtained in experiment is high compare to predicted value of MRR and error in the test result is of 8.144% had been given in Table 4.

Table 4:Confirmation test result for MRR analysis

	Predicted	Experimental	Error (%)
Optimal Parameters	A2B3C3D1E1F1	A2B3C3D1E1F1	-
Material Removal rate($\frac{mm^3}{min}$)	3.0485	3.2968	8.144

6 Conclusions

The wire-ED Turning investigation on MRR has been carried out for INCONEL 718 nickel based super alloy, in this research work the effect of rotational speed, pulse on time, pulse off time, servo voltage, wire feed rate, flushing pressure on MRR have studied by using Taguchi's orthogonal array experimental. The following important conclusions were drawn from this study.

- The increase in pulse on time, rotational speed and pulse off time leads to an increase in the material removal rate. The pulse on time shows the most significant effect on Material removal rate followed by rotational speed, flushing pressure, pulse on off time wire feed rate and servo voltage.
- Machining Parameters are optimized for producing maximum Material Removal Rate, A2,B3,C3,D1,E1,F1(250rpm, 124µs, 40µs, 18V, 2m/min, 1.8bar) have been considered as optimal parametric combinations.
- A mathematical regression model is established to predict the values of material removal rate and it is validated by experimentally with 8.144% errors.

Acknowledgements

Authors gratefully acknowledge the support from the Department of Science and Technology (DST), Government of India, under the project reference number SERB-SB/S3/MMER/0067/2013, also thankful to Dr. Manjaiah. M and Dr. Priyaranjan Sharma for their valuable suggestions during the work.

References

[1] Shabgard MR, Seyedzavvar M, Oliaei SN. Influence of input parameters on characteristics of EDM process. Strojniški vestnik-Journal of Mechanical Engineering. 2011 Sep 15;57(9):689-96. DOI: Shabgard MR, Seyedzavvar M, Oliaei SN. Influence of input parameters on characteristics of EDM process. Strojniški vestnik-Journal of Mechanical Engineering. 2011 Sep 15;57(9):689-96.

[2] Ojha K, Garg RK, Singh KK. MRR improvement in sinking electrical discharge machining: a review. Journal of Minerals and Materials Characterization and Engineering. 2010 Aug 20;9(08):709. DOI: 10.4236/jmmce.2010.98051.

[3] Kuriachen B, Paul J, Mathew J. Modeling of Wire Electrical Discharge Machining Parameters Using Titanium Alloy (Ti-6AL-4V). International Journal of Emerging Technology and Advanced Engineering, ISSN 2250. 2012;2459.

[4] Kumar K, Ravikumar R. Modeling and optimization of wire EDM process. International Journal of Modern Engineering Research. 2013 May;3(3):1645-8.

[5] Haddad MJ, Tehrani AF. Investigation of cylindrical wire electrical discharge turning (CWEDT) of AISI D3 tool steel based on statistical analysis. Journal of materials processing Technology. 2008 Mar 3;198(1):77-85. DOI: https://doi.org/10.1016/j.jmatprotec.2007.06.059.

[6] Mohammadi A, Tehrani AF, Emanian E, Karimi D. Statistical analysis of wire electrical discharge turning on material removal rate. Journal of materials processing Technology. 2008 Aug 26;205(1):283-9. DOI: https://doi.org/10.1016/j.jmatprotec.2007.11.177.

[7] Matoorian P, Sulaiman S, Ahmad MM. An experimental study for optimization of electrical discharge turning (EDT) process. Journal of Materials Processing Technology. 2008 Aug 11;204(1):350-6. DOI: https://doi.org/10.1016/j.jmatprotec.2007.11.058.

[8] Giridharan A, Samuel GL. Modeling and analysis of crater formation during wire electrical discharge turning (WEDT) process. The International Journal of Advanced Manufacturing Technology. 2015 Mar 1;77(5-8):1229-47. DOI: https://doi.org/10.1007/s00170-014-6540-x.

[9] Qu J, Shih AJ, Scattergood RO. Development of the cylindrical wire electrical discharge machining process, part 1: concept, design, and material removal rate. Journal of Manufacturing science and engineering. 2002 Aug 1;124(3):702-7. DOI: https://doi.org/10.1115/1.1475321.

[10] Parthiban M, Manigandan C, Venkadesh GM, Kumar MR. Development of Rotary Axis For Wire Electrical Discharge Machining (WEDM). International Journal of Engineering Research. 2(4): 318-321. ISSN : 2319-689.

[11] Janardhan V, Samuel GL. Pulse train data analysis to investigate the effect of machining parameters on the performance of wire electro discharge turning (WEDT) process. International Journal of Machine Tools and Manufacture. 2010 Sep 30;50(9):775-88. DOI: https://doi.org/10.1016/j.ijmachtools.2010.05.008.

[12] Haddad MJ, Tehrani AF. Material removal rate (MRR) study in the cylindrical wire electrical discharge turning (CWEDT) process. journal of materials processing technology. 2008 Apr 1;199(1):369-78. DOI: https://doi.org/10.1016/j.jmatprotec.2007.08.020.

[13] Rathi MG, Mane DV. Study on effect of powder mixed dielectric in EDM of Inconel 718. International Journal of Scientific and Research Publications. 2014 Nov;4(11):1-7.

[14] UNS N07718, W. Nr. 2.4668

[15] Ghodsiyeh D, Golshan A, Shirvanehdeh JA. Review on current research trends in wire electrical discharge machining (WEDM). Indian journal of science and technology. 2013 Feb 1;6(2):4128-40.

[16] Singh S, Bhardwaj A. Review to EDM by using water and powder-mixed dielectric fluid. Journal of Minerals and Materials Characterization and Engineering. 2011 Feb 10;10(02):199. DOI: https://doi.org/10.4236/jmmce.2011.102014.

[17] Choudhary SK, Jadoun RS. Current advanced research development of electric discharge machining (EDM): a review. International Journal of Research in Advent Technology. 2014 Mar;2(3):273-97.

[18] Sharma P, Chakradhar D, Narendranath S. Evaluation of WEDM performance characteristics of Inconel 706 for turbine disk application. Materials & Design. 2015 Dec 25;88:558-66. DOI: https://doi.org/10.1016/j.matdes.2015.09.036.