# Optimization of process parameters of vibration assisted Electrical Discharge Machining Using AISI D3 steel

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**Abstract- Electrical discharge machining is one of the best non-conventional machining processes which are generally used for machining intricate shapes for tool dies. For some of the machining processes, it is a best machining process as compared to the other conventional machining processes. In this research work, the machining of AISI D3 tool steel using vibration assisted electrical discharge machining (EDM) with a copper tool by using Taguchi methodology has been investigated. The L9 orthogonal array is used to formulate the experimental layout and ANOVA is used to analyze the effect of each parameter on the machining characteristics and to find the optimal choice for each process parameters such as amplitude of vibration, peak current, gap voltage and pulse-on time. It is found that process parameters have a significant effect on response parameters such as material removal rate (MRR) and tool wear rate (TWR).**

**Keywords: Vibration Assisted EDM, MRR, TWR, Taguchi Methodology, ANNOVA**

## I. INTRODUCTION

In today's era as the technology rests its feet in every new invention. So there is need for modification with respect to new discovery, as in the case of materials. It becomes requisite to use modified machining processes. The processes can vary from conventional to non- conventional.

The history of EDM technique goes as far back as the 1770's when it was discovered by English scientist, Joseph Priestly. He noticed in his experiments that electrical discharges had removed material from the electrodes. Although it was originally observed by Priestly, EDM was imprecise and riddled with failures. During research to eliminate erosive effects on electrical contacts, the soviet scientists decided to exploit the destructive effect of an electrical discharge and develop a controlled method of metal machining. In 1943, soviet scientists announced the construction of the first spark erosion machining. The spark generator used in 1943, known as the Lazarenko circuit, has been employed for several years in power supplies for EDM machines and improved form is used in many application. Commercially developed EDM techniques were transferred to a machine tool. This migration made EDM more widely available and a more appealing choice over traditional machining processes [1].

As EDM is a non conventional machining process to machine very hard materials and complicated contours or fragile cavities. The material erodes from work piece by producing rapid and repetitive sparks between tool and work piece by maintaining a small gap between tool and work piece. The value of the small gap between work piece and tool ranges from 10 – 200 μm. Both the tool and work piece stay immersed in a dielectric fluid. In this machining process, work piece is called anode because it is connected with positive terminal and tool is connected with negative terminal that is cathode [3].

EDM is a controlled metal removal process and it is used to remove the metal by mean of electric spark erosion [2]. In this process, the removing of material from the work piece takes place by mean of series of electrical discharge produced by electric pulse generator at short interval between electrode and work piece in the presence of dielectric fluid. In EDM process with the increase in current and diameter of electrode the tool wear rate and material removal get increased [3]. The EDM process can be compared with the conventional cutting process, except that in this case, a suitable shaped tool electrode, with a precision controlled feed movement is employed in place of cutting tool, and the cutting energy is provided by means of short duration electrical pulses [4]. EDM has found ready application in the machining of hard metals or alloys which cannot be machined easily by conventional methods. Thus it plays a major role in the machining of dies, tools, etc made of tungsten carbide or hard steels. Alloys used in aeronautics industry, for example, hastalloy, nimoic, etc, could also be machined conveniently by this process. This process has added advantage of being capable of machining complicated component [5].

To reduce the machining time and to improve material removal rate (MRR), vibration assisted EDM is investigated. Vibration assisted EDM is advancement in the conventional EDM process as it increase the efficiency of the EDM process. In vibration assisted EDM, a fixed frequency vibration was given to the work piece. In each period of vibration, when the work piece is pushed up, the volume of the gap is decreased; it pumps the contaminated dielectric and debris away from the gap. When the work piece is brought down, it allows the entering of clean dielectric. This is because of the vibration frequency which ''shakes off'' the molten work piece materials and helps to improve the flushing.

The work piece vibration induced by ultrasonic action has a significant effect on the performance of the micro-EDM process and efficiency of the ultrasonically aided micro-EDM is up to eight time's greater micro-EDM [6].

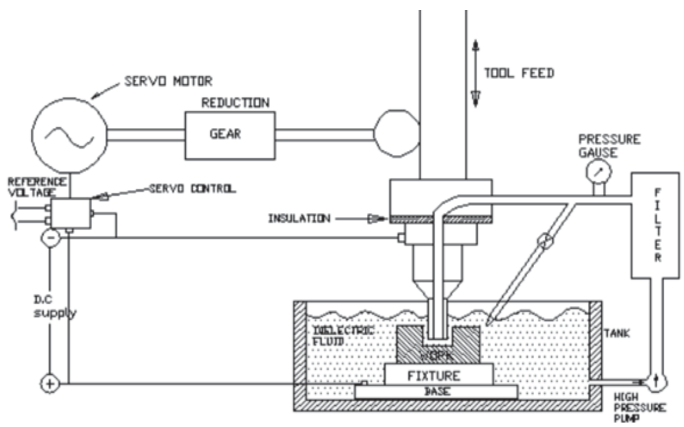


Fig.1: Schematic setup diagram of Electric Discharge Machining

## II. EXPERIMENTAL PROCEDURE

Experiments are conducted on the Electrical discharge machine model Elektra EMS 5535 of Electronica machine tools limited. The work piece used is AISI D3 steel. The chemical composition of the AISI D3 is shown in table 1. This material is used for Blanking, stamping, and cold forming dies and punches for long runs; lamination dies, Bending, forming, and seaming rolls, press tools, Bushes, Drawing dies for bars or wire and cold trimmer dies or rolls.

Fig. 2: Working set up of vibration assisted EDM

Table 1: Chemical composition of AISI D3

| Element | C | Mn | Si | Cr | Cu |
|---|---|---|---|---|---|
| Percentage(Standard) | 2.35 Max | 0.60 | 0.60 | 13.50 Max | 0.25 |
| Percentage(Tested) | 1.98 | 0.316 | 0.330 | 11.06 | 0.0214 |

The copper electrode is used for the experimentation. Copper is one of the most popular electrode material used in EDM. This is because of its conductivity towards electricity. The main reasons for using copper electrode is its easy availability and lower de-burr. It takes longer time to de-burr a copper electrode than to manufacture it. The electrode is of 6mm diameter. Chemical composition of copper electrode is shown in table 2.

Table 2: The chemical composition of the copper electrode

| Cu % | Zn % | Al% | Bi% | Pb% |
|---|---|---|---|---|
| 99.8 | 0.057 | 0.15 | 0.0011 | 0.0008 |

EDM oil was used as a dielectric fluid in this experiment. The weight of work piece and tool is measured by kerro electronic scale which was made in Taiwan and has least count of 0.01gm.

## DESIGN OF EXPERIMENTS

### *A. Taguchi Method*

Taguchi method is an addition to the toolkit of design, process and manufacturing and quality assurance. In contrast to statistical process control, which attempts to control the factors that adversely affect the quality of production, Taguchi method focus on design and development of products and manufacturing processes to deliver quality.

### *B. Signal to Noise Ratio*

Classical experimental design methods are too complex and not easy to use. Furthermore, a large number of experiments have to be carried out as the number of the process parameters increases. To solve this important task, the Taguchi method uses a special design of orthogonal array to study the entire parameter space with only a small number of experiments. The experimental results are then transformed into a signal-to-noise (S/N) ratio. The S/N ratio can be used to measure the deviation of the performance characteristics from the desired values. The categories of performance characteristics in the analysis of the S/N ratio depend upon output parameters to be controlled. As per the requirement, the MRR is taken higher-the-better and TWR is taken lower-the-better. Regardless of the category of the performance characteristic, a larger S/N ratio corresponds to better performance characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio. The design of experiment (D.O.E.) chosen for the electric discharge machining of AISI D3 steel was a Taguchi L9 orthogonal array, by carrying out a total number of 9 experiments along with 4 verification experiments (optional).

### *C. Orthogonal Array*

In L9 ($3^4$) array 9 rows represent the 9 experiment to be conducted with 4 factors at 3 levels of the corresponding factor. The matrix form of these arrays is shown in Table 3 where 1, 2, 3 in the table represents the level of each parameters. The process parameters taken are amplitude of vibration (A), peak current ($I_p$), gap voltage ($V_g$), pulse – on time ($T_{on}$). The response parameters taken are material removal rate (MRR) and tool wear rate (TWR). The values selected for three levels for process parameters are shown in table 4. Table 5 shows the set values of process parameters according to L9 design matrix. Experimental results and calculations of response parameters based on L9 orthogonal array are shown in table 6.

Table 3: Taguchi L9 Orthogonal array Design Matrix

| Exp. No. | Factor 1 | Factor 2 | Factor 3 | Factor 4 |
|---|---|---|---|---|
| E1 | 1 | 1 | 1 | 1 |
| E2 | 1 | 2 | 2 | 2 |
| E3 | 1 | 3 | 3 | 3 |
| E4 | 2 | 1 | 2 | 3 |
| E5 | 2 | 2 | 3 | 1 |
| E6 | 2 | 3 | 1 | 2 |
| E7 | 3 | 1 | 3 | 2 |
| E8 | 3 | 2 | 1 | 3 |
| E9 | 3 | 3 | 2 | 1 |

Table 4: Level values of process parameters

| Exp. No. | Parameters | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| 1 | A | 77 | 98 | 119 |
| 2 | $I_p$ | 10 | 20 | 30 |
| 3 | $V_g$ | 30 | 60 | 90 |
| 4 | $T_{on}$ | 50 | 125 | 200 |

Table 5: Actual Values of L9 design matrix

| Exp. No. | A (μm) | $I_p$ (Amp.) | $V_g$ (V) | Ton (μs) |
|---|---|---|---|---|
| 1 | 77 | 10 | 30 | 50 |
| 2 | 77 | 20 | 60 | 100 |
| 3 | 77 | 30 | 90 | 200 |
| 4 | 112 | 10 | 60 | 200 |
| 5 | 112 | 20 | 90 | 50 |
| 6 | 112 | 30 | 30 | 100 |
| 7 | 119 | 10 | 90 | 100 |
| 8 | 119 | 20 | 30 | 200 |
| 9 | 119 | 30 | 60 | 50 |

Table 6:- Experimental results and calculations of various response parameters based on Taguchi L9 orthogonal array

| Exp. No. | Run No.1 | Run No. 2 | Run No. 3 | MRR ($mm^3$/min.) | Run No.1 | Run No. 2 | Run No. 3 | TWR ($mm^3$/min.) |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.534 | 1.561 | 1.543 | 1.546 | 0.563 | 0.564 | 0.559 | 0.562 |
| 2 | 1.763 | 1.744 | 1.791 | 1.766 | 0.606 | 0.604 | 0.607 | 0.606 |
| 3 | 2.016 | 2.014 | 2.011 | 2.016 | 0.705 | 0.703 | 0.702 | 0.706 |
| 4 | 1.617 | 1.615 | 1.608 | 1.616 | 0.357 | 0.359 | 0.358 | 0.358 |
| 5 | 1.760 | 1.780 | 1.770 | 1.770 | 0.601 | 0.604 | 0.598 | 0.601 |
| 6 | 1.750 | 1.770 | 1.790 | 1.770 | 0.750 | 0.753 | 0.752 | 0.751 |
| 7 | 1.550 | 1.530 | 1.570 | 1.550 | 0.451 | 0.448 | 0.451 | 0.450 |
| 8 | 1.67 | 1.68 | 1.68 | 1.683 | 0.501 | 0.501 | 0.501 | 0.502 |
| 9 | 1.68 | 1.69 | 1.71 | 1.696 | 0.701 | 0.699 | 0.703 | 0.701 |

## III. RESULTS AND DISCUSSIONS

### *A. Effect of process parameters on MRR*

The response table for raw data means for MRR is shown in Table 7 and the corresponding ANOVA table is shown in Table 8.For MRR, the calculation of S/N ratio follows "Larger the Better" model.

Table 7: Response table for MRR

| Level | A (μm) | $I_p$ (A) | $V_g$ (V) | Ton (μs) |
|---|---|---|---|---|
| L1 | 1.777 | 1.571 | 1.667 | 1.671 |
| L2 | 1.719 | 1.740 | 1.693 | 1.696 |
| L3 | 1.643 | 1.828 | 1.779 | 1.772 |
| DELTA | 0.133 | 0.257 | 0.112 | 0.101 |
| RANK | 2 | 1 | 3 | 4 |

Fig.3 and 4 shows that MRR decreases with the increase of amplitude of vibration. In each period of vibration, when the workpiece is pushed up, the volume of the gap is decreased; it pumps the contaminated dielectric and debris away from the gap. When the workpiece is brought down, it allows the entering of clean dielectric. This is because of the vibration frequency which ‘‘shakes off’’ the molten workpiece materials and helps to improve the flushing. At higher amplitude vibrations, the material do not find sufficient time to flush out the material machined. The MRR increases with peak current. The discharge energy is proportional to the peak current in any dielectric fluid. Thus, when increasing peak current, higher energy will be discharged and cause more obvious vaporizing and melting on the machining area. It will also create a larger impulsive force of discharge and obtain a higher MRR. The MRR is increasing with the increase in gap voltage. Increase in gap voltage value will increase the pulse discharge energy which in turn can improve the MRR. The MRR is increasing with the increase in pulse on time. At the short intervals, machining operation time is less and MRR is less. At the large intervals of time the machining operation time is more and MRR is more. Fig. 3 and 4 reveals that the optimum levels of machining parameters for MRR of the vibration assisted EDM are: 77µm amplitude (level 1), 30A peak current (level 3), 90 V Gap voltage (level 3), 200µs Pulse on time (level 3). It is clear that parameter amplitude of vibration, peak current, gap voltage, pulse-on time significantly affect the MRR values. From the ANOVA table 8, it is concluded that percentage contribution of machining parameters in decreasing order is 59.43 % (peak current), 16.06 % (amplitude of vibration), 11.36% (gap voltage) and 9.22% (pulse on time). Therefore, peak current have the maximum effect on material removal rate followed by amplitude of vibration.

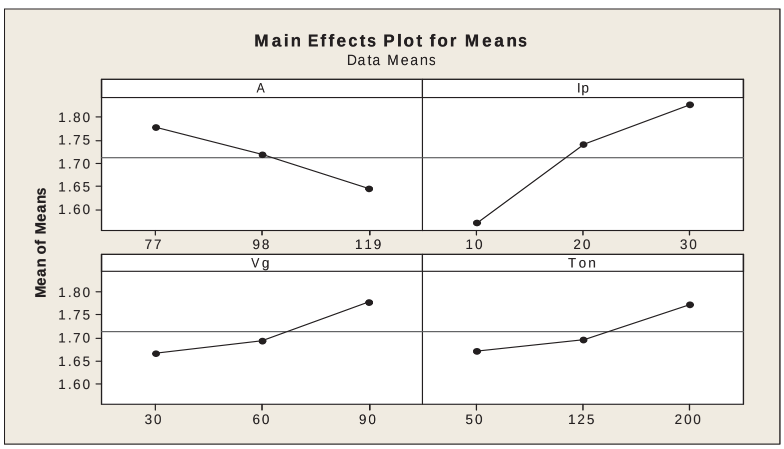


Fig.3: Raw Data curve for MRR

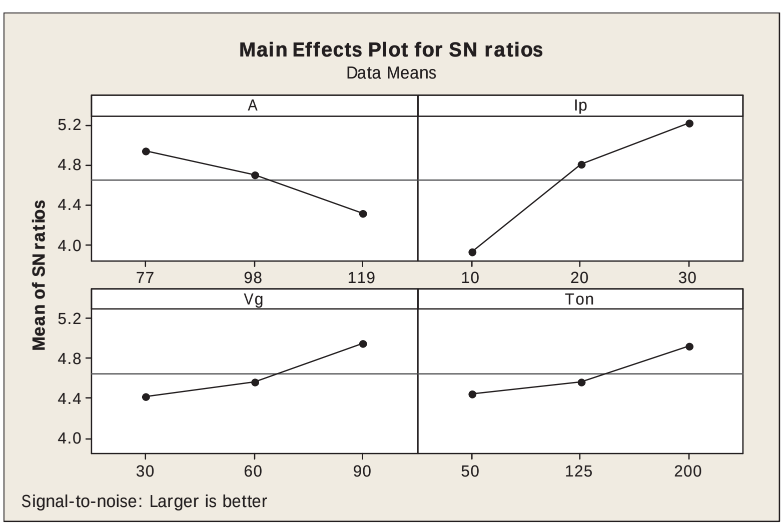


Fig. 4: S/N ratio curve for MRR

Table 8: ANNOVA for MRR

| Source | DOF | Seq. SS | Adj. SS | Adj. MS | F | P | % |
|---|---|---|---|---|---|---|---|
| A | 2 | 0.0266 | 0.0266 | 0.0133 | 16.30 | 0.016 | 16.06 |
| $I_p$ | 2 | 0.0988 | 0.0988 | 0.0484 | 60.39 | 0.001 | 59.43 |
| $V_g$ | 2 | 0.0188 | 0.0188 | 0.0094 | 11.55 | 0.027 | 11.36 |
| $T_{on}$ | 2 | 0.0153 | 0.0153 | 0.0076 | 9.37 | 0.038 | 9.22 |
| E | | 0.0065 | 0.0065 | 0.0032 | | | 3.94 |
| T | 8 | 0.1662 | | | | | 100 |

*B. Effect of process parameters on TWR*

The response table for raw data means for TWR is shown in table 9 and the corresponding ANOVA table is shown in table 10. For TWR, the calculation of S/N ratio follows "Smaller the Better" model.

Table 9:- Response table for TWR

| Level | A (µm) | $I_p$ (A) | $V_g$ (V) | Ton (µs) |
|---|---|---|---|---|
| L1 | 0.625 | 0.457 | 0.605 | 0.622 |
| L2 | 0.570 | 0.570 | 0.555 | 0.602 |
| L3 | 0.551 | 0.719 | 0.585 | 0.522 |
| DELTA | 0.0736 | 0.262 | 0.050 | 0.099 |
| RANK | 3 | 1 | 4 | 2 |

Fig. 5 and 6 shows the effect of amplitude of vibration on TWR. It has been observed that TWR significantly decreases from 77µm to 119µm. This is due to the fact of difference ''shakes off'' due to amplitude of vibrations. When vibration amplitude is increased, the stirring effect is also enhanced. The higher vibration amplitude causes a large pressure difference between the electrode and the workpiece. The dielectric circulation and debris particle removal from the working area are enhanced depending upon polarity. The effect of peak-current on TWR, it is less at 10A and significantly increases towards 30 A. This happened due to more electrical energy is conducted into the machining zone within a single pulse; more tool materials are removed within the single pulse and workpiece is machined more as compare to tool due to its polarity. The TWR is decreasing from 30V to 60V and increasing from 60V to 90V. the difference of TWR is based upon discharge energy which in turn increase and decrease in energy based upon the pulse-on time and duty factor. TWR is maximum at less at 50 µs and decreases as pulse on time is incrasing. At the short intervals, machining operation is fast. But at higher pulse-on time, the expelled tool material will not be flushes away with the flow of the dielectric fluid and the dielectric fluid will not be de-ionized. Fig. 5 and 6 reveal that the optimum levels of machining parameters for least TWR are: 119µm amplitude (level 3), 10A peak current (level 1), 60V gap voltage (level 2), and 200µs Pulse on-time (level 3). It is clear that parameter amplitude of vibration, peak current, gap voltage, pulse-on time significantly affect the TWR values. From the ANOVA table 9, it is concluded that percentage contribution of peak current (77.53%), pulse-on time (11.14%), amplitude of vibration (6.08%) and gap voltage (0.43%). Therefore, peak current have the maximum effect on Tool wear rate and followed by the pulse on time and amplitude of vibration.

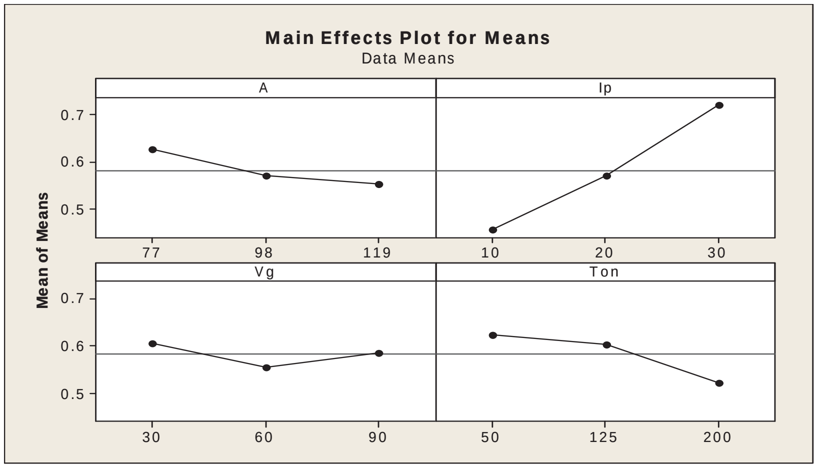


Fig.5: Raw Data curve for TWR

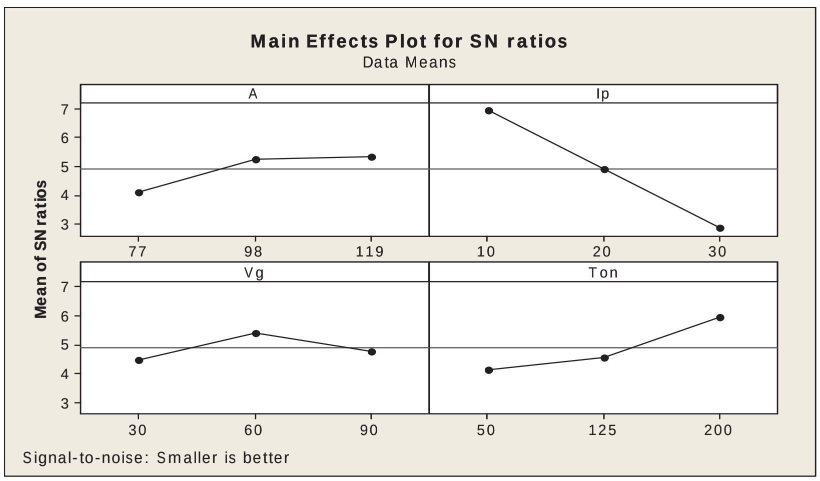


Fig. 6: S/N ratio curve for TWR

Table 10: ANOVA for TWR

| Source | DOF | Seq. SS | Adj. SS | Adj. MS | F | P | % |
|---|---|---|---|---|---|---|---|
| **A** | **2** | **0.0081** | **0.0081** | **0.0040** | **5.07** | **0.088** | **6.08** |
| **$I_p$** | **2** | **0.1035** | **0.1035** | **0.0517** | **64.54** | **0.001** | **77.53** |
| **$V_g$** | **2** | **0.0005** | **0.0005** | **0.0002** | **0.36** | **0.581** | **0.43** |
| **Ton** | **2** | **0.0148** | **0.0148** | **0.0074** | **9.28** | **0.038** | **11.14** |
| **E** | | **0.0064** | **0.0064** | **0.0032** | | | **4.8** |
| **T** | **8** | **0.1335** | | | | | **100** |

Experimental Verification

After performing the statistical analysis on the experimental data, it has been observed that there is one particular level for each factor for which the responses are either maximum (in case of MRR) or minimum (in case of TWR). So for finding the optimum parameter setting for each response factors, the additive model of Taguchi method is used. There are four optimum parameter settings corresponding to the four response factors. The combination of input factor levels, for which optimum settings for process parameters and confirmation value for response parameters are obtained as given in Table 11.

Table11: Optimal Parameter Settings of process parameters for confirmation of response parameters

| **Physical Requirement** | **Optimal Combination** | | | | **Confirmation value for response parameters ($mm^3$/min.)** |
|---|---|---|---|---|---|
| | **A** | **$I_p$** | **$V_g$** | **Ton** | |
| **Maximum MRR** | **77** | **30** | **90** | **200** | **2.016** |
| **Minimum TWR** | **119** | **10** | **60** | **200** | **0.440** |

## IV. CONCLUSION

The effects of vibration assisted EDM are explored using AISI D3 tool steel as work piece and Copper as tool electrode. Experiments have been conducted to investigate MRR and TWR under a different range of process parameters such as amplitude of vibration, peak current, gap voltage and pulse-on time. Taguchi (L9) orthogonal array is used to perform an Analysis of Variance (ANOVA) for raw data.

- The MRR mainly affected by peak current followed by amplitude of vibration.
- The TWR is mainly affected by peak current followed by the pulse on time and amplitude of vibration.
- The higher efficiency gained by the employment of vibrations to workpiece is mainly attributed to the improvement in dielectric fluid circulation. The dielectric fluid circulation facilitates the debris removal and the creation of a large pressure difference between the electrode and the workpiece as an enhancement of molten metal ejection from the surface of the workpiece.
- The optimal value of process parameters for the predicted range of optimal MRR are as follows: 77µm amplitude (A, level 1st), 30A peak current ($I_p$, level 3rd), 90 V gap voltage ($V_g$, level 3rd) and 200µs Pulse on time ($T_{on}$, level 3rd) which provide maximum MRR from workpiece when machined by vibration assisted EDM process.
- The optimal value of process parameters for the predicted range of optimal TWR are as follows: 119µm amplitude (A, level 3rd), 10A peak current ($I_p$, level 1st), 60V gap voltage ($V_g$, level 2nd), 200µs Pulse on-time ($T_{on}$, level 3rd) which provide minimum TWR from workpiece when machined by vibration assisted EDM process.

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