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# PARAMETRIC OPTIMIZATION ON DIE STEEL USING WIRE CUT EDM

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**Abstract** — *Wire cut EDM is one of the non-traditional machining processes. Machining parameters affecting quality characteristics in the machining process is thoroughly studied. In this present study AISI 52100 is used as a work piece. The input parameters selected for optimization pulse on time, pulse off time, voltage and wire feed. Dielectric fluid pressure, wire tension, resistance and cutting length are taken as fixed parameters. The experimental of the Taguchi L32 has been used. For each experiment material removal rate, surface roughness and kerf width was determined by using contact signal to noise ratio measuring system respectively. By using multi objective optimization technique Grey Relational Analysis, in order to optimize the input parameters in wire EDM for AISI 52100. The Analysis of variance is too useful to identify the most important factor. The objective of optimization is to attain the maximize the material removal rate, minimize the surface roughness and minimize the kerf width.*

***Keywords –*** *WEDM, Brass Wire, Taguchi, Anova, Grey relational analysis*

## I INTRODUCTION

Electro-discharge machining (EDM) is a non-conventional manufacturing process, which has been used widely in the dies and tool industry, where machining of hard material. In the EDM process, melt the material at high temperature which generate by the electric sparks, i.e. material removal is achieved primarily by electro-thermal mechanisms. The EDM surface is formed by a series of discrete discharges between the electrode and work piece, and consequently, an inspection of the machined surface reveals the presence of many craters. This machining technique is applicable to a wide variety of conductive materials irrespective of their mechanical properties, e.g. their hardness, strength, or toughness, etc. Since there are no direct contact occurs between the electrode and the work piece, the EDM process are suitable for the machining where conventional machining cannot accommodate.

There are mainly two types of EDM.

1.Die sinking EDM
2.Wire cut EDM

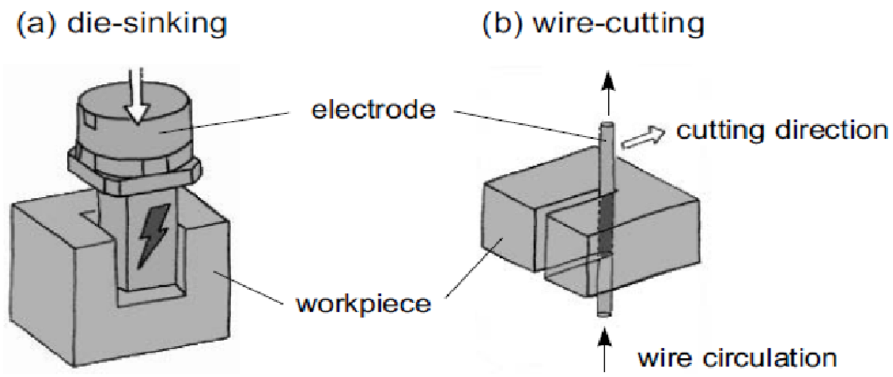


Figure-1. Main types of EDM; Die sinking and Wire cut EDM

The wire-cut EDM is a discharge machine that uses CNC movement to produce the desired contour or shape. It does not require a special shaped electrode, instead it uses Continuous-traveling vertical wire under tension as the electrode as shown in fig1. The electrode in wire-cut EDM is about as thick as a small diameter needle whose path is controlled by the machine computer to produce the shape required. In wire electrical discharge machining (WEDM), or wire-cut EDM, a thin single- strand metal wire, usually brass, is fed through the work piece, typically occurring submerged in a tank of dielectric fluid. This process is used to cut plates as thick as 300mm and to make punches, tools, and dies from hard metals that are too difficult to machine with other methods. The wire, which is constantly fed from a spool, is held between upper and lower diamond guides.

## II LITERATURE REVIEW

**[1] Brajeshkumar Lodhi et all** has been conducted experiment on AISI D3 Steel using L9 Orthogonal Array) Taguchi methodology through wire cut EDM. They were carried out experiments under varying pulse-on-time, pulse-off-time, peak current, and wire feed. Also they were used an orthogonal array, the signal-to-noise (S/N) ratio, and the analysis of variance (ANOVA) to the study the surface roughness. They were determined the effect of various machining parameter such as pulse-on time, pulseoff time, peak current and wire feed for surface roughness. They were found that the pulse on time and current have influenced more than the other parameters considered in this study. The confirmation experiment has been conducted. Result shows that the errors associated with SR is only 3.042 %.

**[2] L.Li et all** has been conducted experiment on wire cut EDM for inconel 718. They were focused on the effect of discharge energy on surface integrity from main cut and trim cuts of INCONEL718. Surface topography by main cut and rough trim cut at high discharge energy show coral reef microstructures with few voids, while random micro voids are dominant characteristics on the EDMed surfaces by trim cuts at low discharge energy. The EDMed surface is isotropic in terms of surface roughness. Roughness was significantly reduced from 3.75 μm to 1.25 μm at low discharge energy.

**[3] Y. S. Liao et all** has been conducted worked on surface quality of part during wire cut EDM. They have carried out research with used ANOVA and F-test. They used process parameter are machining voltage, current-limiting resistance, type of pulse-generating circuit and capacitance which are the significant parameters affecting the surface roughness in finishing process. They were found that a low conductivity of dielectric should be incorporated for the discharge spark to take place. After analyzing the effect of each relevant factor on surface roughness, appropriate values of all parameter are chosen and a fine surface of roughness Ra = 0.22 micro m is achieved. Their research work was limited to finishing process becomes more difficult due to the occurrence of short circuit attributed to wire deflection and vibration when the energy is gradually lowered.

**[4] Ali vaizani shayan et** all has been conducted using air as dielectric medium and they took process parameter like pulse on time, pulse off time, gap set voltage, discharge current and wire tension. They measured cutting velocity (CV) surface roughness (SR) and oversize (OS). They experiments were conducted to investigate effects of process parameters on dry WEDM characteristics and find appropriate ranges for each factor. They used design experiments based on response surface methodology (RSM) and analysis of variances (ANOVA). For increase the predictability, they developed intelligent models have been developed based on back-propagation neural network (BPNN) and accuracy of these models was compared with mathematical models based on root mean square error (RMSE) and prediction error percent (PEP). They concluded that the BPNN creates more accurate prediction rather than mathematical model.

## III METHODOLOGY

### TAGUCHI METHOD

A scientific approach to plan the experiments is a necessity for efficient conduct of experiments. By the statistical design of experiments the process of planning the experiment is carried out, so that appropriate data will be collected and analysed by statistical methods resulting in valid and objective conclusions. When the problem involves data that are subjected to experimental error, statistical methodology is the only objective approach to analysis. Thus, there are two aspects of an experimental problem: the design of the experiments and the statistical analysis of the data. These two points are closely related since the method of analysis depends directly on the design of experiments employed.

### A. Selection of process parameter

The four process cutting parameters in wire cut operation are Pulse on time, Pulse off time, Voltage and wire speed.

*Table .1 Process Parameter*

| Parameter | Unit | Level | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| **Pulse on time** | μs | 90 | 110 | | |
| **Pulse off time** | μs | 40 | 50 | 60 | 70 |
| **Voltage** | V | 22 | 26 | 30 | 34 |
| **Wire speed** | mm/sec | 6 | 9 | 12 | 15 |

### B. Grey Relational Analysis

Through the grey relational analysis, a grey relational grade can be obtained to evaluate the multiple performance characteristic. Than we get, optimization of the complicated multiple performance characteristic can be converted into the optimization of a single grey relation grade. For multiple performance characteristic optimizations using GRA, following steps are followed:

1. Normalization of experimental result for all performance characteristics.
2. Performance of grey relational generating and calculation of grey relational coefficient (GRC).
3. Calculation of grey relation grade (GRG) using, weighing factor for performance characteristics.
4. Analysis of experimental results using GRG and statistical analysis of variance (ANOVA).
5. Selection of optimal levels of process parameters

 

## IV EXPERIMENTAL RESULT AND DISCUSSION

The experiment was conducted in company to measures the value of material removal rate, surface roughness, kerf width for the various combination of input parameter.

***Table .2 L32 orthogonal array with Experimental Readings***

| No | Pulse on (µs) | Pulse off (µs) | Voltage (V) | Wire speed (mm/sec) | MRR $mm^3/min$ | SR (µm) | KW (mm) |
|---|---|---|---|---|---|---|---|
| 1 | 90 | 40 | 22 | 6 | 4.865 | 2.86 | 0.421 |
| 2 | 90 | 40 | 26 | 9 | 4.526 | 2.75 | 0.41 |
| 3 | 90 | 40 | 30 | 12 | 4.325 | 2.56 | 0.35 |
| 4 | 90 | 40 | 34 | 15 | 4.235 | 2.45 | 0.32 |
| 5 | 90 | 50 | 22 | 6 | 4.658 | 2.79 | 0.431 |
| 6 | 90 | 50 | 26 | 9 | 4.3547 | 2.56 | 0.392 |
| 7 | 90 | 50 | 30 | 12 | 4.258 | 2.42 | 0.372 |
| 8 | 90 | 50 | 34 | 15 | 4.125 | 2.39 | 0.301 |
| 9 | 90 | 60 | 22 | 9 | 4.356 | 2.68 | 0.452 |
| 10 | 90 | 60 | 26 | 6 | 4.265 | 2.54 | 0.401 |
| 11 | 90 | 60 | 30 | 15 | 4.125 | 2.5 | 0.385 |
| 12 | 90 | 60 | 34 | 12 | 3.998 | 2.41 | 0.325 |
| 13 | 90 | 70 | 22 | 9 | 4.235 | 2.52 | 0.465 |
| 14 | 90 | 70 | 26 | 6 | 4.012 | 2.39 | 0.421 |
| 15 | 90 | 70 | 30 | 15 | 3.998 | 2.29 | 0.401 |
| 16 | 90 | 70 | 34 | 12 | 3.879 | 2.25 | 0.382 |
| 17 | 110 | 40 | 22 | 15 | 5.989 | 2.98 | 0.4562 |
| 18 | 110 | 40 | 26 | 12 | 5.865 | 2.87 | 0.423 |
| 19 | 110 | 40 | 30 | 9 | 5.758 | 2.69 | 0.364 |
| 20 | 110 | 40 | 34 | 6 | 5.458 | 2.59 | 0.342 |
| 21 | 110 | 50 | 22 | 15 | 5.3568 | 2.84 | 0.456 |
| 22 | 110 | 50 | 26 | 12 | 5.2654 | 2.74 | 0.423 |
| 23 | 110 | 50 | 30 | 9 | 5.1258 | 2.56 | 0.392 |
| 24 | 110 | 50 | 34 | 6 | 5.0125 | 2.35 | 0.335 |
| 25 | 110 | 60 | 22 | 12 | 5.3256 | 2.71 | 0.476 |
| 26 | 110 | 60 | 26 | 15 | 5.286 | 2.61 | 0.423 |
| 27 | 110 | 60 | 30 | 6 | 5.198 | 2.49 | 0.402 |
| 28 | 110 | 60 | 34 | 9 | 5 | 2.32 | 0.35 |
| 29 | 110 | 70 | 22 | 12 | 5.246 | 2.65 | 0.472 |
| 30 | 110 | 70 | 26 | 15 | 5.1985 | 2.45 | 0.442 |
| 31 | 110 | 70 | 30 | 6 | 4 | 2.21 | 0.425 |
| 32 | 110 | 70 | 34 | 9 | 4.258 | 2.02 | 0.392 |

### A. Main Effects Plot of material removal rate

Fig.2 shows that higher material removal rate will meet at pulse on 110µs, pulse off 40µs, voltage 22 volt and wire speed 15 mm/sec From the fig, it has been conclude that the optimum combination of each process parameter for higher material removal rate is meeting at high pulse on time [A2], low pulse off time [B1], low voltage [C1] and low wire speed [D4].

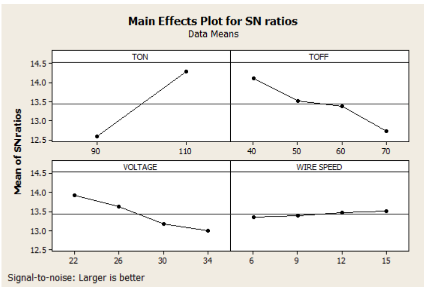


***Figure 2. Effect of control factor on material removal rate***

 

**B. Main Effects Plot of Surface roughness**

Fig.3 shows that lower Surface roughness will meet at pulse on time 90µs, pulse off 70µs, voltage34 volt and wire speed 9 mm/sec From the fig.5.3, it has been conclude that the optimum combination of each process parameter for lower surface roughness is meeting at pulse on time [A1], pulse off time [B4], voltage [C4] and wire speed [D2].

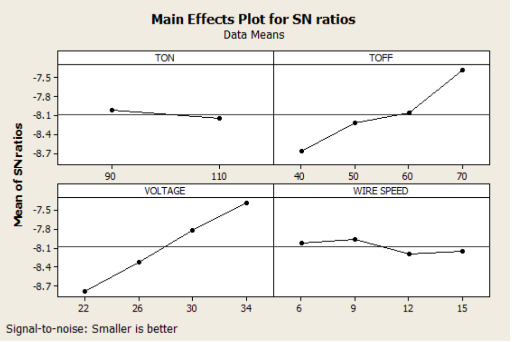


*Figure 3. Effect of control factor on Surface roughness*

**C. Main Effects Plot of Kerf width**

Fig.4 shows that lower kerf width will meet at pulse on time 90µs, pulse off 40µs, voltage 34 volt and wire speed 15 mm/sec. From the fig.5.4, it has been conclude that the optimum combination of each process parameter for lower kerf width is meeting at pulse on time [A1], pulse off time [B1], voltage [C4] and wire speed [D4].

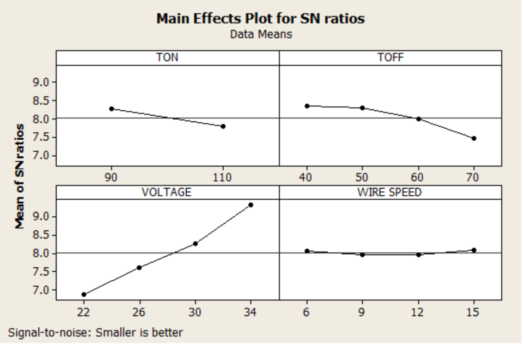


*Figure 4. Effect of control factor on kerf width*

**D. Analysis of Variance for material removal rate**

*Table 3. ANOVA table of material removal rate*

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Pulse on time | 1 | 7.1517 | 7.1517 | 7.1517 | 132.63 | 0.000 |
| Pulse Off time | 3 | 2.4215 | 2.4215 | 0.8072 | 14.97 | 0.000 |
| Voltage | 3 | 1.2854 | 1.2854 | 0.4285 | 7.95 | 0.001 |
| Wire speed | 3 | 0.0634 | 0.0634 | 0.0211 | 0.39 | 0.760 |
| Error | 21 | 1.1323 | 1.1323 | 0.0539 | | |
| Total | 31 | 12.0543 | | | | |
| R-Sq = 91.01% | | | | R-Sq(adj) = 90.61% | | |

From ANOVA result it is observed that the pulse on time, pulse off time and voltage are influencing parameter for material removal rate, because the value of p is less than 0.05 p values.

**E. Analysis of variance for Surface Roughness**

From ANOVA result it is observed that the pulse off time and voltageare influencing parameter for Surface roughness, because the value of p is less than 0.05 p values.

*Table 4. ANOVA table for Surface roughness*

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Pulse on time | 1 | 0.01620 | 0.01620 | 0.01620 | 3.91 | 0.061 |
| Pulse Off time | 3 | 0.56532 | 0.56532 | 0.18844 | 45.45 | 0.000 |
| Voltage | 3 | 0.74967 | 0.74967 | 0.24989 | 60.27 | 0.000 |
| Wire speed | 3 | 0.02153 | 0.02153 | 0.00718 | 1.73 | 0.191 |
| Error | 21 | 0.08707 | 0.08707 | 0.00415 | | |
| Total | 31 | 1.43980 | | | | |
| R-Sq = 93.95% | | | | R-Sq(adj) = 91.07% | | |

### F. Analysis of variance for kerf width

From ANOVA result it is observed that the feed, speed and depth of cut are influencing parameter for Cutting Force, because the value of p is less than 0.05 p values.

***Table 5. ANOVA table for kerf width***

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Pulse on time | 1 | 0.0037023 | 0.0037023 | 0.0037023 | 24.57 | 0.000 |
| Pulse Off time | 3 | 0.0078437 | 0.0078437 | 0.0026146 | 17.35 | 0.000 |
| Voltage | 3 | 0.0524408 | 0.0524408 | 0.0174803 | 116.03 | 0.000 |
| Wire speed | 3 | 0.0001938 | 0.0001938 | 0.0000646 | 0.43 | 0.734 |
| Error | 21 | 0.0031637 | 0.0031637 | 0.0001507 | | |
| Total | 31 | 0.0673443 | | | | |
| R-sq = 95.30% | | | | R-sq(adj) = 93.07% | | |

## V GREY RELATIONAL ANALYSIS

***Table 6. Normalization, GRC and GRG of experimental data***

| Sr No. | Normalized S/N Ratios | | | GRC | | | GRG |
|---|---|---|---|---|---|---|---|
| | MRR | RA | Kw | MRR | RA | Kw | |
| 1 | 0.5214 | 0.8943 | 0.7321 | 0.5110 | 0.8255 | 0.6511 | 0.6625 |
| 2 | 0.3552 | 0.7934 | 0.6743 | 0.4367 | 0.7076 | 0.6056 | 0.5833 |
| 3 | 0.2506 | 0.6093 | 0.3291 | 0.4002 | 0.5614 | 0.4270 | 0.4629 |
| 4 | 0.2027 | 0.4963 | 0.1336 | 0.3854 | 0.4982 | 0.3659 | 0.4165 |
| 5 | 0.4213 | 0.8306 | 0.7833 | 0.4635 | 0.7469 | 0.6977 | 0.6360 |
| 6 | 0.2663 | 0.6093 | 0.5764 | 0.4053 | 0.5614 | 0.5413 | 0.5027 |
| 7 | 0.2146 | 0.4647 | 0.4621 | 0.3890 | 0.4829 | 0.4817 | 0.4512 |
| 8 | 0.1416 | 0.4326 | 0.0000 | 0.3681 | 0.4684 | 0.3333 | 0.3899 |
| 9 | 0.2670 | 0.7271 | 0.8871 | 0.4055 | 0.6469 | 0.8158 | 0.6228 |
| 10 | 0.2184 | 0.5891 | 0.6259 | 0.3901 | 0.5489 | 0.5720 | 0.5037 |
| 11 | 0.1416 | 0.5483 | 0.5370 | 0.3681 | 0.5254 | 0.5192 | 0.4709 |
| 12 | 0.0696 | 0.4540 | 0.1674 | 0.3495 | 0.4780 | 0.3752 | 0.4009 |
| 13 | 0.2022 | 0.5688 | 0.9490 | 0.3853 | 0.5369 | 0.9074 | 0.6099 |
| 14 | 0.0776 | 0.4326 | 0.7321 | 0.3515 | 0.4684 | 0.6511 | 0.4904 |
| 15 | 0.0696 | 0.3226 | 0.6259 | 0.3495 | 0.4247 | 0.5720 | 0.4487 |
| 16 | 0.0000 | 0.2773 | 0.5200 | 0.3333 | 0.4089 | 0.5102 | 0.4175 |
| 17 | 1.0000 | 1.0000 | 0.9073 | 1.0000 | 1.0000 | 0.8436 | 0.9479 |
| 18 | 0.9518 | 0.9033 | 0.7424 | 0.9121 | 0.8379 | 0.6600 | 0.8033 |
| 19 | 0.9094 | 0.7367 | 0.4147 | 0.8467 | 0.6550 | 0.4607 | 0.6541 |
| 20 | 0.7862 | 0.6393 | 0.2786 | 0.7005 | 0.5809 | 0.4094 | 0.5636 |
| 21 | 0.7432 | 0.8762 | 0.9063 | 0.6606 | 0.8016 | 0.8422 | 0.7682 |
| 22 | 0.7035 | 0.7841 | 0.7424 | 0.6278 | 0.6984 | 0.6600 | 0.6621 |
| 23 | 0.6417 | 0.6093 | 0.5764 | 0.5825 | 0.5614 | 0.5413 | 0.5617 |
| 24 | 0.5902 | 0.3892 | 0.2335 | 0.5496 | 0.4501 | 0.3948 | 0.4648 |
| 25 | 0.7297 | 0.7557 | 1.0000 | 0.6491 | 0.6718 | 1.0000 | 0.7736 |
| 26 | 0.7125 | 0.6590 | 0.7424 | 0.6349 | 0.5946 | 0.6600 | 0.6298 |
| 27 | 0.6739 | 0.5380 | 0.6313 | 0.6052 | 0.5197 | 0.5756 | 0.5669 |
| 28 | 0.5845 | 0.3561 | 0.3291 | 0.5461 | 0.4371 | 0.4270 | 0.4701 |
| 29 | 0.6950 | 0.4021 | 0.9816 | 0.6211 | 0.4554 | 0.9645 | 0.6803 |
| 30 | 0.6741 | 0.4963 | 0.8383 | 0.6054 | 0.4982 | 0.7556 | 0.6197 |
| 31 | 0.0707 | 0.2310 | 0.7527 | 0.3498 | 0.3940 | 0.6691 | 0.4710 |
| 32 | 0.2146 | 0.0000 | 0.5764 | 0.3890 | 0.3333 | 0.5413 | 0.4212 |

The higher grey relational grade reveals that the corresponding experimental result is closer to the ideally normalized value. Experiment 17 has the best multiple performance characteristic among 32 experiments, because it has the highest grey relational grade shown in table 6. The higher the value of the grey relational grade, the closer the corresponding factor combination is, to optimal. A higher grey relational grade implies better product quality, therefore, on the basis of the grey relational grade, the factor effect can be estimated and the optimal level for each controllable factor can also be determined.

### A. Main Effect of Factors on Grey Relational Grade (GRG)

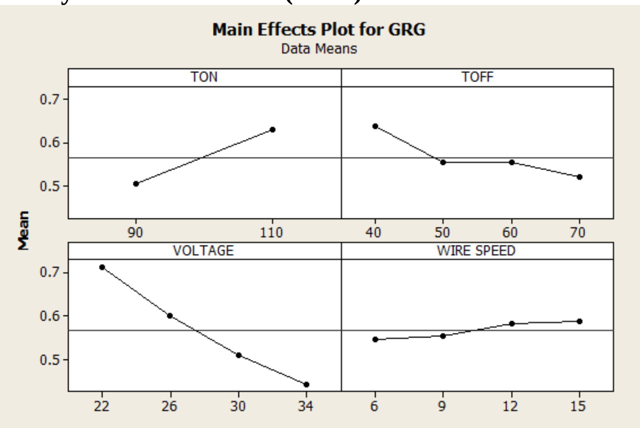


*Figure.5. Effect of control factors plot of SNR of GRG*

For the combined response maximization or minimization, fig.6 gives optimum value of each control factor. It interprets that level A2, B1, C1 and D4 gives optimum result. The mean of grey relational grade for each level of the other machining parameters can be computed in similar manner. The mean of grey relational grade for each level of the machining parameters is summarized and shown in following table.

*Table 7. Main effect of factors on Grey Relational Grade*

| Symbol | Control factor | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|---|
| A | Ton (µs) | 0.5043625 | **062864375** | | |
| B | Toff (µs) | **0.6367625** | 0.554575 | 0.5548375 | 0.5198375 |
| C | Voltage (V) | **0.71265** | 0.599375 | 0.510925 | 0.4430625 |
| D | Wire speed mm/sec | 0.5448625 | 0.553225 | 0.581475 | **0.58645** |

As we know that higher grey relational grade value will give optimum value of MRR, cutting forces, Temperature and surface roughness. So from above table 7, it is concluded that level-2 is higher for pulse on time and level-1 is higher for pulse off time and level-1 higher for voltage and level-4 higher for the wore speed. Thus it is revealed that response will be optimum at pulse on time 110 µs, pulse off time 40 µs, voltage 22 V and wire speed 15 mm/sec.

## VI CONFIRMATION TEST

The confirmation test is the final step of this experimentation. The purpose of conformation test is to validate the conclusion drawn during the analysis phase. In addition, the conformation test needs to be carried out in order to ensure that the theoretical predicted model for optimum results using the software is accepted and in order to verify adequacy of the models that are developed.

In our research study, material removal rate and kerf width has optimal combination are A2, B1, C1, D4 and A1, B1, C4, D4 respectively. Both this optimal combination are match in orthogonal array. So there are not required to confirmation for material removal rate and kerf width.

Estimated value of the surface roughness at optimum combination is A1,B4,C4,D2 which are not present in our present orthogonal array. Thus it have been calculated by adding the average performance to the contribution of each parameter at the optimum level using the following equations:

$$yopt = m+ (mAopt–m) + (mBopt–m) + (mCopt–m) + (mDopt –m)$$

$$m= T/ N$$

**Results of Confirmation Experiment for Surface roughness**

*Table 8 – Confirmation test*

| | OPTIMAL CONDITION | | |
|---|---|---|---|
| | **ESTIMATION** | **EXPERIMENT** | **DIFFERENCES** |
| **LEVEL** | A1B4C4D2 | A1B4C4D2 | |
| Surface roughness | **2.0587** | **2.0215** | 0.0372 |
| **S/N RATIO** | **-6.2719** | **-6.1135** | |

Table shows a comparison between the estimated value of surface roughness at optimum condition and the experimental value. A small difference 3.7 % (0.0372) can be observed between these values. This indicates that the experimental value is close the estimated value. Therefore, this verifies that the experimental result is highly correlated with the estimated result.

## VII CONCLUSION

Experimental investigation on wire electrical discharge machining of AISI52100 has been done using brass wire of 0.25mm. The following conclusions are made.

[1] From the S/N ratio plot the optimum parameter settings for material removal rate at, ie. Ton = 110 µs, Toff = 40 µs, Voltage = 22 V and wire speed = 15 mm/sec.

[2] It can also observed that Ton, Toff and Voltage is the most prominent factor affecting the Material removal rate.

[3] From the S/N ratio plot the optimum parameter setting for surface roughness at, ie. Ton = 110 µs, Toff = 70 µs, Voltage = 34 V and wire speed = 9 mm/sec.

[4] From the S/N ratio plot the optimum parameter setting for surface roughness at, ie. Ton = 90 µs, Toff = 50 µs, Voltage = 34 V and wire speed = 15 mm/sec.

[5] Based on the Grey relational analysis, the optimized input parameter combinations to get all responses like maximum material removal rate, the minimum surface roughness and the minimum kerf width are pulse on time 110 µs, pulse off time 40 µs, Voltage 22 V and wire speed 15 mm/sec.

[6] The Analysis of Variance resulted that the voltage has major influence on the surface roughness (µm) and kerf width (mm) in both the Taguchi optimization method and Grey relational analysis. Whereas the pulse on time has significant effect on the material removal rate.

[7] The objectives such as material removal rete, surface roughness and kerf width are optimized using a single objective taguchi method and multi objective grey relational analysis and the same has been validated with the experimental results.

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