

Design of Micro Energy Pulse Power Supply for Multi Electrode Synchronous Micro-EDM

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Abstract. In order to solve the problem of low efficiency of micro-EDM, a micro energy pulse power supply for multi electrode synchronous micro-EDM was designed. The power supply outputs high-frequency PWM signals from the processor STM32F103RCT6, which processed by the discharge control loop can drive the high power field effect transistor to control the capacitance charge-discharge. Capacitance quantitative energy storage and pulse width adjustment of micro energy pulse are realized by changing the duty cycle of PWM. It combines with gap state detection technology to distinguish the gap state of each electrode and adjust the gap between the workpiece and electrode in time. The Experimental tests show that the power supply can achieve efficient and stable EDM.

1. Introduction

Micro-EDM has a wide range of applications in the field of advanced industrial technology for its high precision, high surface quality and no macro force, such as precision mechanical engineering, micro machinery, microelectronic technology, biomedical engineering, Aeronautics and Astronautics [1]. Among them, the micro pulse power supply is one of the most important parts in realizing micro-EDM. EDM is based on the high temperature and high pressure produced by the pulse discharge between the workpiece and the electrode to melt and vaporize metal. And the metal removal of each discharge is related to the single pulse discharge energy, which is generally between 10^{-6} J and 10^{-7} J [2]. To obtain such a small discharge energy, the design of micro pulse power supply is the key.

At present, the micro energy pulse power supply used in micro EDM is generally only suitable for single electrode discharge machining, and the machining efficiency of complex workpiece with multi micropore array is low. Based on the present situation, a micro energy pulse power supply for multi electrode synchronous micro-EDM based on STM32F103RCT6 processor is proposed. It can realize the micro energy control of multi electrode independent discharge and the accurate identification of the gap state of each electrode. It is committed to improving the machining efficiency and machining precision of the multi microporous parts.

2. The Overall Structure of The Power Supply

The micro energy pulse power supply can be divided into three parts: pulse generation control module, discharge control circuit module and gap state detection module. The pulse generation control module uses the STM32F103RCT6 processor, which mainly uses the PWM output function of the timer to set



the gap voltage reference threshold and control the switch components in the discharge control circuit. The discharge control circuit module is used as the core part of the micro energy pulse power supply to realize the independent control of the micro energy discharge of each electrode. The gap state detection module can detect the gap voltage value in real time and feedback it to the processor. Then the processor determines the current clearance state and drives the stepper motor for servo feed to adjust the machining gap. This design takes the control of three electrode synchronous micro-EDM machining as an example. Each electrode has a separate discharge control module and a gap state detection module. The overall structure of the power supply is shown in Fig.1.

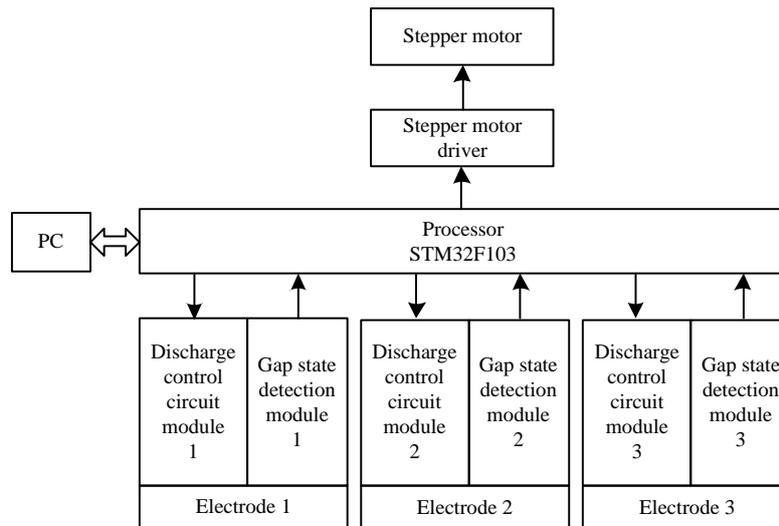


Figure 1. Overall structure of the power supply

3. Hardware Circuit Design of The Power Supply

3.1. Processor Module

The STM32F103RCT6 processor used in this power supply is based on ARM CortexM3 kernel, which has the characteristics of high performance, low power consumption and low cost [3]. The processor has a built-in 64KB FLASH, which can be used to store the processing parameters of the power supply. The system clock frequency is up to 72MHz, the operation speed is fast, the working voltage is 3.3V, the working current is milliampere, and the power consumption is low[4]. In particular, the processor has 32 universal input and output pins (GPIO), 2 advanced timers (TIM1 and TIM8) which can produce as many as 7 PWM outputs at the same time, 4 universal timers (TIM2~TIM5) which can produce 4 PWM outputs and 3 universal synchronous asynchronous transceivers (USART) at the same time. So it can meet the design requirements of the power function well.

3.2. Discharge Control Circuit Module

In EDM, the function of pulse power supply is to produce a certain frequency of unidirectional pulse to supply the energy needed for electrode discharge gap to erode metal. In fact, the process of micro-EDM is a cumulative process of single pulse discharge. In order to obtain higher machining precision and surface quality, the single pulse discharge energy must be controlled [5]. The power supply is designed by the controlled RC pulse discharge circuit, and the high-power field effect tube is selected as the switch control element. It can realize the independent micro energy discharge machining of each electrode. It has high controllability and discharge stability. The whole hardware circuit is shown in Fig.2. The main circuit of the micro energy discharge is controlled by two high-power NMOS field effect transistors T_1 and T_2 , which control the charge and discharge of the capacitor C_0 respectively. The charge capacity of the capacitor can be adjusted by changing the conduction time of the field

effect tube T_1 , and the pulse width parameters can be adjusted by changing the conduction time of the field effect tube T_2 . Two high frequency PWM square wave signals (PWM_A and PWM_B) are produced by the two channels (CH1 and CH2) of the processor's timer (TIM3). The PWM_A signal is separated into two routes after the optocoupler isolation, one of which through the amplifying comparator acts as the position signal of the D trigger, and the other is directly used as the gate driver input of the field effect tube. The PWM_B signal is treated by optocoupler isolation and multistage filtering to obtain an average voltage value as the capacitor charging voltage threshold connected with the reverse phase input of the comparator, and the voltage of the capacitance C_0 connects with the positive phase input of the comparator after the resistance and partial pressure. For the multi electrode independent discharge energy control (In this paper, 3 electrodes are taken as an example), only repeat the design of three partial circuit of the dotted line frame in Fig.2, and then the three parts of the circuit are parallel in A, B, and C.

The specific working process of this module is as follows: first, the D trigger is set to output a high level signal which amplified by the gate driver, then it can drive the field effect tube T_1 to charge the capacitor C_0 . When the voltage of the capacitor is higher than the set threshold voltage, the comparator turns over and provides a positive edge trigger signal for the D trigger. The D trigger outputs a low level signal to turn off T_1 , then opens T_2 , capacitance C_0 begins to discharge, and the cycle repeats itself. The level waveform of the micro pulse discharge control circuit is shown in Fig.3.

By changing the duty ratio of the PWM_B waveform, the capacitor charging voltage threshold can be adjusted. When the duty ratio increases, the capacitor charging voltage threshold increases and the T_1 conduction time increases, so the charging voltage of capacitor C_0 increases. That is, the capacitance discharge energy increases, the machining efficiency is improved but the accuracy of machined surface decreases. On the contrary, when the duty ratio decreases, the charging voltage of capacitor C_0 decreases, so the accuracy of machined surface is improved but the machining efficiency decreases. By changing the duty ratio of the PWM_A waveform, the parameters of pulse width and inter pulse can be adjusted. When PWM_A is high level, field effect tube T_2 works, so the capacitor C_0 discharges and is in the pulse width state. When PWM_A is low level, T_2 is off and is in the inter pulse state. In the process of EDM, it is necessary to adjust the inter pulse timely according to the current state of the discharge, so that the working fluid has enough time to eliminate the heat of ionization and diffusion and to promote the clearance of processing products.

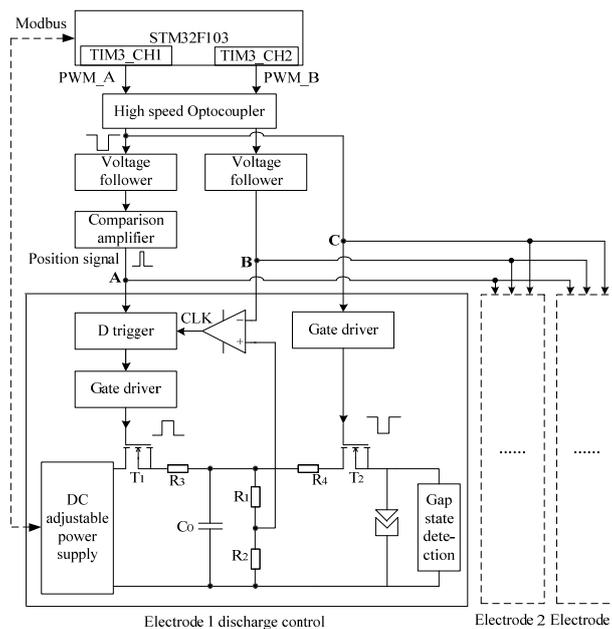


Figure 2. Circuit diagram of power micro discharge control.

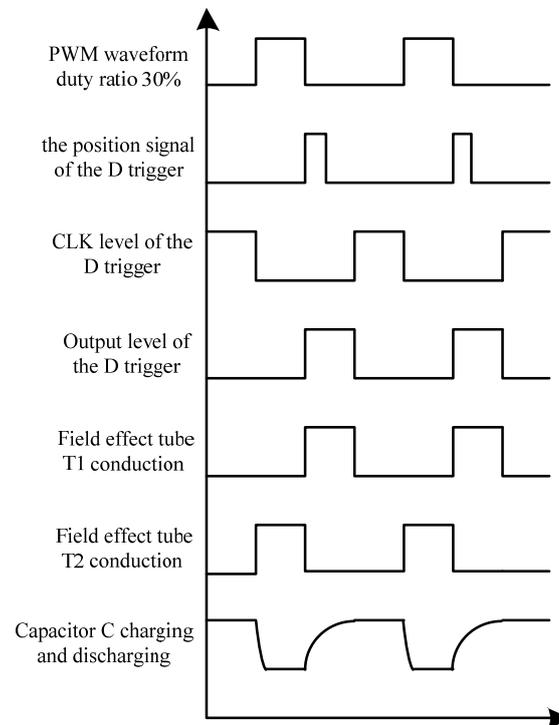


Figure 3. Circuit diagram of each point level

The controlled RC pulse discharge circuit is supplied by a DC adjustable power supply. This power supply uses Modbus to communicate. Its supply voltage can be changed according to the different processing requirements. High and low voltage can be switched during the processing so that the high energy cleaning pulse can be added to improve the machining environment.

3.3. Gap State Detection Module

The detection system of discharge gap state is an important part of EDM. The real-time and accurate detection of discharge state can provide a reliable basis for controlling servo feed and optimizing processing parameters [6]. In the process of EDM, the discharge gap between the workpiece and the electrode is very complex, and it can be divided into five categories, which are open circuit, partial open circuit, normal processing, partial short circuit and short circuit [7]. The power supply can distinguish abnormal discharge and normal processing state by effective gap identification technology, then adjust the processing parameters timely so as to make the EDM stable, ensure processing efficiency and improve processing quality at the same time.

This design mainly uses the mean value detection method of gap voltage, which can effectively identify open circuit and partial open circuit, short circuit and partial short circuit, normal processing. The detection circuit can be divided into two parts: voltage signal acquisition and gap state recognition, as shown in Fig.4. Voltage signal acquisition is a functional circuit that transforms the gap voltage pulse signal to the average value of gap voltage. The gap voltage in figure (a) is filtered by the resistance R_1 , the capacitor C_1 , then and stabilized by the stable voltage diode D_1 to get a smooth average voltage value. Finally, the average voltage is divided by the resistance R_2 and R_3 and becomes the output gap voltage signal V_{out} .

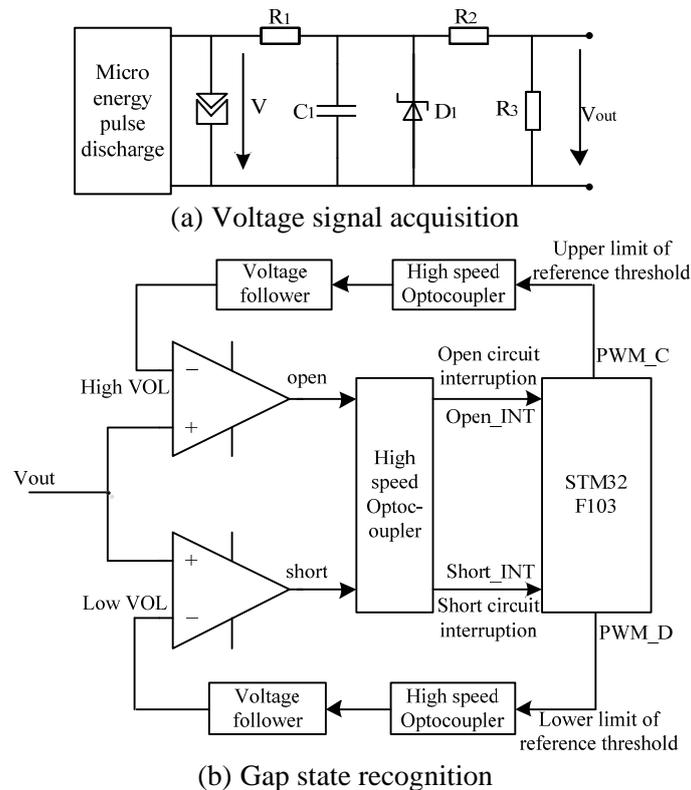


Figure 4. Detection circuit diagram of gap voltage average value

The gap state recognition part is produced by the processor of two PWM square wave signals (PWM_C and PWM_D) as the reference threshold voltage upper limit (High VOL) and the reference threshold voltage lower limit (Low VOL), which can be adjusted by changing the duty ratio of the PWM waveform. The gap voltage signal V_{out} is compared with the upper and lower limits of the reference threshold, and the processor obtains the gap state by processing the comparison results. When the V_{out} is larger than the High VOL, the comparator turns over and produces a rising edge level. The processor enters open circuit interruption and determines that the gap is in open or partial open circuit. When V_{out} is less than Low VOL, the comparator produces a trailing edge level, the processor enters short circuit interruption and the gap is in short-circuit condition.

4. Software Design of The Power Supply

The development environment of this power supply software is KEIL, and programming in C language. The software flow of the STM32F103 processor on the comparator output signal in the gap detection circuit is shown in Fig.5. When EDM begins, the processor calls the gap state recognition program. When the processor detects a rising or trailing edge, which means the processor enters the open circuit or short circuit interruption service program. If the high level (open circuit) or low level (short circuit) signals are detected 50 times continuously without interval, the gap processing state is in open circuit state or short circuit state. If the number of detected level does not continuously accumulate to 50 times, the counter clears and recounts, and the gap processing state is in the normal processing state. This program can eliminate interference to a certain extent and avoid the decline of machining efficiency caused by frequent return of electrodes.

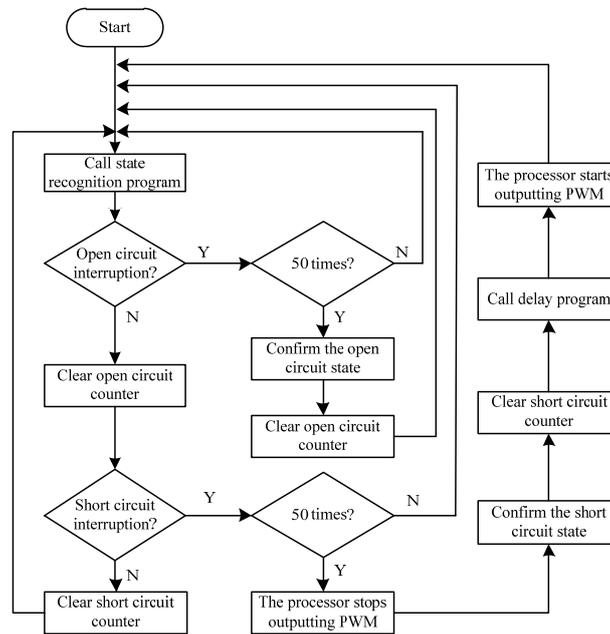


Figure 5. Flow chart of gap state recognition program

After judging the state of each electrode gap, the processor calls the servo feed control program, and the specific process is shown in Fig.6. When the machining gap is in the open circuit state, the processor makes the stepper motor positive rotation to keep the electrode feed normally until the gap is in the normal discharge state. When the gap is in the open circuit state, the stepper motor rotates reversely to make the electrode back down until the gap is in the normal discharge state.

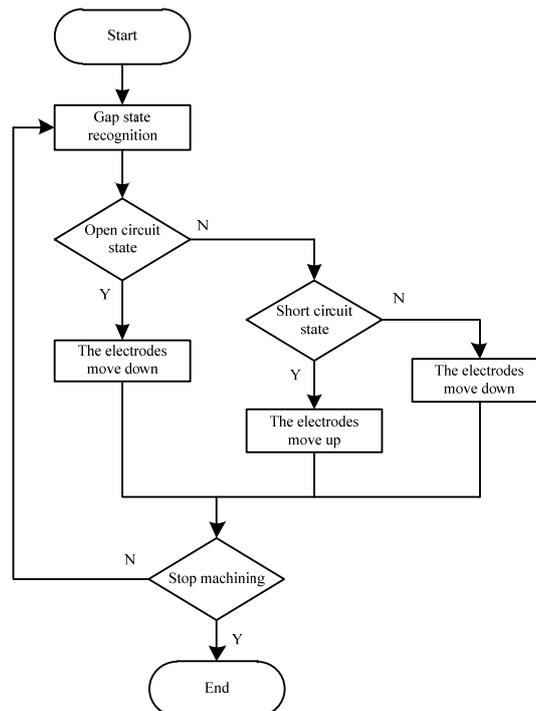


Figure 6. Flow chart of servo feed control program

5. Experiment and Analysis

The power supply is designed to realize precise control of the tiny pulse energy of multi electrode. The selected STM32F103RCT6 processor uses the 72MHz clock, the minimum output pulse is 13.9ns, and the precision of pulse adjustment is 13.9ns, which meets the requirements of machining micro energy. Experimental test conditions: the voltage of the DC adjustable power supply is 100V, the capacitance is $2.2 \mu F$ and the current limiting resistance is $1 k\Omega$. The electrode is connected to the positive pole and its material is 0.1mm tungsten steel. The workpiece is connected to the negative electrode and its material is 3mm stainless steel. The working fluid medium is mechanical oil. The processor output the PWM signal waves whose period is 2083.3ns and the duty ratio is 30% , that is, the time of pulse width is 625.0ns, the time of inter pulse is 1458.3ns, and the oscillograph is measured by the oscilloscope is shown in Fig.7. In EDM, the charge and discharge waveform of the capacitor is shown in Fig.8, and the charging threshold voltage set by the processor is 80V. In normal discharge machining, the discharge waveform measured at both ends of the workpiece and electrode is shown in Fig.9. In addition, the micro energy pulse power supply is applied to the self-developed multi micro pore synchronous EDM machine for continuous and uninterrupted machining experiments. After working for 200 hours, the power supply is still stable and reliable.

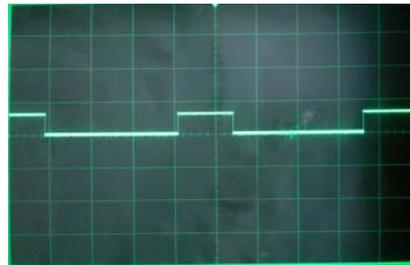


Figure 7. PWM waveform (duty ratio is 30%)

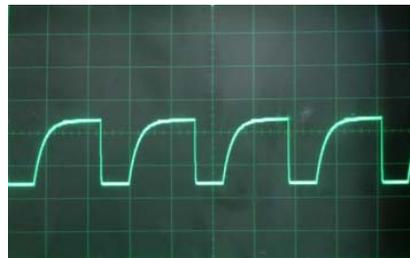


Figure 8. Capacitance charge discharge waveform



Figure 9. Normal discharge machining waveform

6. Conclusion

The design of micro pulse power supply is one of the key technologies of micro-EDM. In this paper, a micro energy pulse power supply for multi electrode synchronous micro-EDM based on

STM32F103RCT6 processor is designed. By changing the duty ratio of two PWM output signals by the processor, the multi electrode independent micro energy discharge control can be realized. The electrode's abnormal discharge machining condition can be effectively identified by the gap state detection technique in order to timely adjust the machining parameters and maintain stable and efficient EDM. The machining experiments show that the power supply has good controllability and stability, and can effectively improve the efficiency of EDM.

Acknowledgments

This work was supported by the Key Research and Development Project of Shandong province under Grant No.2017GGX30124.

The Correspondence author is Mengyou Huo.

The Key Research and Development Project of Shandong province under Grant No.2017GGX30124.

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