KEK PREINJECTOR ACCELERATING COLUMN

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Abstract

A high gradient accelerating column was constructed for a preinjector of a 20 MeV proton linac. The column consists of two big porcelain tubes with a two gap accelerating system. The overall gap length is 22 cm. The column ensures a clean vacuum and has sufficient strength because there is no bonding with any organic adhesive. To prevent breakdown, the operating pressure is kept at several times 10^{-4} Torr in the column.

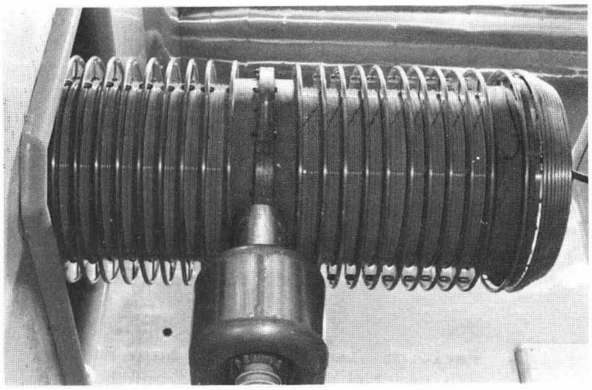

Fig.1 KEK high gradient column. Ions are accelerated from right to left.

Introduction

A high gradient accelerating column was made for the 750 keV preinjector of the 8(12) GeV proton synchrotron at National Laboratory for High Energy Physics (KEK). There are two types of the high gradient column, open[1,2] and enclosed.[3,4] Since the high voltage is supplied by an open Cockcroft-Walton generator, not only the open column but also the enclosed column have surfaces in the atmosphere, so an open column was preferred. The column should have properties of (1) clean vacuum and (2) enough mechanical strength. The latter is a distinct feature at Tsukuba, because it suffers earthquakes several times a year, fortunately they are not so intense. As the open column has a reentrant structure, it should be large enough.

It is well known that the breakdown voltage is not proportional to the insulator length but rather proportional to the square root of its length. Therefore, the electrostatic accelerating tube is usually not a long insulator pipe but a stack of short insulator rings and metal sheets. However, if the column diameter becomes large and some organic adhesive is preferred because of difference in thermal expansion, then it is difficult to satisfy the above mentioned two requirements by the stack.

Since the operating voltage is only 750 kV, a porcelain tube of 3 m long can be an accelerating tube.[5]

Accelerating Column

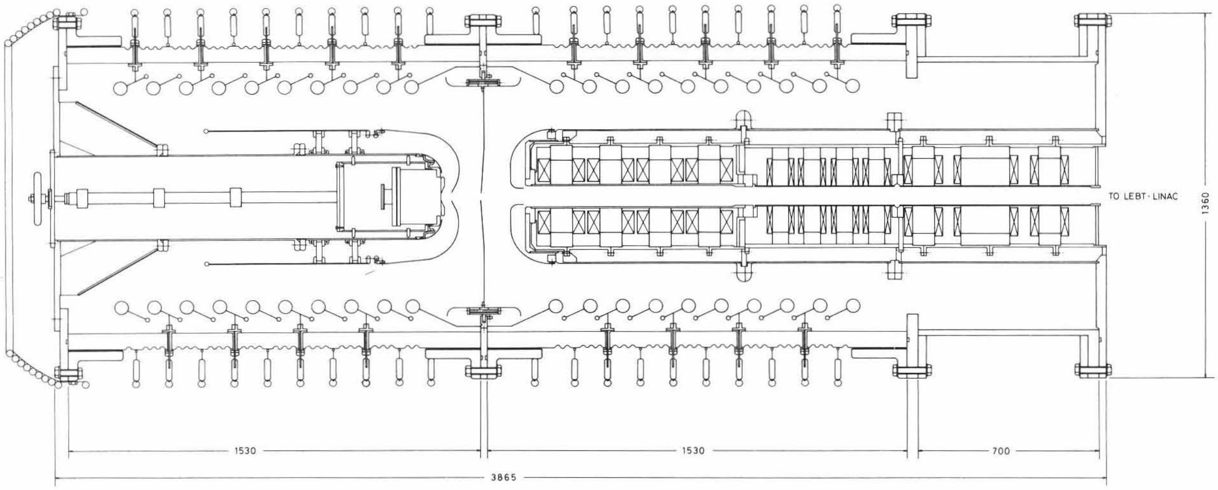

Fig.2 Sectional view of the accelerating column.

Although the insulator itself is usually strong enough against the electric breakdown, its surface suffers flush-over. In the open tube, the outside wall is electrically weaker than the inside wall which is in the vacuum. Therefore, if the potential is distributed uniformly on the outside wall along the tube, and if the inside wall is shielded suitably from bombardment of charged particles, it is possible to make an accelerating tube of reasonable length from a long porcelain tube. To mount a intermediate accelerating electrode easily, the column is made of two tubes each 1.53 m long and 1.01 m inside diameter. Two casterd iron flanges are cemented to each tube at both ends. Since the flange is 20 cm long, the porcelain tube of 113 cm in length should hold a high voltage of 375 kV. The average field is 0.35 MV/m.

The tubes are connected by the metal flanges and the column is supported at the joint of the two tubes by an insulator post. The post has a gear for alignment of the column on it.

The column in site is shown in Fig.1 and Fig.2 is a drawing of its cross section. There are 3 × 9 = 27 holes in each tube. A stem, which passes through the hole, is fixed to the tube as shown in Fig.3. Three stems support one inside and one outside shielding electrodes. The stems also hold springs which surround the tube to give suitable potential along the porcelain surface. Assuming a two-dimensional model as shown in Fig.4, the maximum electric field E_{max} is calculated on the stem by

$$E_{max} = \frac{4\varepsilon_r}{\varepsilon_r + 1 + \frac{a^2}{b^2}(1-\varepsilon_r)} E_0 \qquad (1)$$

where a is the stem diameter, b is the diameter of the hole bored through the porcelain tube, E_0 is the electric field far from the hole, and ε_r is dielectric constant of the insulator and is about 6 for porcelain. If there is very thin air (or vacuum) gap between the porcelain and the stem, that is $a \simeq b$, then the electric field, E_{max}, becomes as high as $2\varepsilon_r E_0$ or 12 E_0 in the gap. E_{max} decreases as decreacing the ratio a/b as shown in Fig.4. As a and b are chosen to be 6 mm and 15 mm respectively, the maximum field is 3.9 times higher than the average field E_0.

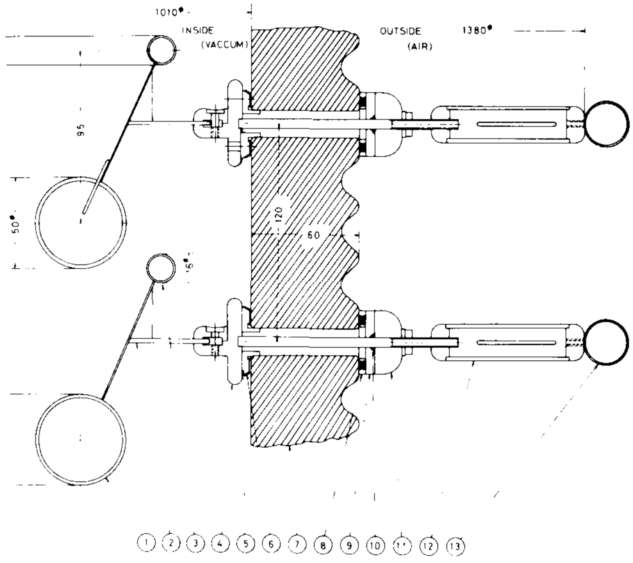

Fig.3 Stems are fixed to the porcelain tube. Three stems support one inside and one outside shielding electrodes.

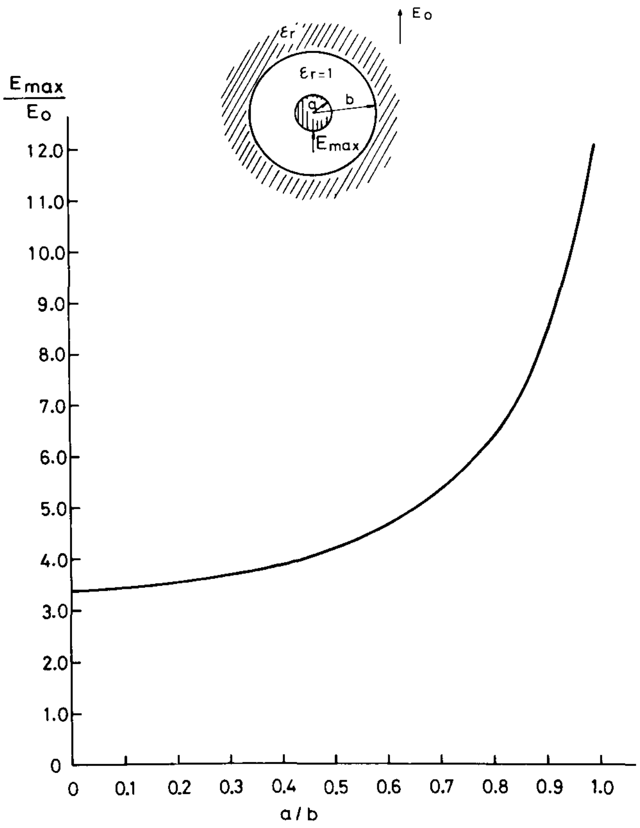

Fig.4 Ratio of stem radius and hole radius a/b vs. the maximum field on the stem.

If there are voids in the porcelain, extremely high electric fields might arise in the voids. If discharges take place in the voids, the porcelain might be destroyed by treeing during long periods of operation. This is a reason that the column was made as long as possible. The tube diameter was determined so that a standard Japanese technician could work easily in the tube to attach or remove the stems and inside shielding electrodes.

Since the bonding with any organic adhesive is avoided, there is no organic material except Viton O rings in the column. The porcelain tubes are glazed except surfaces which are polished to seal the vacuum with the O rings. Although there were several small leaks at the beginning, these leaks were eliminated by careful polishing of the surfaces.

Each tube were separately evacuated by a 1000 ℓ/s sputter ion pump for electrical test. The tube is divided to nine sections with the shielding electrodes supported by the stems. High voltages were applied to the eight sections of the tube for convenience. After conditioning, the tube withstood a voltage of 420 kV with sparking rate of 2~3 per hour at the pressue of several times 10^{-7} Torr.

The weight of the tube is 1,200 kg including the flanges. The mechanical strength was tested as follows: the tube was fixed at one end and 10,000 kg was loaded at the other end perpendicularly to the tube axis for one minute. This is about 10 times higher than the actual load.

Accelerating Electrode

The accelerating electrodes were made of pure titanium plate of 3 mm thick by a hydraulic press. They were originally designed for four-gap accelerating system of Pierce geometry.[6,7] However, we could not find appreciable difference in breakdown voltage between the four-gap system and two-gap system in a vertical model of the high gradient column. The two-gap system was adopted for simplicity as shown in Fig.2. It consists of a 50 keV extractor, shown in Fig.5, a 375 keV intermediate accelerating electrode and a 750 keV grounded electrode. Beam hole diameters are 2.8 cm for the extractor, 5 cm for the intermediate electrode and 6 cm for the grounded electrode. Until March 1976, the accelerating system had Pierce geometry with overall gap length of 31 cm. To increase beam intensity, the gap length was shortened to 24 cm. The accelerating system deviates now from Pierce geometry, because the extractor is connected eventually to an ion source with an 1 kΩ resistor. Thus the overall gap length becomes 22 cm and the average field is 3.4 MV/m.

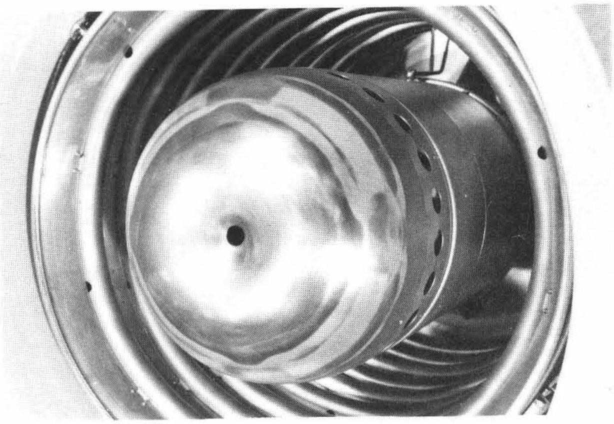

Fig.5 Inside view of the accelerating tube after one year operation.

The accelerating gaps is surrounded by a big shielding electrode which is connected electrically to the intermediate electrode. This structure assures changes in the gap lengths without affecting electric fields along the tubes. Some of the inside shielding electrodes were made of pure titanium and they were distributed in the higher electric fields, whereas others were made of stainless steels.

Operation

Dividing Resistors

The electric field along the column is so big that it is difficult to find commercially available resistors which can be put parallel to the electric field. Therefore, the resistors are put obliquely to the electric field. If the resistor is a thin plate instead of a cylinder, it does not disturb the uniform field along the tube. Then four commercially available flat resistors are connected in series and put between the external shielding electrodes of the accelerating tube as shown in Fig.6. They are protected by two spark gaps. The resistivity and the maximum voltage rating of each resistors are 100 MΩ and 15 kV. The column is installed with four resistor chains in parallel, and the drain current is 420 μA. So far there is no trouble in normal operation.

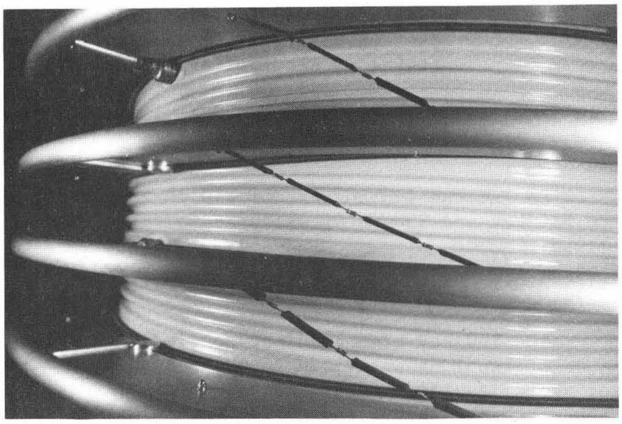

Fig.6 Dividing resistors are put between external shielding electrodes.

Pressure Dependence of Breakdown Voltage

The column is evacuated by a 650 ℓ/s turbomolecular pump. At a pressure of ~10^{-6} Torr, the breakdown takes place at about 500 kV. If hydrogen flows into the column from the ion source and the pressure is raised, then the breakdown voltage increases as shown in Fig.7 until it decreases rapidly at a pressure of 6×10^{-4} Torr. The breakdown voltage is defined by the voltage at which the grounded electrode collects 10 μA of discharge current. Pressures were measured by a small sputter ion pump which was calibrated for air. The anode voltage of the pump is reduced to 80 % of its nominal value. If the pressure is kept at $3\text{~}5 \times 10^{-4}$ Torr, the column withstands a voltage of 800 kV without conditioning process. The voltage is not limited by the column, but is limited by the high voltage apparatus. The sparking rate is less than one per day with ion beam at the pressure of $2\text{~}3 \times 10^{-4}$ Torr. This is similar operating pressure in ref.1. Sometimes there is no sparking over three days. On the contrary, although the overall gap length was 31 cm at the begining of operation, the column suffered frequent break-down at pressure of 1 × 10^{-4} Torr.[8]

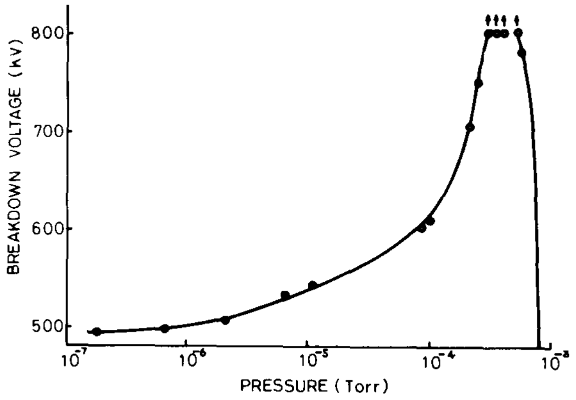

Fig.7 Hydrogen pressure in the column vs. breakdown voltages. ↑ denotes that the voltages is not limited by the column.

So far the ion current of 650 mA is accelerated to 750 keV and 230 mA of which is injected into the linac.

Conclusion

The 750 keV high gradient accelerating column is made of two long porcelain tubes instead of a stack of of short insulator rings and conductor plates. It ensures clean vacuum and enough mechanical strength because of no bonding of any organic adhesive. There is no appreciable change in breakdown voltage between two gaps, 31 cm and 22 cm, at the pressure of several times 10^{-4} Torr of hydrogen. Ions of up to 650 mA are accelerated to 750 keV at the sparking rate of less than one per day. Since July 1974, the column has worked satisfactorily. It is hoped that more intensity will be achieved by a shorter gap.

Acknowledgment

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