VACUUM SURFACE FLASHOVER VOLTAGE INVESTIGATION BASED ON MAGNETIC FLASHOVER INHIBITION EFFECT

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Abstract: Surface flashover in vacuum is a penetrability discharge phenomena which occurs at the vacuum-insulator interface. One of the effective ways to increase the surface flashover voltage is Magnetic Flashover Inhibition. In this work, a series of experiments were carried out to find out the relationships between magnetic field and surface flashover voltage. Our experimental results showed that surface flashover voltage increased 1.8 times by applying magnetic field of 1.1T which is perpendicular to the electric field and parallel to the insulator surface.

1 INTRODUCTION

Surface flashover in vacuum is a penetrability discharge phenomena occurs at the vacuum-insulator interface. With the same applied electric field, surface flashover could happen much more easily than the breakdown of insulators. So， vacuum-insulator interface at which flashover occurs is the weakest link in pulsed power system, and is a key issue in researches of high voltage insulation around the world. Generally speaking, surface flashover in vacuum can be divided into three stages: initial electrons formation, electron multiplication and penetrating conducting pathway. Up to now, there are some models that have been proposed to explain the mechanisms of surface flashover in vacuum, such as the anode-initiated flashover model, the cathode-initiated flashover model, and so on. Among them, the Secondary Electron Emission Avalanche (SEEA) model which is proposed by Boersch *et al* [1] achieves considerable approval. All these models consider secondary electron emission and avalanche as the important processes leading to surface flashover.

The secondary electron emission avalanche proposed by Boersch and co-workers leads to a very simply explanation for the dependence of breakdown field on insulator geometry. Simply stated, the avalanche is presumed to be initiated by electrons field emitted from the cathode, then propagates toward the anode, and electron bombardment of the insulator surface culminates in flashover [2].

The magnetic flashover inhibition (MFI) concept is recommended in the text as [3-5]. The magnetic field is perpendicular to the electric field and parallel to the insulator surface. In this configuration $\boldsymbol{E} \times \boldsymbol{B}$ is directed outward from the surface, and the electrons in the avalanche drift away from the insulator so that the avalanche process is prevented. At the critical value of the magnetic field, which we define as curve b in Figure 1, the electron reintersects the surface tangentially. If the magnetic field is less than the critical value, the electrons still impact with greater energy than in the zero-magnetic field case. For magnetic field is larger than the critical value, electrons do not reintersect the surface and the avalanche is inhibited.

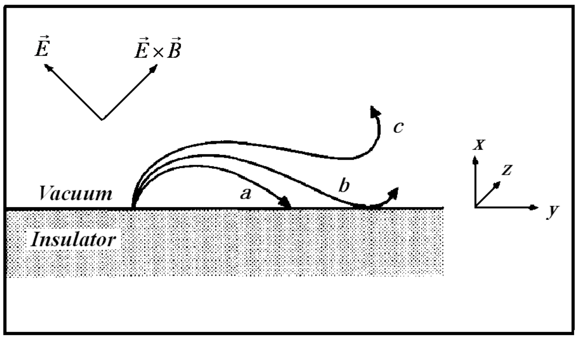


Figure 1: Electron trajectories in SEEA for three different magnetic fields and for emission normal to the surface

If such a magnetic flashover inhibition process were effective, insulators carrying current would have higher flashover strength than insulators carrying no current. Successful operation of insulators at increased electric field stress could reduce the size and cost of future high current pulsers.

2 TECHNICAL APPROACH

This experimental system was designed to accommodate various orientations of electric field, magnetic field and insulator surfaces. Details of the experimental arrangements are provided in the following sections.

2.1 Electric field arrangement

The high voltage test pulsed had a full width at half maximum of 2.5μs and a peak amplitude of 60kV as shown in Figure 2.

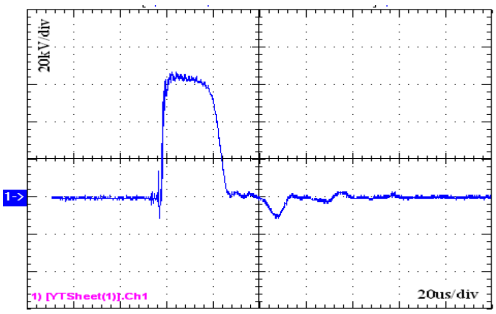
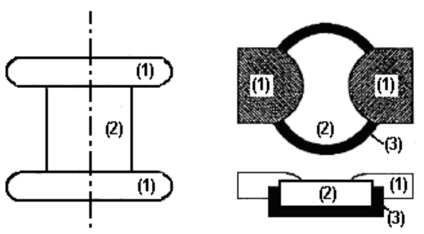


Figure 2: The oscillogram of electric field

Generally, scientists use a parallel plane electrode test architecture to study the high field surface flashover phenomena of insulators in vacuum. The general experimental geometry consisted of two cylindrical electrodes pressed on top of a flat test insulator, with the applied electric field approximately parallel to the insulator surface which is exhibited in Figure 3(a). The surface area of the electrodes exposed to the electric field was considerably larger than that of the mating circular contact area of the insulator. This architecture has the advantage of providing a quasi-uniform electric field along the length of the insulator where surface flashover occurs. It has two distinct disadvantages: Since it is difficult to produce a desired surface finish of the cylindrical surface that is highly uniform, it becomes imperative to compare different specimens with the same surface finish, a goal difficult to accomplish for cylindrical specimens. The flashover activity can occur anywhere around the circular surface of the cylindrical insulator, it is not possible to make unambiguous detection of precursive processes.

We use a new test arrangement whereby the flat face of a cylindrical disk specimen was subjected to high voltage stress using solid finger-shaped electrodes, as exhibited in Figure 3(b). In this arrangement the pillar electrodes do not make contact with the circular edge of the test specimen. Hence, all flashovers occur in the central region between the two electrodes.



(a) (b)

Figure 3: The structure of the electrode: plane-shaped (a) and finger-shaped (b). Electrode is labled as (1), dielectric is labled as (2) and Teflon holder is labled as (3)

2.2 Magnetic field arrangement

Considering the system configuration and latterly investigation, we use the charging solenoids to generate a pulse magnetic field. It works as following: at the outset charging the capacitor with DC, then close the switch, consequently the electric current in the cable winding generates a oscillatory magnetic field. The pulse electric current with a period of 400μs as is shown in Figure 4. The magnetic field is uniform when the solenoids radius are equal to the space between solenoids and could be considered as constant when the period is larger than the electric field's.

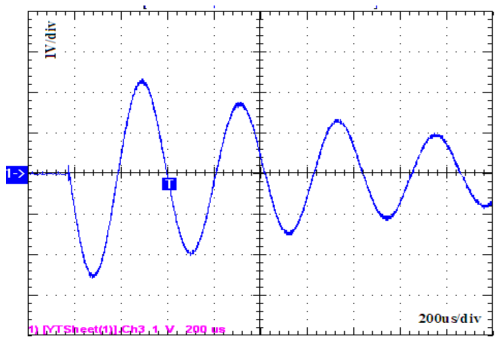


Figure 4: The oscillogram of electric current

A magnetic field must be perpendicular to the electric field and parallel to the insulator surface. The surface flashover is prevented when $\boldsymbol{E} \times \boldsymbol{B}$ is directed outward from the surface, and is promoted otherwise.

Fully consider the electric field, our workable arrangement is sketched in Figure 5. By modulating the direction of current, the secondary electron emission avalanche can be inhibited.

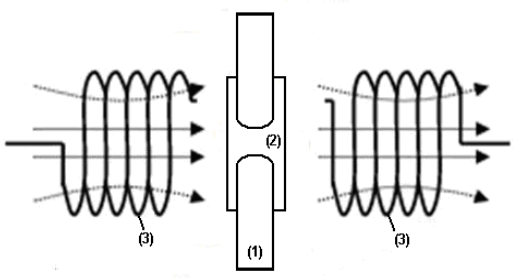


Figure 5: The arrangement of electric field and magnetic field. Electrode is labled as (1), dielectric is labled as (2) and solenoids is labled as (3)

3 RESULTS AND DISCUSSION

3.1 The result of electric field simulation

Figure 6 illustrates the electric field simulation result by using CST. In this Cartesian coordinate system, we define the $+x$ is the direction of cathode while the $-x$ means anode. Obviously, electric field at the cathode is larger than at the anode, and the maximum value appeared at cathode apex.

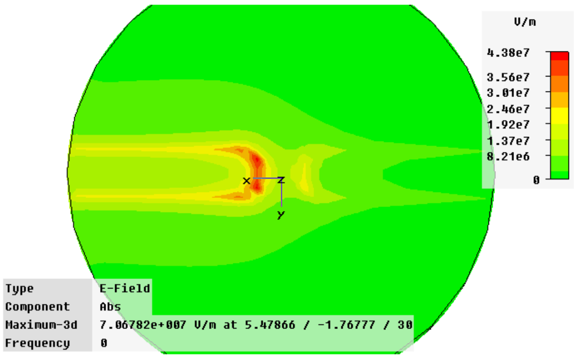
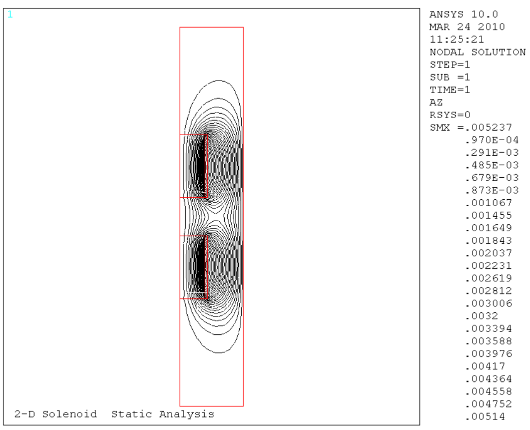


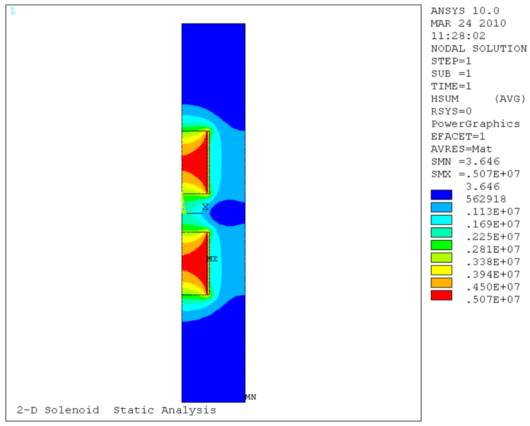
Figure 6: Electric field simulation result

3.2 The results of magnetic field simulations

We made two-dimensional static simulations of the axisymmetric magnetic field on electrodes by using ANSYS. The results of magnetic flux and equipotential lines are demonstrated in Figure 7.



(a)



(b)

Figure 7: Magnetic lines of force (a) and isopotential lines (b)

If the solenoids radius are equal to the space between solenoids, the lines of magnetic force are parallel in the center area which is shown in Figure 8. The region where we study the flashover phenomenon could be considered as uniform.

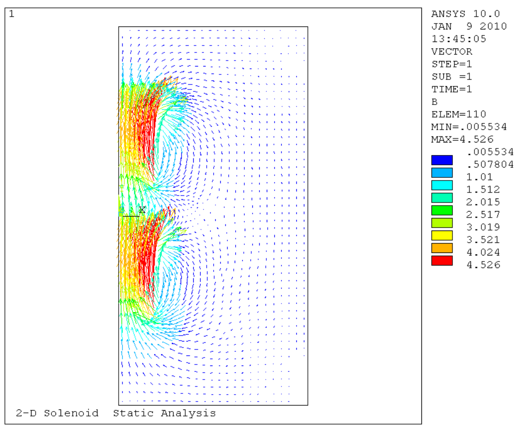


Figure 8: The vector diagram of the magnetic flux

3.3 The results of flashover voltages

The experiments were carried out at a pressure of 10^{-4} Torr, and measured vacuum interface voltages. Figure 9 is the typical oscillogram of voltage when flashover takes place. Comparing with Figure 2, the voltage signal of Channel21 is not remain flat. The reason is when flashover occurs, the circuit parameter especially the electric resistance is drastically changed.

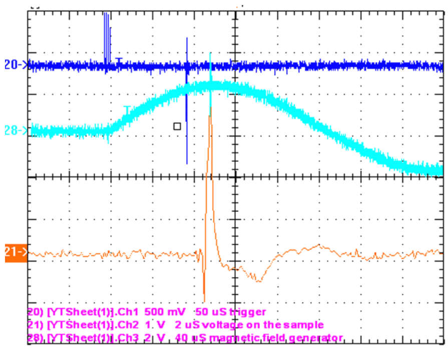


Figure 9: The typical waveforms of flashover

We measured three types voltage of the same sample of polymethyl methacrylate under magnetic fields of different intensity, including first breakdown voltage, conditioned voltage, and hold-off voltage. Due to micro protrusions and the existence of the surface gas desorption, conditioned voltage is more accurate. The results of relationship between magnetic field and the conditioned voltage are plotted in Figure10. When $\boldsymbol{E} \times \boldsymbol{B}$ is directed outward from the surface, this magnetic field is defined as positive direction. The surface flashover voltage increased 1.8 times by applying magnetic field of 1.1T which means the secondary electron emission avalanche is inhibited efficiently. In the opposite, the minimum flashover voltage is at -1.1T.

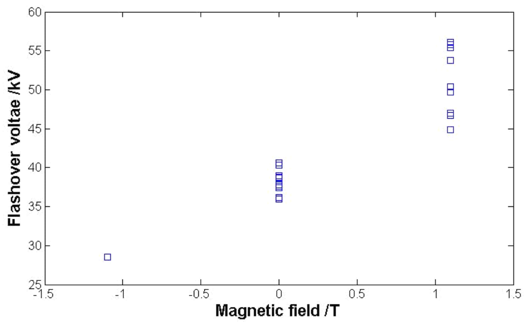


Figure 10: The vector diagram of the magnetic flux

4 CONCLUSION

The experiment have demonstrated the effectiveness of applied magnetic fields in inhibiting or promoting flashover of insulators in vacuum when it is in proper spatiotemporal correlation with the electric field and the sample. The application of external magnetic fields with the $\boldsymbol{E} \times \boldsymbol{B}$ drift away from the surface or into the surface affects the flashover voltage. With higher intensity, the magnetic field is expected to have a stronger effect on the surface flashover in vacuum.

5 ACKNOWLEDGMENTS

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