Modelling, Measurement and Control A
Vol. 91, No. 1, March, 2018, pp. 9-14
Journal homepage: http://iieta.org/Journals/MMC/MMC_A

Experimental research on capacitor discharge machining of insulating ceramics

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https://doi.org/10.18280/mmc_a.910102

Received: 8 December 2017
Accepted: 17 April 2018

Keywords:
electrical discharge machining, insulating ceramics, capacitor, discharge channel

ABSTRACT

Aiming at the features of low efficiency of electrical discharge machining and difficult control of surface roughness of insulating ceramics, this paper proposes a capacitor discharge machining method. This method is to carry out experimental research and mechanism analysis on the effect of capacitor discharge on insulating ceramics removal volume by using high-capacitance capacitor to discharge for short time to auxiliary electrode and insulating ceramics and by the methods of changing capacitance, voltage magnitude, electrode size, type of working media, etc. The experimental results show that the maximum ceramics removal volume produced by capacitor discharge under the action of relevant parameters is 18.53 mm^3. Through metallography effect analysis of insulating ceramics surface with microscope, it concludes that the material removal is mainly in stripping mode. The material removal volume increases as the discharge parameter increases, and it is more sensitive to some parameters, such as medium.

1. INTRODUCTION

Insulating ceramics is a kind of important engineering material, and due to its features of high hardness, high strength, high-temperature insulativity, low thermal expansion coefficient, excellent chemical corrosion resistance, and low density, it is widely applied to machine tools, aerospace, petroleum geology, machinery, electronics, metallurgical and chemical industry, etc. [1-4] Although the insulating ceramics has the above-mentioned excellent features, it is very difficult to machine due to its high hardness, high strength and fragility [5].

The traditional insulating ceramics machining methods, such as mechanical cutting, grinding, supersonic machining and laser processing, all have the universal disadvantages of low machining efficiency and high cost as well as the problem that it is difficult to achieve higher precision and surface quality, thereby seriously affecting the popularization and application of the insulating ceramics [6-8]. At present, most domestic and foreign scholars focus on researching the electrolysis and electrical discharge combined machining technology of insulating ceramics. This machining method uses the discharge process of electrolyte to machine. It has the disadvantages of low precision, low efficiency, easy rusting to machine tools, and environmental pollution, so it is not widely applied to the actual production. Scholars who have done much. research on this machining technology include Tsuchiya Hachiro, Kubota and Chikamori Kunio (Japanese scholars), B .Bhattacharyya (Swiss scholar), K. Allesu (Indian scholar), Guo Yongfeng (Chinese scholar), etc. [9-10] Liu Yonghong and other persons put forward a technology for electrical discharge grinding of auxiliary electrode synchronous servo, using the discharge between synchronous servo feed auxiliary electrode and tool electrode as well as mechanical grinding of the grinding wheel to the workpiece surface to grind the insulating ceramics, and it achieves higher machining efficiency [11]. In Reference [12], using the high-energy capacitor impulse discharge together with the auxiliary electrode servo system to machine the insulating ceramics, it achieves better material removal effect. Through observation with scanning electron microscope, it shows that the ceramics surface removal pit is radial.

In order to preferably obtain the effect of capacitor discharge energy on the ceramics removal rate in the machining process of insulating ceramics, this paper starts from the capacitor capacitance, voltage value, electrode size, conducting medium and other parameters to study the law of effect of capacitor discharge on the material removal volume, and concludes the variation trend of the effect of the above parameters on the insulating ceramics removal rate through analysis on experimental data. Meanwhile, it analyzes the causes of the above process from the aspect of electrical machining mechanism. The experimental data and analysis obtained have certain effect of theoretical support and practical value for electrical discharge machining of insulating ceramics.

2. EXPERIMENTAL PRINCIPLE AND CIRCUIT

2.1 Experimental principle

The capacitor discharge model is as shown in Figure 1-(a). The copper electrode is controlled by a machine tool to gradually approach to the auxiliary electrode copper sheet in the medium machining process. When the distance is small enough, the working medium is ionized under the action of capacitor voltage between the copper rod and the copper sheet to form a plasma discharge channel. The high temperature produced by the discharge channel melts or gasifies the copper rod and copper sheet, and also removes the insulating ceramics. Figure 1-(b) is the schematic diagram of different areas that the discharge channel enables the ceramics workpiece, electrode and auxiliary electrode to be molten and gasified at high temperature and voltage; in this process, also lots of heat energy is released [13-14].

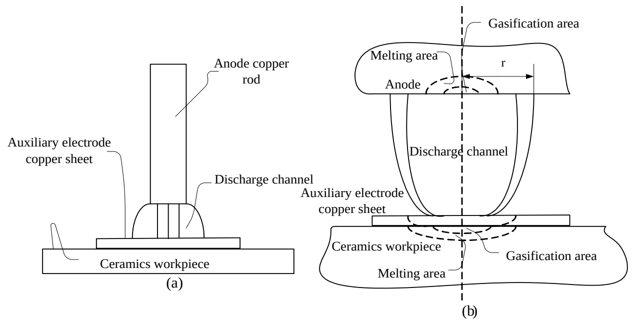


Figure 1. Schematic diagram of impulse discharge on capacitor

2.2 Experimental circuit and conditions

The circuit of capacitor impulse discharge is as shown in Figure 2. The circuit is mainly composed of a rectifier filter, a pre-amplifier DC/DC converter, a post-amplifier sequential pulse controller and a discharge feed system. In the figure, the normally closed and open contacts are interlock devices. When one is closed, the other is certainly open. When the discharge is going on, S_6 is closed, and S_5 is open. When the detector detects the voltage below 25V upon the completion of discharge, S_6 is open, and S_5 is closed, finishing the charge of capacitor C1 and preparing the next discharge machining.

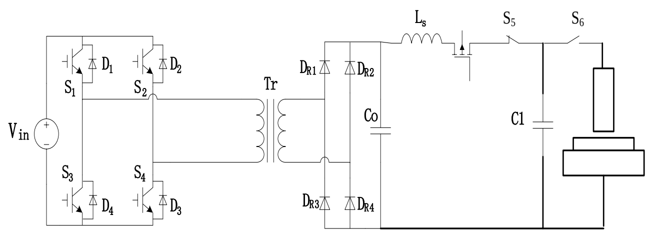


Figure 2. Circuit of capacitor impulse discharge

Table 1. Experimental parameters

Experimental parameters	Experimental values
Working medium	Air, kerosene
Anode	Cooper rods Φ1.5mm, 2*4mm, 4*4mm, 4*6mm, Φ6.0mm
Cathode	Copper sheet 7×2×0.1mm
Workpiece	Al_2O_3 ceramic plate 10×5×0.5cm
Capacitance	6800μF, 10000μF, 16800μF, 22000μF, 32000μF
Voltage	100V, 150V, 200V, 250V, 300V

Adopting a single-factor design scheme, the paper uses a depth measuring instrument to measure the average depth of a removal pit, and calculates the area of removal pit with a scanner and CAD software, to calculate out the insulating ceramics removal volume according to the formula (1). The paper adopts LW200－4CS inverted metallurgic microscope to observe the stripping phenomenon of the ceramics surface. Each experiment is conducted for three times, taking the average value of experimental results as the finial experimental data to handle.

$$V_m = S \times h \tag{1}$$

where, V_m is the ceramics removal volume (mm^3);
S is the area of removal pit (mm^2);
h is the average depth of the removal pit (mm).

3. EXPERIMENTAL RESULTS AND ANALYSI

3.1. The effect of electrical parameters

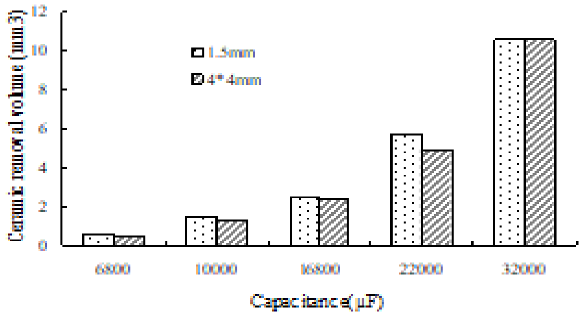
In the traditional electrical machining process, the electrical parameters affecting the machining effect mainly include pulse width, pulse interval, peak voltage, peak voltage, etc. The inspection of the machining effect mainly aims at the material removal rate and surface roughness. While in this paper, the electrical discharge mainly aims at the effect of discharge to the insulating ceramics removal. The main electrical parameters affecting the effect mainly include capacitance and voltage values, and the inspection parameter of the discharge effect is the material removal volume.

3.1.1 The effect of capacitance

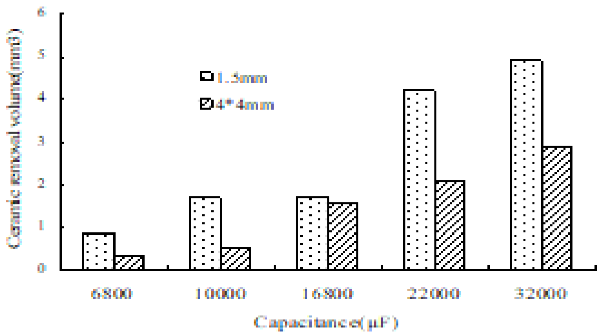
Capacitors with different capacitance valves (6800μF, 10000μF, 16800μF, 22000μF and 32000μF) are adopted to discharge for ceramics removal, thus achieving the relation diagram between ceramics removal volume and capacitance as shown in Figure 3(a) and (b).

Figures 3(a) and (b) show correlation data of ceramics removal volumes formed after machining at two fixed electrode voltages. Figure 3(a) shows the machining data by using the air medium, and Figure 3(b) shows the machining result by using the kerosene medium. Figure 3(a) shows that the effect of capacitance on the ceramics removal volume is great. The ceramics removal volume obviously increases as the capacitance increases, because under the same machining conditions, the greater the capacitance, the more the impulse discharge energy, resulting in stronger discharge effect and more sufficient expansion of discharge channel. So the heating area of the ceramics surface increases accordingly, which causes the continuous increase of the ceramics removal volume. So the heating area of the ceramics surface increases accordingly, which causes the continuous increase of the ceramics removal volume. From different electrode sizes in the figure, it can be seen that in the air, the effect of the electrode sizes on the ceramics removal volume is small; although the effect of electrode Φ1.5 mm on the removal is a little better, the difference between the effect of it and that of another electrode is small. This shows that the expansion sizes of discharge channel are almost same when different electrodes are used to machine in the air. Therefore, the removal effect difference is not obvious.

The result in Figure 3(b) shows that in the kerosene medium, the ceramics removal volume increases as the capacitance increases; compared with the air medium, the ceramics removal volume produced by small-size electrode discharge is obviously bigger than that produced by large-size electrode discharge in the kerosene, because under the same energy, the current density in small-size electrode discharge is higher than that in large-size electrode discharge. In the air, since the constraining force of air molecules is relatively small, the current density difference does not play a leading role. While in the kerosene, since the constraining force of kerosene molecules is obviously stronger than that of air molecules, the explosive force generated by small electrode with high current density is higher than that generated by large electrode with low current density due to the action of constraining force during discharge. Therefore, the effect of large electrode to the removal is inferior to that of small electrode



(a) In the air, voltage 250V



(b) In the kerosene, voltage 250V

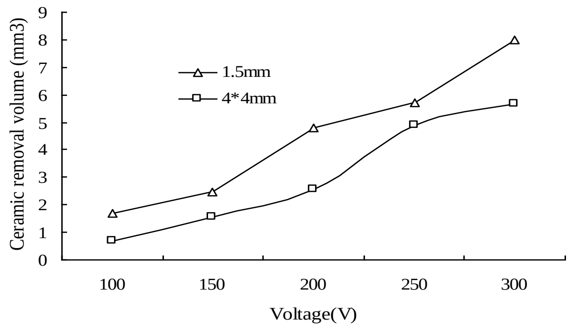
Figure 3. Effect of capacitance to ceramics removal volume

3.1.2 The effect of voltage

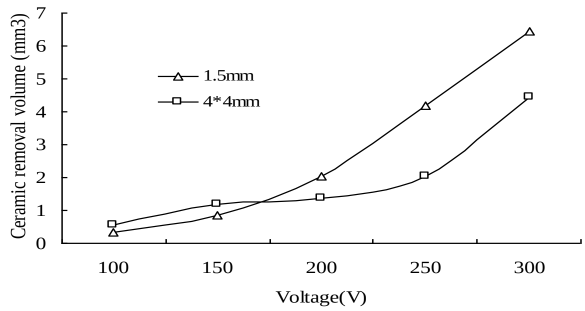
Figure 4(a)-(b) shows the relation curve between the ceramics removal volume and the discharge voltage obtained by using different voltages (100V, 150V, 200V, 250V and 300V) to discharge for removing insulating ceramics.

The relation curve between the insulating ceramics removal volume and the voltage change during discharge at different voltage levels in the air is as shown in Figure 4(a). In the figure, the capacitance is fixed, and the main factor affecting the discharge energy is voltage value. When discharge is occurring, the discharge current increases as the voltage increases, and at the same time, the current density also increases so as to affect the change of discharge channel. Electrons move faster under the action of enlarged electric field and obtain sufficient kinetic energy to collide with the ionized air molecules so as to generate new electrons and ions[15], and increase the internal pressure and temperature of conductive gas. The pressure gradient formed with around air enables the discharge channel to expend rapidly, thus obtaining large-area discharge and material volume removal.

Figure 4(b) shows the relation curve between the ceramics removal volume and the voltage change in the kerosene. From the curve, it can be seen that the difference between the machining effects of two electrodes at the voltage of below 200V is not obvious. When the voltage value varies from 200V to 300V, the ceramics removal volume changes rapidly as the voltage increases, mainly because the constraining force of kerosene molecules is much stronger than that of air molecules. But the energy stored at the voltage of below 200V is insufficient to enable the discharge channel of kerosene medium to expand widely, resulting in the effect that the change in the material removal volume is not obvious. As the voltage peak increases to 300V or so, the energy continuously gathers, and the heat and explosive force produced by discharge exceed the constraining force of kerosene molecules, causing the discharge channel to expend widely so as to rapidly increase the ceramics removal volume.



(a) In the air, capacitance 22000μF

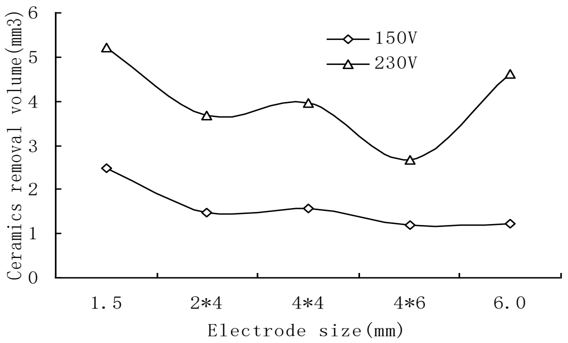


(b) In the kerosene, capacitance 22000μF

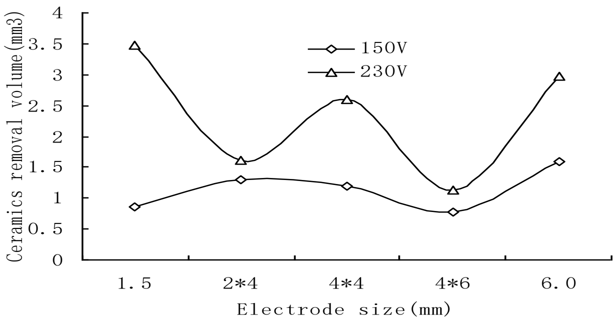
Figure 4. Effect of voltage to ceramics removal volume

3.2 The effect of electrode size

Figures 5 and 6 show the relation curves between the electrode size and the material removal volume in two media at fixed capacitance and voltage. In the capacitor discharge experiment, the effect of electrode size to the ceramics removal volume is smaller than that of electrical parameters. From Figures 6 and 7, it can be seen that the ceramics removal volume produced by small electrode is slightly larger than that produced by large electrode in general under the same electrical parameter, mainly because the working medium changes rapidly after capacitance and voltage are applied between both electrodes, and the cathode surface forms high field intensity as the voltage increases[16-19]. The pointed electrode enables the electric field to easily distort and contribute to breakdown of medium between both electrodes. Therefore, the discharge voltage during machining is lower, the energy affecting the cathode and workpiece is much more during breakdown, and the removal volume produced by small electrode is slightly larger in general.

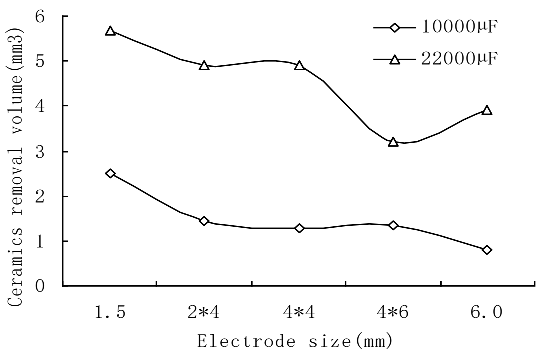


(a) In the air, capacitance 22000μF

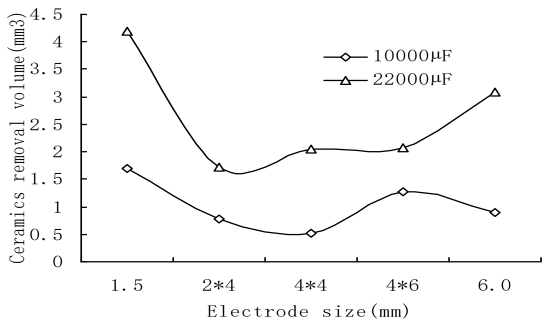


(b) In the kerosene, capacitance 22000μF

Figure 5. Effect of electrode size to ceramics removal volume based on voltage



(a) In the air, voltage 250V



(b) In the kerosene, voltage 250V

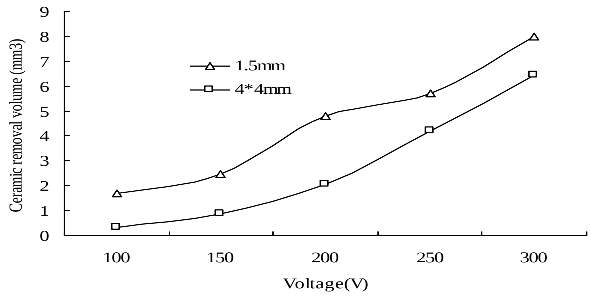
Figure 6. Effect of electrode size to ceramics removal volume based on capacitanc

The removal volumes produced by large electrode in Figures 5 and 6 also change greatly, especially when the capacitance and the voltage are higher, this change is more obvious. There are two main causes: first, when a capacitor is discharging, since ceramics is fragile material, the stripping phenomenon of the material appears at a certain machining parameter, occasionally resulting in randomness of calculation of ceramics removal volume, so data fluctuation appears, and such random error will gradually decrease as the number of data collection samples increases; second, although the pointed electrode enables the electric field to easily distort and contribute to breakdown of media between both electrodes, under the specific conditions, impurities and charged particles in media in small clearance between both electrodes would be pulled into the tip with highest field intensity, the space charge can reduce the inhomogeneity of electric field. In addition, the area of the pointed electrode is small, and the probability of breakdown caused by impurities also will be reduced. Therefore, when the distance between both electrodes is small, the electrode with large area is easier to break down.

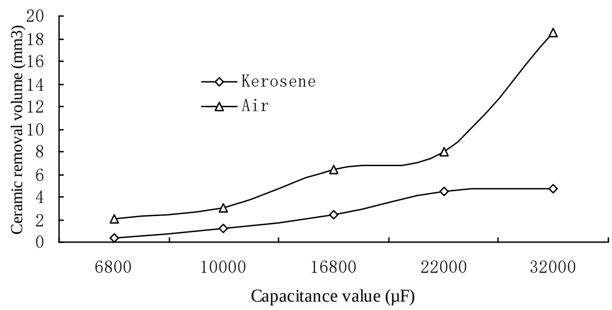
3.3 The effect of working medium

In experiment, we use two working media, namely gas (air) and liquid (kerosene). The relation curve between the discharge parameters and the ceramics removal volume in different media is as shown in Figure 7.

Figures 7(a)~(b) show the contrast result of material removal volumes at different discharge parameters in the air and kerosene. It can be seen that the material removal volume in the air is superior to that in the kerosene, and the variation trend in the air is also consistent with the above analysis result. Therefore, it can be concluded that the ceramics removal volume in the air is larger than that in the kerosene during capacitor discharge, and such trend is especially obvious as the electrical parameter increases gradually.



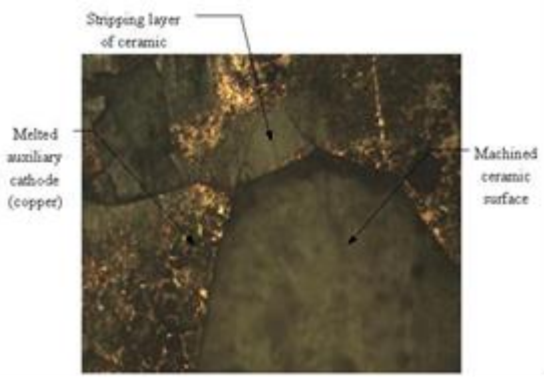
(a) Electrode Φ1.5 mm capacitance 22000μF



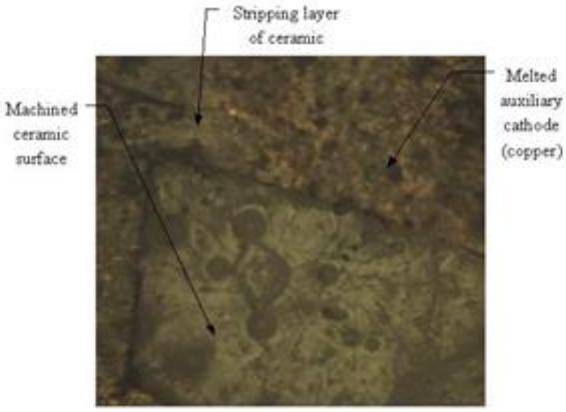
(b) Electrode Φ1.5 mm voltage 250V

Figure 7. Effect of discharge parameters to ceramics removal volume in two media

Figure 8 (a) and (b) respectively show the photographs of crater's edge as seen under metallographic microscopy. These craters are obtained in machining insulating ceramics by anode (copper), auxiliary cathode (copper sheet), air and kerosene as dielectric medium in diesinker that uses transistorized power supply. Machining has been done at different dielectric mediums and at capacitance of 22000µF with voltage 250V. Fig.8 reveals the clear image in two mediums, which the ceramic surface is stripped by discharge.

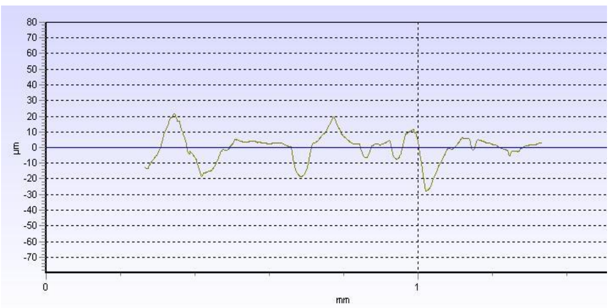


(a) In the air, capacitance 22000µF, voltage 250V, electrode 1.5mm



(b) In the kerosene, capacitance 22000µF, voltage 250V, electrode 1.5mm

Figure 8. Micrograph of EDM ceramics surface by X 200 Metallography



(a) In the air

(b) In the kerosene

Figure 9. Roughness curve of ceramic discharge pits

Figures 9(a)~(b) show the roughness curve of insulating ceramics removal pits. From the figure, it can be seen that the stripping face of discharge pit in the air is obviously stronger than that in the kerosene. Compared with the surface roughness in Figures 9(a)~(b), the one in the kerosene is obviously superior to that in the air; the result is consistent with the law of electrical discharge machining. When discharge machining is conducted to insulating ceramics, the relation between both should be considered comprehensively to improve the surface roughness of material on the basis of ensuring the removal volume.

4. CONCLUSIONS

This paper designs an experimental device for capacitor discharge machining to the insulating ceramics, provides the principle analysis of the device. By studying the law of effect of capacitance, power voltage, electrode size and working media to the insulating ceramics discharge pit and removal volume, it concludes that the ceramics removal volume increases as the discharge capacitance and the voltage increase, but decreases as the electrode size increases. Furthermore, it provides the volume change curves in different media, and studies the features of capacitor discharge experimental materials for insulating ceramics machining in different media. Both materials and auxiliary electrode simultaneously experience the process of gasification and melting during discharge. The materials are mainly gasified due to the action of high temperature and voltage at the center of the discharge channel, and the parts around the materials are removed mainly in the form of melting and stripping due to the action of heat stress. The above data analysis has a certain theoretical basis and practical guiding significance for the capacitor discharge machining of insulating ceramics.

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