A NEW APPROACH TO PREINJECTORS

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1. Introduction

It has been realized for some time that the conventional preinjector, consisting of an ion source and focusing electrodes followed by a long accelerating column, could be simplified. If the vacuum breakdown problems could be overcome, then acceleration to the final energy in one step, across a single gap, has many advantages. Focusing could be done at earth potential thus reducing the quantity of equipment which has to be operated on the high voltage platform. The beam would be accelerated rapidly thus minimizing the effects of space charge.

Some work on the principle of single gap acceleration is described below.

2. A Single Gap Acceleration Experiment

An obvious first step is to arrange a pair of electrodes in a vacuum vessel and have a conventional ion source in the high voltage electrode. As a quick preliminary experiment, the apparatus illustrated in Fig. 1 was set up. In this case a standard rf source was operated at earth potential and the beam was accelerated to a negative potential across a single gap. This circumvented the need for the high voltage electrode. The latter contained a collector cup with a transverse magnetic field for secondary electron suppression, the only measure of beam current being a resistor on the low voltage side of the energy storage capacitor, as shown.

With no beam present the "pressure effect" was observed when a voltage was applied to the gap. The steady loading currents of several hundred μA which occurred at 3×10^{-5} Torr dropped to a negligible value at a pressure of about 5×10^{-4} Torr.

A beam current of about 40 mA (pulse length 1 ms) was accelerated to -220 kV without breakdown of the gap at a pressure of 10^{-3} Torr in hydrogen. These values were the maximum available from the various power supplies at the time.

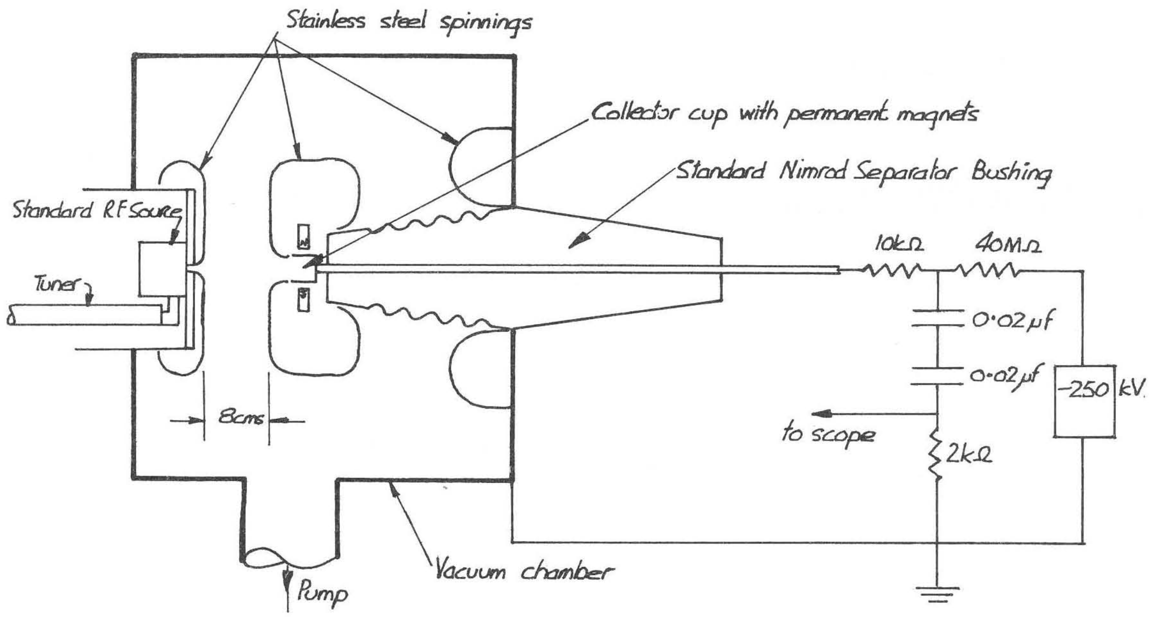

FIG. 1 Diagram of single gap experiment

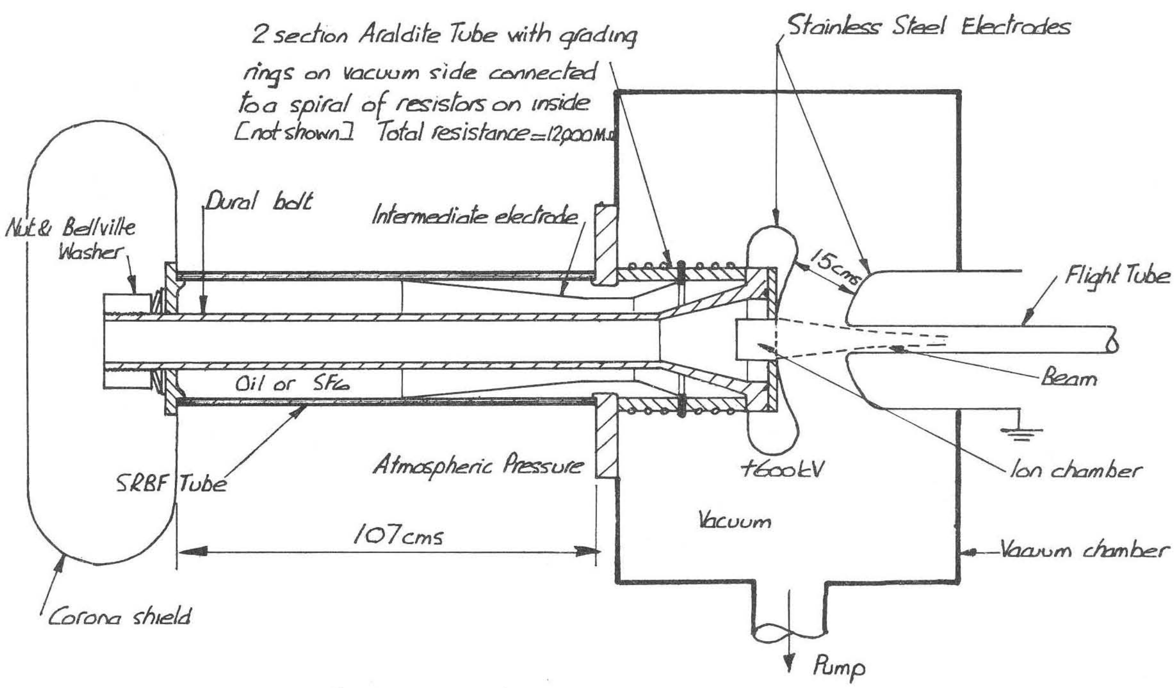

FIG. 2 Scaled-up Ion Source with 600 kV Lead-in Bushing

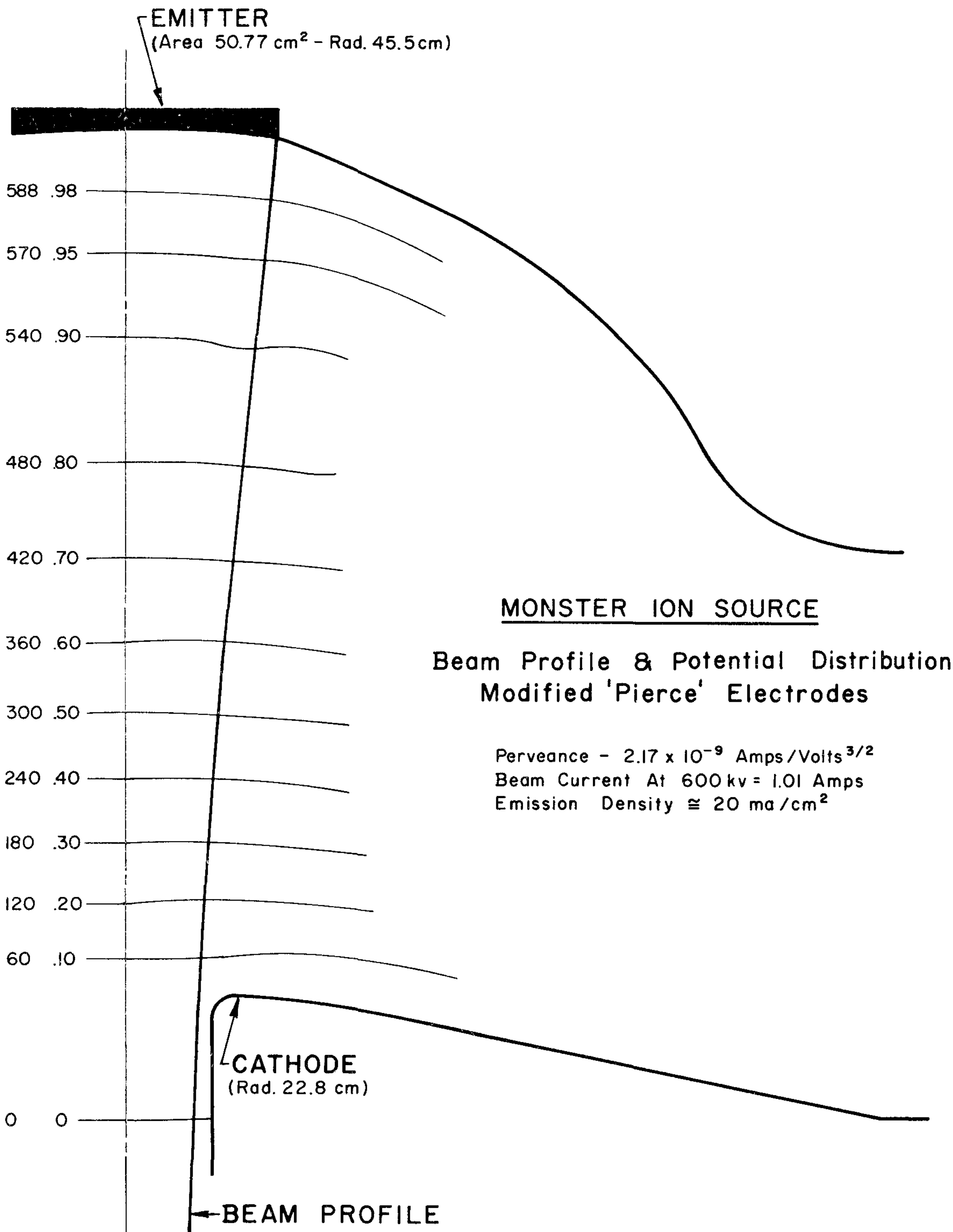
EMITTER
(Area 50.77 cm² - Rad. 45.5cm)
588 .98
570 .95
540 .90
480 .80
420 .70
360 .60
300 .50
240 .40
180 .30
120 .20
60 .10
0 0
CATHODE
(Rad. 22.8 cm)
BEAM PROFILE
MONSTER ION SOURCE
Beam Profile & Potential Distribution
Modified 'Pierce' Electrodes
Perveance - 2.17 x 10⁻⁹ Amps/Volts³ᐟ²
Beam Current At 600 kv = 1.01 Amps
Emission Density ≅ 20 ma/cm²

FIG. 3

3. A Scaled Up Ion Source

The "pressure effect" makes it feasible to operate some sort of ion chamber and an accelerating gap at the same pressure, thus avoiding the canal or orifice needed in conventional sources to limit gas flow. The ions could be extracted over a large area at low current density from a discharge operating in the pressure range 10^{-3} - 10^{-4} Torr.

Work is proceeding on a device utilizing this principle as shown in Fig. 2.

A discharge chamber is housed in the end of a lead-in bushing. It has a gridded aperture 8 cm in diameter through which the ions are extracted. The extraction voltage corresponds to the accelerating voltage of a conventional preinjector, 600 kV in this case. The electrodes of the single gap have surfaces which are parts of concentric spheres. The radii of the anode and cathode are 30 cm and 15 cm respectively. With an ion emitting aperture of 8 cm diameter, assuming spherical space-charge flow and ignoring the hole in the cathode, the perveance is 3.6×10^{-9} $A/V^{3/2}$ for protons. Thus at 600 kV the space-charge limited proton current would be 1.7 A, requiring an emission current density at the plasma boundary of 30 mA/cm^2. The optics in the accelerating gap is illustrated in Fig. 3.

Two possible low pressure discharges are being examined as plasma sources--a Penning type and a discharge using an electrostatic electron trap.[1]

The design of the lead-in bushing is a major technological problem. The design shown in Fig. 2 consists of four parts, a mounting flange, an epoxy resin cylinder about 30 cm long and 34 cm diameter projecting into the vacuum chamber, a bakelite tube 107 cm long and the same diameter, and finally a strong tubular tie bolt down the center to hold the assembly together and give access for electrical leads to the ion chamber. The space between the bolt and the tubes is filled with transformer oil (and possibly compressed SF_6 at a later date). The surface of the epoxy resin tube is electrically graded by means of 8 metal rings on the outside (i.e. the vacuum side) connected through the epoxy resin to a spiral of resistors on the inside (i.e. immersed in oil). The total resistance is 12,000 M . The outside of the bakelite tube (i.e. in air at atmospheric pressure) may also be graded. An intermediate electrode is incorporated into the bushing as shown to make the radial potential distribution more uniform in the gap between the bolt and mounting flange.

Acknowledgements

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VAN STEENBERGEN: In your figure you show an H. V. electrode aperture about equal to the beam diameter at that location. The rectilinear beam is of course a zero emittance approximation, which is not true in practice. A certain fraction of the beam will end up outside the beam periphery determined with the "Pierce" approach. As a consequence, one would expect secondary electron production on the H. V. electrode when the aperture diameter is close to the theoretical beam diameter.

WROE: Yes.

CURTIS: What was the distance across the gap? If the gradient is high enough, that angular divergence due to thermal motion would not be very large, would it?

WROE: It shouldn't be. The gap is 23 cm and the beam radius 4 cm.

MORGAN: A comment. As you know we normally extracted at 150 kV from a duoplasmatron ion source. We have also extracted at 300 kV with a 1-cm gap. This is for either a 50% duty cycle or dc operation. There are other possible complications, but there is no indication of it being advantageous to operate in an increased pressure range. In fact a lower pressure range of $\sim 3 \times 10^{-6}$ torr is better for stability in our case.

WROE: Well there is a feeling these days in the vacuum breakdown field that you can divide the phenomena into two parts: short gaps where the fields are high and gaps several centimeters long where the mean fields are quite low. The pressure effect is observed in the long gap case.

HUBBARD: How do you supply the power to the ion source?

WROE: Down the tube--the bolt that holds the whole thing together is hollow. The idea is to use such a simple ion chamber that few supplies will be necessary. However, if you put a duoplasmatron in there with many supplies needed, there will be some difficulty. However, there is a 2-1/2-inch hole down the bolt which holds the assembly together.

HUBBARD: But then you have to have it up at high voltage in the back end? You need a platform just like a conventional machine?

WROE: Oh sure, you need a platform.

KELLEY: you say a PIG source, for example, looks like a good thing. I was wondering, in making your ions in the ion source, how are you sure that you have an essentially zero energy cathode. You said everything was calculated for zero initial velocities.

WROE: Yes it is. That is what the computer program assumes, though it won't be true in practice. The ions will have initial velocities. But the initial energy is quite small compared to the total potential of the gap.

VAN STEENBERGEN: I am interested in hearing the pressure effect mentioned here in connection with voltage breakdown. This came up some time ago when the pressure in the linac was being discussed. I wonder if it could be useful in a linac to improve the maximum attainable gradient, say by running the linac at a pressure of 10^{-4} mm Hg instead of 10^{-6} mm Hg.

WROE: Well, I won't be sure about that. This phenomenon seems to manifest itself in the case of long gaps at low pressure. I am not sure this has been observed in impulse or rf breakdown--just dc. The theory of this is nowhere near as advanced as the short gap case. There are some quite acceptable theories in the short gap case of breakdown where the mean fields are high and you can invoke some sort of field emission at the cathode to start the thing off. The mean fields here, across these gaps, are nowhere anywhere big enough for that. In the old days one of the earliest theories was that you have a particle interchange; an electron or negative ion is emitted here, crosses the gap, and liberates an ion which comes back and a chain reaction is set up. The effect of putting gas in as far as I understand it is just that you might get an occasional charge exchange event or scattering which interferes with this particle interchange. There are also micro discharges which you probably know about. If you observe the current through this gap, even though it is not breaking down, you see bursts of current. These micro discharges are also suppressed while working in this pressure range. I think there is no doubt that it occurs for the dc case.

NORDBY: I would be afraid in linacs at 10^{-4} mm Hg that your mean free path goes down pretty fast.

WROE: Well, it is true that it will be close to the gap dimensions. You are working in a rather critical position, if you put the pressure up too high, you come onto the low pressure side of the Paschen curve. You have to try to ride this rather tricky edge between the two.

NORDBY: I think you are all right at 23 cm, but in a couple hundred-foot tank things might be bad.

WROE: Yes, that is true.

FEATHERSTONE: We do observe in the Minnesota tanks that sparking becomes a problem when we get much above 10^{-5} torr.

BLEWETT: I guess this suppression of breakdown by gas pressures is observed mostly in dc separators. I believe the gas that is conventionally used is nitrogen. Are you sure this is true of hydrogen?

WROE: I talked to the Bevatron people and they use argon and they do not think it would make much difference what gas was used. Fundamentally, if the idea of charge exchange is correct, I don't really see why it should make much difference.

CURTIS: I think there is some information on that from the people at Ion Physics Corporation, who have used various gasses in their dc gaps, and they observed the improvement with all of these. They do not really prefer one gas over another, particularly, I think.

OLEKSIUK: Did you mention what you expected the sheath thickness to be?

WROE: It is just given by this formula. This is a very simple calculation for the one-dimensional case.

OLEKSIUK: This is just the Debye length that people talk about?

WROE: No, it would depend on the voltage you apply between the plasma and the cathode, you see.