ME 794 Project Progress Report

Study of the Parameters in Wire EDM through Design of Experiments

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Background and motivation:

Wire Electrical Discharge Machining (WEDM) is a vital non-traditional machining process for creating complex shapes in conductive materials with high precision. A key performance metric in WEDM is the Material Removal Rate (MRR), which is influenced by several machining parameters including pulse-on time, pulse-off time, discharge current, voltage, wire tension, wire feed rate, and duty cycle.

Despite its importance, WEDM is a complex process with numerous interacting variables, making it challenging to achieve optimal performance. While previous research has explored the effects of various parameters on MRR, a comprehensive understanding and optimization remain ongoing efforts. This course project in "Statistical Design of Experiments" aims to address these knowledge gaps by systematically investigating the impact of selected input parameters on the MRR using statistical methodologies.

Objectives:

The overall goal of this project is to investigate the effect of various input parameters in the Wire EDM process on the Material Removal Rate (MRR) using a statistical Design of Experiments (DOE) approach.
The specific objectives of this project are to:

• Identify the significant input parameters (wire feed, pulse on and off time, voltage) that have a statistically significant effect on the Material Removal Rate (MRR) in the Wire EDM process.
•Understand the main effects of each significant input parameter on the MRR.
•Explore potential interaction effects between the input parameters.
•Develop a statistical model to predict the Material Removal Rate (MRR).
•Check the validity of the developed model.
•Identify optimal or near-optimal settings for the significant input parameters to achieve a desired MRR.

Tasks/Plan :

Task 0: Literature Review and Preliminary Trials

- Conduct preliminary trials to verify the feasibility of parameter settings

Task 1: Design of Order of Experiments

- Use a **2^4 full factorial design** (16 unique runs, 2 replicates → 32 total experiments).
- Randomize run order to avoid influence of unknown factors and to minimize bias from machine warm-up or environmental drift.
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Task 2: Experiment Execution

- Use AccuteX AU-300iA Wire EDM machine to conduct all 32 experiments on Aluminium sheet of thickness 2 mm
- Measure Material Removal Rate (MRR) for each experiment in a following formula:
  - kw (kerf width) -

- loc (length of cut)
- t (thickness) = 2 mm

$$\text{MRR} = \frac{(kw \times loc \times t) + (\frac{\pi}{2} \times (\frac{kw}{2})^2 \times t)}{time}$$

Task 3: ANOVA Statistical Analysis

- Identify significant main effects and first order interaction effects on MRR
  SubTask : Check Assumptions of ANOVA
    - Normality of Residuals (Use a Normal Probability Plot of residuals ,if points follow a straight line, normality holds)
    - Independence of Residuals (Residuals vs. Time Plot: Residuals should be randomly scattered)
    - Homogeneity of Variance (Residuals vs. Fitted Values Plot should be structureless)
- If p-value < 0.05, the factor significantly affects MRR (**95 % confidence Interval is considered**)
- Interaction Plots to understand dependencies.
- Develop a Regression model to predict MRR based on significant factors and their interaction.

$$MRR=\beta0+\beta1 \cdot Ton+\beta2 \cdot Toff+\beta3 \cdot V+\beta4 \cdot WF+\beta5 \cdot (Ton\times Toff)+\beta6 \cdot (Ton\times V)+\beta7 \cdot (Ton\times WF)+\beta8 \cdot (Toff\times V)+\beta9 \cdot (Toff\times WF)+\beta10 \cdot (V\times WF)+\beta11 \cdot (Ton\times Toff\times V)+ \ldots\ldots+\beta14 \cdot (Toff\times V\times WF)+\beta15 \cdot (Ton\times Toff\times V\times WF) + \text{Error (residual)}$$

Perform model validation using R^2 statistic and prediction error analysis

Task 4: Validation and Optimization

- Identify optimal parameter settings for maximum MRR
- Confirm model predictions with 3 validation runs at optimal settings

Experimental Design

Resources & Equipment:

Material: Aluminium sheet (Thickness = 2mm) (acquired from MTL)
Machine: AccuteX AU-300iA Wire EDM Machine (MTL)
Digital Microscope: Elikliv (High Performance & Sustainable Manufacturing Lab)

Independent Variables:

Input Parameters (variable) : (All input parameters are considered for 2 levels as follows)

1) Ton (Pulse on Time) = 600 ns, 1050 ns
2) Toff (Pulse off time) = 4us, 9us
    - Pulse duration controls how long the electrical discharge lasts. A longer pulse duration may lead to deeper sparks, affecting material removal and surface finish
3) V (open circuit voltage) = 83V, 110V
    - The applied voltage controls the discharge energy in the EDM process, affecting the spark intensity and the material removal rate
4) WF (Wire Feed) = 92mm/s, 205 mm/s

- A higher wire feed rate generally increases MRR by improving cutting speed and debris removal, but beyond an optimal limit, it can cause wire breakage or instability. A lower wire feed rate reduces MRR due to inefficient material removal and poor flushing

Constant Parameters (kept constant during experiment):

5) Ip (AC Low energizing fine finish cutting)
6) Cutting Speed
7) Wire Tension, Wire Material, Wire Diameter
8) Dielectric fluid type and it's flow rate

Output Parameter(Dependent Variable) (Response): MRR (Material Removal rate)

Permissions were acquired from MTL and preliminary experiments were conducted under the supervision of Mr. Arun Nair

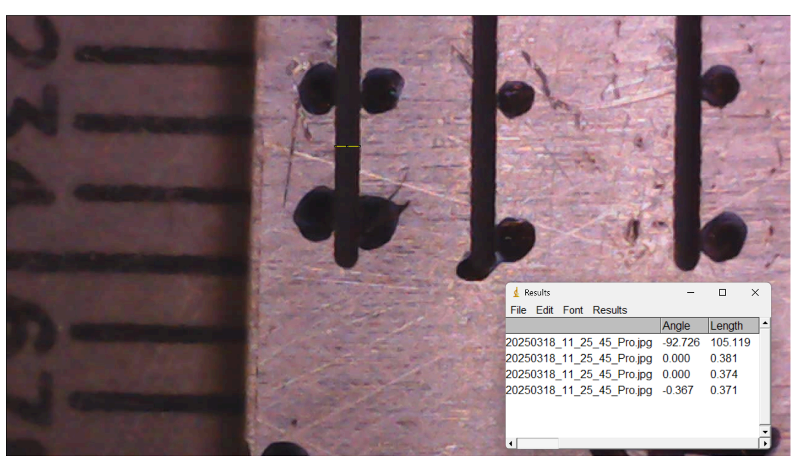
For preliminary trails, wire feed was kept constant (92 mm/s). Following are the set of parameters we chose to vary for the 4 trials:

1. Ton
2. Toff
3. Voltage

Sr. No.	Ton (ns)	Toff (µs)	Voltage (V)	Time (s)	Kerf Width (mm)	MRR (mm^3/s)
1	1050	4	110	311	0.384	0.025067
2	1050	4	83	307	0.381	0.025192
3	600	4	83	307	0.374	0.024722
4	600	9	83	308	0.371	0.024442

Length of cut (loc) = 10 mm
Thickness (t) = 2 mm
For the first run, wire breakage was observed.

Post-processing:



A digital microscope was utilized to capture the images of the machined sample and ImageJ software was used to measure the kerf width for each run. Since the image processing software involves manually placing the line for measurements, it could introduce significant sources of error.

Potential Sources of Variability & Control Strategies:

Source of Variability	Impact on Experiment	Control Strategy
Machine warm-up effects	MRR may fluctuate due to thermal expansion	Randomize run order to distribute effects evenly
Environmental factors (temperature, humidity)	Affects dielectric fluid properties, machining stability	Conduct experiments in a controlled lab setting
Wire electrode wear	Alters cutting precision over time	Use new wire for each experimental run
Measurement error	Inconsistent MRR calculations (due to human error)	Use calibrated measuring instruments and repeat measurements

Blocking Strategy: To reduce the effect of uncontrollable variations, the experiment will be blocked based on:

- Workpiece Material Batch – Different material batches can introduce variability, so experiments will be conducted in a single batch per block.

Replication Strategy : Each run will be replicated two to three times to account for correct estimation of error.

Expected outcomes

- Factor Significance: Identification of dominant parameters (e.g., ton and voltage likely critical).
- Interaction Effects: Discovery of key interactions (e.g., ton×toff affecting debris accumulation).
- Predictive Model: Equation to estimate MRR with ±5% accuracy.

References

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2. Ramakrishnan, R., & Karunamoorthy, L. (2005). Multi-response optimization of wire EDM operations using robust design of experiments. *The International Journal of Advanced Manufacturing Technology*, DOI: 10.1007/s00170-004-2496-6. Springer-Verlag London Limited.

3. Kanlayasiri, K., & Boonmung, S. (2007). Effects of wire-EDM machining variables on surface roughness of newly developed DC 53 die steel: Design of experiments and regression model. *Journal of Materials Processing Technology*, 192–193, 459–464.