HIGH VOLTAGE INSULATORS FOR PARTICLE ACCELERATORS*

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Abstract In modern high energy particle accelerators there are many component parts and devices which operate at high voltages in vacuum, e.g., injectors, inflectors, beam choppers and velocity separators. Since the surface voltage stress attainable across insulators is generally lower than across plane gaps, the physical size of the apparatus is governed by the high voltage performance of the support insulators in vacuum. In this paper the author discusses the various factors affecting the insulator performance, in the light of his experience with NIMROD, the 7 BeV proton synchrotron and the design of a d.c. injector for an intense neutron generator machine which was under study at Chalk River, Canada.

INTRODUCTION

The technological importance of high vacuum insulation has resulted in a growing number of investigations into the phenomenon of insulator flashover in vacuum. In a recent review article the author has summarized the available data[1]. The factors which affect the insulator performance are: insulator shape and material, design of triple (insulator-electrode-vacuum) dielectric junction, residual gas pressure and composition, nature of applied voltage (pulsed or d.c.), and in the case of accelerators the presence of ionizing radiation.

The most probable mechanism of insulator flashover involves field emission of electrons at the cathode-insulator junction; these electrons bombard the insulator surface releasing more electrons and leaving the insulator surface positively charged. The charged insulator distorts the electric field and eventually leads to a breakdown along the insulator surface. Important secondary processes, e.g., desorbtion of gases, must play a crucial role in the final development of a discharge channel, which has the appearance of a low pressure gaseous discharge. The relative role of the various factors mentioned earlier is discussed below.

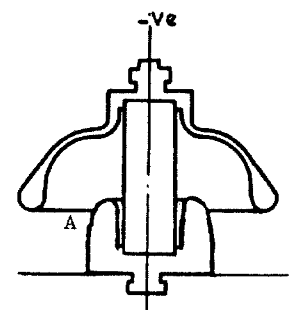
FACTORS AFFECTING BREAKDOWN

Electrode Material and Cathode-Insulator Junction

A variety of electrode materials (copper, aluminium, stainless steel, aluminium/magnesium alloys) have been investigated. For a given insulator material, there is no noticeable difference in the high voltage performance between the various electrode materials. This is not surprising since the insertion of a solid dielectric lowers the voltage capability of a plane vaccum gap, thereby masking the effect of particular electrode material. However, for long-term performance anodised aluminum electrodes have proved very satisfactory on NIMROD[2]. This may be because anodising significantly lowers the level of pre-breakdown currents for large area electrodes at large spacings.[3]

Two methods have been widely used to minimize the undesirable effects of an imperfect cathode-insulator junction, viz., electrostatic shielding of the cathode-insulator junction, and, shaping of the insulator (e.g. conical frusta). The improvement is claimed to be due to the reduction of the field at the junction in the first case and by the control of the field normal to the insulator surface in the latter case. Both these methods reduce the electron bombardment of the insulator surface. The experience of the various investigators is summarized elsewhere[1,4]. In the case of h.v. apparatus in an accelerator there are ionizing radiation present and it is usual to provide a line-of-sight shield for the insulator. One such design is shown in Figure 1. In this case the maximum electric field exists at some distance from the insulator surface (point A in Figure 1). Such an arrangement tends to draw charged particles away from the insulator surface and could favourably affect the transient pressure rise near the surface (see below).

Figure 1



Charging of the Insulator and Gas Evolution

Many investigators have observed a faint glow near the anode as the d.c. voltage across an insulator is increased during 'conditioning'. The glow slowly extends towards the cathode as the voltage is increased and usually leads to a breakdown. This charge/discharge process is accompanied by a transient rise in the risidual gas pressure. In vacuum systems using oil-vapour pumps the most significant rise is in the partial pressure of hydrogen, probably due to the break-up of the hydrocarbon fragments of the

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oil vapour. The charge/discharge process, along with other ionizing radiations, can lead to the growth semiconducting polymerized organic films on the insulator surface; these films may limit the ultimate life of an insulator in an accelerator.

Attempts to discharge the surface by depositing high resistivity conducting films (ceramic oxides) have met with limited success. The main difficulty appears to be manufacture of a stable high resistivity ($10^{10}\Omega$/sq.) film suitable for vacuum operation.

Insulator Material

A large variety of insulating materials have been used by various investigators and the results are summarized elsewhere[1]. A maximum gradient of 100 kV/cm. has been attained in the author's laboratory for alumina ceramic samples about 2 cms. long. The following general comments may be helpful for an accelerator designer:

(a) The material must have low porosity and be free from surface defects (cracks, bubbles and inclusions). Ordinary porcelain, zircon and composite materials like mycalex are poorer in performance than high density alumina and pyrex glass. Transparent material like glass and clear acrylics have the advantage of permitting visual inspection. Glazed ceramics are not very good since the surface contains numerous small bubbles. In the high density aluminas the manufacturing process can play a significant role. For example, samples produced by hot-press and iso-static molding are better than conventional molding and extrusion processes.

(b) The insulator surface must be stable at elevated temperatures and must be chemically inactive in the presence of water vapour, charged particle bombardment and electrical stress. Water vapour is the most significant constituent of high vacuum systems. Under high surface gradient adsorbed water can initiate ionic conduction. Organic materials are particularly susceptible to chemical changes under charged particle bombardment. Significant increase in the partial pressure of hydrogen during insulator ageing may well be due to polymerization of organic materials. In this respect, Teflon, Plexiglass and high density polyethelyne are better than cast epoxies.

In the author's experience high density aluminas make the most suitable insulation material for vacuum applications. Pyrex glasses are almost as good except for their lower mechanical strength and thermal conductivity.

Insulator Shape

Shaping an insulator to minimize electron bombardment of the surface has been tried by various investigators. For d.c. and uni-directional pulse voltages, there is a significant improvement in the voltage hold-off when the narrow-end of a conical frustum is made the anode (~20% for d.c. voltages). It should be added that the effect of electrode and insulator shape must be considered together.

Nature of Applied Voltage

The duration and nature of the applied voltage also makes a significant difference in the insulator performance. For short duration pulses ($\sim$100 ns) the insulator surface flashover may be twice as high compared to d.c. voltages. However, the improvement for longer pulses ($\sim$100μs) is not as great (<20%)[4]. Dynamic pressure near the insulator under different voltage conditions could probably cause the difference in performance.

CONCLUSIONS

The relative role of insulator charging and gas evolution in the final stages of breakdown is not fully resolved. However, any device to minimize these processes will improve the insulator performance, e.g. conducting surface coatings and provision of additional pumping near the insulator.

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