CHALK RIVER EXPERIENCE IN THE OPERATION OF HIGH CURRENT 100% DUTY FACTOR ACCELERATING COLUMNS

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Summary

Two high current 100% duty factor dc accelerators have been built and are being commissioned at Chalk River. One is a 750 keV accelerator designed to investigate problems in the acceleration of dc proton beams in the 50-100 mA range; the other is a 25 mA, 300 keV D^+ dc accelerator designed for a 4×10^{12} s^{-1} fast neutron source. The 750 keV accelerator has been in operation with beam currents up to 40 mA. Beam induced voltage breakdown problems encountered in the commissioning of the high-gradient accelerating columns of these accelerators will be described. Changes in column design philosophy brought about by these problems will be discussed.

Introduction

Electrically produced neutrons may have important roles to play in future fission power stations[1] and in the investigation of materials problems for the controlled thermonuclear research programs[2]. The accelerators required to generate these neutrons must be capable of average ion currents greater than 0.1 A. Two 100% duty factor ion accelerators are being built at Chalk River: one, a 3 MeV proton accelerator designed to investigate problems in the acceleration of dc beams in the 50-100 mA range[3]; the other a 25 mA, 300 keV deuteron accelerator designed to produce 4×10^{12} fast neutrons per second[4]. These accelerators both use high gradient dc accelerating columns intended to produce low emittance ion beams and this paper will describe their operation at high current.

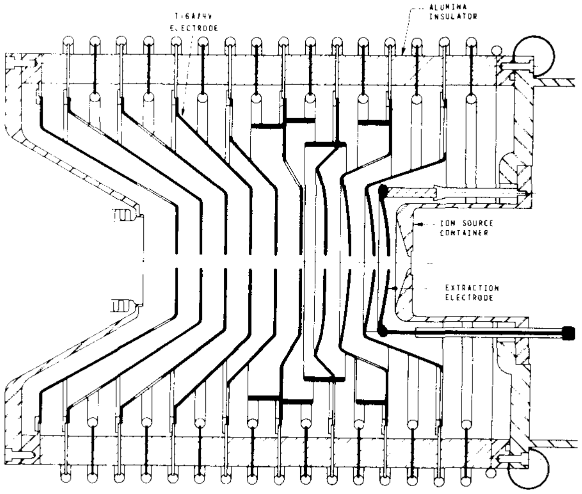

Fig. 1 Cross-sectional view of 750 kV accelerating column.

Description of Columns

A cross section of the 750 kV accelerating column of the proton accelerator is shown in Fig. 1. It consists of seventeen 534 mm I.D. by 32 mm high unglazed alumina rings (Coors AD96) bonded to flat Ti6Aℓ4V annular discs with polyvinyl acetate. Demountable Ti6Aℓ4V electrodes are used and are shaped to produce a Pierce potential distribution over the first 200 kV of acceleration followed by a uniform 3.1 MV/m gradient. The penultimate electrode is held several kV negative with respect to ground to prevent electrons from the beam transport system entering the column. The potential across each insulator is 50 kV.

A section through the 300 kV accelerating column and ion source assembly is shown in Fig. 2. This two gap column consists of six 343 mm I.D. by 33 mm high unglazed alumina rings similarly bonded to Ti6Aℓ4V annular discs with polyvinyl acetate. The front of the ion source container and the extraction electrode have Pierce geometry. The negatively biased suppressor electrode serves the same function as the penultimate electrode of the 750 kV column. Ti6Aℓ4V skirts attached to the conductor annular discs hide the insulators from the beam. The average accelerating gradient is 3.0 MV/m.

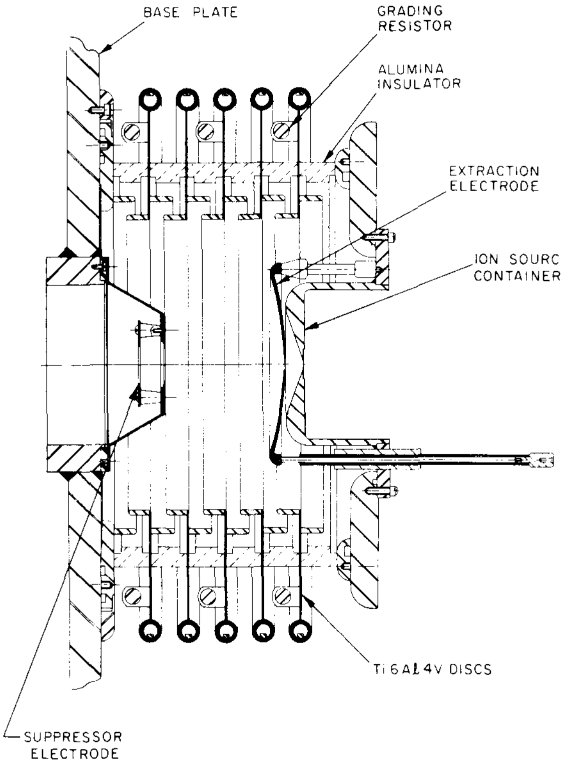

Fig. 2 Cross-sectional view of 300 kV accelerating column and ion source.

Both accelerating columns are contained within SF_6 vessels and use metal-oxide resistor chains to define the voltage gradient.

Operating Experience

Following high voltage conditioning both columns will withstand design voltages indefinitely in the absence of beam. Eight hour spark free periods have been obtained at the power supply voltage limits of 800 kV and 305 kV respectively. When ion beams are accelerated, however, frequent breakdowns occur, even at voltages 50-100 kV below design, until the columns are "current conditioned". The amount of current conditioning required before operation at design voltage is possible, depends on the recent history of the accelerating column. It is necessary to current condition the 750 kV column at 650 or 700 kV if the column has been opened to atmosphere or if the beam intensity is higher than that accelerated in recent operation. Once the column has been operated at 750 kV for longer than 30 minutes without breakdown at a specific current, operation at that current without additional conditioning is normally possible. The minimum breakdown rate after full conditioning is influenced by ion source geometry and operating parameters. Typically at 20 mA operation breakdown rates are ∿ 1/h. Low current operation (6 mA) has been possible for breakdown free periods of up to 8 hours.

Reducing the accelerating gradient on the 750 kV column does not produce a large improvement in reliability. Over the range 600-750 kV the beam-induced breakdown rate at 20 mA is proportional to the voltage once the current conditioning plateau has been reached. Increasing the apertures of the non-Pierce electrodes from 20 to 26 mm to reduce beam interception produced no measurable effect on breakdown rates and showed that not much can be obtained from further increases.

Similar but more severe beam-induced breakdown problems occur in the 300 kV column. Breakdown free operation at 300 kV with beams of 5-10 mA has not been possible for times greater than 15 minutes. Current conditioning, while observed, is not as effective as in the 750 kV column.

Breakdown Investigations

The mechanism of beam-induced breakdowns is not understood. It is difficult to establish whether components showing spark damage have triggered the breakdowns or are damaged as the result of breakdowns initiated elsewhere in the column.

The ion source-extraction electrode assembly (Fig. 3) may provide the trigger for some of the observed breakdowns. The extraction electrode which is supported by three alumina insulators is an important focussing element whose operating potential is dependent on beam intensity and ion source geometry. Fluctuations in this potential because of insulator breakdowns, microdischarges or beam intensity fluctuations may cause a large increase in beam spill and trigger a breakdown.

Ion source operating conditions produce significant changes in the breakdown rate of the 750 kV column. In a series of column reliability measurements the arc and coil currents of the duoplasmatron ion source were adjusted over a wide operating range in such a manner that the beam current was maintained constant. Large changes in the breakdown rates were produced even though only minor changes in the beam emittance or in the amount of beam intercepted by the electrodes occurred (typically 10 μA for 20 mA beams). Attempts have been made to relate the breakdown rate to magnetic effects of the ion source coil on electrons and insulator charging around the extraction electrode support assembly, but the relationship between breakdown rate and ion source parameters is not yet understood.

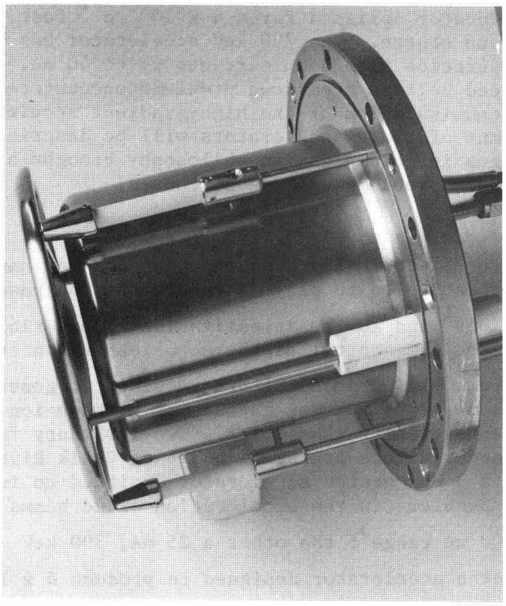

Fig. 3 Ion source container and extraction electrode assembly for 750 kV column.

Radiation produced by electrons generated by beam spill and background gas ionization may trigger breakdowns by mechanisms such as photoelectron emission. To investigate the effects of radiation on the column without the effects of ion source operation parameters the ion source was removed from the 300 kV column and an electron-emitting filament was installed at ground potential. The radiation intensity outside the column SF_6 vessel was monitored and the electron current was adjusted to produce the same radiation intensity as that observed when an ion beam was accelerated. Corrected for absorption by the column structure, the intensity at the insulators was estimated at 0.8 R/h. Breakdowns of the column occurred at a rate approximately proportional to the radiation intensity and were similar whether the radiation was ion beam or electron beam produced.

Irradiation of the column with external radioactive sources of ^{60}Co (∿ 1.2 MeV gamma rays) and ^{241}Am (0.059 MeV gamma rays), which reproduced the radiation field intensity at the column insulators approximately, failed to induce voltage breakdowns. It would therefore appear that very low energy quanta from the electron bremsstrahlung and ion recombination spectra are primarily responsible for the breakdown mechanism.

Examination of the 300 kV column after about 100 h of operation with beam revealed a large number of voltage breakdown tracks on the ceramics and evidence of sparking having occurred across the vacuum gap between the Ti6Aℓ4V skirts.

Examination of the 750 kV column after several thousand breakdowns over three years operation revealed only minor sparking damage on the upstream surfaces of the electrodes near the beam aperture (Fig. 4) together with five voltage breakdown tracks on the internal ceramic surfaces.

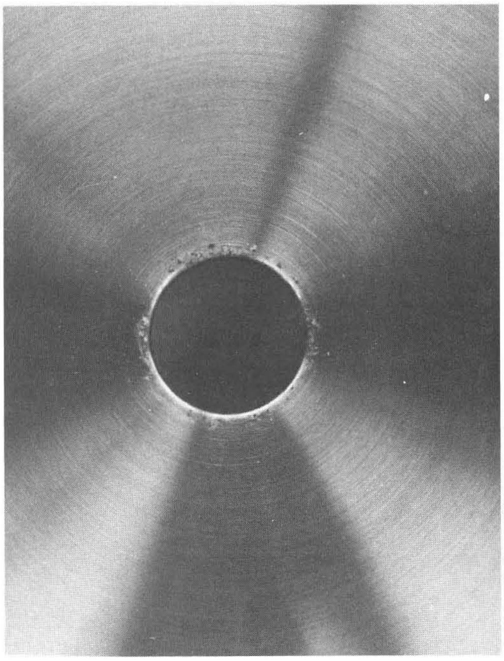

Fig. 4 Electrode surface damage in upstream area of beam aperture. Aperture diameter is 20 mm.

The primary voltage breakdown problems with the 300 kV column appear to be associated with the insulator. It is not yet known whether this is because of the failure to hide the conductor-insulator bond adequately from the beam or to the choice of materials. The reason for the comparative absence of spark damage evidence in the 750 kV column is not understood.

Design Changes

A large number of breakdown mechanisms are known and column design requires numerous compromises to be made. Designs incorporating those compromises effective at low current fail at high current and new compromises must be added to improve reliability. It appears necessary to design electrode geometry so that the electric fields near the insulators are less sensitive to photoelectron emission and to design the electrodes to provide better shielding of the insulators from the ion beam for low energy X-rays and ultra-violet light.

Successful high current dc columns such as the one used on the DCX-2 plasma injector at Oak Ridge National Laboratory[5] have been built. This 600 kV, 4 gap accelerator operated for many days without breakdowns with a 100 mA beam[6]. The insulating material which was glazed porcelain with a corrugated geometry showed no voltage standoff problems in radiation fields estimated to be ∿ 100 R/h[6].

A new design for the 300 kV column, now being tested, is shown in Fig. 5. It uses three 254 mm I.D. 86 mm high unglazed alumina insulators available from a previous experiment bonded to stainless steel rings; demountable stainless steel electrodes are shaped to provide greater insulator shielding from the beam and to minimize the electric field at the ceramic-metal bond. Stainless steel has been chosen partly because of its availability and partly to avoid possible problems caused by large outgassing bursts from titanium electrodes used in a hydrogen atmosphere[6]. Pierce gradient geometry in the ion source region has been abandoned in favour of minimizing electrode areas. The average accelerating gradient remains 3.1 MV/m and although the maximum insulator surface gradient is larger (1.9 MV/m versus 1.5 MV/m) than on the previous design, it is reduced near the insulator-conductor interface.

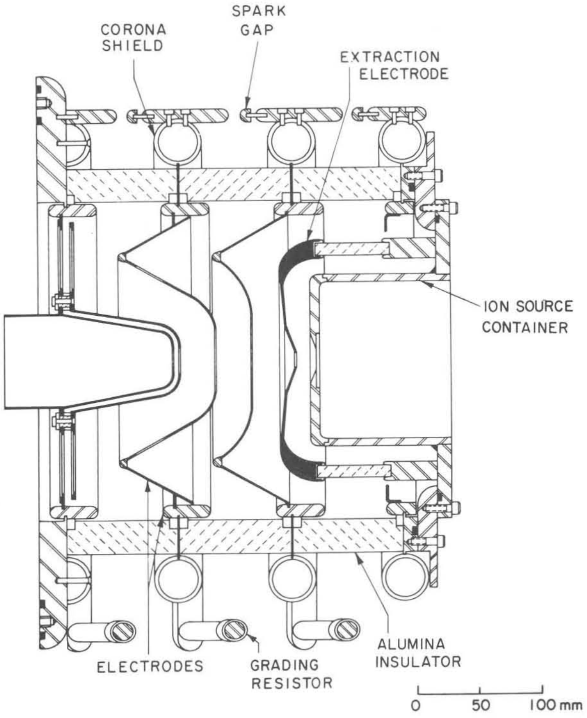

Fig. 5 Cross-sectional view of new 300 kV accelerating column design.

Geometry and materials changes to be made to the 750 kV column have not yet been determined and will depend on the results obtained from tests with the new 300 kV column.

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