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# Experimental Studies on Ti-6Al-4V by Wire EDM Process and Optimization of Process Parameters with Modified TLBO Algorithm

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**Abstract—***Titanium alloys are newly developed advanced materials and are used in many of the industries including aerospace industries. The titanium alloys having excellent mechanical properties such as high strength to weight ratio, but the titanium alloys are having poor machinability characterestics. In order to machining of titanium alloys some of the non conventional machining processes have been founded. Wire Electro Discharge Machining Process is one such advanced process is used to produce intricate shapes when the hard metals like titanium to be cut. In this work an investigation of the effect and optimization of process parameters on the material removal rate, surface roughness and kerf width of Ti-6Al-4V alloy with the help of wire electro discharge machining with zinc coated brass wire of diameter 0.25mm. The proper setting of these process parameters were determined by using Taguchi method using four factors each at three levels to know the behavior of responses such as material removal rate, surface roughness and kerf width. The optimization problem was formulated by using process parameters and process responses. Finally Modified TLBO Algorithm is implemented to find out the effective Wire EDM process parameters***.**

***Keywords***— *Wire EDM; Ti-6Al-4V alloy; Zinc coated Brass Wire; Modified TLBO.*

## I. INTRODUCTION

Wire Electro Discharge Machining is one of the non-traditional machining process used for machining a complicated to machine materials like zirconium, titanium and their alloys and also used for producing intricate shapes which are not possible to produce in conventional machining methods. Wire EDM process is used to machining the electrically conductive materials only. Wire EDM is mostly used to cut plates of thickness as 300mm and to make punches, tools and dies from hard metals. Wire EDM is also used to machine materials like composites and inter-metallic materials. Fig.1. shows the basic working principle of the Wire EDM process. The material removal is takes place due to continuous sparks occurs between tool and work piece electrodes and then the eroded material is flushed away from machining zone with the help dielectric fluid (deionized water) which is continuously supplied during the machining. Material properties of Ti-6Al-4V as per ASTM B265 Grade: 5 as shown in Table 1.

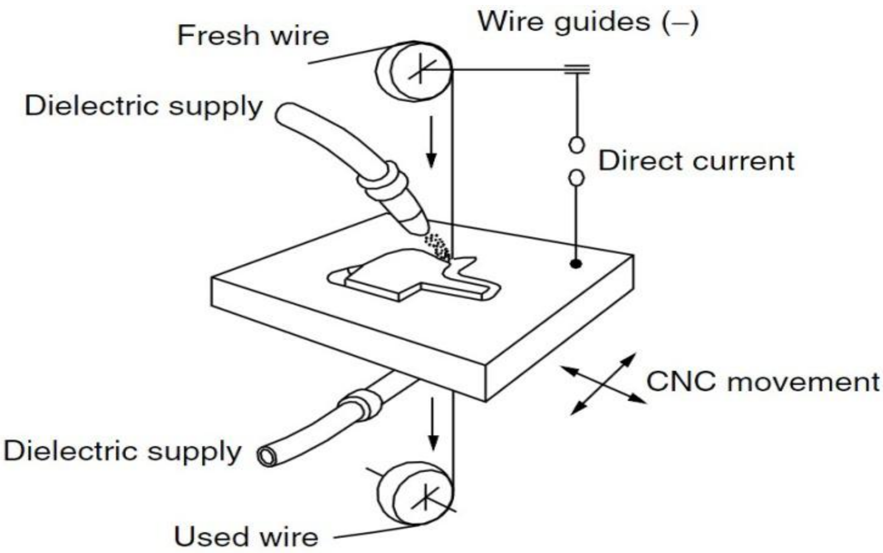


Fig.1. Basic Wire EDM Principle

 

Table 1. Material properties of ASTM B265 Grade: 5

| **Density (kg/mm$^3$)** | **4.45×10$^3$** |
|---|---|
| **Hardness (BHN)** | 334 |
| **Ultimate tensile strength (MPa)** | 895 |
| **Yield tensile strength (MPa)** | 828 |
| **Young's modulus(GPa)** | 114 |
| **Poisson ratio** | 0.34 |
| **Elongation (%)** | 10 |
| **Fatigue strength (MPa)** | 515 |

Many of the researchers have conducted various investigations for better performance of the WEDM process to obtain better machining outputs like higher material removal rate and good surface [1] A.V.S Ram Prasad et al. (2014) has investigated on machining parameters to know the effect on MRR and surface roughness in Wire EDM operations of titanium alloy. Based on the investigations performed the most significant parameters on both MRR and surface roughness were found to be pulse on time and peak current. [2] Siva Prasad Arikatla et al. (2013) investigated the effect of wire electrical discharge machining process parameters including pulse on time, pulse peak current, spark gap voltage, wire feed rate, water pressure, servo feed rate and wire tension on surface roughness and material removal rate. Experimental results reveal that, as pulse on time, pulse peak current and servo feed rate increase the surface roughness increases. But as spark gap set voltage, water pressure, wire feed rate and wire tension increase the surface roughness decreases. [3] Amruta rout et al. (2016) has attempted to improve the performance characteristics such as MRR, machining time, surface roughness and overcut. Finally the MOORA method was applied to find out the most optimum parameters for machining. In order to optimize the process parameters during Wire EDM of D3 steel [4] Lodhi and Agarwal (2014) performed L9 orthogonal array of experiments and then found out the discharge current is the most influencing factor on surface roughness. [5] Ravindranath Bobbili, V. Madhu, A.K. Gogia (2015) were investigated the effect of process parameters such as pulse on time, pulse off time, peak current and spark voltage on material removal rate, surface roughness and gap current. The experiments concluded that most significant variables that improved the responses are pulse on time, pulse off time, peak current and servo voltage. [6] S. Balasubramanian et al. (2011) conducted l8 orthogonal array of experiments and reveals that the grey relational analysis is more scientific than the Taguchi's method for evaluating response characteristics. [7] Vamsi Krishna et al. (2010) performed experiments based on Taguchi's L27 orthogonal array of design and developed a regression model, and also made an attempt to optimize the surface roughness with the help of genetic algorithm. Experimental results revealed that lower ignition pulse current and lower spark time gave the good surface finish. [8] Anish kumar et al. (2012) modeled the electrical parameters of WEDM of pure titanium using Response Surface Methodology. They enumerated Box-Behnken design for optimization of MRR, surface roughness and wire wear ratio. Six parameters are pulse on time, pulse off time, peak current, spark gap voltage, wire feed and wire tension are selected as machining parameters. It was observed that MRR increases with the increase of peak current and decreases of pulse off time.

The purpose of the present work is to study the effect of process parameters on machining responses of Ti-6Al-4V with the help of Wire EDM process using the Taguchi L27 design of experiments, the combination of process parameters are pulse-on time, pulse-off time, servo voltage and wire feed on MRR, SR and Kerf width. Finally the parameters were optimized by using Modified Teaching Learning based Optimization Algorithm and also these are compared with the Genetic Algorithm results.

## II. EXPERIMENTAL PROCESS PARAMETERS AND DESIGN

The product quality in the Wire EDM process is always influenced by the process parameters like pulse-on time, pulse-off time, servo voltage and wire feed. Proper selection of those parameters can cause high MRR, low surface finish and smallest kerf width. In the present work, Taguchi method, a powerful method for parameter design of performance characterestics, which is based on the $L_{27}$ design of experiments. Finally modified TLBO is used to know the optimal process parameters for maximum MRR, minimum surface roughness and smallest kerf width. Four process parameters such as pulse-on time, pulse-off time, servo voltage and wire feed are selected each at three levels as shown in Table 2. The levels of pulse-on time are 105, 110 and 115 µs, the levels of pulse-off time are 58, 60 and 62 µs, the levels of servo voltage are 40, 45 and 50 V and the levels of wire feed are 6, 7 and 8 mm/min. According to the Taguchi quality design $L_{27}$ ($3^{\wedge 13}$) orthogonal array table with four columns and twenty seven rows was chosen for the experiments as shown in Table 3.

Table 2. Process parameters and their control factor levels used in the experiments.

| Symbols | Control factors | Level1 | Level2 | Level3 | Units |
|---|---|---|---|---|---|
| **A** | Pulse on time | 105 | 110 | 115 | μs |
| **B** | Pulse off time | 58 | 60 | 62 | μs |
| **C** | Servo voltage | 40 | 45 | 50 | V |
| **D** | Wire feed | 6 | 7 | 8 | m/min |

Table 3. Taguchi experimental Model (L27 orthogonal array)

| S. No | A | B | C | D |
|---|---|---|---|---|
| **1** | 105 | 58 | 40 | 6 |
| **2** | 105 | 58 | 45 | 7 |
| **3** | 105 | 58 | 50 | 8 |
| **4** | 105 | 60 | 40 | 7 |
| **5** | 105 | 60 | 45 | 8 |
| **6** | 105 | 60 | 50 | 6 |
| **7** | 105 | 62 | 40 | 8 |
| **8** | 105 | 62 | 45 | 6 |
| **9** | 105 | 62 | 50 | 7 |
| **10** | 110 | 58 | 40 | 6 |
| **11** | 110 | 58 | 45 | 7 |
| **12** | 110 | 58 | 50 | 8 |
| **13** | 110 | 60 | 40 | 7 |
| **14** | 110 | 60 | 45 | 8 |
| **15** | 110 | 60 | 50 | 6 |
| **16** | 110 | 62 | 40 | 8 |
| **17** | 110 | 62 | 45 | 6 |
| **18** | 110 | 62 | 50 | 7 |
| **19** | 115 | 58 | 40 | 6 |
| **20** | 115 | 58 | 45 | 7 |
| **21** | 115 | 58 | 50 | 8 |
| **22** | 115 | 60 | 40 | 7 |
| **23** | 115 | 60 | 45 | 8 |
| **24** | 115 | 60 | 50 | 6 |
| **25** | 115 | 62 | 40 | 8 |
| **26** | 115 | 62 | 45 | 6 |
| **27** | 115 | 62 | 50 | 7 |

### 2.1 Experimental Setup

The pieces were cut along the length of the workpiece using wire EDM machine (Sprintcut, M/S Electronica Machine Tools Ltd, India) which is a four axis computer nemerical control type Wire EDM, as shown in Fig. 2. Wire Electro Discharge Machine consists of power supply unit, dielectric unit, positioning system and drive system. The machining was carried out on the workpiece by hold the workpiece on the worktable with the help of clamps and bolts. The workpiece is connected to the positive terminal of the power supply, while the tool electrode is connected to the negative terminal of the power supply. Maachine uses an iso-frequent pulse generator with a maximum operating current of 40A. The specifications of Sprintcut Wire EDM as shown in Table 4.

Table 4. Specifications of Sprintcut Wire EDM

| Description | Wire EDM | |
|---|---|---|
| **Model** | EPULSE-$0A | |
| **Types of work materials** | MS, Al, SS, Tiatniumand EN Steels | |
| **Types of wire materials** | Copper, brass and zinc coated brass | |
| **Longitudinal travel range** | Y axis | 400mm |
| | V axis | +/- 40mm |
| **Lateral travel range** | X axis | 300mm |
| | U axis | +/- 40mm |
| **Vertical travel range** | Z axis | 225mm |
| **Work table size** | 650×440mm | |
| **Maximum work piece size** | 600×780×200mm | |
| **Maximum work piece weight** | 400kg | |
| **Main table feed rate** | 900mm/min | |
| **Resolution** | 0.0005mm | |
| **Wire feed rate** | 0-15m/min | |
| **Wire tension** | 2.5kgf | |
| **Wire guide type** | Diamond closed | |
| **Electrode diameter** | 0.25mm | |
| **Taper angle** | Max. Taper angle +/-30$^{0}$ | |

 


Fig. 2. Experimental setup

The process parameters such as pulse-on time, pulse-off time, servo voltage and wire feed were selected as input parameters for the experiments. The work materials is used for conducting the experiments is TI-6Al-4V and having dimension 110 mm*90mm*8.5mm. The chemical composition of the workpiece material is shown in Table 5. And tool material was used as zinc coated brass wire.

 

Table 5. Chemical composition of Ti-Al-4V

| Element | % Content |
|---|---|
| Aluminum | 6.16 |
| Vanadium | 3.90 |
| Iron | 0.18 |
| Carbon | 0.030 |
| Titanium | 89.73 |

The MRR, surface roughness and kerf width of the machined suface are the performance measures to determine the machining quality in the present study. The cutting of pieces by using different input process parameters as per Taguchi L27 design are shown in Fig.3. During the machining the MRR ($mm^3/min$) is calculated from the cutting speed data directly displayed by the machine tool display unit and width of cut is 6mm, height of work piece is 8.5mm and the MRR can be calculated by using equation 1 as shown below.

MRR= Cutting speed* Width of cut* Height of work piece ($mm^3/min$) …..(1)

In the experiments, the surface roughness of the Wire EDM machined work piece is measured by using Talysurf surface measuring instrument which is shown in Fig.4. While Kerf width is measured with the help of Tool maker microscope shown in Fig.5.

Fig.3. Cutting of Ti-6Al-4V as Per Taguchi L27 on Wire EDM

 


Fig.4. Talysurf surface roughness measuring instrument

Fig.5. Tool maker microscope

### III. RESULT AND DISCUSSION

The experimental design and corresponding results from the experimental plan for MRR, SR and Kerf width are shown in Table 6. Now here formulated a regression models for response characteristics using Minitab 17 Software and finally the process parameters are optimized by using Modified TLBO algorithm.

**Table 6. A result for Experimental design runs by Taguchi L27 methods**

| S.No | A | B | C | D | MRR ($mm^3$/min) | SR (µm) | KW (mm) |
|---|---|---|---|---|---|---|---|
| 1 | 105 | 58 | 40 | 6 | 57.63 | 3.2713 | 0.3423 |
| 2 | 105 | 58 | 45 | 7 | 55.59 | 3.1357 | 0.3430 |
| 3 | 105 | 58 | 50 | 8 | 54.06 | 3.3567 | 0.3860 |
| 4 | 105 | 60 | 40 | 7 | 55.08 | 3.5613 | 0.3780 |
| 5 | 105 | 60 | 45 | 8 | 54.315 | 3.3450 | 0.3880 |
| 6 | 105 | 60 | 50 | 6 | 53.04 | 3.1256 | 0.3360 |
| 7 | 105 | 62 | 40 | 8 | 53.55 | 3.6439 | 0.3250 |
| 8 | 105 | 62 | 45 | 6 | 54.213 | 3.4597 | 0.3670 |
| 9 | 105 | 62 | 50 | 7 | 49.98 | 3.3256 | 0.3240 |
| 10 | 110 | 58 | 40 | 6 | 84.15 | 3.4321 | 0.3140 |
| 11 | 110 | 58 | 45 | 7 | 82.62 | 3.3856 | 0.3400 |
| 12 | 110 | 58 | 50 | 8 | 80.58 | 3.3656 | 0.3180 |
| 13 | 110 | 60 | 40 | 7 | 79.05 | 3.4653 | 0.3390 |
| 14 | 110 | 60 | 45 | 8 | 77.52 | 3.4457 | 0.3570 |
| 15 | 110 | 60 | 50 | 6 | 74.46 | 3.5183 | 0.3660 |
| 16 | 110 | 62 | 40 | 8 | 53.55 | 3.4983 | 0.3630 |
| 17 | 110 | 62 | 45 | 6 | 53.04 | 3.4435 | 0.3650 |
| 18 | 110 | 62 | 50 | 7 | 52.02 | 3.3612 | 0.3420 |
| 19 | 115 | 58 | 40 | 6 | 89.76 | 3.5324 | 0.3150 |
| 20 | 115 | 58 | 45 | 7 | 84.15 | 3.4915 | 0.3140 |
| 21 | 115 | 58 | 50 | 8 | 82.62 | 3.4286 | 0.3360 |
| 22 | 115 | 60 | 40 | 7 | 83.895 | 3.5975 | 0.3680 |
| 23 | 115 | 60 | 45 | 8 | 80.58 | 3.3148 | 0.3860 |
| 24 | 115 | 60 | 50 | 6 | 80.07 | 3.4235 | 0.3690 |
| 25 | 115 | 62 | 40 | 8 | 79.815 | 3.4396 | 0.3810 |
| 26 | 115 | 62 | 45 | 6 | 79.203 | 3.4427 | 0.3730 |
| 27 | 115 | 62 | 50 | 7 | 78.54 | 3.3984 | 0.3630 |

### 3.1 Material Removal Rate

The contribution of each process parameter on material removal rate is calculated. The most significant contribution of parameters that effects the material removal rate are 79.9% contributed by pulse on time and 18.97% contributed by pulse off time was shown in table7.

Table7. Analysis of variance results for the material removal rate

| Factor | DOF | Sum of square | Variance | Contribution (%) |
|---|---|---|---|---|
| **A** | 1 | 3789.53 | 3789.53 | 79.9 |
| **B** | 1 | 899.57 | 899.57 | 18.97 |
| **C** | 1 | 53.57 | 53.57 | 1.13 |
| **D** | 1 | 0.06 | 0.06 | 0.00126 |
| **Total** | 4 | 4742.73 | | 100 |

### 3.2 Kerf Width

The contribution of each process parameter on kerf width is calculated. The most significant contribution of parameters that effects the kerf width are 81.09% contributed by pulse off time and 18.37% contributed by wire feed was shown in table8.

Table 8. Analysis of variance results for kerf width

| Factor | DOF | Sum of square | Variance | Contribution (%) |
|---|---|---|---|---|
| A | 1 | 0.000014 | 0.000014 | 0.539 |
| B | 1 | 0.002106 | 0.002106 | 81.09 |
| C | 1 | 0.000012 | 0.000012 | 0.46 |
| D | 1 | 0.000477 | 0.000477 | 18.37 |
| Total | 4 | 0.002597 | | 100 |

### 3.3 Surface roughness

The surface roughness of the machined work piece is measured, the most effective parameter is on surface roughness is servo voltage and its contribution is around 53.52% and also the pulse on time contributed around29.447% on surface roughness. The contribution levels of parameters are shown in Table 9.

Table 9. Analysis of variance results for surface roughness

| Factor | DOF | Sum of square | Variance | Contribution (%) |
|---|---|---|---|---|
| A | 1 | 0.039593 | 0.039593 | 29.447 |
| B | 1 | 0.020903 | 0.020903 | 15.55 |
| C | 1 | 0.071972 | 0.071972 | 53.52 |
| D | 1 | 0.001987 | 0.001987 | 1.478 |
| Total | 4 | 0.134455 | | 100 |

 

### 3.4 Optimization of Wire EDM Process Parameters using Modified TLBO Algorithm

Optimal performance characterestics are found out with Modified TLBO algorithm with the help of experimental results and regression equations. The single objective optimization for the responses is conducted. A computer code has been developed using MATLAB R2015b for the parametric optimization of Wire EDM process by considering the following parameters: population size=30 and number of generations=500. The regression equations for MRR, SR and KW are shown below

$$Y_{MRR}=-23.3 +2.912A -3.535B -0.347C +0.06D \quad (1)$$

$$Y_{SR}=1.857 +0.00938A +0.01701B -0.01265C +0.0105D \quad (2)$$

$$Y_{KW}=-0.0305 +0.00017A +0.00541B +0.00016C +0.00515D \quad (3)$$

The optimal combination of parameters for maximizing MRR and minimizing SR, KW values of controlled Wire EDM operation. The optimum values of process parameters are listed in Table 10. This table also shows the results when the GA was used to optimize the above mentioned responses.

Table10. Single objective optimization results

| Optimization method | Response | Value | pulse on time | Pulse off time | Servo voltage | Wire feed |
|---|---|---|---|---|---|---|
| **GA algorithm** | MRR | 43.310 | 105 | 62 | 50 | 6 |
| | SR | 3.312 | 105 | 58 | 50 | 6 |
| | KW | 0.413 | 105 | 58 | 40 | 6 |
| **MTLBO algorithm** | MRR | 49.855 | 105 | 62 | 50 | 6 |
| | SR | 3.154 | 105 | 58 | 50 | 6 |
| | KW | 0.333 | 105 | 58 | 40 | 6 |

It is clearly observed that MTLBO algorithm performs the better way than that of Genetic algorithm with respect to optimum values of the process responses. The MRR is gradually increased from 43.310mm$^3$/min to 49.985 mm$^3$/min, SR is drastically reduced from 3.312µm to 3.154µm and KW is gradually reduced from 0.413mm to 0.333mm.

### 3.5 Multi-Objective optimization

Multi-objective optimization has been defined to find out a vector of decision variables while optimizing (i.e. minimizing or maximizing) several objectives simultaneously, with a given set of constraints. In the present work, three such objectives namely maximizing MRR and minimizing SR and KW are considered simultaneously for the multi-objective optimization. Weight method was implemented in the present work for multi-objective optimization.

The single objective functions forms the previous section are put together for multi-objective optimization. The normalized multi-objective function ($Z_1$) is formulated considering equal weights factors to all the objectives and is given by the following equation 4.

$$\text{Min}(Z_1)=0.25\times SR/SR_{min}+0.25\times KW/KW_{min}-0.25\times MRR/MRR_{max} \quad (4)$$

Where $SR_{min}$, $KW_{min}$ and $MRR_{min}$ are the minimum values of MRR, SR and KW respectively; and $MRR_{max}$, $SR_{max}$ and $KW_{max}$ are the maximum values of MRR, SR and KW. Table 11. Shows multi-objective optimization results of GA and MTLBO.

Table 11. Multi-objective Optimization results

| Optimization method | Response | Value | pulse on time | Pulse off time | Servo voltage | Wire feed |
|---|---|---|---|---|---|---|
| **GA algorithm** | MRR | 62.96 | 105 | 58 | 40 | 6 |
| | SR | 3.382 | | | | |
| | KW | 0.334 | | | | |
| **MTLBO algorithm** | MRR | 91.92 | 115 | 58 | 40 | 6 |
| | SR | 3.325 | | | | |
| | KW | 0.323 | | | | |

 

It was clearly observed that the optimum combination of process parameters that maximize MRR and minimize SR, KW are pulse on time=105 µs, pulse off time=58µs, servo voltage=42V and wire feed=6m/min. Comparing the results of GA the MRR is increased from 63.446 $mm^3$/min to 91.92.144 $mm^3$/min, SR decreased from 3.382 µm to 3.325 µm and KW was reduced from 0.334 mm to 0.323 mm. Finally it was clearly observed that the multi-objective function using MTLBO gave a better result by fulfilling all the objectives.

## IV. CONFIRMATION TEST

The optimal parameters are found out. The confirmation test was conducted to find out the improvement between the MTLBO optimal process parameters and previous experimental parameters results on process responses. Finally it was observed that the optimal parameters that gave by MTLBO have been satisfied the experimental results with an improvement of 10%.

## V. CONCLUSION

In the present study, the MTLBO algorithm was applied to determine the optimal process parameters for achieving better machining characterestics. Both single and multi-objective optimization problems were solved using MTLBO algorithm. The comparison was done with other population based optimization algorithm GA and it was observed that MTLBO gave better results than that of GA. This algorithm can be applied as a global optimum tool for selecting process parameter values. Hence the MTLBO is proposed to optimize process parameters on Wire EDM for better improvement in machining characterestics.

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