High Voltage Insulation, Diagnostics and Energetic Electron and Photon Beam Interactions

1. DC Properties of Modern Filled Epoxy Insulation

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The reliability of electric insulation is strongly dependent upon the control of electric stresses, since higher stresses weaken insulation and can lead to premature failure. Furthermore, unlike for AC voltage, with applied DC voltage slow moving charges can migrate and accumulate within the insulation over time. Such charge accumulations can significantly enhance the internal stress at localized regions and thereby reduce the reliability of DC apparatus. This work is especially concerned with electric power apparatus, and hence is concerned with higher voltages (typically greater than 10 kV), but the basic phenomena investigated may be applied to a broad range of applications that employ DC voltages at most all levels.

Two advanced techniques are employed in this work to quantify charge migration; (1) the measurement of actual net space-charges within the epoxy insulation and (2) high sensitivity current measurements to quantify the amount of terminal currents related to the accumulated space charge. The space-charge measurement uses high-resolution ultrasonics. The space-charge itself, activated by a small nanosecond applied voltage pulse, stimulates an acoustic wave via the Lorentz force. The acoustic wave travels to the insulation surface where it is measured via a sensitive broadband detector. The measured acoustic wave is then directly related to the amount, position and polarity of space-charge contained by the insulation. The very sensitive current measurements to the femtoamp level are enabled by a highly stabilized voltage supply and design of the insulation sample configuration, which keeps the main component of the electric field perpendicular to the insulation surface thereby reducing leakage currents. Additionally all measurements were made in dry-N2 to remove moisture induced conduction.

Space-Charge Measurements

The studies made have demonstrated that space-charges accumulate near the electrodes within the insulation. These near surface charges are homo-charges and accumulate near both anode and cathode electrodes (typically within 30μm). These charges can have very long relaxations times of weeks and months and hence are shown to be the cause for high localized electric fields. There are major dipole charges as well due to on electrode image charges and the near surface charges. The amount and depth of the near surface homo-charges increased when the time at voltage was increased and this dependence corresponds to drift / diffusion as the primary charge transport process. The origin of these charges does not appear to be classical electrode emissions, but more related to surface states and chemical potential. Temperatures ranged to 70°C with greater charge accumulation at higher temperatures. This temperature effect is consistent with an expected increase in drift/diffusion at higher temperatures. The space-charge induced internal fields across a grounded sample were found to reach 30% of the field with an applied voltage. Hence space-charge accumulation by epoxy insulation is of practical importance and these studies point to the basic physical processes that can control the phenomena. The near-surface charges indicate that the metal-insulator interface is a critical part of the process.

Absorption – Desorption Current Measurements

Corresponding terminal currents were observed under conditions that induced near surface space-charges. These currents decayed about inversely with time, in agreement with the Curie von Schweidler relation. The low current values indicate an effective resistivity of 10^{18} ohm-cm, consistent with the long persistence of accumulated charges. There was good correlation between the amount of terminal current and the accumulated space-charge by the insulation. Both rough surface and higher temperatures yielded greater currents and charges. These DC current measurements indirectly confirm the space-charge measurements and add support to the overall need to control the space-charge accumulation processes in insulators. The intent of these studies is to determine the basic processes that cause space-charge accumulations and thereby point the way to reduce their effects and enhance practical DC insulation reliability.

Future efforts in this work are planned to examine the solid-metal interface is greater detail.

2. Energetic Electron and Photon Beam Interactions

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The 3.5 MeV electron accelerator was upgraded to improve the beam handling systems. This Van de Graaff type accelerator produces DC beams from under 0.5 MeV to 3.5 MeV energy. The current is controllable from very low levels of just a few 100 electrons per second for single event electron counting, to beams of 100 µampere. Additionally cooled high-Z targets are used to convert the electron beam into a high-energy gamma ray photon beam. This year the facility has been used in a variety of irradiation experiments with energetic electrons and gamma rays.

These studies include charge implantations and dose distributions in dielectrics. Here the interest is charge-trapping and direct electron implantation provides a controlled means to deposit electrons deep within solid insulators. Such charges were observed to persist for months in high resistivity materials. Work has also continued with polymer processing by radiation induced cross-linking for biocompatible hip and knee replacement materials. Irradiated polymers exhibit greatly extend life as discovered by earlier work with this machine and today are used in most all implants world-wide. The longer life means a single replacement may last the life of the recipient. The new efforts concern hydrogels and the possibility to create an injectable collagen replacement material for knees. An injectable treatment avoids the costs and recovery from the present-day full surgery approach.

Controlled energy and intensity energetic electron beams from the accelerator were also used in satellite sensor development and calibration for solar flare detection. Most all satellites today have adequate space and power to operate efficient solar flare detectors, which enable the gathering of valuable data about these destructive natural events that can damage electric power systems. These new sensors are modern version of an earlier sensor calibrated years ago in this facility, which is on the Voyager spacecraft and is still working.

The gamma beam was employed in nuclear resonance fluorescence tests, which identify hazardous materials by the unique stimulated photon emissions associate with each material. Due to the high energy of these photons they penetrate thick materials (even steel) and hence can be used for the rapid inspection of large objects such as cargo containers.

Future work with the accelerator will examine implanted charge transport in dielectrics as well as continue the development of hip and knee replacement/repair materials. Basic gamma photon physics experiments are also expected to continue.