Research on Single Pulse Electrical Discharge Grinding Polycrystalline Diamond

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Abstract. With the requirement of 'high efficiency, precision, flexibility and green manufacturing' processing of modern cutting technology, PCD materials have been widely used. EDM is part of the effective methods to process PCD materials. Single pulse discharge grinding is one of the bases for studying the mechanism of EDM. Choose 2 micron particle sizes of PCD compact as processed material, the duration of the research on EDM single pulse discharge on the material removal efficiency (such as the radius of the corrosion pit, corrosion pit depth and the ratio of radius, etc.).The test results show that, with the increase of the discharge duration, the radius of the discharge pit increases rapidly, then slowly increases, and finally flattens out. The radius of the heat affected area increases rapidly and then increases slowly. With the increase of the duration of discharge, the ratio between the depth and the radius of the pit is changed in the range of 0.1~0.25, which is basically decreasing. With the increase of pulse duration, the discharge pit radius increases rapidly, and finally becomes flat. The radius of the affected zone first increases rapidly and then increases slowly.

1. Introduction

Polycrystalline diamond (PCD) that is one of substitution products of traditional cutting tool has been widely applied in the manufacturing industry of developed countries in recent 20 years, because of its high hardness, good impact toughness, abrasion resistance uniformity, excellent heat resistance, thermal conductivity and other properties [1]. The use of PCD tool in machining nonferrous metals and alloys, such as aluminum alloy, copper alloy, titanium alloy, compared to solid tungsten carbide, has enabled machining speed to be completed. Thread quality to be improved and the burr to be virtually eliminated [2, 3].

Electrical discharge grinding (EDG) is perhaps one kind of discharge machining process that based on the pulse discharging electric corrosion principle. EDG uses thermal energy to machine electrically conductive solid material parts regardless of their geometry [3].

There were plenty of valuable research results on EDM techniques. In Y.H. JIA study [3], PCD cutting tool surface affected layer thickness and structure distribution was investigated. The influence of electrode material in machining PCD cutting tool was summarized. In literature [4], they investigated the effects of wheel rotation as well as debris flow direction on the quality of PCD tools based on a series of EDG experiments. Experimental results showed the debris that flowed toward the cutting edge could significantly affect the edge sharpness and symmetry of the tool, which was critical

for the smaller edge apex angle. The adhesion mechanism of TiC powder was discussed from the shape and composition distribution of discharge pit and the voltage and current waveform during discharge in Tsunehisa Suzuki paper [5]. They consider that the melted and re-solidified TiC was located in the crater when the voltage remained constant during discharge process. In Xuyang Chu study [6], a series of novel analysis and experiments were carried out on the respective mechanism of two pulse generators by using single discharge pulse. The discharge characteristics of two kinds of generators were discussed. The difference of discharge channel radius of single pulse plasma model was presented. In addition, the thermal effect of a single pulse heat model was analyzed. In Tomohiro Koyano paper [7], high resistivity materials such as mono-crystalline silicon were used as electrodes to reduce the removal of materials with single pulse discharge. The results show that when the electrode resistance increases, the peak current decreases and the pulse duration increase. In literature [8], in order to determine the mechanical properties such as the tool wear and material removal rate, copper was used as tool electrode for single pulse discharge experiment. The crater was analyzed by a digital microscope. Statistical analysis was established and the influence of input process factors was evaluated. In Liu J.W study [9], the influence of processing medium and clearance distance on the processing performance of metal matrix composites was studied. The processing characteristics of single pulse EDM in air and emulsified oil media were compared. The research showed that the discharge mode exists in the form of arc in both media.

The aim of this investigation is to study the effect of a single pulse discharge duration on material removal. It lays a solid foundation for further exploring the mechanism of removing PCD materials in micro-EDG.

2. Experimental study on single pulse EDM

A single pulse control power source for common electrical discharge is designed, as shown in Fig. 1. The basic idea of a single pulse control circuit is that when a single pulse power supply is energized, a pulse can be generated by pressing a switch button. The control circuit is shown in Fig 2. Adopt positive polarity processing, that is, the workpiece is connected to the positive electrode, the electrode is connected to the negative electrode, the medium is electric spark fluid. The accumulation of total energy associated with the loss of energy, and dissipating the energy associated with the thermal conductivity of materials, the greater the thermal conductivity of materials, the faster the heat loss, energy accumulation is smaller, the same time energy release and the smaller the explosive force. Therefore, it is preliminarily concluded that the thermal conductivity of the material may play a certain role in attenuating the spark explosive force produced during EDM.

The peak value of energy density plasma channel decided the highest pressure of discharge channel, and the energy density along the rate decided the nature of the channel pressure release, change the faster, the channel before the collapse of phase transformation zone the higher the degree of superheat, dissolve the vapor phase, the greater the energy of an explosive release effect is strong, phase change materials separation, the more thoroughly, the greater the amount of material removal in.

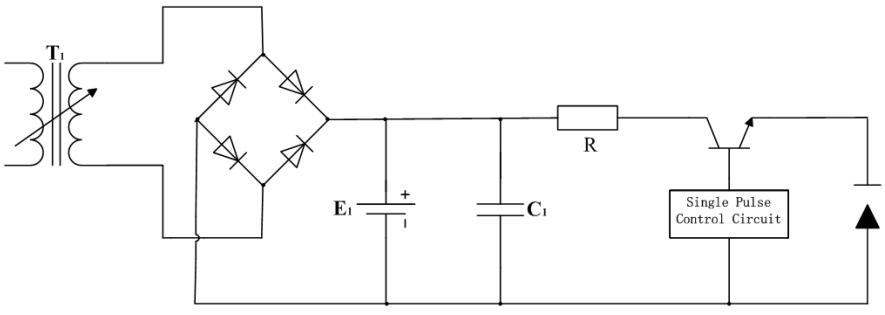

Figure 1. Single pulse control power supply.

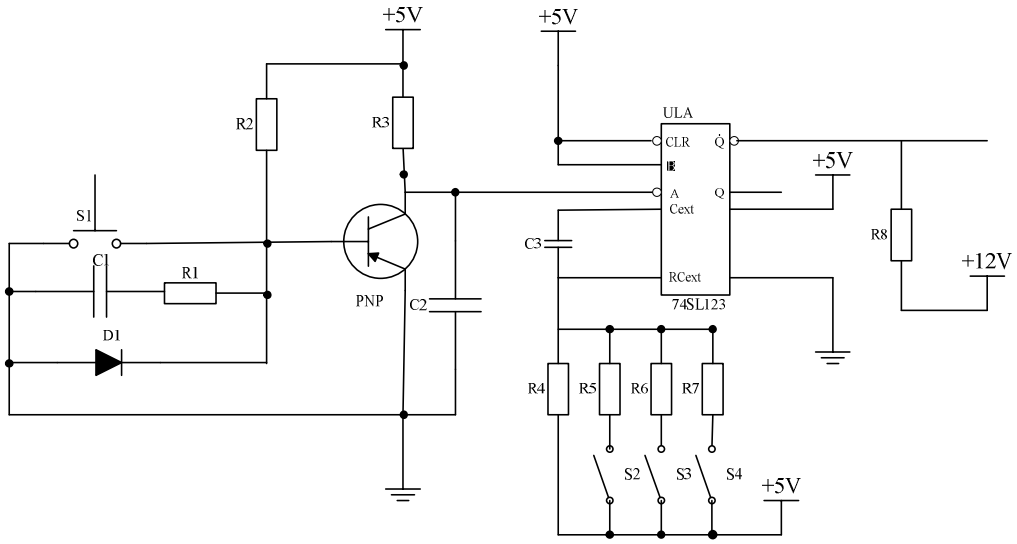

Figure 2. Single pulse control circuit.

Single pulse discharge machining PCD material discharge generated by the corrosion pit shape very rules, as shown in Fig. 3, presents the obvious block off formation of the pit, almost no trace material melt, area is larger, the corrosion pit depth is relatively small, and continuous pulse discharge processing, things are different.

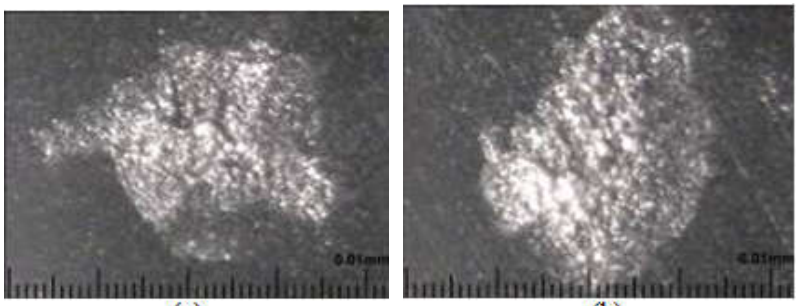

Figure 3. Polycrystalline diamond corrosion pit by EDM using different working liquid.

The main reason for the irregular shape produced in the discharge machining of PCD material is the property of PCD material itself. PCD material is different from other ordinary material, it is under high temperature and high pressure by the single crystal diamond and metal bond under the catalytic action of high temperature and high pressure synthesis material, large brittleness, high melting point, when the EDM process, because of the PCD material is made of conductive adhesive and conductive junction of diamond single crystal, so the processing surface is not conductive everywhere, in every single crystal grain alternating between growth, forming a conductive grid, they mainly by catalyst, the adhesive of the metal and some of carbide; EDG process, the first on the grid discharge, discharge the heat generated by the melt metal on the grid or vaporization, therefore, in the conductive grid area of diamond single crystal under the effect of discharging the heat generated by the melt or graphitization, according to mobile theory of plasma channel, plasma channel is discrete in time, the channel, after the formation of contact with the channel area of the adhesive on the metal by the joule - edge magnetic thermal instantaneous heated to very high temperature and evaporation explosion, form a corrosion marks on electrode material, since then, the channel moves to following the explosion of another conductive at small pit edge, Heat it up and explode, leaving a corrosion mark, and continue

until the end of the discharge. Due to the unevenness of the PCD material, a highly irregular discharge pit is formed as shown in Fig. 3.Due to PCD material is belong to the brittleness material, high melting point of diamond single crystal, and the thermal conductivity of diamond single crystal is great, and the discharge time is very short, therefore, in electrical discharge machining, the adhesive material in the discharge network in melting state, and the diamond single crystal may be partially melting or graphitization, in under the action of electric explosive force, the discrete material is thrown on the conductive grid, due to the high temperature synthesis PCD materials when adding a small amount of catalyst and adhesive material, its in the molten material is very little, so the fracture had no obvious melting trace. The radius and depth of discharge pit are larger and smaller.

The rapid increase of plasma channel formation, current leads to rapid rise of temperature in the plasma channel, plasma channel in the high temperature will be through the liquid medium and two electrode materials distributing, due to the discharge in a very short time, within the channel heat is not lost that cause thermal explosion. The explosive force is related to the degree of heat accumulation, the size of the associated with the rate of heat loss at the same time, and in the process of the same liquid medium, heat loss is associated with the thermal conductivity of electrode materials, therefore, the size of the explosive force is associated with the thermal conductivity of materials, the greater the thermal conductivity, the heat lost the faster, the same time energy accumulation is smaller, the energy release and the smaller the explosive force. Therefore, processing of PCD requires more energy and shorter pulse lead time.

3. Influence of single pulse discharge duration on discharge current

The variation trend of discharge current and discharge maintenance voltage with discharge duration is shown in Fig. 4 and Fig. 5. The discharge maintaining voltage is the average value of the gap voltage during the normal spark discharge process, and the discharge current is the average value of the current through the current limiting resistance. It can be seen from this figure that the discharge current fluctuates within the range of 0.35~0.45A, while the maintenance voltage fluctuates within the range of 15-20 v, neither of which is affected by the discharge duration and the open circuit voltage. Spark discharge first need to have enough high open circuit voltage and small enough to ensure there is enough of the spark gap of the high field strength makes the dielectric breakdown, when dielectric breakdown after discharge plasma channel formation, circuit by open into conducting state, electrode resistance from infinity to a finite value. At the same time, the gap voltage by the open circuit voltage drop rapidly maintenance of discharge voltage, discharge current increases rapidly from zero and stable in a certain range, the discharge current value depends on the current limiting circuit resistance and resistance of plasma channel.

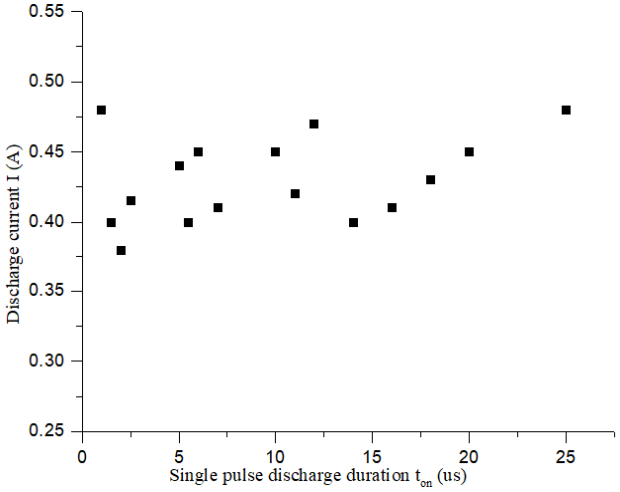

Figure 4. The relationship between pulse duration and discharge current.

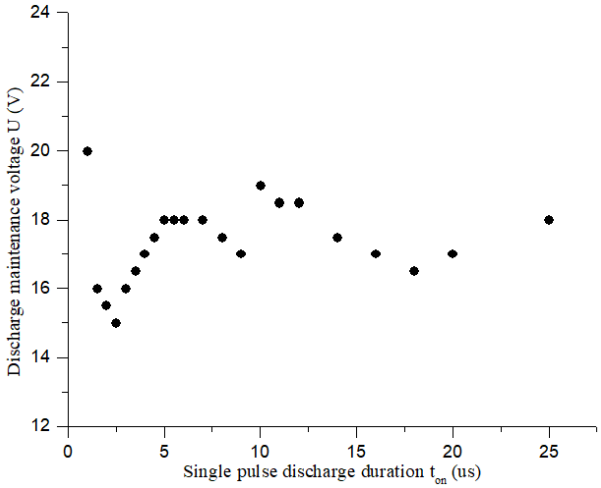

Figure 5. The relationship between pulse duration and discharge maintenance voltage

4. Influence of single pulse discharge duration on discharge pit radius

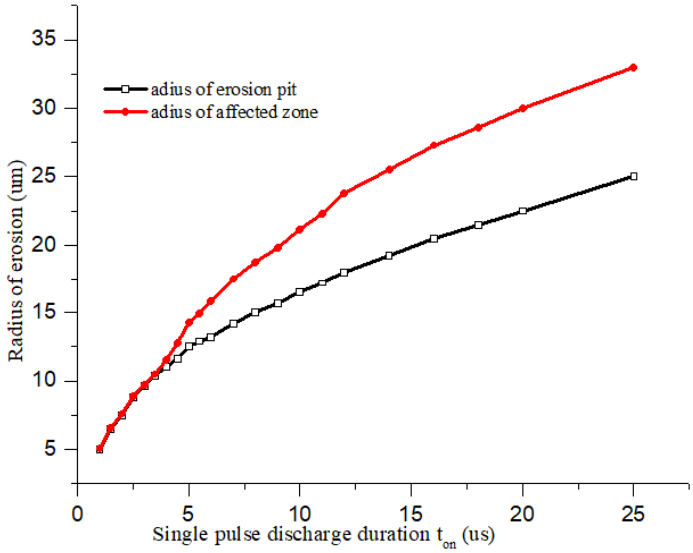

Figure 6. The relationship between pulse duration and corrosion radius.

From Fig. 6, it can be seen that the discharge pit radius first increases rapidly, then increases slowly, and finally becomes flat with the increase of pulse duration. The radius of the affected zone first increases rapidly and then increases slowly. Discharge duration in 4us, within the basic coincidence depressions in heat affected zone radius. Points at the beginning of the discharge, discharge energy density and temperature is very high, heat in the electrode surface to spread, therefore, is passed to the workpiece discharge can be consumed mainly in material of flipping and vaporization, and through the heat conduction, the proportion of energy consumption is very less. Therefore, the energy efficiency of a short pulse discharge is very high. With the increase of duration of discharge, the discharge plasma channel rapidly expand, the discharge energy density and temperature of the point quickly reduced, more material is burned, and have more proportion of the energy transfer to the workpiece electrode surface by means of heat conduction, the heat affected zone size continues to increase. Therefore, after the discharge duration is greater than 4us, the energy utilization rate of EDG decreases with the increase of the discharge duration.

5. Influence of discharge duration on pit depth and depth ratio

The variation trend of discharge pit depth and depth ratio with discharge duration is shown in Fig. 7. As can be seen from Fig. 7, under the same current condition, the pit depth increases slightly with the increase of pulse width, but the change is not obvious. The ratio of pit depth to radius, that is, the depth to diameter ratio changes within the range of 0.1~0.25, and generally decreases with the increase of discharge duration. After the discharge starts, with the increase of the discharge duration, the pit radius increases rapidly and then slowly increases until it becomes flat, and the pit depth always fluctuates within a large range. Therefore, the pit depth diameter ratio fluctuates in a large range with the increase of discharge duration, and presents the overall gradually decreasing atrium potential.

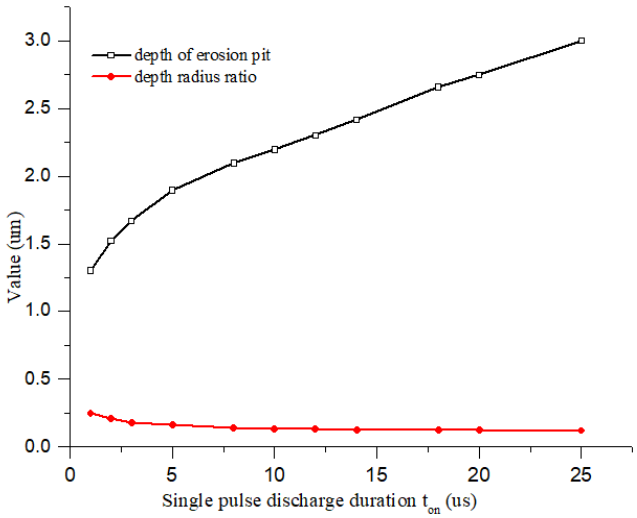

Figure 7. The relationship between pulse duration and corrosion depth.

6. Summary

From the above analysis, the following conclusions can be obtained:

(1). with the increase of the discharge duration, the radius of the discharge pit increases rapidly, then slowly increases, and finally flattens out. The radius of the heat affected area increases rapidly and then increases slowly.

(2). with the increase of the duration of discharge, the ratio between the depth and the radius of the pit is changed in the range of 0.1~0.25, which is basically decreasing.

(3). with the increase of pulse duration, the discharge pit radius increases rapidly, and finally becomes flat. The radius of the affected zone first increases rapidly and then increases slowly.

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