



E-ISSN: 2664-8784
 P-ISSN: 2664-8776
 Impact Factor: RJIF 8.26
 IJRE 2025; 7(2): 171-177
 © 2024 IJRE
www.engineeringpaper.net
 Received: 13-07-2025
 Accepted: 25-08-2025

Kwang Song Kim
 Institute of Robotic
 Technology, Kim Chaek
 University of Technology,
 Kyogu-60, Sungni Street,
 Pyongyang, Democratic
 People's Republic of Korea

Yong Nam U
 Institute of Robotic
 Technology, Kim Chaek
 University of Technology,
 Kyogu-60, Sungni Street,
 Pyongyang, Democratic
 People's Republic of Korea

Su Nam Choe
 Institute of Robotic
 Technology, Kim Chaek
 University of Technology,
 Kyogu-60, Sungni Street,
 Pyongyang, Democratic
 People's Republic of Korea

Su Gyong Ryang
 Institute of Robotic
 Technology, Kim Chaek
 University of Technology,
 Kyogu-60, Sungni Street,
 Pyongyang, Democratic
 People's Republic of Korea

Correspondence
Kwang Song Kim*
 Institute of Robotic
 Technology, Kim Chaek
 University of Technology,
 Kyogu-60, Sungni Street,
 Pyongyang, Democratic
 People's Republic of Korea

Simulation of spark discharge characteristic in electric discharge machine using double pulse power

Kwang Song Kim, Yong Nam U and Su Nam Choe

DOI: <https://www.doi.org/10.33545/26648776.2025.v7.i2c.124>

Abstract

Electrical discharge machine (EDM) is one of the widely used manufacturing methods in aerospace industry and difficult-to-machine materials field. But the research on theoretical basis and machining mechanism of EDM is insufficient. This paper presents a new method for increasing the material removal rate (MRR) in EDM by introducing composite pulse power with pre-ignition excitation voltage and end pulse inrush current. The pre-ignition excitation voltage provides high effect of spark discharge and end pulse inrush current effectively reduces the thickness of the recast layer. In order to prove this effectiveness, experiment and simulation is invested. Spark discharge characteristics are studied based on the simulated model of composite pulse power in MATLAB/SIMULINK environment. Also experiments show that pre-ignition voltage excitation of the pulse produces effective spark pulses and end pulse inrush current decrease recast layer. Finally introduction of composite pulse power in EDM can provide higher material removal rate than traditional single pulse power.

Keywords: EDM, spark discharge, pulse generator, composite pulse power, pre-ignition excitation voltage, end pulse inrush current

Introduction

Electrical discharge machining (EDM) is one of the most widely used machining methods as an important component of advanced manufacturing technologies with its unique machining advantages [1]. EDM uses the heat generated by spark discharge to cut work-piece and it is capable of processing high-brittleness, high-toughness, high-strength, and high-hardness conductive material [1]. Also, EDM is a kind of non-contact processing technology and has no macro cutting force during processing [2, 3]. So it is capable of processing a variety of complex surfaces, narrow slit, and low rigidity parts and can guarantee good processing surface quality and machining accuracy [4, 5]. Therefore, unique processing advantages of EDM make it to be an extremely important and irreplaceable processing means in aerospace industry, new materials industries, mold industry, and other fields [6, 7]. But research on theoretical basis and mechanism of EDM is still in an unfledged stage and it has been becoming a serious obstacle to its further improvements [8, 9]. The working principle of EDM process is based on the thermoelectric energy created between a work-piece and an electrode submerged in a dielectric fluid with the passage of electric current [10, 11].

When pulse voltage is applied between tool electrode and work-piece, electric field is formed between two poles. The electric field strength is proportional to voltage and inversely proportional to distance between two poles [12]. Electric field strength increases when voltage increases or distance decreases. When electric field strength of cathode surface reaches the breakdown field strength, field-induced electron emission will occur and electrons escape from the cathode surface. Under the effect of electric field, electrons move toward anode at high speed and collide with molecules or neutral atoms in dielectric fluid to produce collision ionization.

Negatively charged particles and positively charged particles (positive ions) are formed, which leads to an avalanche of charged particles, so that dielectric fluid is broken down and a discharge channel forms [12]. Then, dielectric fluid in gap would be vaporized because of instantaneous high temperature caused by sudden rise of current. Then, some hydrocarbons in dielectric fluid are decomposed into H₂ and C particles. With the vaporization and thermal decomposition of dielectric fluid, a metal material is also melted until boiled. Volume of

dielectric fluid after thermal decomposition and metal vapor increases instantaneously, so the molten and vaporized metal material is thrown out. After the metal material is removed, erosion pits are formed on tool electrode and work-piece. As pulse voltage drops to zero, pulse current drops rapidly to zero. The dielectric fluid is deionized and discharge is over. Some parameters that affects the EDM process include discharge voltage, frequency of current, gap between tool electrode and work-piece, ignition delay time, pulse on time, pulse off time, properties of dielectric fluid, conductivity of electrodes, eroding area etc^[11].

Presently, there is no unified comprehension about mechanism of EDM due to its complexity and particularity. EDM technology is still facing a big bottleneck

problem unsolved: low molten material removal rate, resulting in low machining speed and poor surface quality^[15].

In this paper, a composite pulse power with pre-ignition excitation voltage and end pulse inrush current is proposed in EDM, and the effect of removing recast layer by the action of end pulse inrush current and the enhancement of discharge efficiency by the introduction of pre-ignition excitation voltage is simulated and experimental verified.

2. A Method of discharge pulse power in EDM using a composite pulse power and its experiment

2.1 Composite pulse power with pre-ignition excitation voltage

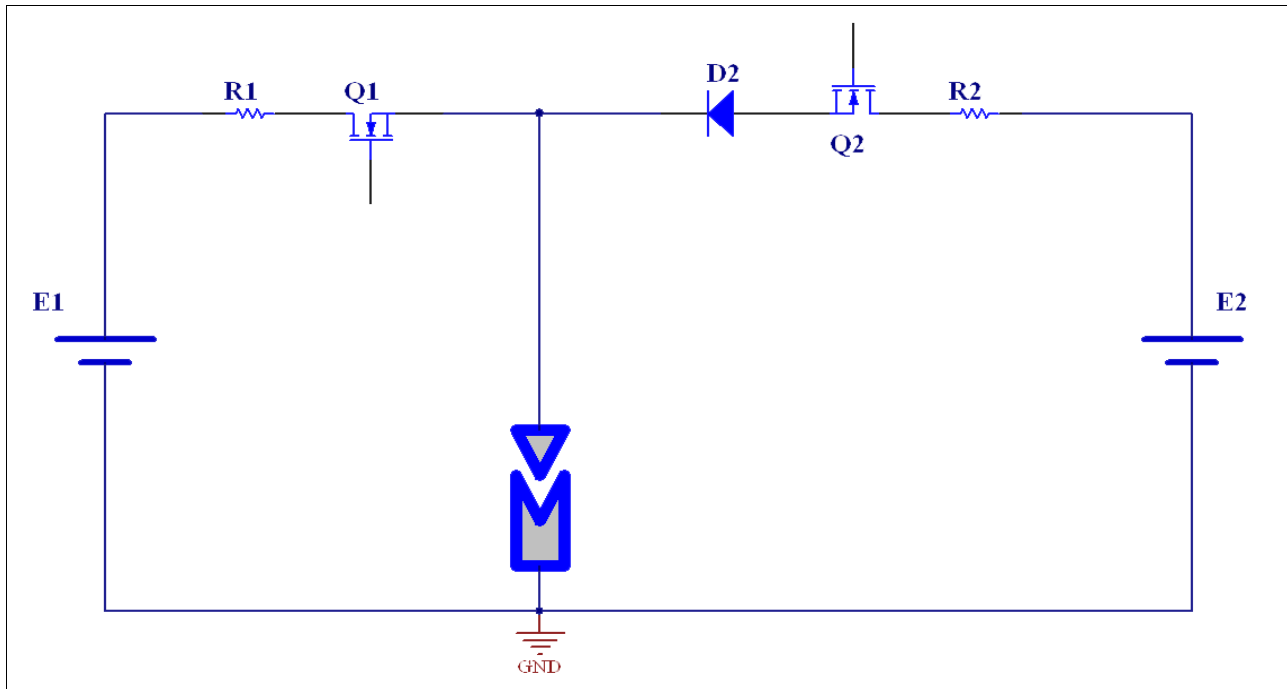


Fig 1: Composite pulse generator with pre-ignition excitation voltage

Fig. 1 shows the composite pulse generator with pre-ignition excitation voltage.

The composite pulse power with pre-ignition excitation voltage in EDM consists of a high-voltage switched discharge circuit and a low-voltage switched discharge circuit.

The high-voltage switching discharge circuit consists of a switch Q1 that switches the high-voltage source and a current-limiting resistor R1, which acts to form the pre-ignition excitation voltage at the beginning of the discharge. At the beginning of the discharge, an electric field is needed to break the dielectric liquid and form the discharge channel, which is the larger the gap voltage, the higher the dielectric liquid breakdown rate and the shorter the

discharge breakdown delay time.^[14] Hence, it combines high voltages (140-300 V) greater than the magnitude of the open discharge voltage (80-100 V) used in conventional single pulse power supply. High voltage pulses are only excited during discharge initiation and not during discharge.

The low-voltage switching discharge circuit consists of a switch Q2 that switches the low-voltage source, a current limiting resistor R2, and a diode D2 that separates the high voltage and low voltage sources. The low-voltage switching discharge circuit provides the main current of the discharge as in the single pulse source. Fig. 2 shows the discharge voltage and discharge current profiles in the discharge gap in an EDM using a composite pulse power with pre-ignition excitation voltage.

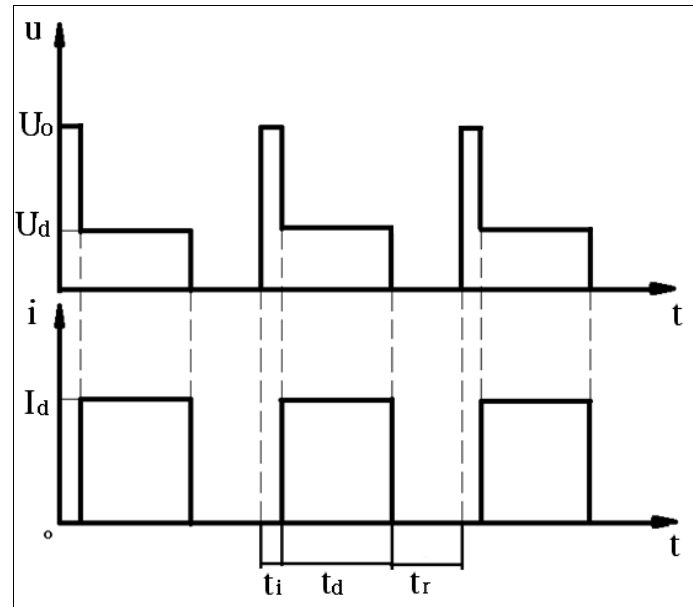


Fig 2: Discharge voltage and discharge current profiles in the discharge gap in an EDM using a composite pulse power with pre-ignition excitation voltage

In Fig. 2, the discharge voltage in the discharge gap is turned on the switches Q1 and Q2 simultaneously during the ignition time t_i to open circuit voltage u_0 , which is represented by the voltage of the high voltage source. The voltage of the high voltage source is high enough to exceed the breakdown voltage of the dielectric fluid, so that the insulation of the gap is broken down to form the discharge channel. During the discharge time t_d , the switch Q1 is turned off and Q2 still remains open, so that the main current of the discharge current is flowing through the low-voltage switching discharge circuit. During the recovery time t_r , the switches Q1 and Q2 are closed, so that the insulation of the gap is recovered and this process is repeated. The use of composite pulse power with the pre-ignition excitation voltage can increase the rate of breakdown of the dielectric liquid and shorten the ignition delay time, thus increasing the material removal rate.

2.2 A composite pulse power with end pulse inrush

current

The advantage of the composite pulse power with end pulse inrush current is that high pulse current is applied at the end of the discharge period, effectively removing the recast layer on the surface of the work piece, thus increasing the material removal rate. In conventional EDM, only 1-20% of the molten material is removed and most of the molten material remains on the surface of the discharge crater to form the recast layer^[15].

This phenomenon causes the whole machined surface to be covered by countless of discharge craters to form a thick recast layer, which leads to a slow machining rate and a decrease in machined surface quality.^[15]

To solve this problem, a method of delivering inrush current at the end of the discharge cycle is presented. Fig. 3 shows the discharge current waveforms in the conventional EDM and EDM with the combination of the front, middle and end inrush currents.

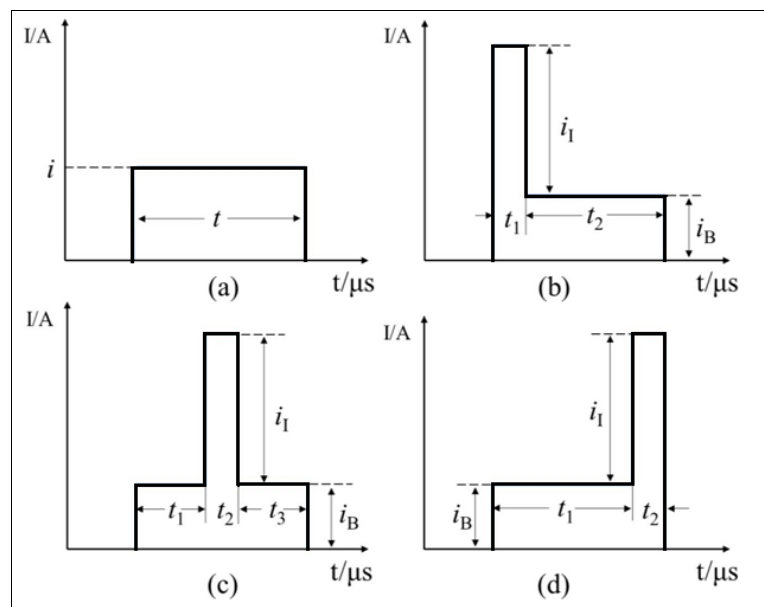


Fig 3: Discharge current during conventional pulse power and composite pulse power with end pulse inrush current

- (a) discharge current in EDM using conventional pulse power
- (b) discharge current in EDM using composite pulse power with inrush current located in front (c) discharge current in EDM using composite pulse power with inrush current located in middle (d) discharge current in EDM using composite pulse power with inrush current located in end

In Fig. 3, (a) is the discharge current waveform in the conventional EDM using a single pulse power, and (b), (c) and (d) show the discharge current waveform in the EDM when a pulse power with an inrush current in front, middle and end of the discharge period is used.

Here i_b is the main discharge current, and i_i is the inrush current in front, middle, and end. Through repetitive experiments, the researchers verified that EDM with end inrush current had the smallest recast layer thickness. ^[15]

2.3 Composite pulse power with pre-ignition excitation voltage and end pulse inrush current

We propose a composite pulse power with an end pulse inrush current and the pre-ignition excitation voltage that can increase the breakdown rate of the dielectric fluid and remove effectively that removal of the recast layer. Fig. 4 shows a composite pulse power that combines the pre-ignition excitation voltage and the end pulse inrush current.

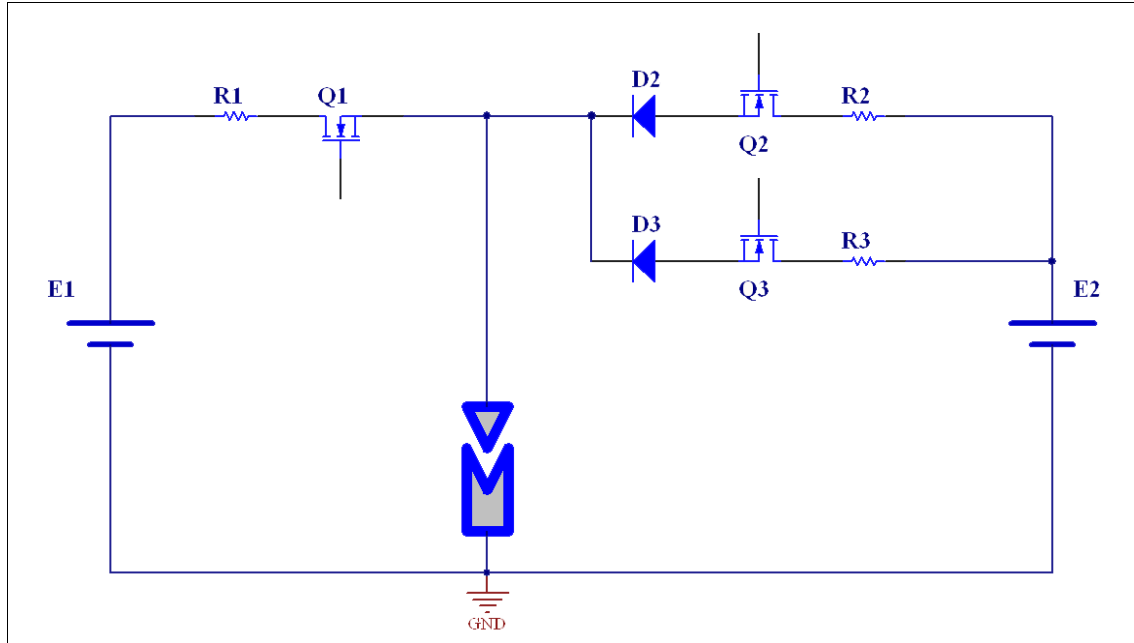


Fig 4: The composite pulse power with pre-ignition excitation voltage and end pulse inrush current

3. Simulink and Results in MATLAB/SIMULINK

3.1 Equivalent model and simulation of discharge pulse power

Spark discharge gap could be equivalent with gap equivalent resistor (R_g) in series with gap equivalent inductor (L_g). The principles of determining values of R_g and L_g , are as follows.

First, gap impedance is calculated according to gap voltage and gap current after gap breakdown. Second, L_g is determined by duration of gap voltage and gap current, and gap peak current. (Eq. 1)

$$\begin{cases} R_g = \frac{u_o - u_d}{i_d} \\ L_g = \frac{t_d}{\int_0^i \frac{di_d}{u_d - i_d R_g}} \end{cases} \quad (1)$$

Using MATLAB/SIMULINK, a model of the discharge pulse power in EDM using a composite pulse power is constructed and simulated.

Table 1 gives the parameters used in MATLAB/SIMULINK and Fig 5 shows simulation model.

Table 1: Parameters of simulation model

parameter	signal	value
High voltage(V)	V_h	140
Low voltage(V)	V_l	85
Pulse on(us)	T_{on}	70
Pulse off(us)	T_{off}	30
Ignition time (us)	T_d	10
Limiting resistor of high power(Ω)	R_1	300
Limiting resistor of low power(Ω)	R_2	15
Limiting resistor of inrush current(Ω)	R_3	1
Discharge resistor(Ω)	R_d	6
Discharge inductor(uH)	L_d	1

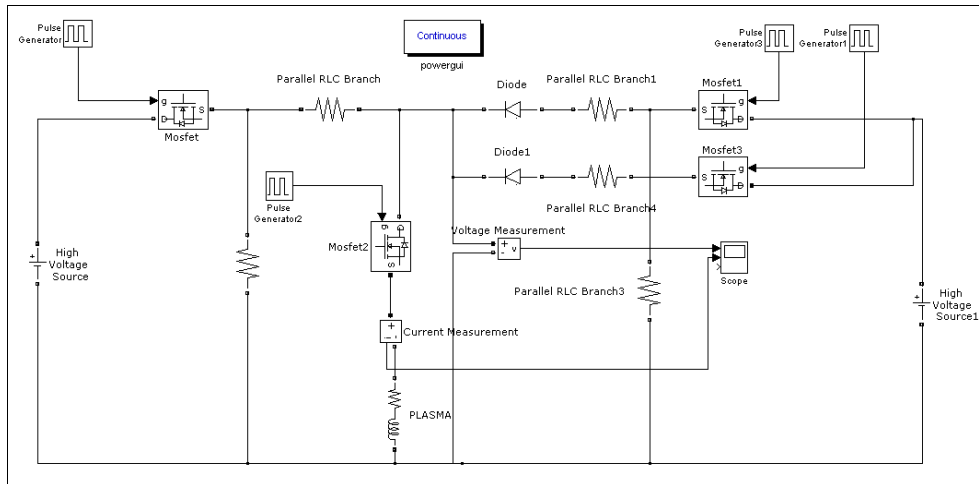


Fig 5: Simulation model of pulse power in EDM using composite pulse power

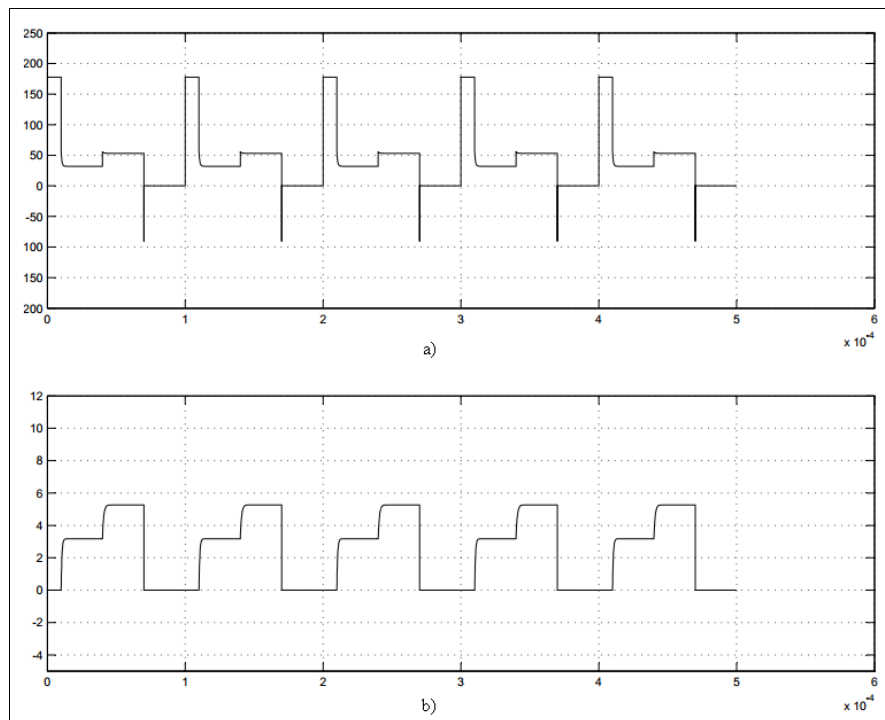


Fig 6: Simulation result, (a); discharge voltage waveform (b) discharge current waveform.

3.2 Simulation Results and Discussion

The simulation results are shown in Fig. 6. The simulation results show the current waveforms in the discharge gap shown in Fig. 3. The pre-ignition excitation voltage was applied at the beginning of the discharge, the main discharge current was provided after ignition, and an inrush current was observed at the end. At the beginning of the discharge, the pre-ignition excitation voltage is applied, which breaks down the dielectric fluid insulation for $10\mu s$, and then the main discharge current begins to flow. An inrush current flows for $30\mu s$ at the end of the discharge. During the inrush current, an increase in the discharge voltage was observed because the discharge gap was equivalent to a fixed resistance and inductance. Through this simulation, the effect of the pre-ignition excitation voltage at the beginning of the discharge and the inrush current action at the end of the discharge are considered.

4. The Experiment and results in EDM using composite pulse power with the pre-ignition excitation voltage and

the end pulse inrush current

4.1 The Experiment in EDM using composite pulse power with the pre-ignition excitation voltage and the end pulse inrush current.

In order to verify the superiority of EDM with composite pulse power, which combines the pre-ignition excitation voltage and the end pulse inrush current, a comparison experiment with the conventional single-pulse power is carried out on the die sinking EDM machine for material removal rate. The high voltage of EDM machine is 140 V, low voltage is 85 V, and the low voltage pulse power is adjustable from 0 to 60 A.

The applying of pre-ignition excitation voltage is $10\mu s$, the magnitude of the end pulse inrush current is set to the maximum current value (60 A) of pulse power and its duration is $30\mu s$. The composition of the alloy work piece used in the experiment is shown in Table 2

Also, kerosene was used as a dielectric fluid and commercial copper was used as a tool.

Table 2: The composition of the alloy work piece used in the experiment

material	C	Cr	Ni	Mo	V
Weight (%)	0.38	1	1	0.2	0.2

In the experiment, the material removal rate (MRR) is considered separately for different conditions with and without pre-ignition excitation voltage and with and without end pulse inrush current.

The calculation method of material removal rate can be found by the following equation:

$$MRR = \frac{V_b - V_a}{t} \quad (2)$$

Here

V_b - Volume of material before processing

V_a - Volume of material after processing

t - Machining time

Each experiment is compared by measuring the time taken for 40 mm drilling in a rough regime (high discharge current and long pulse time) using a cylindrical tool of 10 mm diameter.

4.2 Experimental Results and Discussions

In the experiment, the factors affecting material removal rate are mainly the discharge current and pulse-on time, and the pulse-off time does not significantly affect the process.

Hence, experiments are carried out with different discharge currents and pulse-on times.

The experimental results are shown in Table 3.

Table 3: experimental results

No	Discharge current (A)	Pulse on (μ s)	Pulse off (μ s)	MRR1 (mm ³ /min)	MRR2 (mm ³ /min)	MRR3 (mm ³ /min)
1	20	100	120	12.79	20.37	25.73
2	20	200	120	19.24	24.33	31.33
3	20	300	120	23.12	26.87	35.64
4	30	100	120	21.45	30.28	42.49
5	30	200	120	31.86	36.55	55.30
6	30	300	120	33.38	39.18	58.42
7	40	100	120	32.18	45.45	47.54
8	40	200	120	48.02	57.60	70.68
9	40	300	120	64.25	69.74	94.38

As shown in Table 3, the experiments were carried out with the discharge current varying 20, 30 and 40 A, pulse-on time of 100, 200 and 300 μ s, and the pulse-off time fixed at 120 μ s. MRR1 is the material removal rate when conventional single pulse power is used, MRR2 is the material removal rate when the pre-ignition excitation voltage is applied, and MRR3 is the material removal rate when the pre-ignition excitation voltage and the end pulse inrush current are introduced. The experimental results in the table clearly show the increase of the material removal rate by the introduction of the pre-ignition excitation voltage and the introduction of the end pulse inrush current. Table 4 shows the growth rate of the material removal rate of each experiment.

Table 4: The growth rate of the material removal rate

No	Discharge current (A)	Pulse on (μ s)	Pulse off (μ s)	MRR2/MRR1	MRR3/MRR1
1	20	100	120	1.59	2.01
2	20	200	120	1.26	1.63
3	20	300	120	1.16	1.54
4	30	100	120	1.41	1.40
5	30	200	120	1.15	1.51
6	30	300	120	1.17	1.49
7	40	100	120	1.41	1.04
8	40	200	120	1.20	1.23
9	40	300	120	1.09	1.35

As can be seen in Table 4, the effectiveness of applying the pre-ignition excitation voltage and the end pulse inrush current is significant. When only the pre-ignition excitation voltage is applied, the material removal rate is increased by a maximum of 1.59 times, especially when the pulse-on time is 100 μ s, the effect is all more than 1.41 times higher. However, the increase rate is 1.09-1.17 times less effective when the pulse-on time is 300 μ s. This indicates that the reason for this effect is the effective spark discharge during the initial discharge and the short ignition time.

Also, with the introduction of the pre-ignition excitation voltage, the material removal rate increased by a maximum of two times with the introduction of the end pulse inrush current.

This effect is more pronounced for the larger difference between the main discharge current and the inrush current. This indicates that the recast layer at the end of the discharge is effectively removed by the introduction of the end pulse inrush current with efficient discharge by the

introduction of the pre-ignition excitation voltage, resulting in higher material removal rate.

5. Conclusion

To speed up EDM machining, a composite pulse power with pre-ignition excitation voltage and end pulse inrush current is proposed, and simulation is carried out in MATLAB/SIMULINK environment to validate the control method and verify the effectiveness of the proposed composite pulse power through experiments.

In EDM machining, a pre-ignition excitation voltage is introduced to provide an efficient spark discharge by applying a high excitation voltage at the beginning of the discharge to increase the probability of breaking the dielectric liquid insulation.

In addition, an effective end pulse inrush current was introduced to remove the recast layer at the end of discharge. Therefore, a method is proposed to increase the material removal rate by introducing a composite pulse

power with an pre-ignition excitation voltage and an end pulse inrush current.

- 1) Simulation model of the pulse power with pre-ignition excitation voltage and end pulse inrush current of EDM is established and simulated in MATLAB/SIMULINK environment to verify the accuracy of the simulation model and its control method.
- 2) Through experiments on the pulse power with the pre-ignition excitation voltage and end pulse inrush current of EDM machine, a comparison between the pulse powers with the single pulse power, and with the initial excitation voltage, and with the initial excitation voltage and the end-pulse inrush current is made.

The results demonstrated the effect of increasing the material removal rate in a pulse power with initial excitation voltage compared to a single pulse source, and increasing the material removal rate of a pulse source with both pre-ignition excitation voltage and end pulse power compared to a pulse power with pre-ignition excitation voltage.

Acknowledgements

The authors wish to acknowledge the insightful comments of the anonymous reviewers, whose comments have helped improve this paper substantially.

References

1. Fan YS, Bai JC. Study on volt-ampere characteristics of discharge for transistor resistor pulse power of EDM. *The International Journal of Advanced Manufacturing Technology*. 2018;96:3019-3031.
2. Chu XY, *et al.* Analysis of mechanism based on two types of pulse generators in micro-EDM using single pulse discharge. *The International Journal of Advanced Manufacturing Technology*. 2017;89:3217-3230.
3. Dehghani D, *et al.* Discharge analysis of EDM pulse generator. *Journal of Physics*. 2020;1-8.
4. Ali MY, Karim ANM, *et al.* Comparative study of conventional and micro WEDM based on machining of meso/micro sized spur gear. *International Journal of Precision Engineering and Manufacturing*. 2010;11(5):779-784.
5. Li CJ, *et al.* An EDM pulse power generator and its feasible experiments for drilling film cooling holes. *The International Journal of Advanced Manufacturing Technology*. 2016;87(5-8):1813-1821.
6. Shabgard M, Ahmadi R, Seyedzavvar M. Mathematical and numerical modeling of the effect of input parameters on the flushing efficiency of plasma channel in EDM process. *International Journal of Machine Tools and Manufacture*. 2013;65:79-87.
7. Abdulkareem S, Khan AA, Zain ZM. Effect of machining parameters on surface roughness during wet and dry wire-EDM of stainless steel. *Journal of Applied Sciences*. 2011;11:1867-1871.
8. Wang W, Liu ZD, Shi WT, Zhang YD, Tian ZJ. Surface burning of high-speed reciprocating wire electrical discharge machining under large cutting energy. *The International Journal of Advanced Manufacturing Technology*. 2016;87(9-12):2713-2720.
9. Li CJ, Bai JC, Ding JJ, Fan YS. Gap current voltage characteristics of energy-saving pulse power generator for wire EDM. *The International Journal of Advanced Manufacturing Technology*. 2015;77(5-8):1525-1531.
10. Jia ZX, Song YM, Xie ZW. Research on discharge gap volt-ampere characteristics of WEDM. *Electro Machining Module*. 2003;6:16-19.
11. Achebe PN. Simulation of Electrical Discharge Machine (EDM) process pulse generator profile. *International Journal of Science and Management Studies (IJSMS)*. 2019;43-47.
12. Chandra B, Singh H. Machining of aluminum metal matrix composites with Electrical Discharge Machining - a review. *Materials Today: Proceedings*. 2015;2(4-5):1665-1671.
13. Fan YS, *et al.* Research on maintaining voltage of spark discharge in EDM. 18th CIRP Conference on Electro Physical and Chemical Machining (ISEM XVIII). *Procedia CIRP*. 2016;42:28-33.
14. Ghoreishi M, Tabari C. Investigation into the effect of voltage excitation of pre-ignition spark pulse on the Electro-Discharge Machining (EDM) process. *Materials and Manufacturing Processes*. 2007;22(7):833-841.
15. Yue XM, Sun Q, Fan J, Han JX, Zhang QH. High-efficiency EDM based on a composite pulse current. *The International Journal of Advanced Manufacturing Technology*. 2023;127:1433-1446.