점화코일용 에폭시의 부분방전 특성

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Partial Discharge Characteristics of Epoxy for Ignition Coil

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Abstract : The automobile equipped with a gasoline engine uses the ignition coil, namely, a high voltage generator, to make the mixed fuel ignited and burned in the combustion chamber, which results in the power to drive the engine. The ignition coil functions to convert a low voltage of the primary into a high voltage of the secondary by switching method, which will be transmitted to the electrode. Here, if the ignition coil has a defect even a little, it cannot function well. In this study, it was chosen epoxy molding ignition coil in recently and epoxy resin which is insulation material as specimens, and it was measured the characteristics of the partial discharge occurring to the specimens when those were applied to a voltage, and thereby, it was researched and analyzed the distribution of phase angle, amount and count of discharge due to the changing voltage, And as the result is applying to the actual automobile ignition system, it can be expected the enhancement of the performance of the ignition coil and the reliability of the electrical equipment.

초록 : 가솔린 엔진을 장착한 자동차는 고전압발생장치인 점화코일을 이용하여 고전압을 발생 연소실 내의 혼합기를 점화 및 연소시킴으로써 동력을 얻고 엔진을 구동하게 된다. 점화코일은 1차측 낮은 전압을 스위칭 작용으로 2차측 높은 전압을 발생시키고, 이를 전극으로 보내는데, 점화코일에 작은 결함이 발생하게 되면 제 성능을 발휘하지 못한다. 본 연구에서는 현재 사용하고 있는 에폭시 성형 점화코일과 절연재료인 에폭시수지를 시료로 선택하여 시료에 전압이 인가될 때 발생하는 부분방전 특성을 측정하여 전압변화에 따른 위상각, 방전전하량 및 발생빈도수 등의 분포를 연구하고 검토한 결과를 실제 자동차점화장치에 접목시켜 점화코일의 성능향상과 전기장치의 신뢰성 확보에 기여하고자 한다.
Key Words : partial discharge, epoxy resin, discharge current, air void, copper particle

1. Introduction

Ignition coil molded in epoxy resin is used for the gasoline automobile engine and it is insulated with the superior insulation material to get the electric property for the electric stability and reliability. The current is flowed to the ignition coil and some lower voltage is applied to the 1st coil using the induction activity, an electric property, and surge voltage is generated in the 1st coil when switching the interrupter. As is provided to the ignition plug in the combustion chamber the high voltage is generated by means of the mutual induction activity between the 1st coil and 2nd coil, so that the engine is driven with the energy obtained by igniting the mixed gas with the electric spark generated by the current crossing over the gap between the positive electrode and the negative one, which are insulator[1]. The open loop type of ignition coil was used even until recently, and it uses the mixed insulation oil which can maintain insulting ability by preventing the shorting circuit between the 1st coil and

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2nd one and layers as the inserting liquid insulation oil capable of conducting the function of insulation and cooling by the current of insulation oil. But if driving lasts for a long time, the ignition coil decreases in performance due to the deterioration and the weakening of insulation resistance[2,3]. Also, the ignition coil used at present is indeed excellent in ignition performance, semi permanent, able to be made more lightweight through miniaturization and easy to check up, but it has the danger of weakening of insulation performance and shortening of life due to the mixing of impure elements and the internal damage etc. So the inspection of internal state of the ignition coil etc must be made, but still insufficient in the methods and information concerned. And partial discharge(PD) is generated in polymer insulation material with the void, recently the insulator of the ignition coil makes used of epoxy resin[4,6]. Hence, in order to solve and supplement all kinds of problems, it was examined and considered the influence of the PD occurring to the epoxy molding ignition coil with the void that can be generated in epoxy resin which is insulation material of ignition coil. And then it is intended to offer the basic data to predict the life of ignition coil[4[1]-[8]].

2. Specimen and Experiment

2.1. Specimen

The epoxy specimen which is the insulation material of ignition coil has been produced in sheet type by eliminating bubbles and hardening first at 90[℃] for 2.5[h] and secondly at 140[℃] for 2.5[h] following hardening conditions after mixing and agitating the brown epoxy resin of the specific gravity of 1.83 and at the ratio of combination of 100 : 28 acid anhydride at the normal temperature in a vacuum. And the physical properties of volume resistivity and dielectric loss using the ASTM D257 are $2.9\times10^{13}[\Omega\cdot m]$ and 1.47 at 100[℃] respectively. We are prepared the air void of 1[mm^3] and copper particle (diameter 1.12 [mm], length 1[mm]) at the specimen inside.

2.2. Experiment

2.2.1. Physical properties

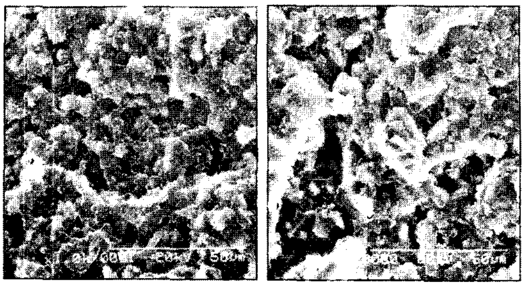

(a) sheet type (b) molding type

Photo. 1. SEM of specimen

In order to examine the physical properties of the specimen of epoxy produced under the same conditions, it was obtained by photographing cross section using a scanning electron microscope(SEM). Photo. 1 shows cross section SEM micrographs of epoxy specimen. It is confirmed that the bonding structure of sheet type and molding type for ignition coil is similar.

2.2.2. Partial discharge properties

A discharge amount was measured at AC 60[Hz] using PD measurement equipment which was manufactured by AVO Co. in order to examine PD properties of epoxy specimen. calibration signal coupler was connected to the higher voltage generating equipment and then the PD measurement equipment was calibrated with 50[pC] after applying the voltage by connecting the specimen to the electrode[6]. Afterwards the data was acquired immediately by means of the measurement equipment to detect discharge amount and generation counts by phase for about 10[sec]. and then discharge amount and generation counts were obtained using Matlab program for the information obtained by 3D graph with the data layer in a cycle. Fig. 1 shows the electrode and specimen to measure PD.

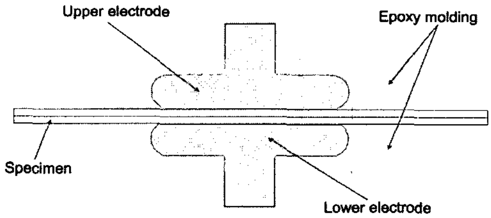


Fig. 1. Electrode and specimen

3. Results and discussion

3.1. Voltage dependency of Φ-q-n distribution

3.1.1. No void

Fig. 2, which is Φ-q-n distribution of no void specimen at the time of applied voltage 3[kV]~10[kV] in order to examine the PD properties of epoxy specimen, shows that the PD properties do not appear, as the insulation performance of epoxy specimen is excellent under the applied voltage of 5.0[kV]. Fig. 2(a), which is the PD properties of applied voltage of 6[kV], shows that positive polarity records the electric discharge amount of 15,328[pC] and the generation counts of 730 in the phase angle range of 0°~105° and that negative polarity records the electric discharge amount of 14,736[pC] and the generation counts of 415 in the phase angle range of 175°~250° and 280°~330°. And Fig. 2(b), which is the PD properties of the applied voltage of 7[kV], shows that positive polarity records the electric discharge amount of 82,056[pC] and the generation counts of 3,009, and that negative polarity records the electric discharge amount of 128,200[pC] and the generation counts 2,814. It seems to be caused by the contribution of the electron that the positive polarity is greater than negative one in the greatest and total counts, but the negative polarity is greater by 156[%] than the positive one in the amount of discharge[4]. Fig. 2(c), which is the PD properties measured at the applied voltage of 8[kV], shows that positive polarity records the electric discharge amount of 263,984[pC] and the generation counts of 6,821 in the phase angle range of 0°~110°, that negative polarity records the electric discharge amount of 372,808[pC] and the generation counts of 7,226, and that the electric discharge amount is three times greater than at the applied voltage of 7[kV]. Fig. 2(d), which is the PD properties at the applied voltage of 10[kV], shows that the greatest counts is much greater in the positive polarity, that the total counts are similar in the positive polarity(22,726) and negative one(23,969) and that the electric discharge amount, which is 1,064,256[pC] in the phase angle range of 0°~120° in the positive polarity, and 1,608,928[pC] in

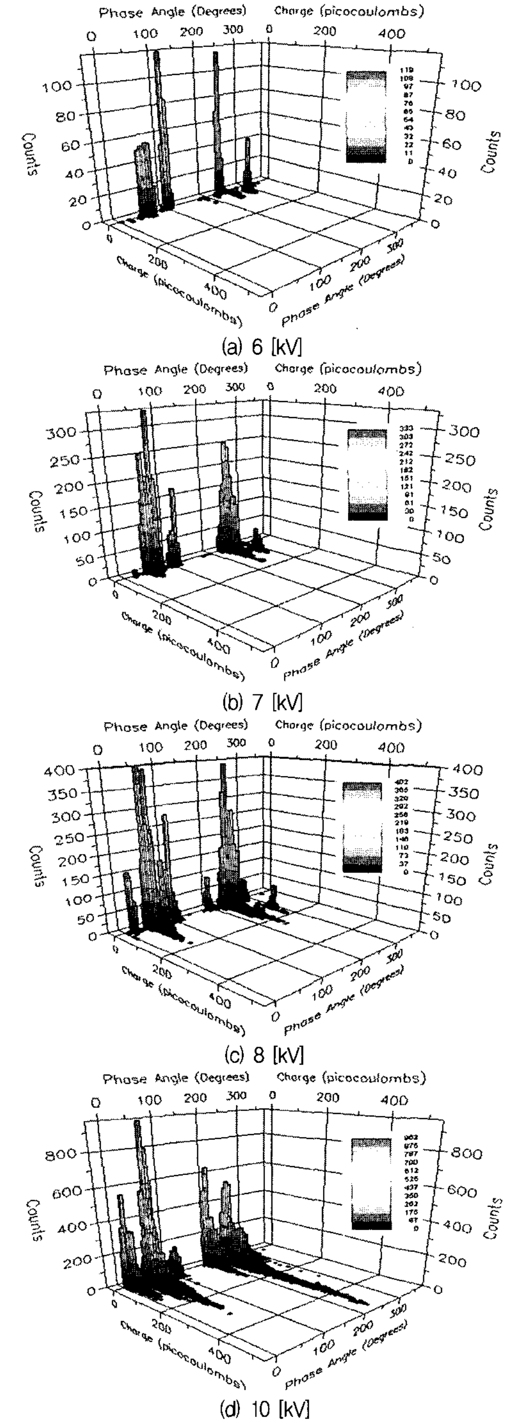
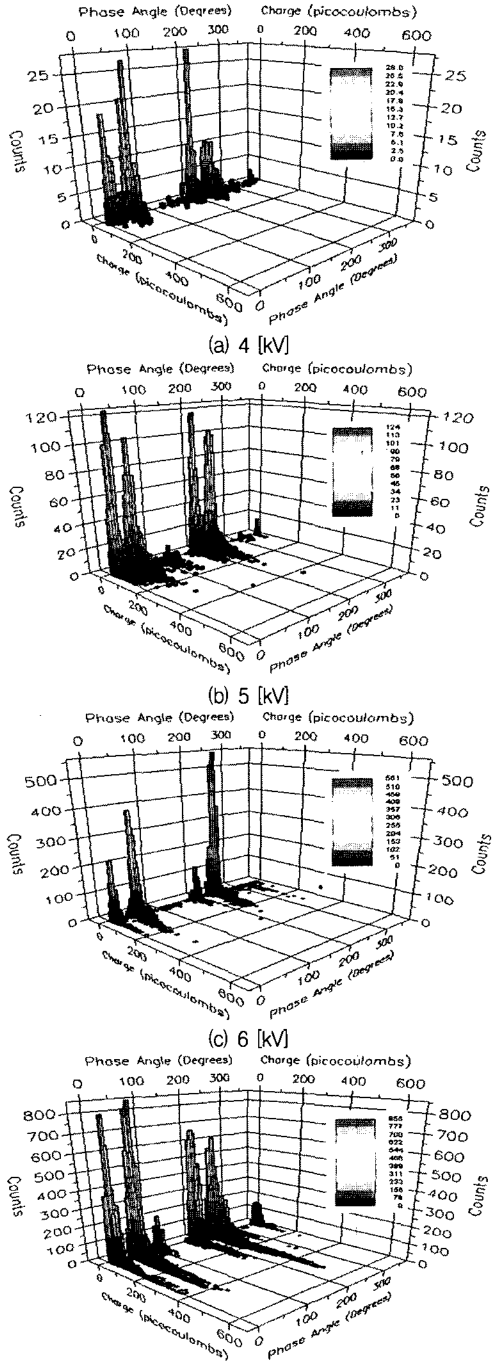


Fig. 2. φ-q-n distribution of no void

the phase angle range of 180°~300° in the negative polarity, and it is confirmed that in the negative polarity is greater by 151[%] than in the positive one. Accordingly, it is shown that the higher the applied voltage goes up, the more the discharge amount and the generation counts increase and that the electric discharge amount is greater in the negative polarity than in the positive one. Which seems to be caused by the fact that the contribution of the positive polarity is greater than that of the negative one. And the average electric discharge amount is more or less greater in the negative polarity than in the positive and the total average discharge amount increases linearly.

3.1.2. Air void

Fig. 3, which is Φ-q-n distribution of no void specimen at the time of applied voltage 3[kV]~8kV] in order to examine the PD properties of epoxy specimen. Fig. 3(a), which is Φ-q-n distribution at the time of applied voltage 4[kV], shows that positive polarity records the electric discharge amount of 13,149[pC] and the generation counts of 344 around the phase angle range of 0°~75° and 130° that negative polarity records the electric discharge amount of 11,100[pC] and the generation counts of 289 under the total phase angle range. The electric discharge amount is a little more in the positive polarity than in the negative one, but the average discharge amount is the same in both polarities. Fig. 3(b), which is the PD properties at the time of applied voltage 5[kV], shows that positive polarity records the electric discharge amount of 126,800[pC] and the generation counts 2,545 in the area twice wider than 4[kV] and that negative polarity records the electric discharge amount of 121,750[pC] and the generation counts of 2,456. The electric discharge amount is almost similar in both polarities. Fig. 3(c), which is the PD properties at the time of applied voltage 6[kV], shows that positive polarity records the electric discharge amount of 200,100[pC] and the generation counts of 4,617 in the almost general area that negative polarity records the electric discharge amount of 240,200[pC] and the generation counts of 5,964. The electric discharge amount is greater by 120[%] in the negative polarity than in the positive one.



(a) 4 [kV]

(b) 5 [kV]

(c) 6 [kV]

(d) 8 [kV]

Fig. 3. φ-q-n distribution of air void

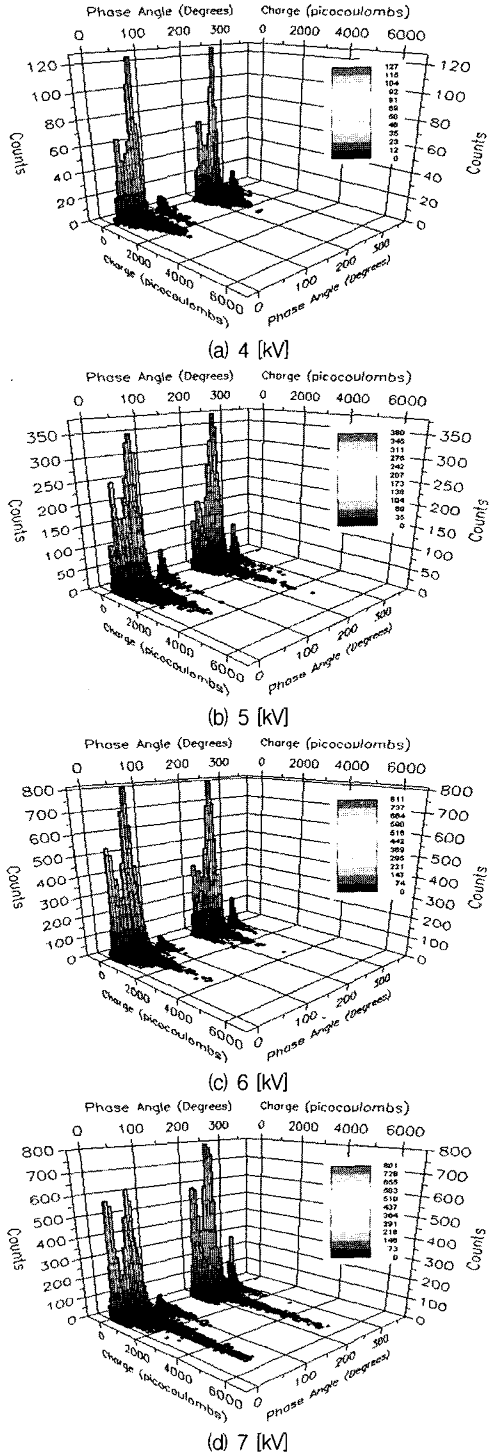
Fig. 3(d) shows that positive polarity records the electric discharge amount of 1,249,000[pC] and the generation counts of 23,918 under the applied voltage of 8[kV] and that negative polarity records the discharge amount of 24,200[pC] and the generation counts of 5,964. The discharge amount is greater by 142[%] in the negative polarity than in the positive one, which seems also to be caused by the fact that the increase of the applied voltage promotes the contribution of the electron in the negative polarity[9,10]. The higher the applied voltage goes up, the more the discharge amount and the generation count increase, at the voltage more than 6[kV], the discharge amount and counts are greater in the negative polarity than in the positive one, but in the positive than in the negative under the comparatively low voltage. At the voltage less than 6[kV], the average discharge amount is the same or similar in both polarities, but at the voltage more than 6[kV], greater in negative polarity. And if air void exists, the average discharge amount is greater in the same electric field than that of no void.

3.1.3. Copper particle

Fig. 4, which is the Φ-q-n characteristics at the time of applied voltage 3[kV]~7[kV] in order to examine the PD properties of copper particle existing specimen, shows that voltage at the start of discharge is lower than other voids.

Fig. 4(a), which is Φ-q-n distribution at the time of 4[kV] on the copper particle existing epoxy specimen, shows that positive polarity records the electric discharge amount of 1,017,800[pC] and the generation counts of 1,978 and that negative polarity records the electric discharge amount of 1,048,900[pC] and the generation counts of 2,046. The discharge amount and generation counts are greater in no void than in other voids. Fig. 4(b), which is Φ-q-n distribution at the time of applied voltage 5[kV], shows that positive polarity records the electric discharge amount of 5,510,800[pC] and the generation counts of 10,861 and that negative polarity records the electric discharge amount of 5,474,900[pC] and the generation counts of 11,285. The discharge amount is similar in both polarities.

Fig. 4(c), which is Φ-q-n distribution at the time of applied voltage 6[kV] on the copper particle specimen, shows that positive polarity records the electric discharge amount of 7,717,400[pC] and the generation



(a) 4 [kV]

(b) 5 [kV]

(c) 6 [kV]

(d) 7 [kV]

Fig. 4. φ-q-n distribution of copper particle

counts of 17,590 in the phase angle range of 0°~110°

and that negative polarity records the electric discharge amount of 8,404,300[pC] and the generation counts of 19,759 in the phase angle range of 180°~300°. The greatest discharge amount is greater in the positive polarity, but the total discharge amount is also greater in the negative polarity which is greater in the total counts[7,10].

Fig. 4(d), which is Φ-q-n distribution at the time of applied voltage 7[kV], shows that positive polarity records the electric discharge amount of 11,142,000 [pC] and the generation counts of 18,628 in the phase angle range similar to that at the voltage of 6[kV] and that negative polarity records the discharge amount of 11,954,000[pC] and the generation counts of 23,987. The discharge amount is greater in the negative polarity.

Especially, the total discharge amount is greater by 143[%] and the total counts are greater by 114[%] than under the applied voltage of 6[kV]. At the time of increasing applied voltage on the copper particle epoxy specimen, the discharge amount is similar in both polarities under the comparatively low voltage of 5 [kV], but greater in the negative polarity at the voltage of more than 6[kV] due to the contribution of the electron and the average discharge amount in the positive[4,7]. And if copper particle exists in the specimen, the average discharge amount is about ten times greater than other voids. Accordingly, if conducting metals exist in the specimen, the PD is easy to appear and the insulation is lower. Fig. 5 shows discharge current gotten by applied voltage of 3[kV]~8[kV] into no void, air void and copper particle, respectively.

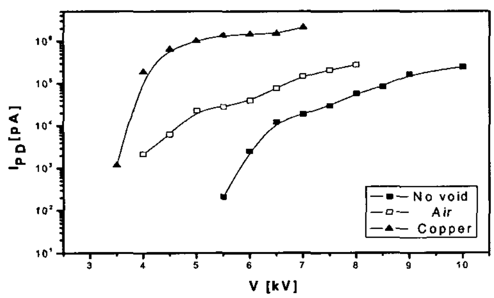


Fig. 5. Discharge current due to void

No void specimen starts to discharge at 5.5[kV] and increases comparatively faster until 6.5[kV] but increases slowly after 6.5[kV]. No void appears lower discharge current than void one. This means that insulating ability of the specimen is excellent, especially because of PD is occurring inside specimen, it is considered. In case of air void, it starts to PD at 4[kV] and increases a bit faster and rises slower comparatively after 5.5[kV]. It is considered that the reason why the starting point of the discharge voltage comes down is the existence of air void forms a discharge pole inside of the void. Also, the copper particle starts to discharge at applied voltage of 3.5 [kV] and increases swiftly until 4[kV] then the rate of increase comes down a bit. This is considered as that the conductive material affects the discharge to occur easily, as a result, the starting point of discharge voltage comes down and the discharge amount grows up.

3.2. Time dependency of q-n distribution

3.2.1. No void

Fig. 6 is q-n distribution showing the PD properties of specimen at the time of applied voltage 6.5[kV] for 60[min]. PD distribution immediately after applied voltage 6.5[kV] on no void sheet type specimen shows that positive polarity records the electric discharge amount of 52,136[pC] in the phase angle range of 0° ~70° and the generation counts of 1,437, and that negative polarity records the electric discharge amount of 85,352[pC] and the generation counts of 2.584. Accordingly, the discharge amount is greater by 163 [%] in the negative polarity, which seems to be caused by the contribution of the electron.

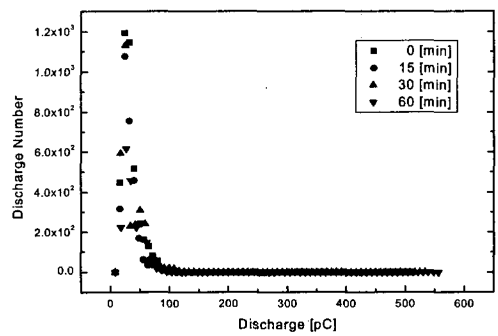


Fig. 6. *q-n* distribution of no void

Fig., which is q-n distribution after 15[min] of applied voltage, shows that positive polarity records the electric discharge amount of 36,632[pC] and the generation counts of 1,174, and that negative polarity records the discharge amount of 55,568[pC] and the generation counts of 1,758. Accordingly, the negative polarity is greater in counts than the positive and 151[%] greater in discharge amount due to the contribution of the electron. The discharge amount at 30[min] and 60[min] is almost similar, which seems to be caused be stabilized with the passage of time.

Accordingly, the discharge amount is greatest at the beginning of measurement and stabilized with the passage of time; the counts are the greatest shortly after applied voltage and second great after 1[min]. This is caused by the fact the movement of electron is active to be stabilized at the beginning. Besides, if no void exists in the specimen, the average discharge amount is almost similar in both polarities and is greater in the positive shortly after applied voltage, but in the negative with the passage of time.

3.2.2. Air void

Fig. 7 is q-n distribution at the time of applied voltage 6.5[kV] for 60[min]. Figure, which is q-n distribution immediately after applied voltage on air void specimen, shows that positive polarity records the discharge amount of 336,470 [pC] and the generation counts of 7,732 and that negative polarity records the discharge amount of 509,330 [pC] and the generation counts of 11,072.

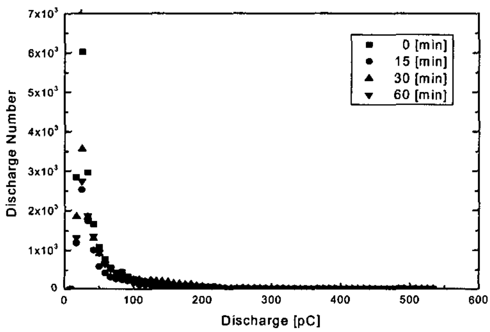


Fig. 7. *q-n* distribution of air void

Accordingly, the discharge amount is greater by 151[%] in the negative polarity, which seems to be caused by the greater counts in the negative polarity and active contribution of the electron. Fig., which is q-n distribution after 15[min] of applied voltage, shows that positive polarity records the electric discharge amount of 364,340[pC] and the generation counts of 5,498 in the total area and that negative polarity records also the electric discharge amount of 338,740 [pC] and the generation counts of 5,313 in the total area. The greatest generation count is much greater in the positive, but the total generation counts and discharge amount are almost similar in both polarities. Fig., which is q-n distribution respectively after 30 [min] and 60[min], shows that the phase angle range is narrower and that the discharge amount is more or less diminished. Accordingly, the discharge pillar is formed due to the radiation of spectrum from ultraviolet rays to visible one at the beginning of discharge, that electric charge is accumulated on the surface of void due to the discharge pillar, generating converting electric field which is characterized by the periodicity of increasing until the specific time and reaching the specific discharge amount. And, the average discharge amount is almost similar in both polarities.

3.2.3. Copper particle

Fig. 8 is q-n distribution at the time of applied voltage 6.5[kV] for 60[min]. Figure, which is q-n distribution at once after applied voltage, shows that positive polarity records the discharge amount of 7,808,000[pC] and the generation counts of 15,174 in the phase angle range of 0°～110° and that negative polarity records the electric discharge amount of 8,669,200[pC] and the generation counts of 18,830 in the phase angle range of 180°～230°. But it is confirmed that the average discharge amount is greater in the positive polarity than in the negative one. Fig., which is q-n distribution after 15[min], shows that positive polarity records the electric discharge amount of 4,035,100[pC] in the phase angle range similar to that shortly after applied voltage and that negative polarity records also the discharge amount of 3,776,500 [pC].

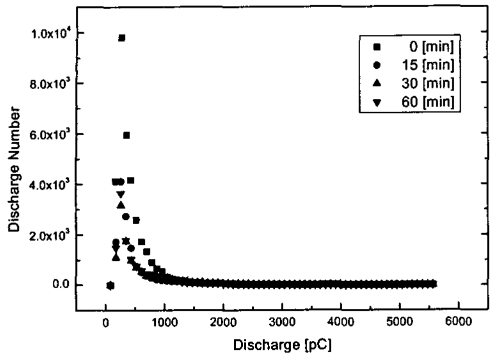


Fig. 8. *q-n* distribution of copper particle

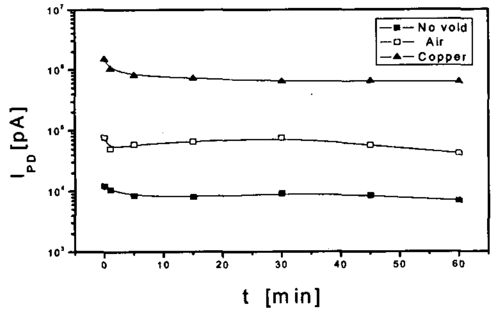


Fig. 9. Discharge current due to time

Accordingly, the average discharge amount is greater in the positive than negative one. Fig., which is distribution after 30[min] and 60[min], shows that the phase angle range is distinct, that the discharge amount decreases more and more and that the average discharge amount decreases more conspicuously in the negative polarity than in the positive one, as the greatest and total generation counts increase.

Accordingly, which shows that the discharge amount increases at the beginning of discharge due to the contribution of inner discharge, decreasing with the passage of time and stabilizing, but that if electric field is imposed, the movement of carrier is accelerated at the beginning, stabilizing increasingly with the passage of time and decreasing more or less the discharge amount. Accordingly, the counts and discharge amount are high at the beginning of measurement, but decreases and stabilizes with the passage of time. And the average discharge amount of copper particle is greater in the positive electrode than in the negative one. Fig.9 shows discharge current gained by the applied voltage of 6.5[kV] into no void, air void and copper particle for 60[min]. Properties of discharge current decrease a bit in the beginning of the applied voltage and appears uniformly after more 10 [min], and the copper particle shows 8×10^5[pA] of discharge current as the greatest, the air void shows 6×10^4[pA] of discharge current and no void shows 8×10^3[pA] of discharge current. As a result, it is confirmed that the starting point of discharge voltage appears as the lowest at the conductive void and appears as the highest at no void because the breakdown voltage decreases to 1/10~1/100 when void is inside specimen.

4. Conclusions

It is based on the study of the PD properties of molding epoxy specimen, to investigate the electric characteristics of automobile ignition coil, it is confirmed the following conclusions :

1) In the molding sheet type epoxy, the average discharge amount increases linearly in accordance with the applied voltage and a little greater in the negative electrode.

2) In the PD properties of void existing specimen, the average discharge amount of copper particle is over ten times greater than that of air void, that of air void is little influenced by polarities and that of copper particle is a little greater in the positive polarity.

3) In the time dependency of partial discharge amount, discharged current decreases and stabilizes with the passage of time.

4) The application of the basic data on partial discharge to the prediction of life can contribute to the performance enhancement of ignition equipment and the production of excellent parts.

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