THE EFFECTS OF TAGUCHI METHOD AND ANOVA IN OPTIMIZING PARAMETERS FOR ENHANCING POWER OPTIMIZATION FOR ELECTRICAL DISCHARGE

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ABSTRACT

Energy consumption in machining process is still a challenge in industries nowadays. A lot of new technologies have been invented to ease the machining and manufacturing process in industry. However, energy optimization in Electrical Discharge Machining (EDM) wirecut is still not fully figured out by manufacturers. The purpose of this experiment was to find the suitable parameter that was consumed for power optimization in EDM wirecut to cut the energy usage in machining process as it would affect the environment. Pulse on (Ton), pulse off (Toff) and cutting voltage (V) with 3 different levels were the variable parameters for this experiment which ranged between (1-16) µs, (6-300) µs and (2-255) V respectively. The outcome result that considered was the total power consumption, and material removal rate (MRR). In this experiment, material known as Stavax ESR (AISI420) was used as the workpiece to achieve the result of power optimization in EDM wirecut. In addition, the Design of Experiment was defined by using Taguchi method. This method was used to reduce the number of experiments, save energy, time and maximize the MRR value. The data analysis and optimization method used for this study was signal-to-noise ratio (S/N ratio) and ANOVA analysis. The most significant variable that was found is the Pulse-ON. The best machining parameters that are generated to produce the best results with minimum value of total power consumption and maximum value of MRR are Pulse ON= 5 µs, Pulse OFF= 52 µs and Voltage =3V.

Keywords: *Taguchi, Power consumption, MRR, WEDM, Stavax.*

1.0 INTRODUCTION

EDM wirecut is used widely in industry to cut complex design into a specific product at low number of production due to its slow cutting process. Automotive, medical and aerospace are the industries examples that used EDM wirecut in their production. However, the energy consumption in EDM wirecut is still not improved and uses more power for the cutting process. Even though the EDM machine is set on standby-on mode, it was found that certain minimum amount of electricity is still consumed during in that condition [1]. This study will evaluate the relation between the variable parameter which is Pulse on, pulse off and cutting voltage towards the dependent variable of the experiment which is the MRR and the total power consumption in the cutting process. Hence, the purpose of this experiment is to find the best parameter to use whereas to increase the power optimization during the cutting process in EDM wirecut while also maximizing the material removal

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rate (MRR) to maintain the quality of the product. The cutting process of EDM wirecut shown in Figure 1.

There are a few objectives that need to be determined for this experiment to accomplish the study of parameter optimization of wirecut EDM for power consumption. The objectives are as below:

i. To determine cutting conditions relations of Stavax ESR material in EDM wirecut by using Taguchi method as design of experiment (D.O.E.) with three different levels of factors.
ii. To optimize the best machining parameter value combination between cutting voltage, pulse on and pulse off that will reduce the power consumption of EDM wirecut during machining process.
iii. To analyze the parameters with the most significant parameter by using ANOVA to produce low energy consumption

There are a lot of optimization methods that can validate the process parameter to the purpose of the experiment such as Teaching learning-based optimization (TLBO), Taguchi, ANOVA, RSM and Graph theory and utility concept (GTUC)[2]. The Taguchi method was found to improve process performance with the least number of experiments. It is a need to reduce the cost of the experiment, cycle time and determine the desired result. A study shows that by using Taguchi method, the study only needs 9 experiments to be done to achieve the result [3]. The most influence parameter on the outcome is identified by the parameter with the biggest arithmetic difference between its highest mean S/N ratio value and its lowest mean S/N ratio value. The experimental parameters that result in the highest mean S/N ratios are considered as the parameter's ideal operating value [4,16].

Taguchi method provides an accessible and systematic approach to design optimization for cost, quality, and performance [2],[15]. The use of a loss function is recommended by the Taguchi design, which is further transformed into a signal-to-noise (S/N) ratio to measure the deviation between experimental and desired values. The S/N ratio is defined as the ratio of the mean value of quality characteristics of the response to the corresponding standard deviation. The level of each factor that could optimize the response can be determined using this ratio [6,7]. In the analysis of the S/N ratio, three categories of performance characteristics are considered: lower-the-better, higher-the-better, and nominal-the-better [8,9]. It is important to note that statistical analysis, usually carried out using analysis of variance (ANOVA), is typically performed to evaluate the statistically significant variables. Therefore, the determination of the optimum conditions for a process can be achieved by combining a Taguchi design with ANOVA analysis[10-12].

A study has shown that the higher MRR had occur when the machining time increase due to the increase of Ton value. High value of Ton producing large thermal energy which consume to higher energy use. In another study, The MRR was found increased as well as the increment of current at all levels by using the combination parameter of Pulse on time, pulse off time, voltage and wire tension [4],[5],[15]. Most of the studies that had been carried out resulted in the higher value of MRR are proportional with the current usage that led to higher energy consumption [6]. The MRR formula is Eq. 1.

$$MRR\left(\frac{mm^3}{min}\right) = F \times D_w \times H \quad (1)$$

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where;

F (mm/min) = Machine feed rate
F = (60l/t)
l (mm) = Cutting length
t (sec) = Machining time
D_w (mm)= Wire diameter
H (mm) = Workpiece thickness

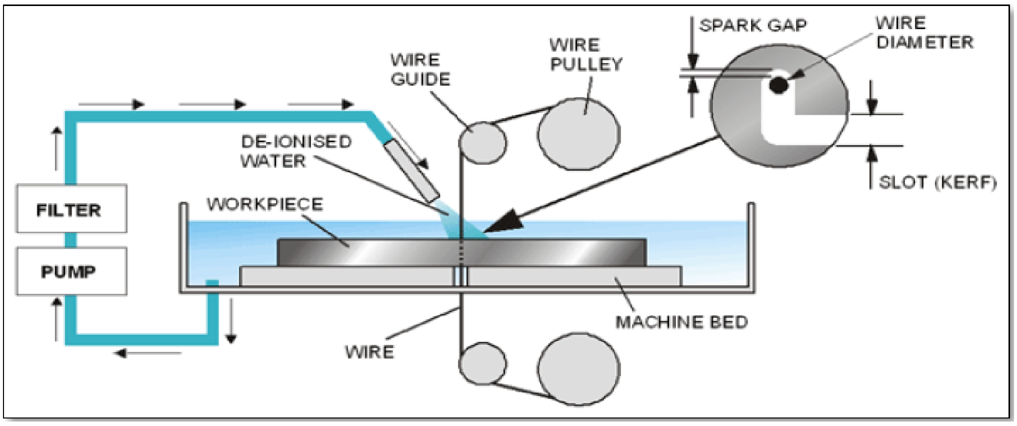

Figure 1: EDM wirecut cutting process

2.0 METHODOLOGY

The methodology starting with selecting design parameter which use pulse-ON, pulse-OFF and voltage as independent variable to generate dependent variable of power consumption and MRR. The material selection was Stavax ESR and the design of experiment was generated by using Taguchi Method. The information of power consumption and time taken was recorded to find the value of MRR. Taguchi method and ANOVA analysis was used to analyze the data and to determine the optimization parameter for the study. The flowchart of methodology shown in Figure 2.

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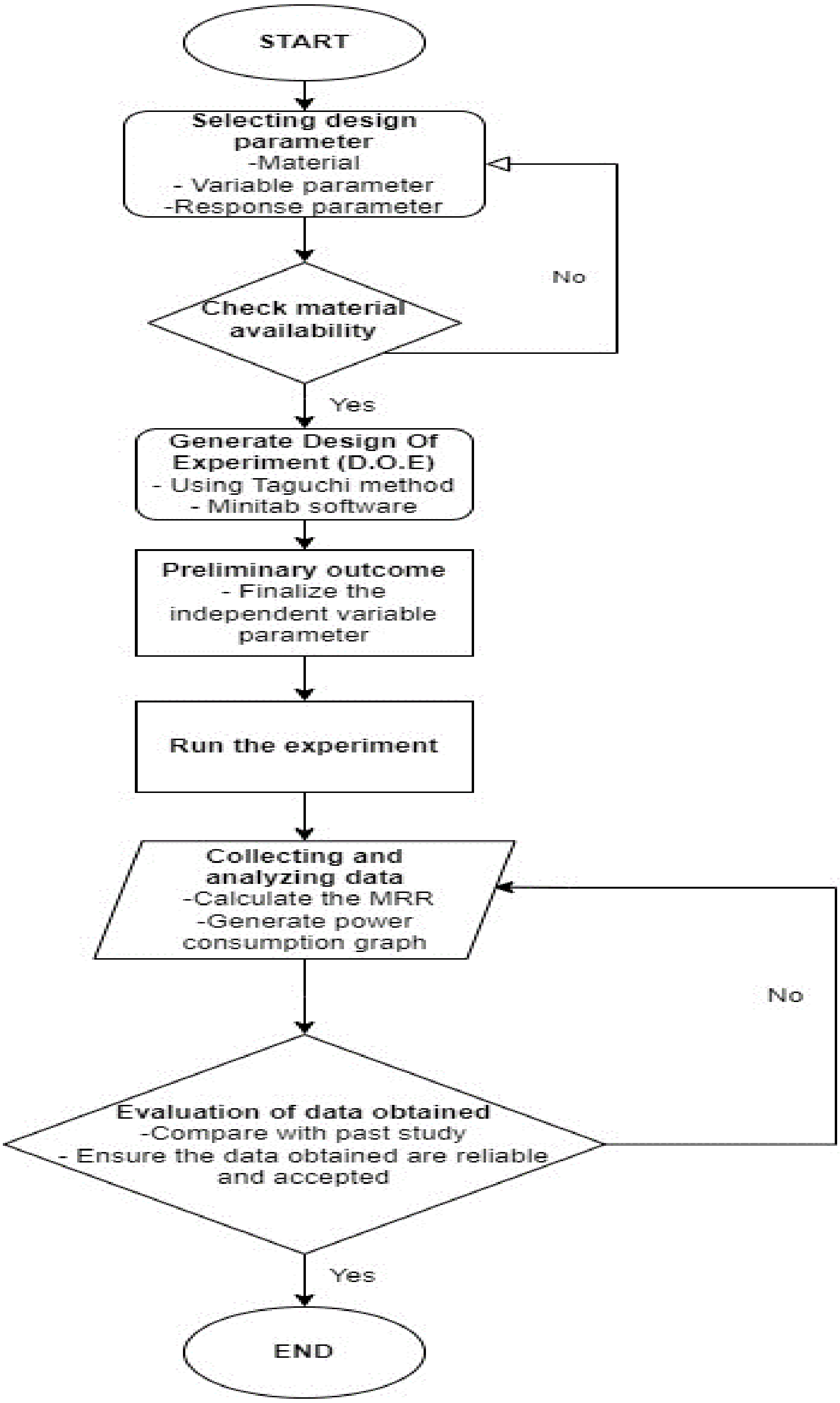

Figure 2: Flowchart of the study

2.1 Design of Experiment (D.O.E)

Taguchi method was selected as the Design of Experiment (D.O.E) in this study to determine the direction of the experiment in terms of the parameter used in the experiment and the cutting path generation for the specimen was straight path with 1cm of length and width.

Taguchi method is one of the D.O.E. that commonly used in experiments for optimization purpose at minimum number of experiments. A *regression analysis* provides an equation to predict new data and define the statistical connection between one or more

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predictors and the response variable. Regression analysis also determines the influence of one or more variables on another variable. Regression analysis estimates the coefficients or parameters of the regression equation, which represent the strength and direction of the relationship between the dependent variable and the independent variables. In regression analysis, the P-value will be highlighted to determine the significance of the independent variable towards the dependent variable which is MRR and total power consumption.

As the design of experiment method chosen was Taguchi method, the experiment design was created by using Minitab Statistical Software. In this study, 3 factors were chosen (voltage, pulse-on and pulse-off) with 3-different levels of each factor. By using the L9 orthogonal array (OA), the Taguchi method developed the experiment was only needed to run nine times with different parameters. Two dependent variables will be observed to achieve the objective which is the power consumption and MRR which then will be transformed into S/N ratio to evaluate the performance characteristic. The Taguchi method is inconsiderate to the variations of uncontrollable noise factors since it is more focused on the effects of variations towards quality characteristics rather than on the averages [5,13-14]. The cutting parameters were generated as Table 1.

Table 1: Cutting parameters

No. of experiment	Pulse ON (µs)	Pulse OFF(µs)	Voltage (V)
1	1	6	3
2	1	29	7
3	1	52	15
4	3	6	3
5	3	29	7
6	3	52	15
7	5	6	3
8	5	29	7
9	5	52	15

2.2 Experimental Equipment

The experiment involved three crucial pieces of equipment which is the machine, material and power analyzer. The machine used for the experiments is Fanuc Alpha-0Ic which is a model of CNC wire EDM machine. Meanwhile, Stavax ESR, a premium grade stainless steel was the material used in this experiment as Stavax is widely used in medical field which is the material for the sterile syringe. This equipment needs high hygiene which is compromised by Stavax ESR material with the properties of good corrosion resistance. A simple power analyzer (Fluke 345 PQ Clamp Meter) was used to measure the power consumed during the machining process.

3.0 RESULT AND DISCUSSION

Table 2 below shows the result obtained from the experiments done. A set of nine experiments with different parameters was performed to optimize the best machining parameter value combination between cutting voltage, pulse on and pulse off. The total power consumption during the machining process was calculated. The MRR of each parameter also had been determined to measure the best parameters that contribute to the maximum MRR value.

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Table 2: Experimental result and data

No. of experiment	Pulse ON (μs)	Pulse OFF(μs)	Voltage (V)	Time taken (sec)	Total power consumption (W)	MRR (mm³/min)
1	1	6	3	3019.2	38440.00	5.96
2	1	29	7	2280.0	40478.00	7.89
3	1	52	15	2400.0	37139.00	7.50
4	3	6	7	622.8	30194.00	28.90
5	3	29	15	261.0	39167.00	68.97
6	3	52	3	493.2	28243.00	36.50
7	5	6	15	432.6	32900.00	41.61
8	5	29	3	249.0	27676.00	72.29
9	5	52	7	251.4	28358.00	71.60

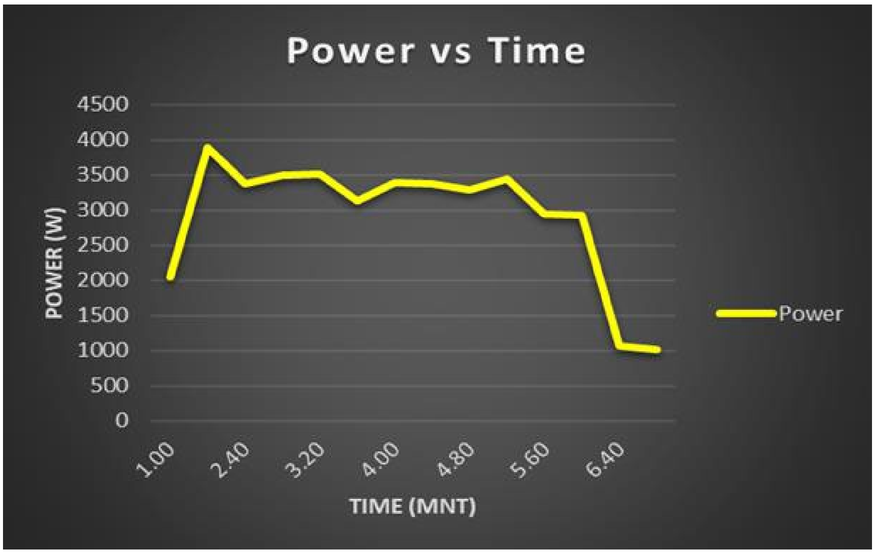

Figure 3: Total power consumption result for experiment 7

Figure 3 shows the total power consumption graph for experiment 7. The graph shows a sudden increment at the start of the cutting process. The sudden increment was caused by the increment of current used by the machine from rest condition to the desired current. The wobbling pattern as in the graph was indicating the Pulse-ON and Pulse-OFF value that been chosen for the parameter. The graph started to experience a rapid decrease after 5.60 minutes. The rapid decrease shows that the workpiece had been completely cut and the current is lowering back to initial condition.

3.1 ANOVA Analysis

The result of total power consumption and MRR was analyzed by using the Analysis of Variance (ANOVA) and Signal to Noise ratio (S/N). The ANOVA analysis will identify the significance and reliability of the factors towards the response output to improve the machining process in WEDM.

As for total power consumption, the General Linear Model obtaining the R-sq for Pulse ON, Pulse OFF and voltage factors are significant at 90.68% confidence level. Therefore, the independent variables can explain as much as 90.68% variance of the total power consumption. In GLM, the most important output that need to be determine is the variability in the parameter to provide an optimized result. A higher R-sq percentage indicates that a greater proportion of the variance is accounted for by the model, suggesting a better fit or stronger relationship. For MRR response variable, there are 89.99% of the

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variability that can be explained by the independent variable. As a conclusion, all the predictors had contributed to obtain a valid and accurate data that can be used to analyze the optimization of the MRR and total power consumption as in Table 3.

Table 3: Model summary for general linear model

Total power consumption	R-sq = 90.68%
MRR	R-sq = 89.99%

3.2 Regression Analysis

The significance of every factor also had been identified for the response output by comparing the P-value in the regression analysis. The P-value that is below 0.05% is considered as the most significant factor towards the model. The P-value of each factor for total power consumption regression analysis is as stated in Table 4. The pulse ON factor contributes to the P-value as much as 0.015 which is very significant compared to the other two independent factors. This result shows that pulse ON is a significant factor that affects the total power consumption compared to other factors which have P-value that is more than 0.05%.

Table 4: Regression analysis for total power consumption

Source	F-value	P-value	Contribution (%)
Pulse ON	13.19	0.015	56.35
Pulse OFF	1.09	0.344	4.65
Voltage	4.13	0.098	17.65

For MRR response variable, the pulse ON also had the lowest P-value among the independent variables which is 0.011 as in Table 5. This shows that Pulse ON is also the most significant factor that influences the MRR result. Pulse on also had the highest contribution in determining the MRR while voltage has the lowest contribution which is 0.07%.

Table 5: Regression analysis for MRR

Source	F-value	P-value	Contribution (%)
Pulse ON	15.22	0.011	72.14
Pulse OFF	0.86	0.395	4.10
Voltage	0.01	0.910	0.07

3.3 Optimization Machining Parameters

Total power consumption

By using Taguchi analysis, the optimization of machining parameters was determined. Based on Table 6, the response table for Signal to Noise ratios (S/N) had shown that the most influence factors that contribute to total power consumption was Pulse ON (µs) as the first rank, followed by Voltage (V) and Pulse OFF (µs). The values shown for each factor in every level are the indicator for the levels that should be chosen during the machining process. The highest value among the levels should be used. As example, Level-3 of Pulse ON factor had the highest value among other levels which is -89.41. So, level-3 of Pulse ON which is 5µs should be chosen during the machining process to produce a minimized result of total power consumption during machining process.

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Table 6: Response table for S/N ratio (power consumption)

Level	Pulse ON (µs)	Pulse OFF (µs)	Voltage (V)
1	-91.75	-90.55	-89.85
2	-90.16	-90.95	-90.27
3	-89.41	-89.82	-91.20
Rank	1	3	2

MRR

For MRR output, the 'larger is better' option was chosen as the higher value for MRR is better for machining performance. As shown in Table 7, the response table for S/N ratio of MRR had been generated. Pulse ON was ranked as the first factor that influences the MRR value during the machining and followed by Pulse OFF and voltage as the second and third rank respectively.

Table 7: Response table for S/N ratio (MRR)

Level	Pulse ON (µs)	Pulse OFF (µs)	Voltage (V)
1	16.99	25.70	27.98
2	32.41	30.63	28.09
3	35.55	28.61	28.89
Rank	1	2	3

Response optimization

Minitab software had generated a solution for the best combination of parameters to achieve the objectives of the study by using ANOVA analysis. Based on Table 8, the best machining parameter that should be chosen to produce the best results with minimum value of total power consumption and maximum value of MRR are Pulse ON= 5 µs, Pulse OFF= 52 µs and Voltage =3V. The composite desirability indicates the settings seem to achieve favorable results for all responses as a whole.

4.0 CONCLUSION

The optimization of WEDM for total power consumption and MRR research achieved its objectives. The cutting conditions relations of Stavax ESR material in WEDM had been determined by using 9 experiments with different parameters that generated by Taguchi method. Then, the best machining parameter value combination between cutting voltage, pulse on and pulse off had been optimized to reduce the power consumption of WEDM during the machining process as listed in Table 8 above. Lastly, it was found that pulse ON was the most significant parameter to produce low energy consumption. By using ANOVA method, the most significant parameter was found and can be used for future research. Overall, all the data was acceptable and achieved the objectives of this study.

Table 8: Response optimization

Pulse ON (µs)	Pulse OFF (µs)	Voltage (V)	Total power consumption fit (W)	MRR fit (mm³/mi)	Composite Desirability
5	52	3	25101	62.7872	0.9256

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this paper.

REFERENCES

[1] Straka, L., & Kuchta, P. (2021). Quality optimization of the machined surface in terms of electric energy consumption in the WEDM process. *MM Science Journal*.

[2] Said, M. S. M., *et al.* (2021). Comparison between Taguchi method and response surface methodology (RSM) in optimizing machining condition. *International Conference on Robust Quality Engineering*.

[3] Sathiyaraj, S., *et al.* (2020). Wire electrical discharge machining (WEDM) analysis into MRR and SR on copper alloy. *Materials Today: Proceedings, 33*, 1079–1084.

[4] Reddy, M. C., *et al.* (2021). An experimental investigation and optimization of energy consumption and surface defects in wire cut electric discharge machining. *Journal of Alloys and Compounds, 861*, 158582.

[5] Noor, R. M., Ramli, M. I., Zubair, A. F., Hemdi, A. R., & Kataraki, P. (2022). Optimization of cutting parameters to improve power consumption and material removal rate in high efficiency milling. *Journal of Mines, Metals and Fuels, 69*(12A), 164.

[6] Soundararajan, R., Ramesh, A., Mohanraj, N., & Parthasarathi, N. (2016). An investigation of material removal rate and surface roughness of squeeze casted A413 alloy on WEDM by multi response optimization using RSM. *Journal of Alloys and Compounds, 685*, 533–545.

[7] Okolie, J. A., *et al.* (2021). Modeling and process optimization of hydrothermal gasification for hydrogen production: A comprehensive review. *The Journal of Supercritical Fluids, 173*, 105199.

[8] Thamizhmanii, S., Saparudin, S., & Hasan, S. (2007). Analyses of surface roughness by turning process using Taguchi method. *Journal of Achievements in Materials and Manufacturing Engineering, 20*, 503–505.

[9] Nalbant, M., Gökkaya, H., & Sur, G. (2007). Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning. *Materials & Design, 28*, 1379–1385.

[10] Choudhary, S., Kant, K., & Saini, P. (2013). Analysis of MRR and SR with different electrode for SS 316 on die-sinking EDM using Taguchi technique. *Global Journal of Researches in Engineering Mechanical and Mechanics Engineering, 13*(3).

[11] Tyagi, Y., *et al.* (2012). Parametric optimization of CNC drilling machine for mild steel using Taguchi design and single to noise ratio analysis. *International Journal of Engineering Science and Technology, 4*(8), 3758–3766.

[12] Raju, B. N., Rao, C. M., & Kumar, B. B. A. (2018). Application of signal-to-noise (S/N) ratios and ANOVA for the prediction of optimal designs of multiple performance characteristics. *Journal of Industrial Mechanics, 3*(2), 1–9.

[13] Abhishek, & Sorout, N. (2020). Multi objective optimization of process parameters on MRR and TWR in EDM for EN 353 material using Grey-Taguchi method. *International Journal of Engineering Research & Technology, 9*(4), 178–182.

[14] Goyal, S., Kandra, V. S., & Yadav, P. (2016). Experimental study of turning operation and optimization of MRR and surface roughness using Taguchi method. *International Journal of Innovative Research in Advanced Engineering, 3*, 44–50.

[15] Gupta, M., & Kumar, S. (2015). Investigation of surface roughness and MRR for turning of UD-GFRP using PCA and Taguchi method. *Engineering Science and Technology, an International Journal, 18*, 70–81.

[16] Chaudhari, S., Nikalje, A. M., & Chaudhari, G. E. (2024). Optimizing material removal rate and surface roughness by utilizing Taguchi and TOPSIS approaches. *Interactions, 245*, 187.

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