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Summary

The comparison of pulsed vs. dc arc operation for nitrogen and argon shows a shift in charge distribution toward the higher charge states for the pulsed case. Tests with various magnetic field shapes along the arc column show a significant increase in high charge state output for a uniform field compared to the case with a field low at the cathodes.

Introduction

In the summer of 1974 a new test facility was set up by the 88-Inch Cyclotron group to develop Penning Ion Gauge (PIG) sources for positive heavy ions with high charge states. High charge states are very important to the Cyclotron because the energy of the beam varies as the square of the charge.[1] The goal of this program is to optimize the high charge state output of the PIG source by systematic variations of source parameters. The operation of the source at only 10-15 kV above ground makes it convenient to put as much power into the source as needed, and to use auxiliary coils to vary the magnetic field. Most of the results are applicable to the internal source of a cyclotron, and to external sources for a cyclotron or electrostatic accelerator, which can then inject a linac for example. The results reported here are the first obtained from this facility. The parameters studied are pulsed vs. dc arc conditions, and variation of the magnetic field shape in the arc column.

Description of Facility

The heavy ion source test facility consists of several sources, a magnet providing magnetic field for the arc and for charge state analysis, a Faraday cup and scanning wires for beam measurements. This system is shown in Fig. 1. The magnet geometry is based on the standard Berkeley HILAC design for the 750 kV injector. The magnetic field can be varied up to 11 kG but is 4-5.5 kG in these tests. The source is biased at typically + 10 kV so that the beam emerges at ground potential for convenient measurement of intensity and emittance. The anode is water cooled copper. The beam exit slit is in a replaceable tantalum insert with a beam exit slit .04 in x .50 in in size. The arc bore diameter is .375 in and the distance between cathodes is 5.1 in. The cathodes are heated by the arc. To strike the arc the voltage is increased to 3 kV and the gas pressure is increased. The arc strikes in a few seconds. The puller is made of tantalum. It has a slit .05 - .08 in x .56 in in size, spaced .05 in away from the anode. The angle of bend of the beam is 120 degrees to give beam analysis and radial focusing. The edge angle of the magnet exit is 23 degrees to the beam normal, for axial focusing. In addition to the main magnet coils there are pole face "mirror" coils to adjust the magnetic field along the arc column. The range of field profile control is shown in Fig. 2, for a main field in the range used here for the higher charge states. For the nitrogen and argon charge state distributions reported here the standard field used is the most uniform case of 500 A in the mirror coils.

Arc Pulser Power Supply

A high power pulsed arc supply has been designed, built and recently made operational. It can deliver up to 10 A of average current at up to 3 kV. Peak currents of up to 40 A are available. It produces current-regulated square-wave pulses as short as 10 μs and with a duty factor variable from 0-100%. It can be used for either the test-facility source or the internal 88-Inch Cyclotron source. A circuit description follows.

The basic circuit is shown in Fig. 3. A 4 kV, 10 A dc power supply with an output capacitor bank of 130 μF is applied to the arc terminals of the PIG ion source through a tetrode V1 (Eimac type 4CW 50,000C) which acts as a switch and series current regulator under control of a reference level generator and negative feedback loop.

For use in the ion source test stand, the arc power supply, series tube V1, and associated circuitry are electrically isolated to permit biasing of the source at a positive potential of up to 12 kV. V1 cathode operates 4kV below the extraction bias potential and is a common point for isolated power supplies and the arc current shunt. It is the most convenient point for comparison of reference and current feedback signals.

V1 is actuated by V2, a bootstrap type driver with floating input from isolated operational amplifier A2. Under quiescent conditions V2 is cut off by the negative biased output of A2, and V1 grid is held below cut off by conduction of V3 to the negative 850V bias power supply. A reference signal from a variable pulser (Hewlett-Packard type 8003A) or from a dc reference power supply, is generated at ground potential, applied directly to an LED-phototransistor isolator, and transmitted to the input of comparator A1 at V1 cathode potential. A1 compares the transmitted reference with the signal fed back from the arc current shunt at V1 cathode, and relays a signal proportional to the difference through a second LED-phototransistor isolator to the input of A2. Positive going output of A2 causes V2 to conduct and raises the grid of V1 above cutoff. Assuming that the ion source cathodes are hot enough to produce an arc at less than the maximum available arc voltage of about 3 kV, plate current will flow in V1 and be stabilized by the negative feedback loop.

The dc loop gain is approximately 100, flat to 15 kHz. Unity gain in the loop is at 300 kHz. The pulse rise time is 5 μs. The maximum pulse current available with negative grid operation of V1 is above 40 A. For continuous operation the pulser is rated at 30 A maximum pulse current and 10 A average dc. The duty factor may

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be increased to 100% as pulse current is reduced. For pulse widths greater than 10 msec. the pulse current is restricted to 10 A. Minimum pulse width is 10 μs and maximum repitition rate is 20 kHz. Typical service is with pulse widths in the range 1 to 5 ms at 25% to 95% duty factor. Continuous operation at 60 Hz and 120 Hz is avoided because of the possibility of overloading single phases of the arc power supply rectifier.

Operation is described above for a running condition with source cathodes hot enough to start an arc at a voltage less than 3 kV. This is insufficient voltage to start arc conduction at normal operating gas pressure when the source cathodes are cold. No plate current can flow in V1, and, as its grid comes above cut-off, screen current rises steeply. An auxiliary feedback loop, not shown in Fig. 3 senses high screen current and limits it under tight control of the arc current reference level. The screen current is held at its rated value of 1A while ion source gas pressure is increased to the point where an arc will strike. As plate current begins to flow in V1 its screen current subsides, and the reference level can be increased, as the source cathodes heat, to produce a stable arc at a current above 2A. The gas pressure can then be reduced to the operating level, and the arc current can be adjusted to the desired pulse or dc conditions.

Results

A survey of PIG sources by Bennett[2] shows that the highest fraction of high charge states has been obtained under pulsed conditions. So the first set of data to be obtained was the comparison of the charge state distribution of nitrogen under dc and pulsed conditions. The runs described here lasted 3-5 hours. Usually the output of high charge states dropped about a factor of 2 by that time, so the source was removed for cleaning. The charge distribution data may have an error of up to a factor of about 2 for the relative intensities of high and low charge states, because the beam is larger than the Faraday cup aperture. The data are shown in Fig. 4. The gas and extraction conditions were optimized for N^{5+}. The extraction voltage was constant at 10 kV. Since the magnetic field was varied to measure the various charge states, the relative distribution of the charge states will be somewhat different from the case of constant field. But the shift from dc to pulsed should be approximately the same as the constant field case. A mirror coil current of 500 A was chosen, to give an approximately uniform magnetic field (± 10%) as shown in Fig. 2. The average arc current was 8 A for both cases. Arc voltage was 500 V for dc and somewhat higher for pulsing. The dc output of N^{5+} is increasing with arc current in this region, so a current near the maximum rating of the supply was chosen. For the pulsed case a 33% duty factor was chosen, with 1 ms pulse length and 3 ms period. It is interesting that pulsing shifts the charge distribution toward the higher charge states, as expected, giving a factor of 2-3 more N^{5+} than with dc operation.

Another interesting parameter is the mirror field current. An experiment was reported by Bennett and Gavin[3] in which the field was lower at the cathodes than at the center of the arc column, to allow higher power operation. However, the high charge state output was much less than with a uniform field. Also Burrows and Green observed[4] that a low field at the cathode performed poorly for high charge states. Since we had been operating another version of the source in this magnet without mirror coils, we wished to find the importance of going to a uniform field. Fig. 5 shows the intensity of N^{5+} versus the mirror coil current. The results, like those of the other groups, show a significant increase in output when going from a field about 50% lower at the cathodes to an approximately uniform field. The gas and main magnet current were optimized at each point. The N^{5+} increased a factor of 4-5. It was hoped that an even larger mirror coil current would provide ion reflection near the cathodes and give longer confinement time and higher charge states. The data tend to verify this, but there was too much loading of the high voltage supply to go much higher at present.

The tests done for nitrogen were repeated for argon. Fig. 6 shows charge state distributions taken for dc and pulsed conditions. The arc current was set at 3.5 A for both dc and pulsing operation. This was approximately optimum for Ar^{7+}. The voltage was about 700 V for dc and higher for pulsing. The results show a shift toward higher charge states with pulsing, similar to the nitrogen data.

The last result obtained here is the dependence of Ar^{7+} on mirror coil field, shown in Fig. 7. The results again show an increase of output with increasing mirror field. A decrease in the minimum gas flow necessary to sustain the arc was observed as the mirror current was increased for the dc case. This is interpreted to indicate a longer confinement time.

Some tests have also been made using the pulsed arc supply on the internal source for the 88-Inch Cyclotron. This source is similar to the test stand source and operates in a uniform field of 15-17 kG. For Ar^{7+} beam, improvements due to pulsing are similar to those of the test facility, when the arc bore diameter is the same: .375 in. However, a large increase in output for dc operation has been observed by decreasing the bore diameter to .250 in by using either tantalum sleeves or special anodes. In this case a smaller additional gain is obtained by pulsing. Usable beams of Ca^{7+}, for example, are made possible with the smaller bore. The arc power is about the same with the two bore sizes, so the power density is increased about a factor of 2 for the small bore. Apparently the high charge states require a higher arc density either in space or time.

Acknowledgements

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Figure Captions

Fig. 1. Schematic views showing: Top) the mirror PIG source in the test facility. Bottom) the beam extraction and subsequent focus into an electron-suppressed Faraday cup.

Fig. 2. The magnetic field strength for several values of mirror coil current is shown as a function of position along the central axis of the arc column. The location of the mirror coils as well as the anode and cathodes are indicated in the upper portion of the figure.

Fig. 3. A simplified schematic of the arc pulsed power supply. The approximate voltage wave forms and currents are shown for a 30A peak, lms arc current pulse.

Fig. 4. Charge state distribution for nitrogen gas for an approximately uniform magnetic field (mirror coil current of 500 A). Gas flow and extraction conditions were optimized for N^{5+}.

Fig. 5. Variation of extracted N^{5+} beam current intensities as a function of mirror coil current for both pulsed and dc arc conditions. The cross-hatched regions are bounded by data taken with a freshly cleaned source (upper bounds) and with the same source after several hours of operation (lower bounds).

Fig. 6. Charge state distribution for argon gas for approximately uniform magnetic field (mirror coil current of 500 A). Gas flow and extraction conditions were optimized for Ar^{7+}.

Fig. 7. Variation of extracted Ar^{7+} beam current intensities as a function of mirror coil current for both pulsed and dc arc conditions.

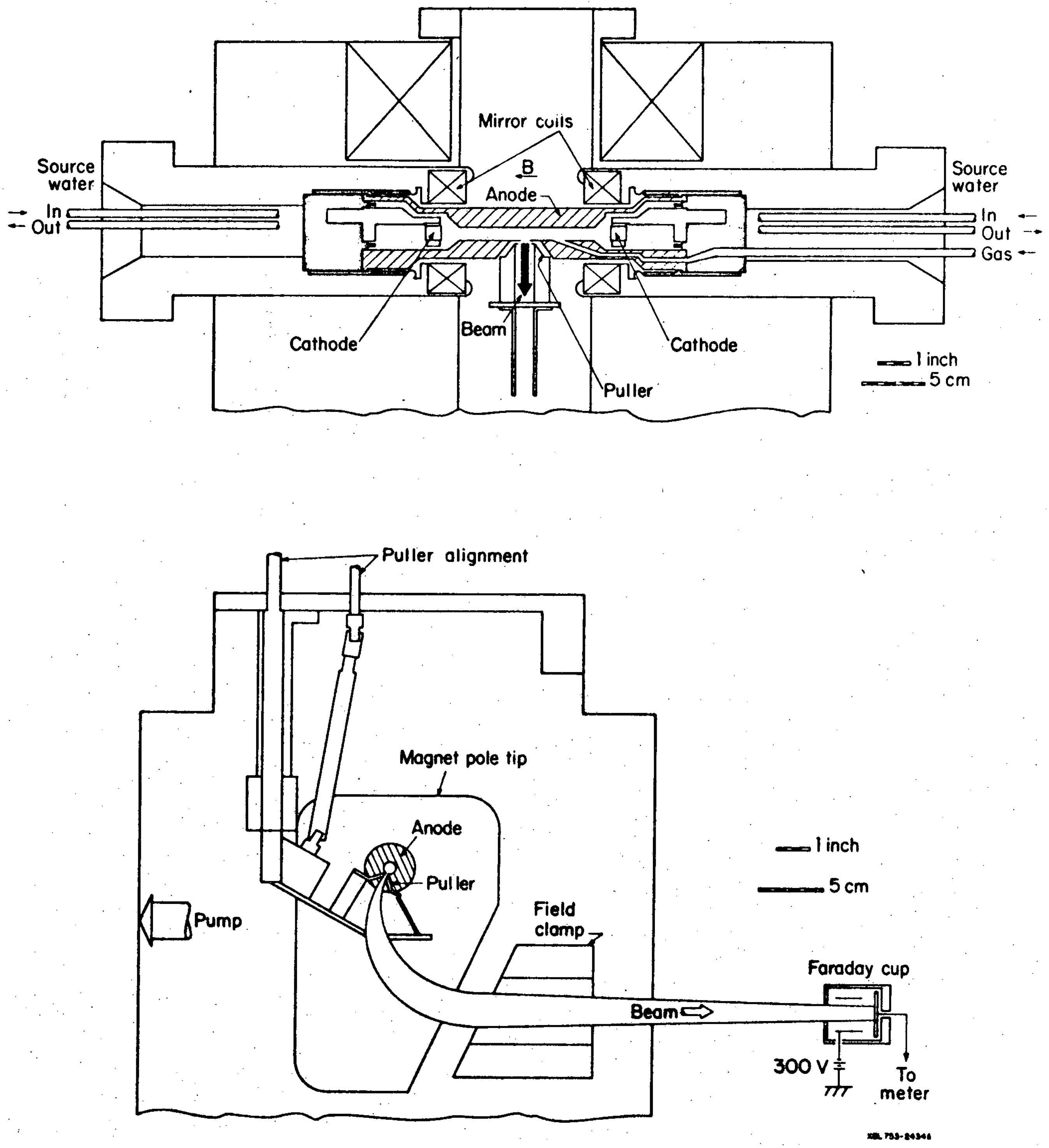
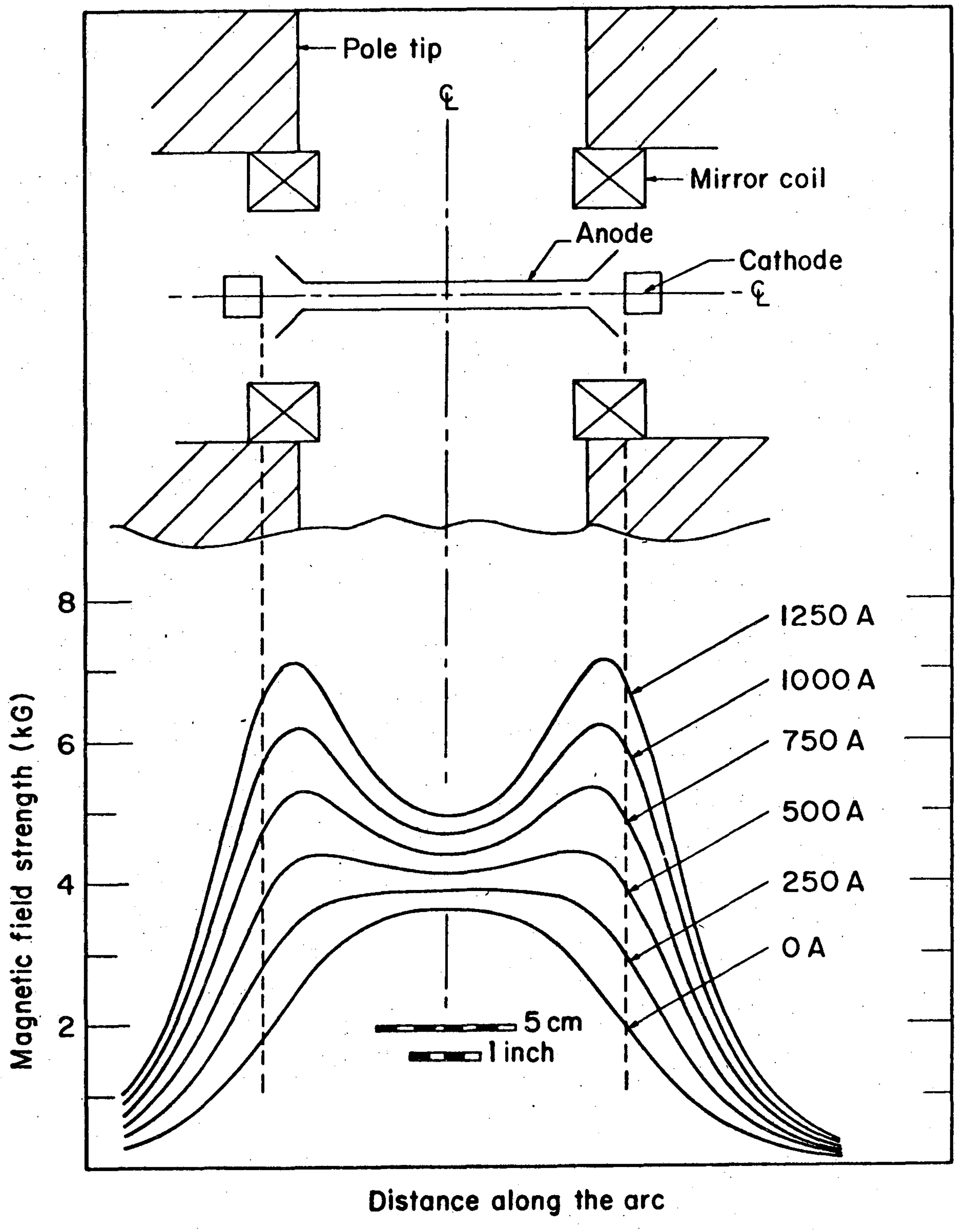
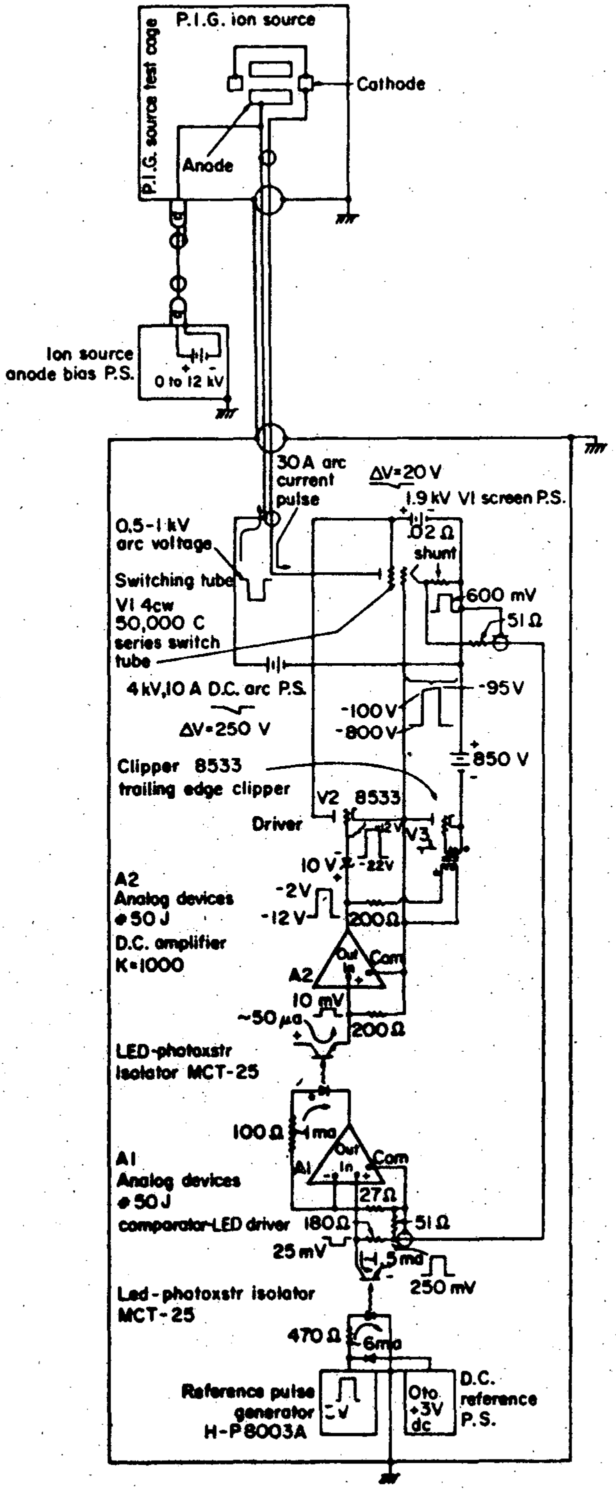

Mirror coils
B
Anode
Source water
In
Out
Source water
In
Out
Gas
Cathode
Beam
Cathode
Puller
1 inch
5 cm
Puller alignment
Magnet pole tip
Anode
Puller
Pump
Field clamp
Faraday cup
Beam
300 V
To meter
1 inch
5 cm
XBL 753-24346

Fig. 1



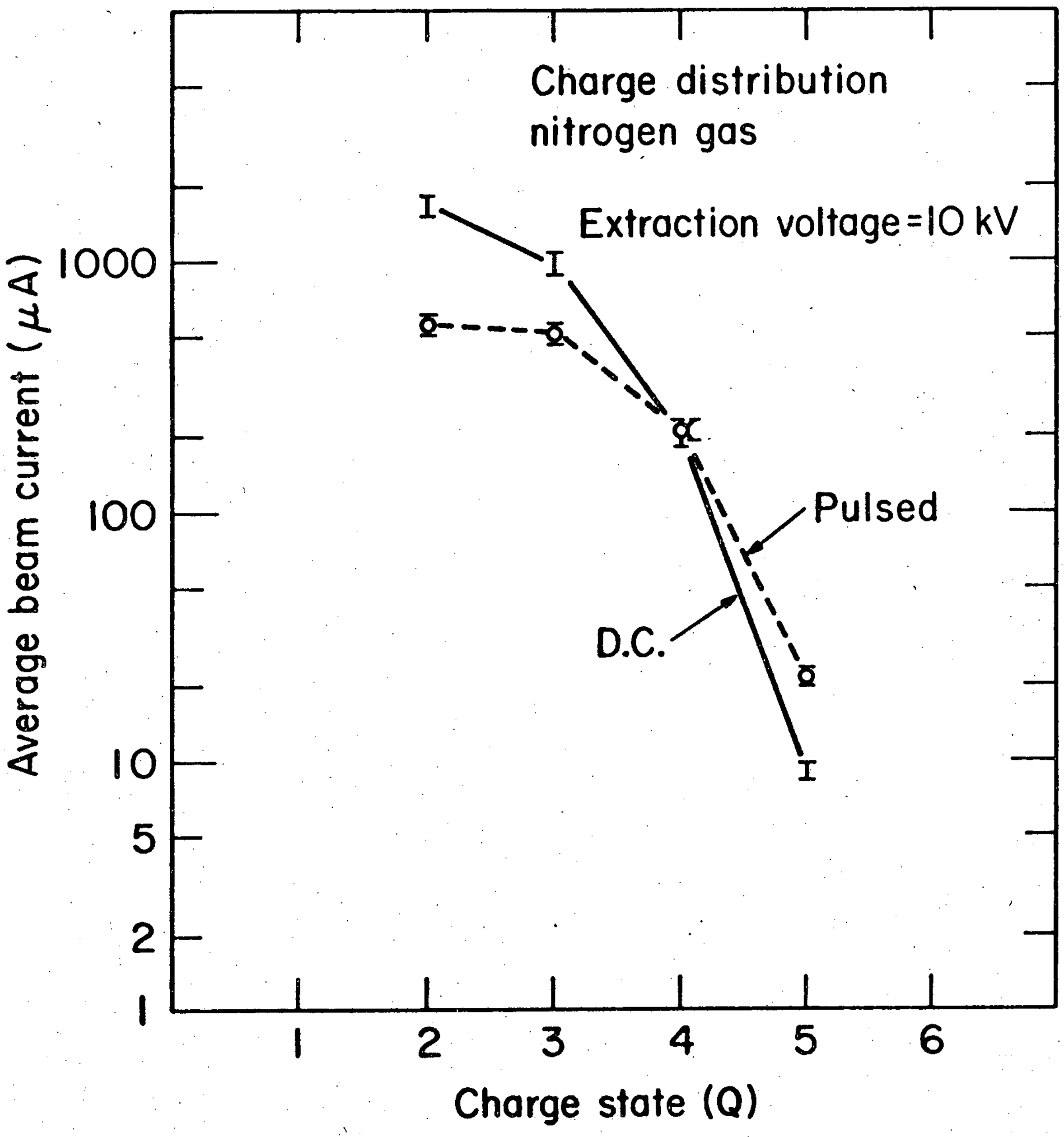
Pole tip
℄
Mirror coil
Anode
Cathode
℄
8
6
4
2
Magnetic field strength (kG)
1250 A
1000 A
750 A
500 A
250 A
0 A
5 cm
1 inch
Distance along the arc
XBL 753-2433

Fig. 2



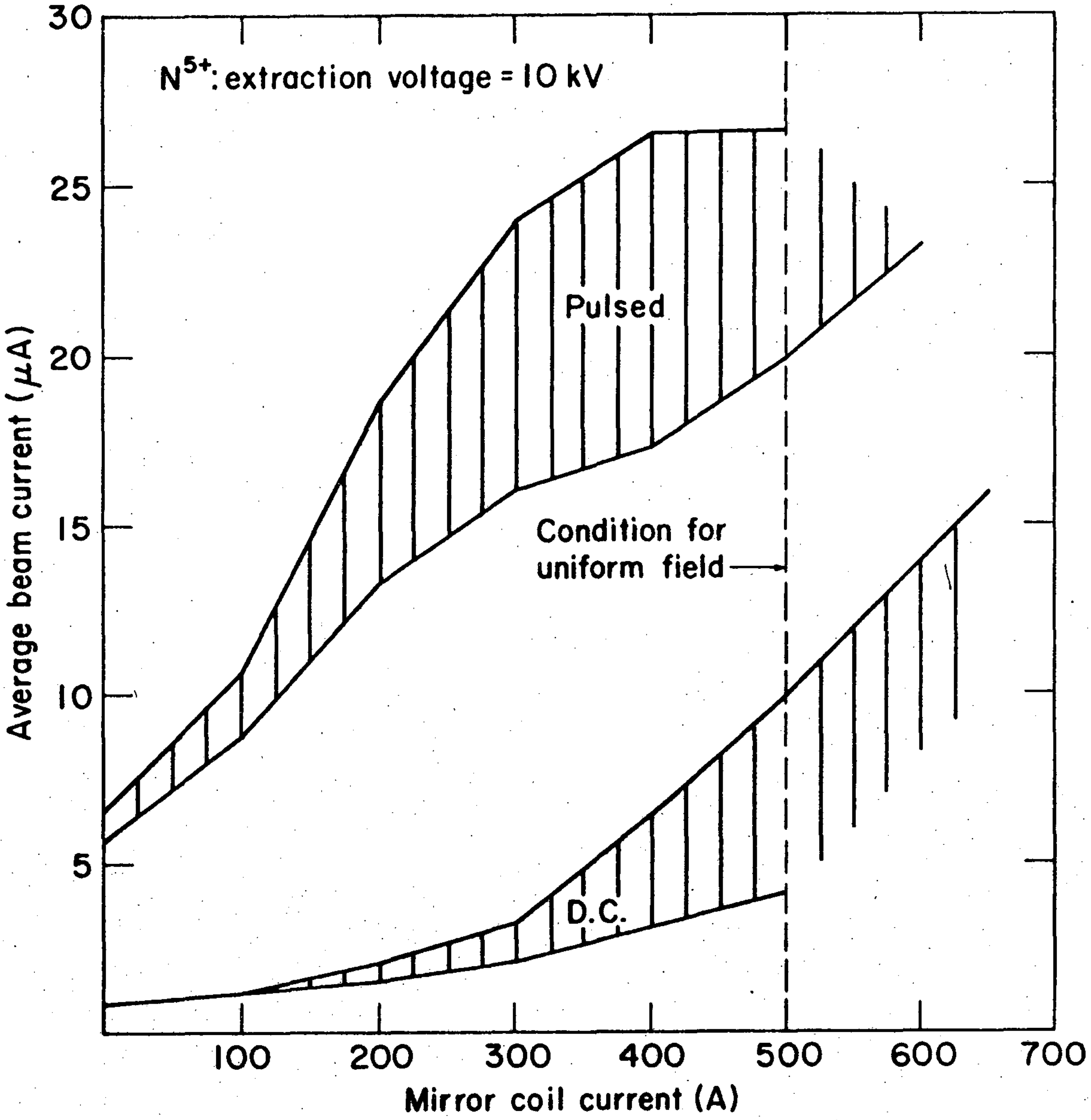
XBL 783-2439

Fig. 3



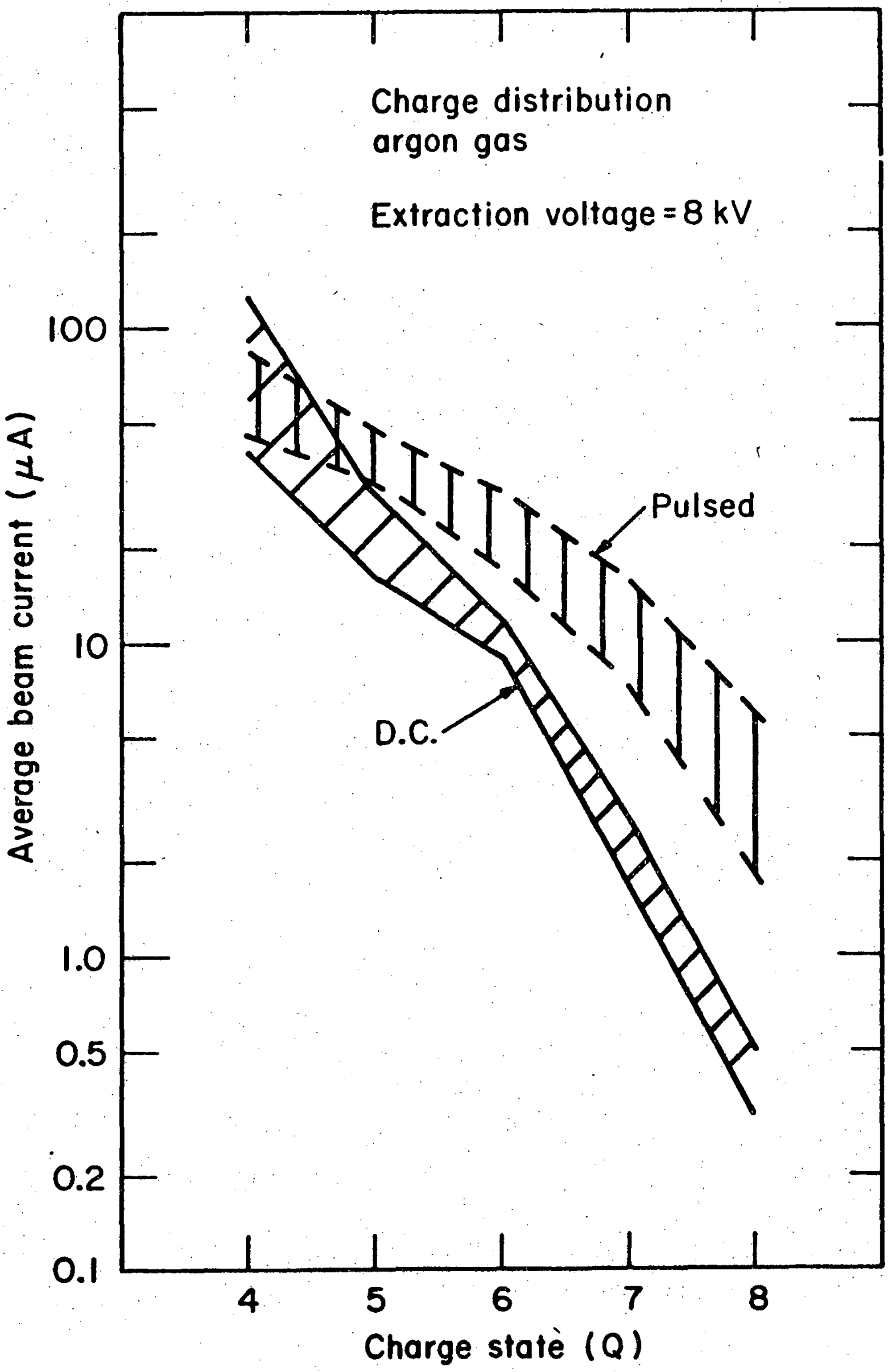
XBL 753-2436

Fig. 4



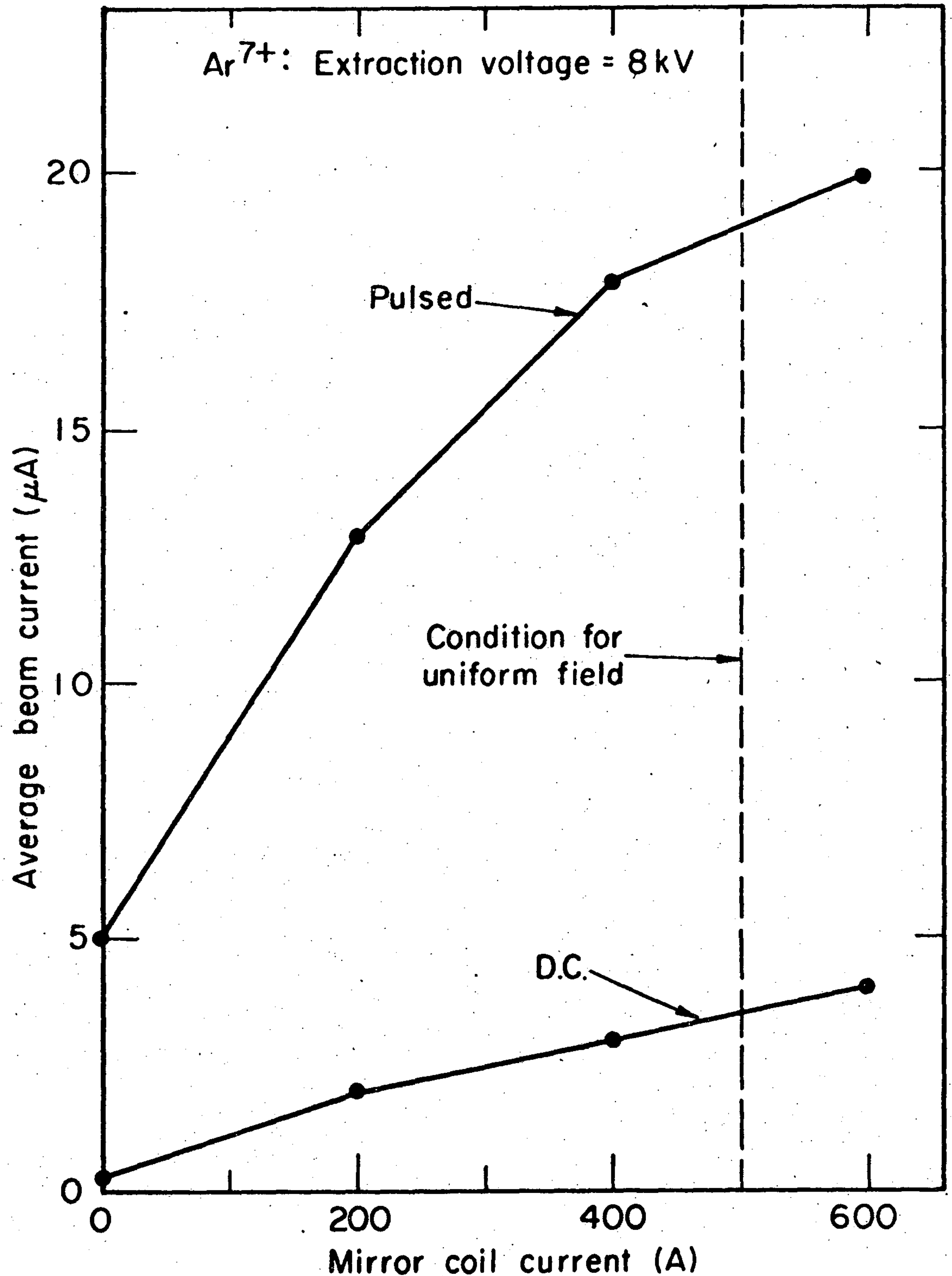
N^{5+}: extraction voltage = 10 kV
Pulsed
Condition for uniform field
D.C.
Average beam current (μA)
Mirror coil current (A)
30
25
20
15
10
5
100
200
300
400
500
600
700
XBL753-2438

Fig. 5



XBL 753-2437

Fig. 6


Ar^{7+}: Extraction voltage = 8 kV
Pulsed
Condition for uniform field
D.C.
Average beam current (μA)
0
5
10
15
20
0
200
400
600
Mirror coil current (A)

XBL753-2447

Fig. 7

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