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Effect of Copper Particle on the PD Characteristics in a Coaxial Duct with Mixture of SF_6 (10%) and N_2 (90%) Gases

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Abstract**—**Insulation performance of a gas insulated system is severely affected by particle contaminants. These metallic particles adversely affect the characteristics of insulating system. These particles can produce surface charges due to partial discharge activities. These particles which are free to move enhance the local electric fields. This paper deals with the influence of conducting particle placed in a co-axial duct on the discharge characteristics of gas mixtures. Co-axial duct placed in a high pressure chamber is used for the purpose. A gas pressure of 0.1, 0.2 and 0.3 MPa have been considered with a 10:90 SF_6 and N_2 gas mixtures. The 2D and 3D histograms of clean duct and duct with copper particle are discussed in this paper.

Keywords**—**Coaxial duct, gas insulated system, gas mixtures, metallic particle, partial discharges, histograms.

I. Introduction

SULPHUR HEXAFLUORIDE (SF_6) gas has been regarded as ideal for electrical power equipment since the 1960's due to its superior insulation and interruption characteristics. SF_6 gas is one of the most extensively and comprehensively studied molecular gases to date largely because of its many commercial and research applications. Because of its basic physical and chemical properties such as nontoxic, non-flammable, non-explosive, and thermal stability, it is widely used in the power industries [1]. It is widely used from several KV to the EHV class of gas insulated systems, gas blast circuit breakers, and gas insulated transmission lines [2]. SF_6 gas is a strong electronegative gas both at room temperature and at temperatures well above ambient, which principally accounts for its relatively high dielectric strength. The breakdown voltage of SF_6 gas is nearly three times higher than air at atmospheric pressure [3]. Even though SF_6 gas has outstanding electrical insulating properties, its impact on global atmosphere have been intensively debated and discussed. SF_6 gas forms highly toxic and corrosive compounds when subjected to electrical discharges. SF_6 gas is also an efficient infrared absorber, and due to its chemical inertness is not rapidly removed from the earth's atmosphere. Environmentalists have seriously considered the contribution of SF_6 gas to ozone depletion and the global greenhouse effect. The high global warming potential of SF_6 gas has raised several questions about its use. The fear is about excessive release of SF_6 gas into atmosphere and the Power industry inherently bases its possible contribution to the greenhouse effect on the projections about the future consumption of SF_6 gas. The global production of SF_6 gas is very small and its effective contribution as a greenhouse gas is considered to be negligible. However, efforts are made to minimize the use of SF_6 gas for electrical applications However, labeling SF_6 gas as a greenhouse gas made the scientists to find a substitute for SF_6 more urgent [4]. Intensive research efforts are being made to find substitute for SF_6 [5].

Even though the application of gas insulated system in electric transmission systems has been increasing in many countries because of their compactness, non-flammable nature and high degree of reliability; the degree of compactness of the GIS is severely restricted due to the problems caused by the increase in operating stresses. One of the most important problems in GIS is the presence of conducting particles which might accidentally contaminate the GIS gaps. Metallic particles cause serious problems which affect the long term performance of GIS. These contaminating particles reduce the voltage withstand ability of gas insulated systems. These particles may result from mechanical abrasions and vibrations due to load cycling as well as the entry of other contaminants during assembly. It is an accepted fact that in spite of best efforts, particle contamination can never be avoided but only minimized.

The contaminating particles may be either insulating or conducting in nature. Further, they may be free to move under the influence of the applied field or may be fixed to the electrodes. These free conducting particles cause high field distortions [6]. In this study, the effect copper particle on the PD characteristics of the insulation system is presented and discussed.

The results of some investigations show clearly that nitrogen at high pressure is to be seen as one of the most pollution free insulating gases for the technological use in high voltage equipment [7]. The dielectric strength of nitrogen could be increased by the addition of a small amount of electronegative gas. N_2/SF_6 gas mixtures can be used instead of pure SF_6, as long as the SF_6 gas is not legally forbidden. As a further advantage, the N_2/SF_6 gas mixtures, with small

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amounts of SF_6, have lower boiling temperature values than pure SF_6.

In this study, a mixture of SF_6 and N_2 gases in the ratio of 10:90 has been used to determine the effect of conducting particle on Partial Discharge characteristics in a co-axial duct

II. Experimental Details

A. Equipment Used

The co-axial duct used has a length 150 mm with inner diameter of 45 mm. The central cylindrical shaped solid conductor is of 175 mm length and 15 mm diameter. Both Duct and central conductor are made of Non-magnetic stainless steel grade 304. The photographic view of the co-axial duct is shown in Fig. 1. The central conductor is directly coupled to the high voltage. The outer duct is connected to a separate terminal which is grounded. The outer duct is also free from sharp edges and micro protrusions.

The conical spacer made of nylon/PMMA material is fabricated from a molded 5 cm solid rod and the inner conductor is fitted into the conical spacer with great care with silver adhesive. This is for the better contact between the insulator and the conductor to fill micro voids. The unit consisting of spacer and central conductor is inserted into the co-axial duct.

The heart of the experimental set-up is the high pressure test chamber. The epoxy high pressure chamber is designed mainly for studies on conical spacers. The volume of this chamber is about 3.5 liter and is fabricated with a material having sufficient tensile, compressive and shear strength to take care of all mechanical stresses that can be encountered during high pressure studies. The high voltage conductor is directly fixed to the top flange of the chamber. Fig. 2 shows the photograph of the high pressure chamber.

Fig. 1 Co-axial Duct

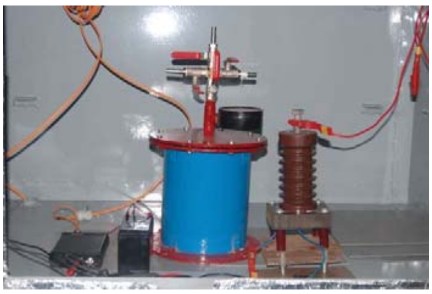

Fig. 2 High pressure test chamber

The conducting particle of 0.8 mm diameter and 10 mm length of bare copper conductor is used. No special tip geometry was used. The particle was fixed vertically on the central conductor. A small amount of silicon adhesive was used for the purpose. Care was taken that no tip was covered with adhesive.

The test equipment mainly consists of MPD540 Advanced Partial Discharge Measuring and Analysis System of Mtronix Precision Measuring Instruments as shown in the Fig. 3. The circuit connection is as shown in Fig. 4.

Fig. 3 MPD540 advanced PD measuring system with coupling capacitor

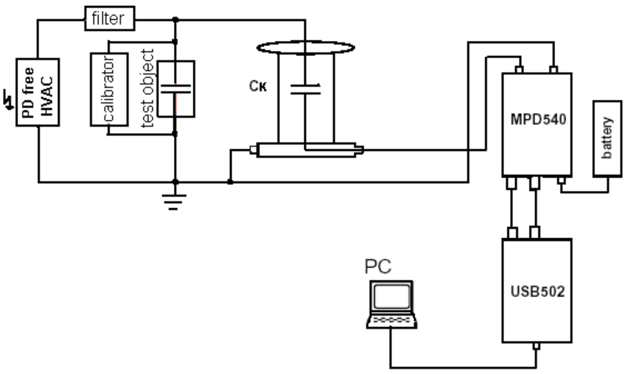

Fig. 4 Circuit connection

III. Experimental Results

PD measurements were carried out on a co-axial duct first without any particle and next with copper particle placed on the central conductor. For each condition, experiments were conducted for a pressure of 0.1, 0.2 and 0.3 MPa.

The 2D PD histogram in case of a clean co-axial system consisting of SF_6 - N_2 (10:90) gas mixture at 0.1 MPa pressure is shown in Fig. 5 and corresponding 3D PD histogram is shown in Fig. 6. At 0.1 MPa, the PD activity is observed to be more prominent under positive cycle of ac as seen in the histograms. Further, PD activity is confined to 36^0 and 144^0 for the positive half cycle and for the negative half cycle it is confined to 216^0 and 324^0. The number of PD events is 1.8 PDs/sec (maximum) in case of the positive half cycle whereas, it is about 0.6 PD/sec in the negative half cycle. Even the spread of discharge magnitude is larger during the negative half cycle. It is obvious that at low pressure, the effect of SF_6 is not significant and the results observed are attributed to effects of roughness of central conductor and duct and their impact on discharge initiation.

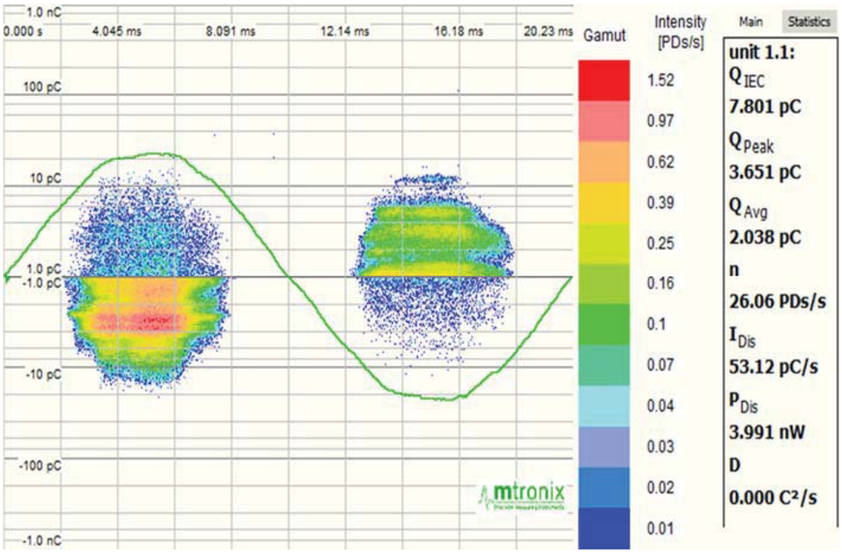

Fig. 5 2D PD Histogram of a clean duct at 0.1 MPa

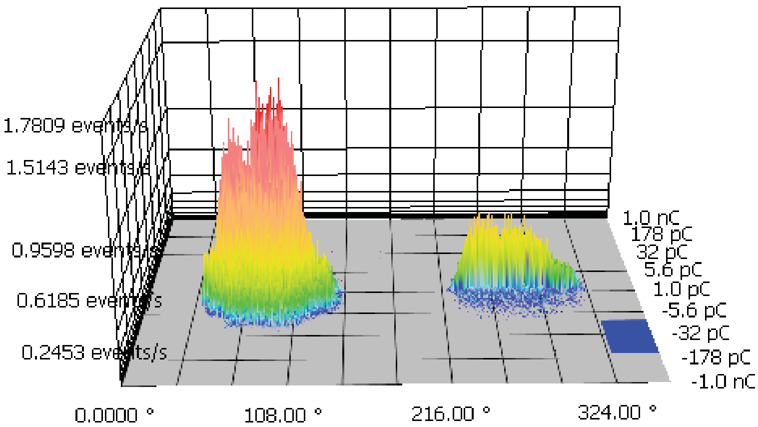

Fig. 6 3D PD Histogram of a clean duct at 0.1 MPa

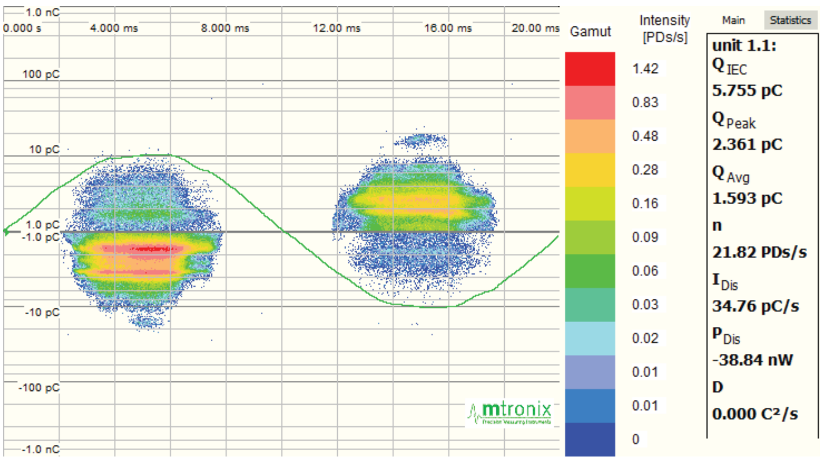

Fig. 7 2D PD Histogram of a clean duct at 0.2 MPa

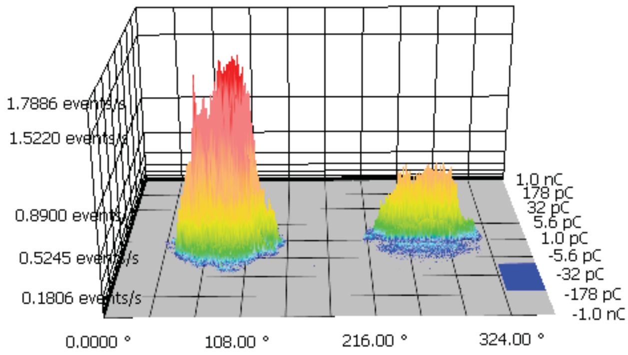

Fig. 8 3D PD Histogram of a clean duct at 0.2 MPa

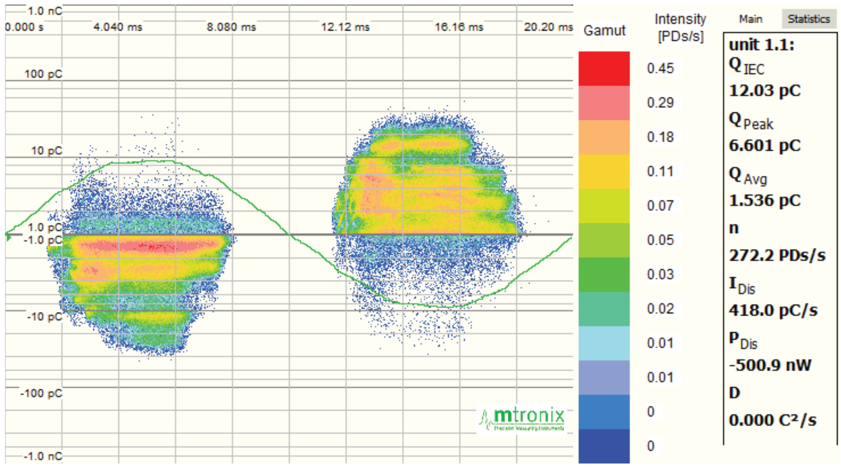

Fig. 9 2D PD Histogram of a clean duct at 0.3 MPa

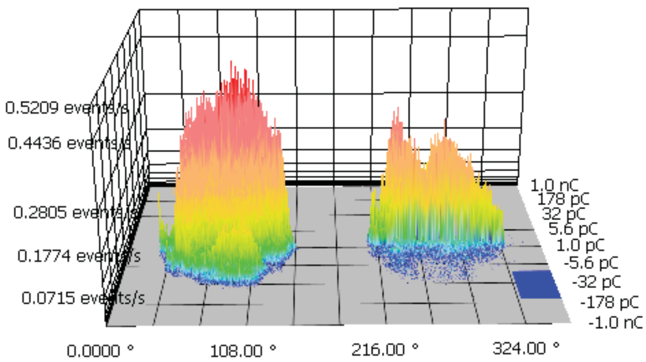

Fig. 10 3D PD Histogram of a clean duct at 0.3 MPa

If we consider Fig. 5, in relation to the intensity chart furnished, the discharges seen during positive half cycle having PD magnitude of 10 pC are due to PDs of intensity 0.97 PDs/sec to 1.52 PDs/sec. However, corresponding values on the negative cycle are very insignificant. Hence, under the given experimental condition, PD during positive half cycle is very dominant. The results are duly supported by the 3D histogram in Fig. 6.

With increase in gas pressure to 0.2 MPa, though the situation continues to be the same, the PD intensity during positive half cycle has contributions from 0.83 to 1.42 PDs/sec. The relative contribution during the negative half cycle is less both in terms of density and PD magnitude. The 2D and 3D PD histograms at 0.2 MPa are shown in Figs. 7 and 8 respectively. The 3D PD histogram clearly shows that the number of discharge events is consistently high on the positive half cycle. Major contributions are from 0.48, 0.83, and 1.42

PDs/sec, whereas during positive half cycle, there are larger contributions from low intensity PD discharges of magnitude less than 0.16 PDs/sec. Therefore, even with the increase in gas pressure, the behavior of the clean duct in terms of PDs continues to be same.

The results of 2D and 3D PD histograms at 0.3 MPa for clean duct are shown in Figs. 9 and 10 respectively. There is a transition at this pressure with slight increase in discharge activity during negative half cycle as well as increase in PD magnitude. This region of pressure may be due to the corona stabilization region and increase in non-uniformity coming into picture. There is a considerable increase in low magnitude PD having very high number density in the positive half cycle which is not present in the negative half cycle. A better and clean picture emerges from the 3D PD histogram shown in Fig. 10. A considerable decrease in 'n' value is observed during positive half cycle and with all other characteristics being similar to previous cases. It is interesting to note that with increase in gas pressure, there is every indication of increase in PD activity during the negative half cycle resulting in a situation close to symmetry.

Figs. 11 and 12 show the 2D and 3D PD histogram at a pressure of 0.1 MPa due to presence of free Copper particle of 0.8 mm diameter and 10 mm length. Due to Copper particle, there is increase in PD activity in the negative half cycle and PD events/sec is also comparatively higher. This is totally different from what is observed in a clean duct.

Figs. 13 and 14 show the 2D and 3D PD histogram for duct with Copper particle at 0.2 MPa. With increase in pressure, there is increase in 'n' but the corresponding change in PD activity between the two ac half cycles is very much reduced. This clearly shows that the increase in gas pressure or the effectiveness of SF_6 gas results in suppression of discharges. This is also clear indication of decrease in PD magnitude.

The PD histogram for a co-axial geometry with Copper wire particle at 0.3 MPa is shown in Figs. 15 and 16. As compared to 0.2 MPa, there is slight increase in PD pulses of marginally higher magnitude but the high intensity PDs are invariably of low magnitude. Hence, there is no appreciable change when the pressure is increased from 0.2 MPa to 0.3 MPa.

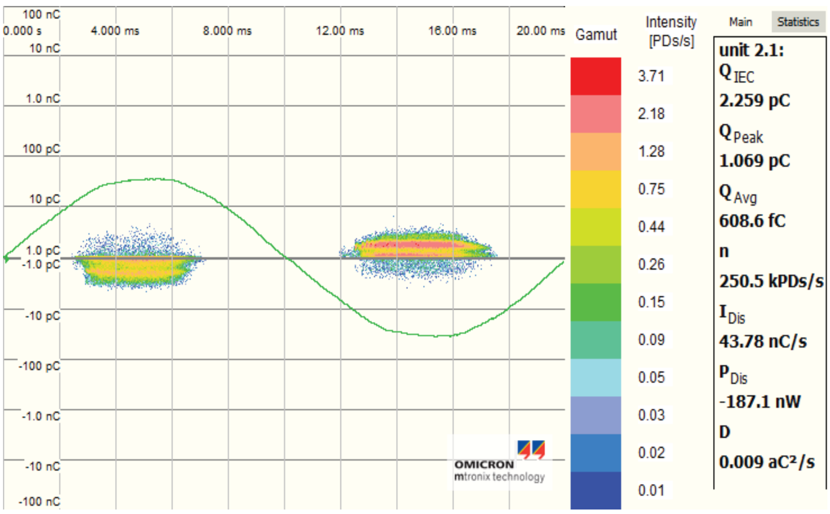

Fig. 11 2D PD Histogram with copper particle at 0.1 MPa

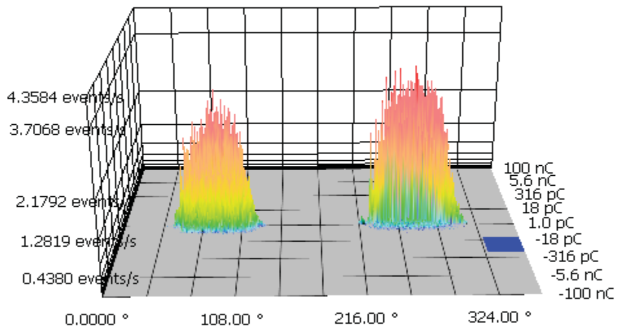

Fig. 12 3D PD Histogram with copper particle at 0.1 MPa

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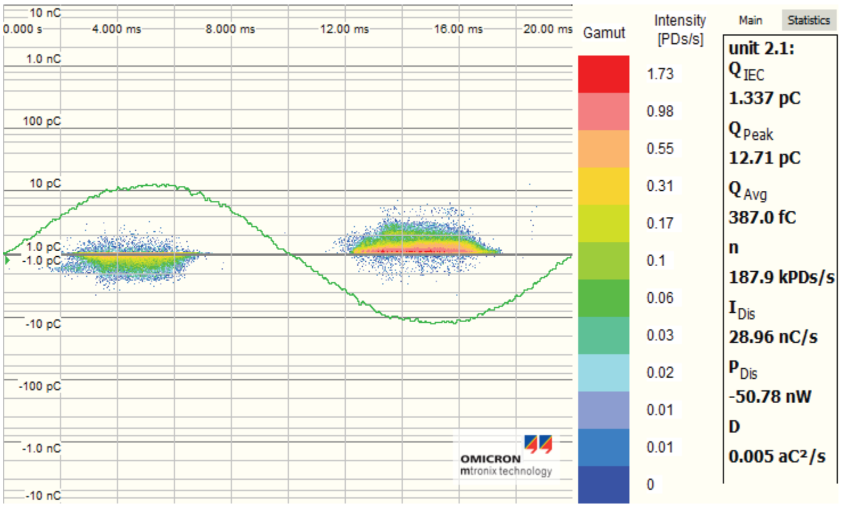

Fig. 13 2D PD Histogram with copper particle at 0.2 MPa

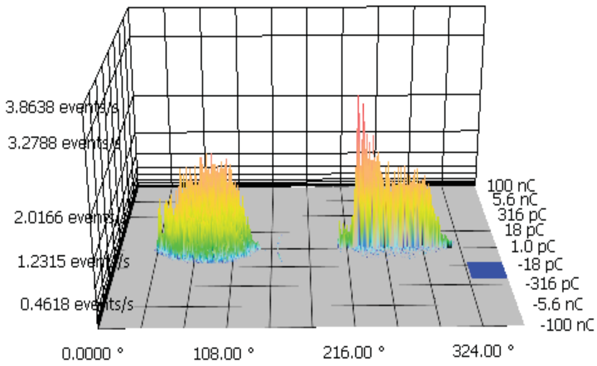

Fig. 14 3D PD Histogram with copper particle at 0.2 MPa

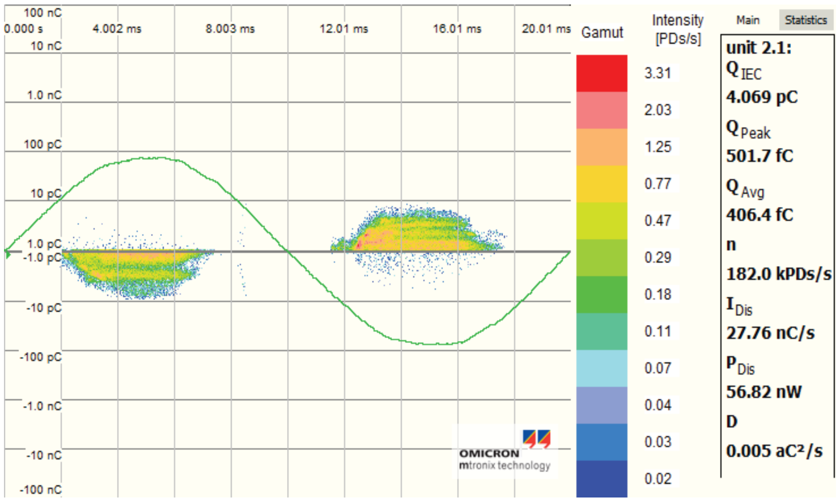

Fig. 15 2D PD Histogram with copper particle at 0.3 MPa

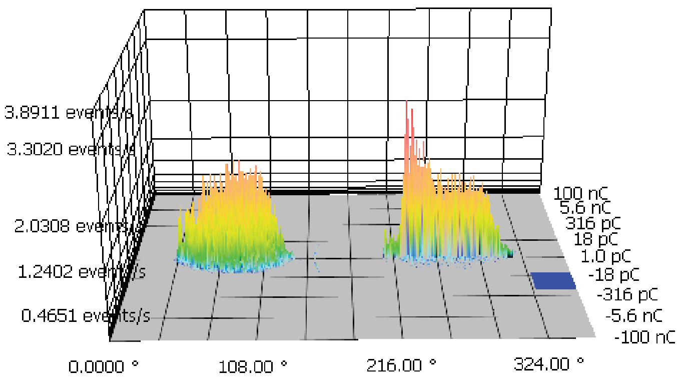

Fig. 16 3D PD Histogram with copper particle at 0.3 MPa

IV. Conclusions

1. With copper particle, the number of PDs/second increases abnormally in a clean duct. i.e. from 26.06 PD's/s (clean duct) to 250kPD's/s. (duct with copper particle) at 0.1 MPa.
2. For a clean duct, the event/second is only 1 whereas for a duct with copper particle it increases to1.25 events/second at 0.2 MPa.
3. The discharge current in a clean duct is 16.95 nC/s, whereas for the duct with copper particle on the central conductor is 53.12 pC/s. That means, with particle, the discharge current in a duct increases 3 times when compared to a clean duct.
4. In a clean duct, the PD activity is observed to be more prominent under positive cycle of ac as seen in the histograms. But with copper particle, there is hardly any discharge activity during positive half cycle. However, the negative half cycle, there are random PD pulses of very high magnitude.

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