TEST OF LASL ION SOURCE WITH 750-kV ACCELERATING COLUMN*

C. Robert Emigh, E. A. Meyer, and Donald W. Mueller
University of California
Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87544

ABSTRACT

The 750-kV high-intensity injector for the LAMPF accelerator has been constructed and was put into operation on June 9, 1970. Specifications were met by a 25-mA pulsed beam of protons, 500 μsec in length with a repetition rate of 120 Hz, and a beam emittance area less than 2π cm-mrad. The ion source is a Von Ardenne duoplasmatron with a 1.4-cm diam expansion cup. The column operates at 750 kV and has an exact Pierce geometry extraction system.

The ion source is operated at +750-kV level by light-link control from ground level equipment. The system is capable of conversion to computer control when computer operation becomes available. Hydrogen pumping is accomplished by ion pumps operating at both ends of the accelerating column.

The exact Pierce geometry of the accelerating column is formed by shaped Ti alloy electrodes, with an electrostatic electron trap built into the column at the high-energy end. High-voltage insulation is accomplished by an acrylic jacket filled with SF_6 at 6 psig. Unique features of the jacket are its transparency for observing corona and spark discharges, and its nine access ports for ease of assembly and maintenance of the accelerating column.

Introduction

The five main areas of the 750-kV high-intensity injector for the LAMPF accelerator are the Cockcroft-Walton (C-W) generator, control system, ion source, accelerating column, and the beam-transport system. Figure 1 shows the C-W generator on the left, the equipment dome on the right containing the vacuum and control systems, and the accelerating column in the background. The ion source is located inside the accelerating column and the beam-transport system is located outside the aluminum-walled Faraday cage. Beam-transport system and control system operations are reported in separate papers.

The C-W generator was designed to LASL specifications, built in Switzerland by Haefely, and reassembled here. It is capable of 1-MV operation and has been tested to this level in our installation. At 750 kV, it can supply 50 mA of pulsed proton current at 0.05% regulation.

Various parts of the accelerating column, the ion source, and the vacuum system are illustrated in Fig. 2.

Ion Source

Details of the construction of the ion source have been previously published.[1] The present source, Figs. 3a and 3b, has been improved by several mechanical modifications. The plasma aperture has been reduced to 0.025-in. diam with a length of 0.010 in. It is drilled in a 0.005-in. thick piece of mild steel with a 0.005-in. thich copper layer plated on the cathode side. The hydrogen flow through this aperture is 2-cc atm/min. The ceramic ring which insulates the intermediate electrode assembly from the main body of the ion source has been made larger and moved around the corner to eliminate metal deposition from the high temperature plasma aperture region. Copper is used for the water jacket and all brazing is done with a copper-silver eutectic, hydrogen fired. This technique eliminated difficulties experienced with flux inclusions in the preceding models. The use of hard solders containing Cd and Zn have been eliminated in accordance with good vacuum practice. Vacuum-baked viton O-rings have been used dry for all O-ring seals. All insulators in the vacuum regions of the source are now ceramic, including those used to isolate the Pierce anode.

A current control loop, shown schematically in Fig. 4, has been added to the arc pulser.[2] Feedback from a current sensing resistor is used to compensate for changes in the arc impedance during the pulse. The arc current can be held flat within a few percent after an initial transient. Means of eliminating the initial transient, which may be aggrevated by the turn on of the feedback loop, are being investigated at the present time.

Accelerating Column

The accelerating column is cylindrically shaped, 5-ft in diam by 10-ft long, and is positioned horizontally between the +750-kV equipment dome and the grounded Faraday cage wall. As shown in Fig. 2, it consists primarily of:

a) an evacuated ceramic accelerating tube of Pierce geometry,

b) two conical cantilever members supporting the tube from end flanges,

c) an acrylic jacket which surrounds the tube and supports the end flanges, and

d) a voltage distribution system for applying the proper potential to the Pierce electrodes.

Accelerating Tube

The extraction system was designed on the basis of a 50-mA pure proton beam. However, the column is equally capable of extracting a proton-ion mixture in accordance with the curves of Fig. 5. For example, 40 mA of total current extracted for initial operation contained about 54% proton current, 30% H_2^+ current, and 16% H_3^+ current. Because of the high current density, the shapes of the anode and the various electrodes are determined from an exact Pierce theory,[3] as shown in Fig. 6. The third and fourth electrodes from the ground end are simple cones approximating Pierce geometry and the last two are thick planar electrodes that act as an electron trap. The beam line aperture is 2-cm diam on all electrodes except the last two where it is larger to avoid scraping by the divergent beam at the exit aperture. Each electrode is machined from a single billet of 6 Al-4V titanium alloy and buffed to a 4-8 μ in. finish. Pumpout holes are staggered to prevent direct line electron backstreaming.

The accelerating tube consists of a series of thin titanium alloy washers insulated from one another by 1-1/4 in. thick alumina rings. The washers furnish mechanical support for the electrodes and provide means of applying the proper potential on the various electrodes. Polycarbonate[4] is used as the adhesive for bonding the titanium washers and stress-relief flanges to the alumina rings. This flange design with mechanical decoupling between the flange and adhesive bond has completely eliminated the persistent leakage problem observed on an earlier model with conventional flanges. After bonding, the titanium surfaces were masked and the entire tube cleaned by blasting with 120-grit aluminum oxide grain. Overall dimensions of the tube are 16-in. o.d. x 22-in. long.

Support Cones

The double-cone cantilever support for the ion source and accelerating tube are shown in Fig. 7. The exploded view on the left shows the titanium electrodes of Pierce geometry that fit inside the tube. High conductance pumpout of the accelerating tube is provided by 15 large 2-1/4 in. diam holes, shown in Fig. 8, leading to the annular space between the two cones which connects to the vacuum system in the equipment dome. Note also in Fig. 8, the location of the twelve light-link penetrations. The region inside the inner cone allows convenient access to the ion source from inside the dome (Fig. 2) at ambient pressure without disturbing the SF_6

environment in the acrylic jacket.

The exit-end cone with bellows and reentrant can attached is shown in Fig. 9, balanced and ready for insertion into the acrylic jacket. The ion source double-cone with accelerating tube attached is handled in a similar manner for final assembly. The bellows provides the necessary flexible attachment to the accelerating tube which eliminates critical dimensional requirements on mating and applies 400-lb compression on the tube as a precautionary measure. The reentrant can, Fig. 6, is actually an extension of the reentrant feature of the cone itself, permitting the closest possible positioning of the beam-line components to the emergent beam, yet keeping these components directly accessible from outside the column.

Acrylic Jacket

The 4-ft diam by 10-ft long centrifugally cast acrylic jacket of 3/4-in. wall is the primary structural element of the accelerating column module. From its end flanges, it supports the two cantilever cones and contains SF_6 at 6 psig as the insulating gas.

Access must be provided to the inside of the jacket for several reasons. It is necessary to attach the bellows to the accelerating tube inside the jacket after the cantilever cones are inserted from each end of the jacket. Aluminum conductor spokes must be connected between the sections of the accelerating tube and the middle corona rings along the i.d. of the jacket. Access also allows repairs (e.g., leak sealing) to be made on line. The jacket has been opened about twenty times to date for various reasons, like removing conductor spokes, polishing sharp edges, replacing connectors, adjusting spark gaps, removing lint, and soldering leads. Opening and closing access ports is a matter of minutes. A design without this feature would probably take two days to remove the module from the line, disassemble, repair, reassemble, and realign the beam line and quadrupoles.

Transparency of the jacket is highly desirable for visual observation and photographic recording of corona or sparking external to the accelerating tube. Any problems of this nature can be quickly pinpointed and corrected. While the nine access ports allow one to reach everywhere inside the jacket, working inside requires that one be able to see what he is doing. For this reason, transparency of the jacket is essential for effective maintenance and assembly, as shown in Fig. 10.

Voltage Distribution System

The voltage at each of the accelerating tube electrodes is determined by the bleeder resistors, Fig. 2, extending down the length of the column. Nine parallel strings are used with a total bleeder current of 1.1 mA. For quick maintenance, bleeder resistors plug into spring-loaded recesses in the outer corona rings. These standard resistors have performed very well with no failures to date. Voltage between rings is 54 kV except near the ion source where it is 27 kV and between the electron trap rings, where it is -10 kV. Voltages on the outer corona rings are applied to the accelerating electrodes by conducting spokes, which are positioned along equipotential surfaces as determined by computer studies.

Vacuum System

The vacuum system in the dome (Fig. 11) consists of a vacuum manifold with a 10-in. line leading to a gate valve and an Ultec 2000 liter/sec H_2 ion pump on each side of the dome. The parallel construction allows sufficient room for reaching inside the inner cone to change the ion source and also provides second pump redundancy. Only one pump is installed at the present time and is performing very well, operating at H_2 flow rates as high as 6-cc atm/min for hours without thermal runaway. Also shown in Fig. 11 is the large pumpout opening in the vacuum manifold where it attaches to the accelerating column module and supports that end of the column. Flexibility is provided in the vacuum manifold support to prevent overstressing the acrylic jacket when bolting these units together.

Since dome space is a premium item, a portable, contaminant-free roughing system (Fig. 12) is used to start the ion pump. This is a modified Ultek CFR system with a Bell & Gossett DVI-S dry vacuum pump (on left), substituted for the usual blower. Thus the system can be operated continuously, and the sorbtion pumps can be reactivated under pump vacuum. A titanium sublimation unit utilizing the NRC 211 getter pump has been added (on right) to ensure that ion pumps loaded with hydrogen from previous ion source operation can be started readily. The flexible metal hose at the right connects to the roughing line through a port in the dome wall. Pumpdown of the 500-liter accelerating column system is quite fast, taking less than 30 min to reach pressures below the glow discharge range where the ion pump starts instantly. The ultimate pressure reached is 4×10^{-8} torr.

Test Results

The column ready for voltage testing is shown in Fig. 13. In addition to the internal structure, conductor spokes, access ports, several of the 9 bleeder resistor strings and one of the 3 sets of protective spark gaps are shown. The acrylic jacket is filled with SF_6 at 6.0 psig after purging with 1 tank (200 cu ft) of dry N_2. The column was voltage-conditioned 3 months ago, reaching 838 kV, and has since run for periods up to 9 hours without sparkover. No further voltage conditioning was required on initial beam tests or after the system had been let up to 1 atm of dry N_2 for one hour. The highest gradient in the column is about 94-kV/cm near the electron trap, as shown in Fig. 14(a). Use of a shroud ring and enlarging the corona rings should reduce the maximum gradient to 66-kV/cm as shown in Fig. 14(b). This modification is ready for installation and should allow a reduction of SF_6 pressure.

A typical set of ion-source operating parameters for producing a 750 keV - 25 mA proton beam are as follows: arc current, 23 A; arc pulse voltage, 100 V; arc chamber pressure, 200 microns as read by a thermocouple gauge uncorrected; accelerating column pressure, 1×10^{-5} torr as read on an ion gauge; and arc magnet current, 1.2 A. The duty factor of the beam was varied up to 6% with pulse lengths up to 500 μsec and repetition rates up to 120 Hz. The emittance of the beam has been measured at 1.8 π cm-mrad.

Figure 15a shows the control room CRO traces of a 500-μsec, 120-Hz, 38-mA beam. The next-to-bottom trace shows the total beam current measured at the exit aperture of the accelerating column by a beam current transformer. The bottom trace shows the extractor current (1st electrode of the Pierce geometry) which is virtually zero except for an early spike associated with the turn-on transient. The top trace is the arc pulser voltage, and the next trace is the arc current at 22 A. Figure Figure 15b shows the traces of the beam current at various locations along the beam-transport system. The middle trace shows the total current entering the double 45° bend portion of the transport system and the lowest trace shows the proton current after the bends. Thus, the proton ratio is seen to be 66% in this case.

The present ion source and its cathode have been in continuous operation for ∿ 5 months. Its operation has been very satisfactory, with most of our problems being in the proper operation of the arc modulator.

References

*Work performed under the auspices of the U. S. Atomic Energy Commission.

1. C. R. Emigh and D. W. Mueller, The LASL High-Duty-Factor Ion Source, Proc. of the 1968 Proton Linear Accelerator Conference, pp. 293-305.

2. C. R. Emigh, E. A. Meyer, and D. W. Mueller, Test of LASL Ion Source with 200-kV Pierce Asselerating Column, Proc. of 1969 Particle Accelerator Conference, pp. 46-50.

3. C. R. Emigh, The 'Pierce' Geometry: An Accelerating Column Design, Proc. of the 1966 Linear Accelerator Conference, pp. 398-402.

4. E. P. Ehart and S. E. Newfield, Polycarbonate as an Adhesive, LASL Internal Report, LA-3890 (1968).

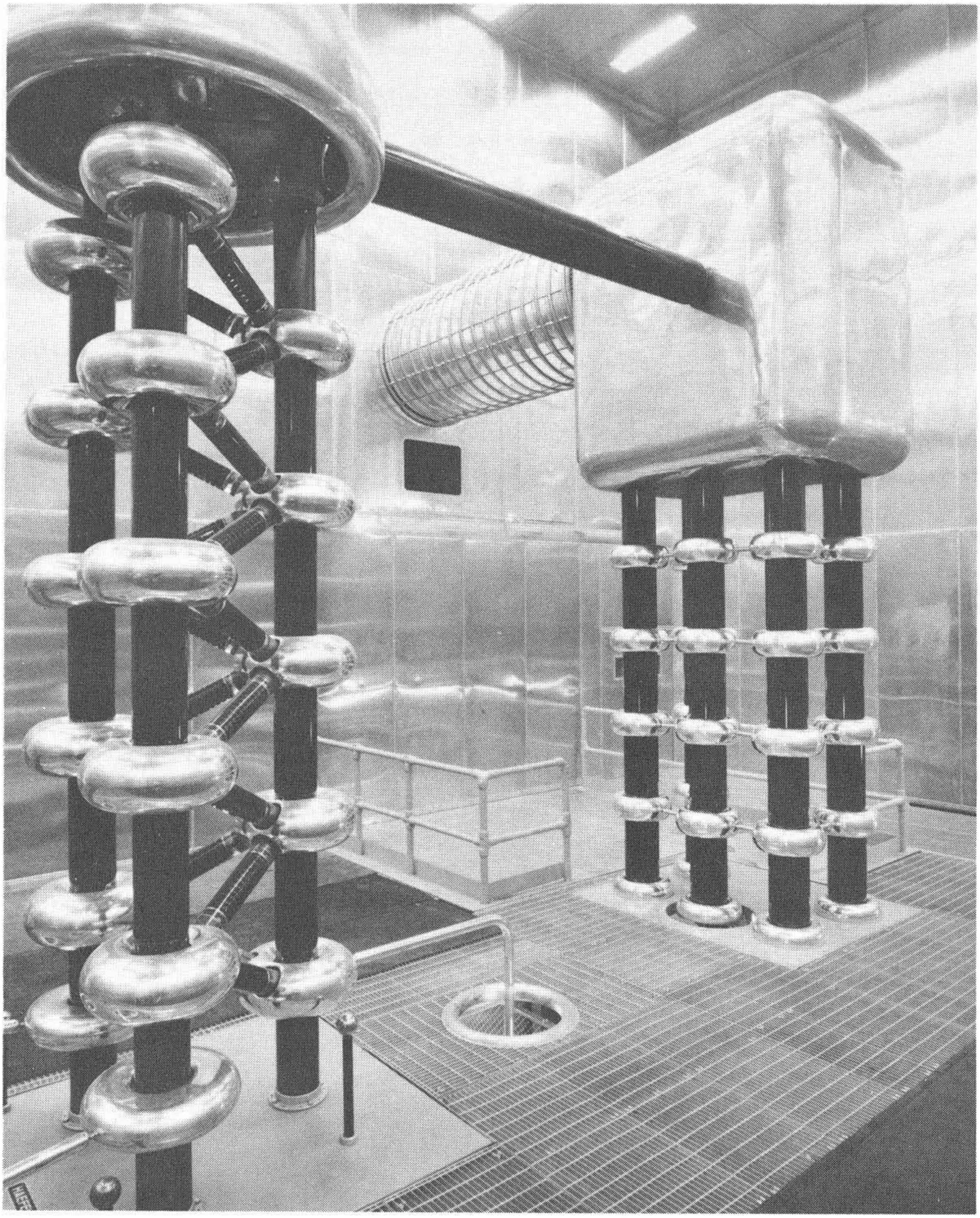

Fig. 1. The 750-kV high-intensity injector for the LAMPF accelerator.

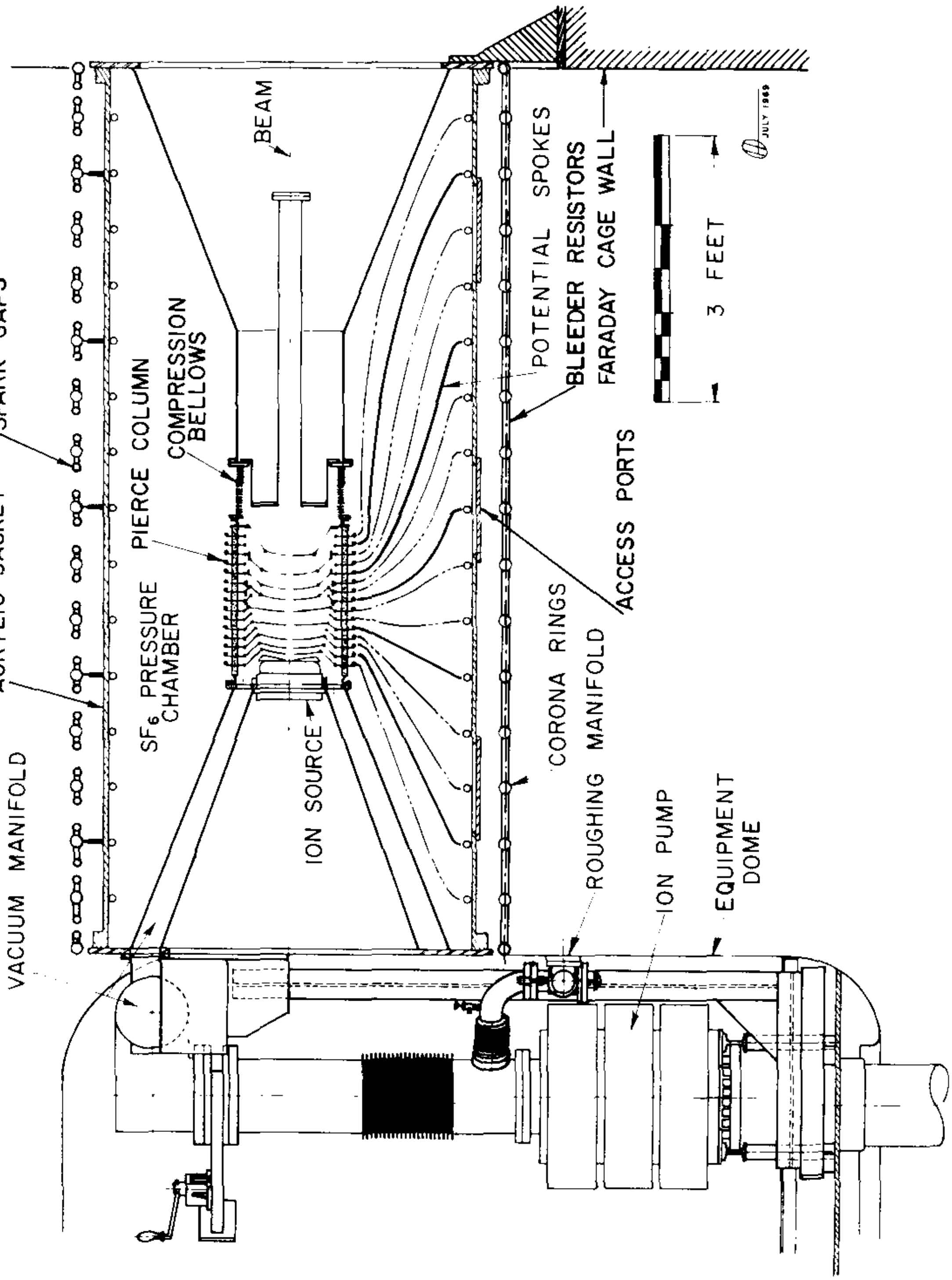

Fig. 2. The 750-kV accelerating column, ion source, and vacuum system.

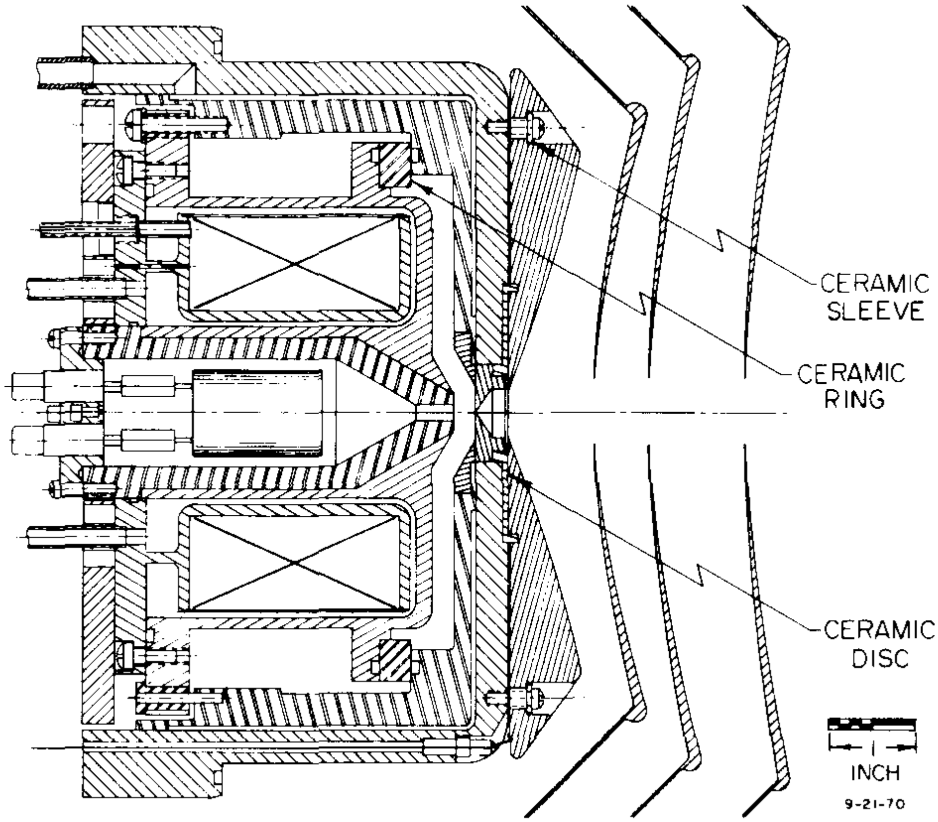

Fig. 3(a). Details of the ion source now in use.

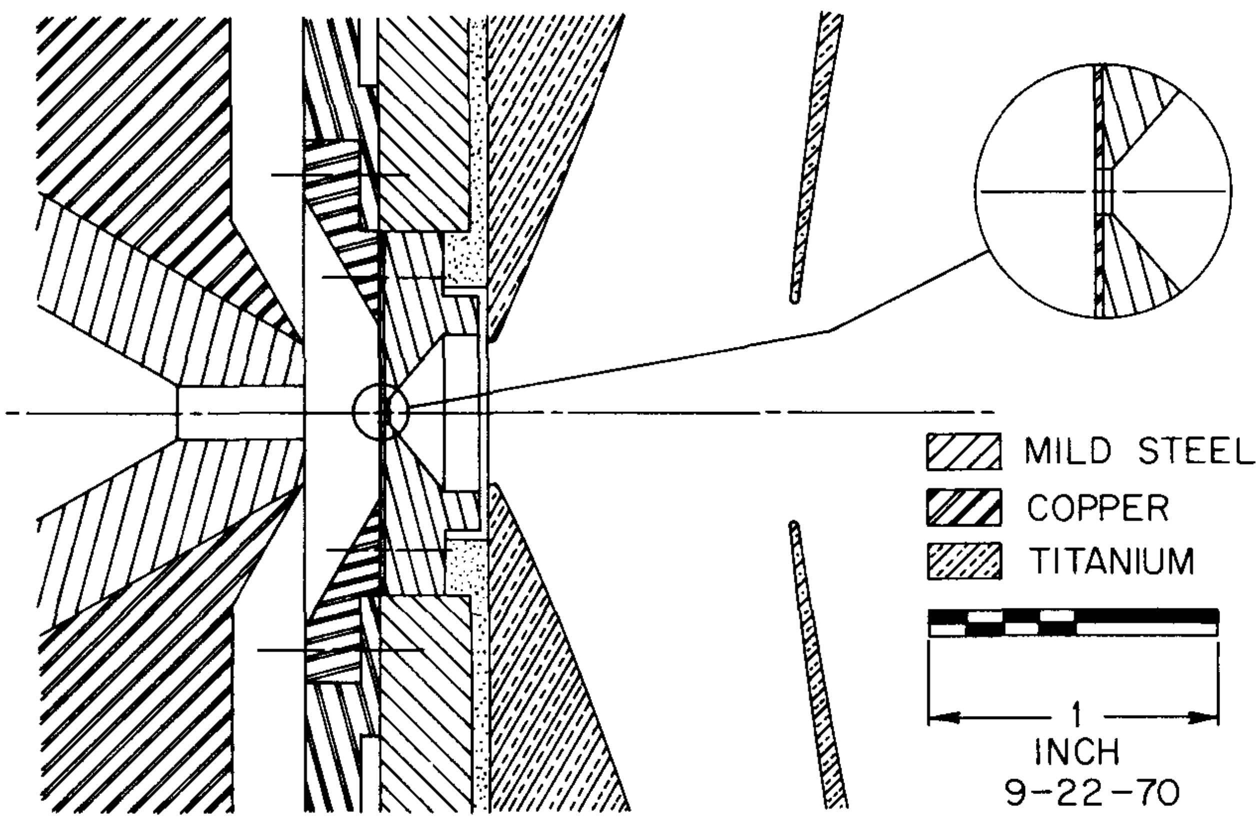

Fig. 3(b). The intermediate electrode nose, plasma aperture, cup, and extraction electrode in greater detail. The aperture is made with 0.025-in. diam through 0.005 in. of copper and 0.005 in. of mild steel.

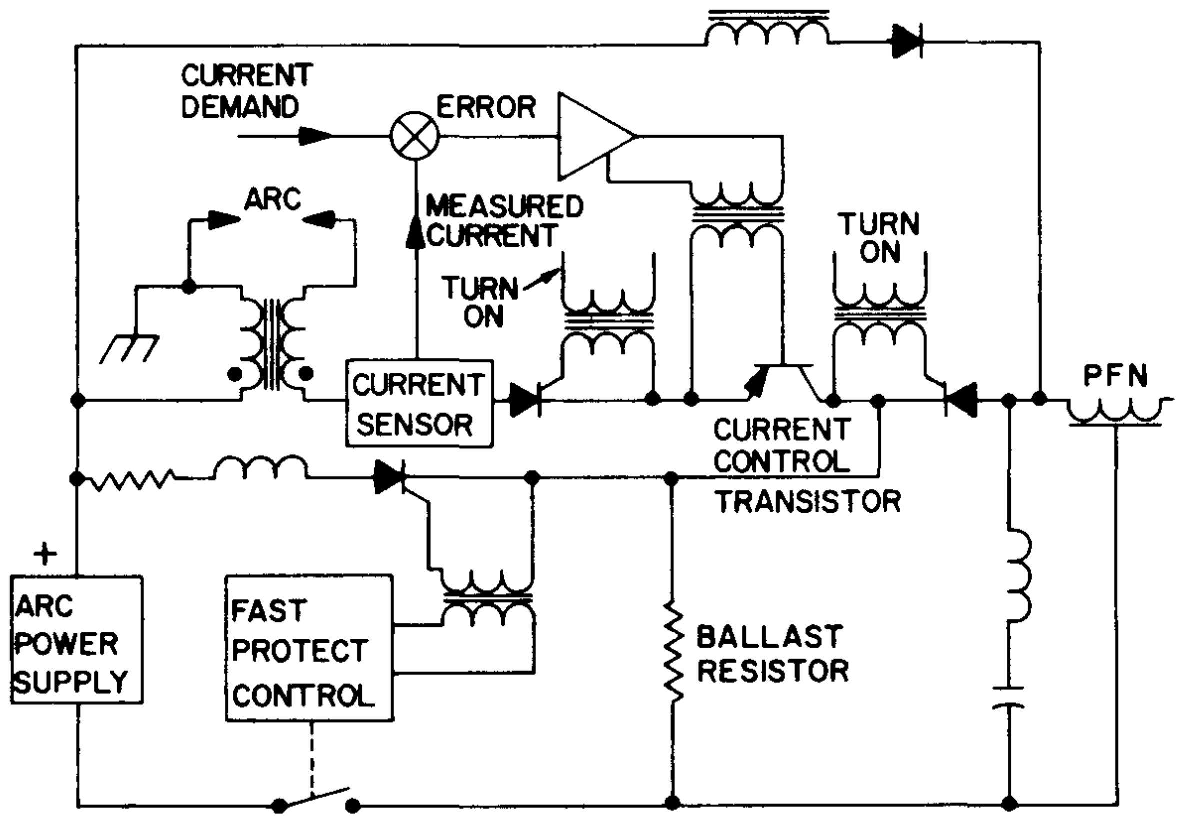

Fig. 4. Schematic of arc pulser circuit showing the arc current control loop.

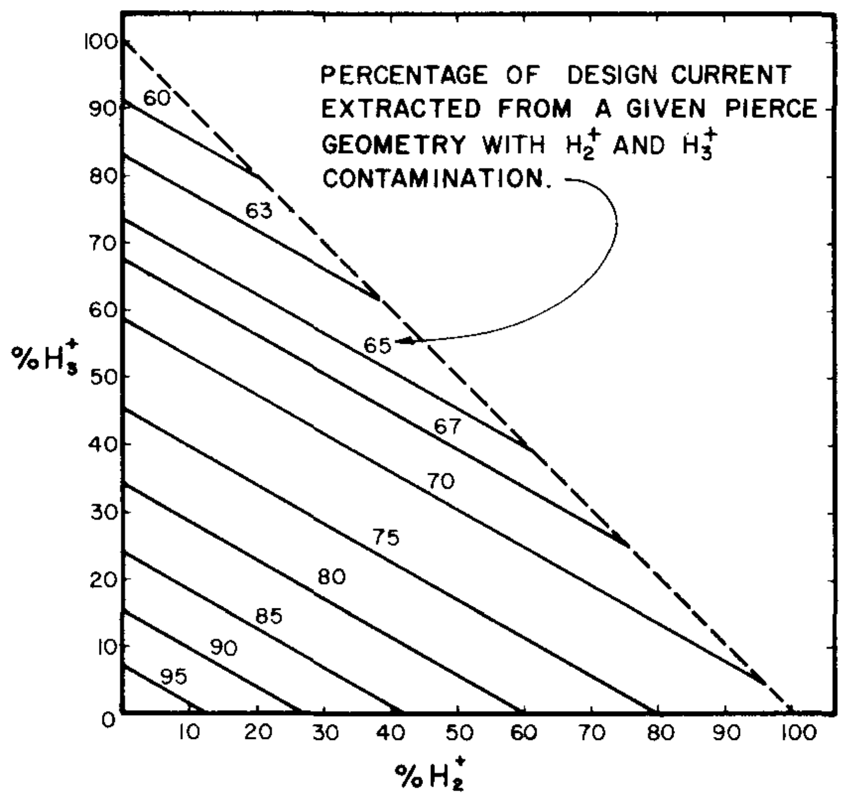

Fig. 5. The Pierce column was designed on the basis of a 100% proton beam (50mA). With slower moving H_2^+ and H_3^+ ions present, the design space charge is reached at reduced currents. This plot gives the fraction of the 100% proton current associated with H_2^+ and H_3^+ dilution.

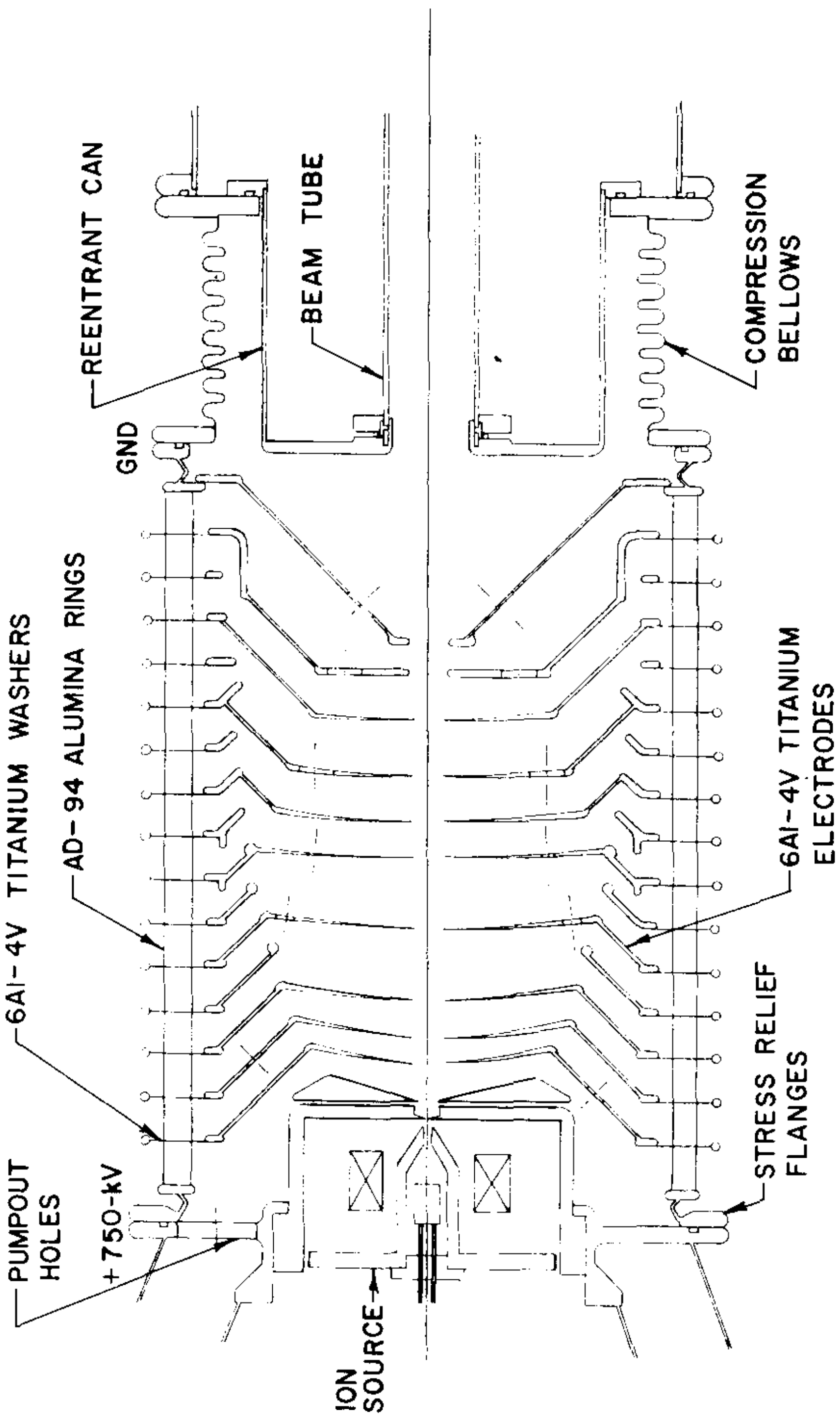

Fig. 6. Internal structure of the ion source and accelerating column.

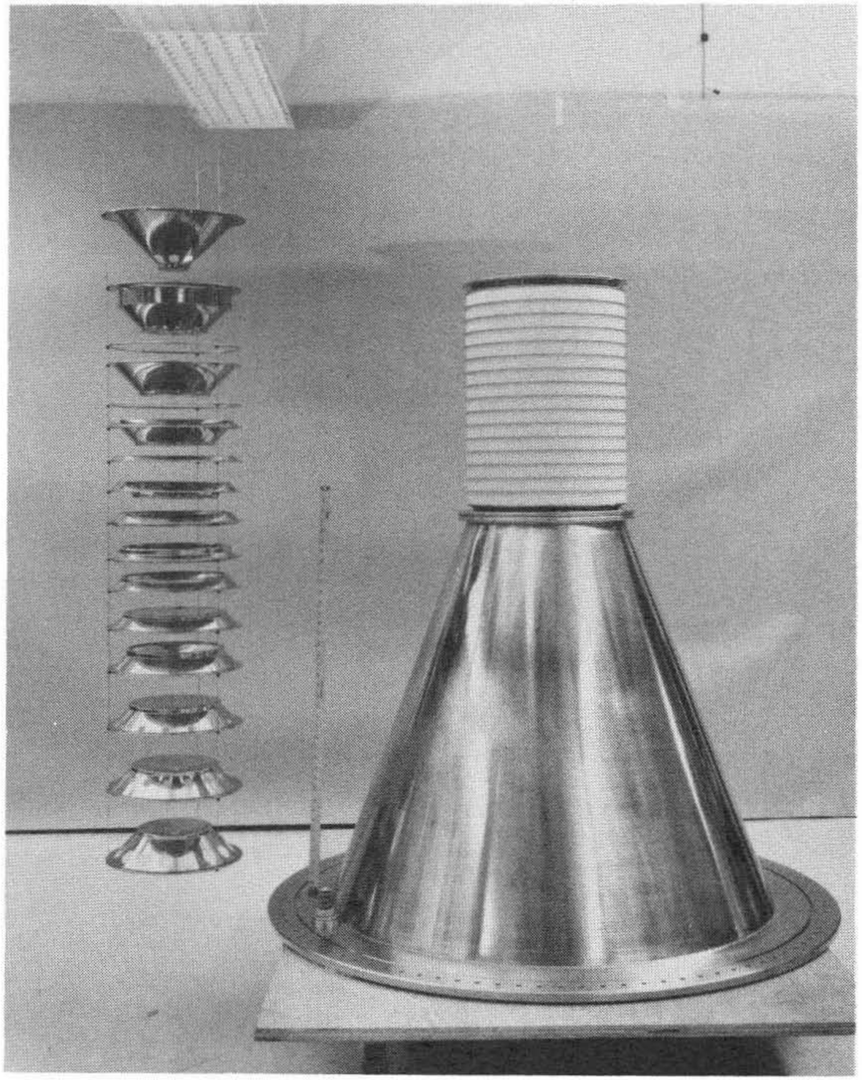

Fig. 7. Accelerating tube mounted on the top of the double-cone cantilever support. The titanium electrodes that fit into the accelerating tube are shown on the left.

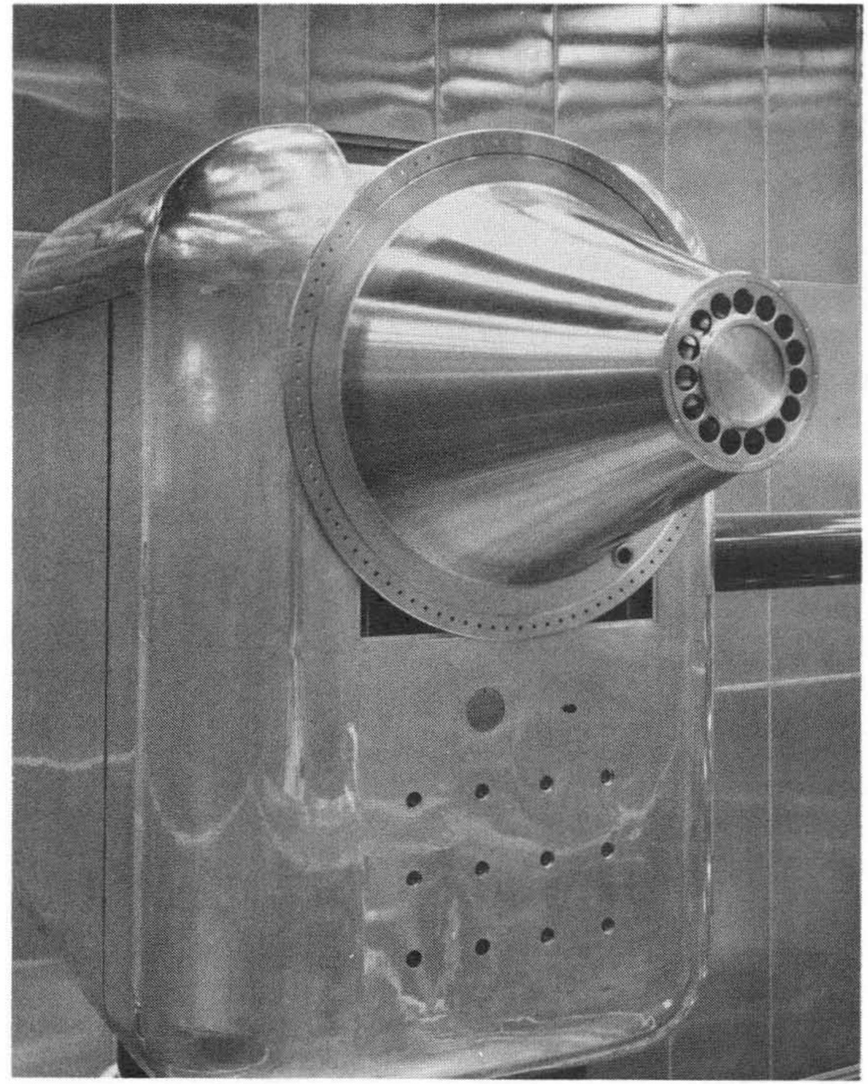

Fig. 8. Double-cone cantilever support for the ion source and accelerating tube mounted to the vacuum system of the equipment dome for ion source studies. This cone is normally installed as part of the accelerating column module before attachment to the dome.

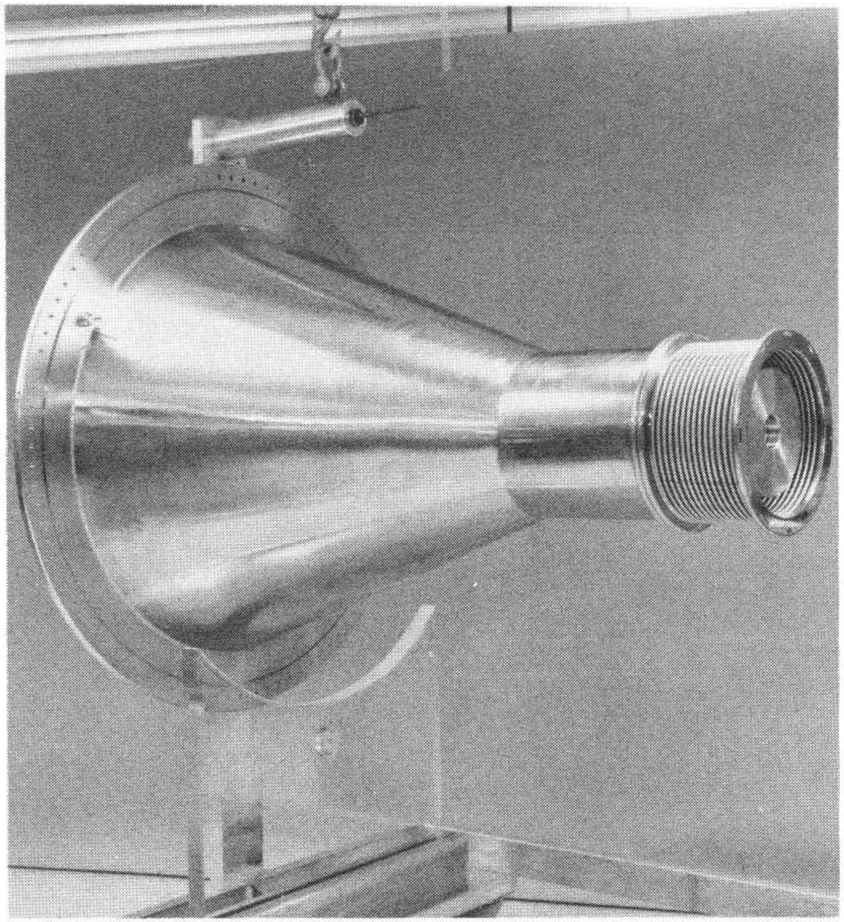

Fig. 9. Exit-end cone, compression bellows, and reentrant can balanced on an L-shaped bracket in the assembly position. The dolly for supporting the acrylic jacket, shown in the assembly position, permits voltage testing at 120 kV between titanium electrodes of the accelerating tube.

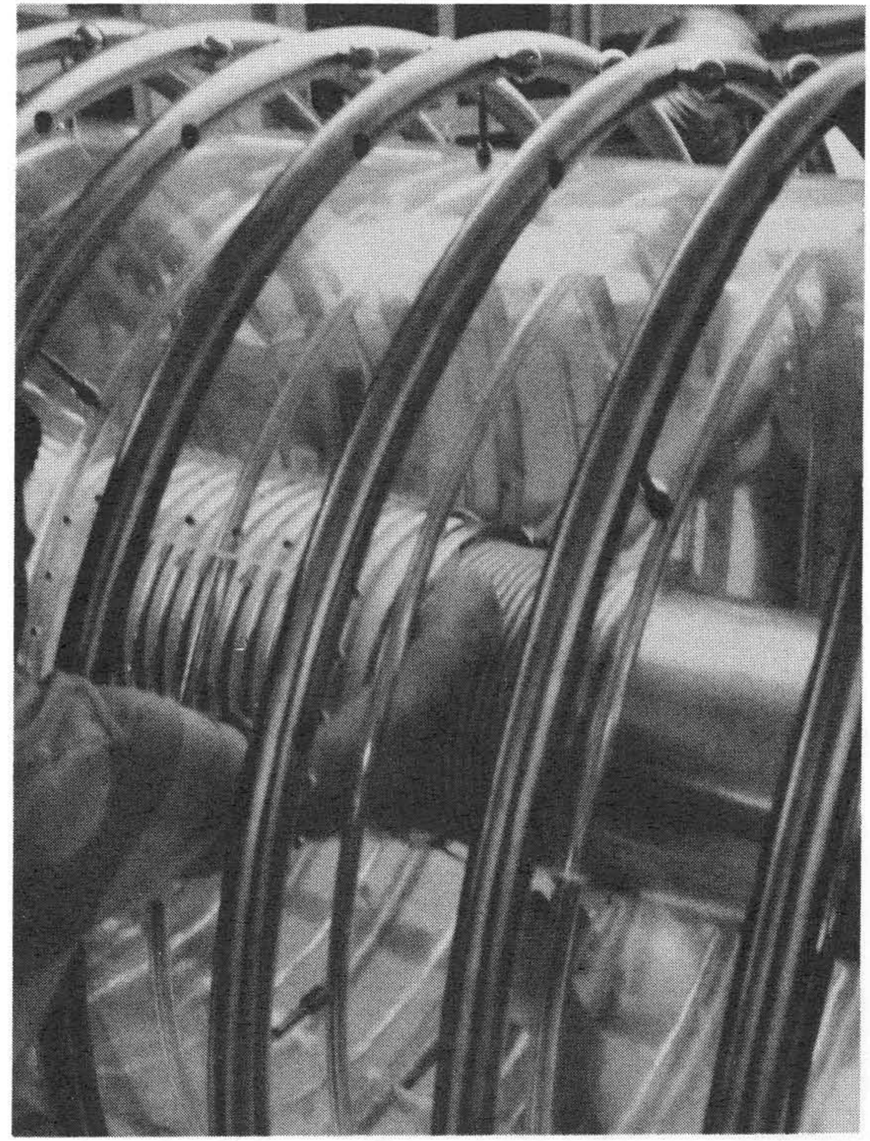

Fig. 10. Maintenance and assembly inside the acrylic jacket. Transparency of the jacket and access ports make this a simple on-line operation.

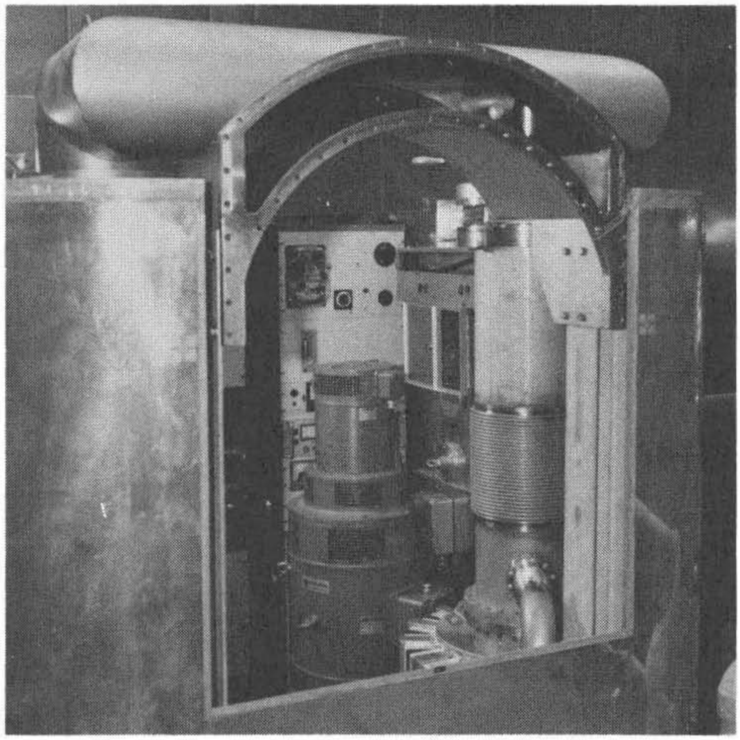

Fig. 11. Equipment dome with top section removed. The vacuum manifold is shown (top) with the 15-kW generator (center) for operating dome equipment such as ion pump (lower right). The accelerating column bolts to the manifold at the curved opening.

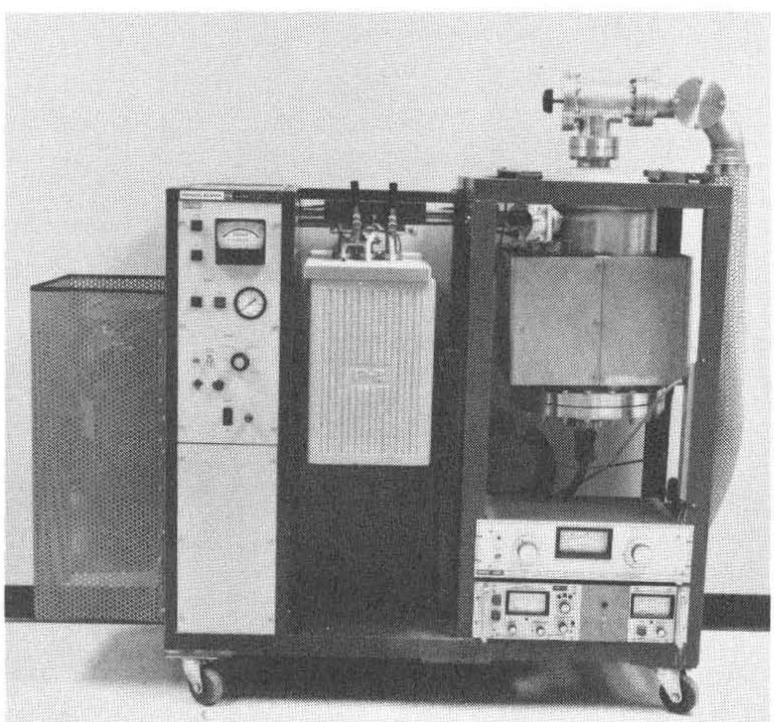

Fig. 12. Portable, contaminant-free roughing system showing the oilless vacuum pump on the left, the sorption pump in the center, and the titanium sublimator on the right.

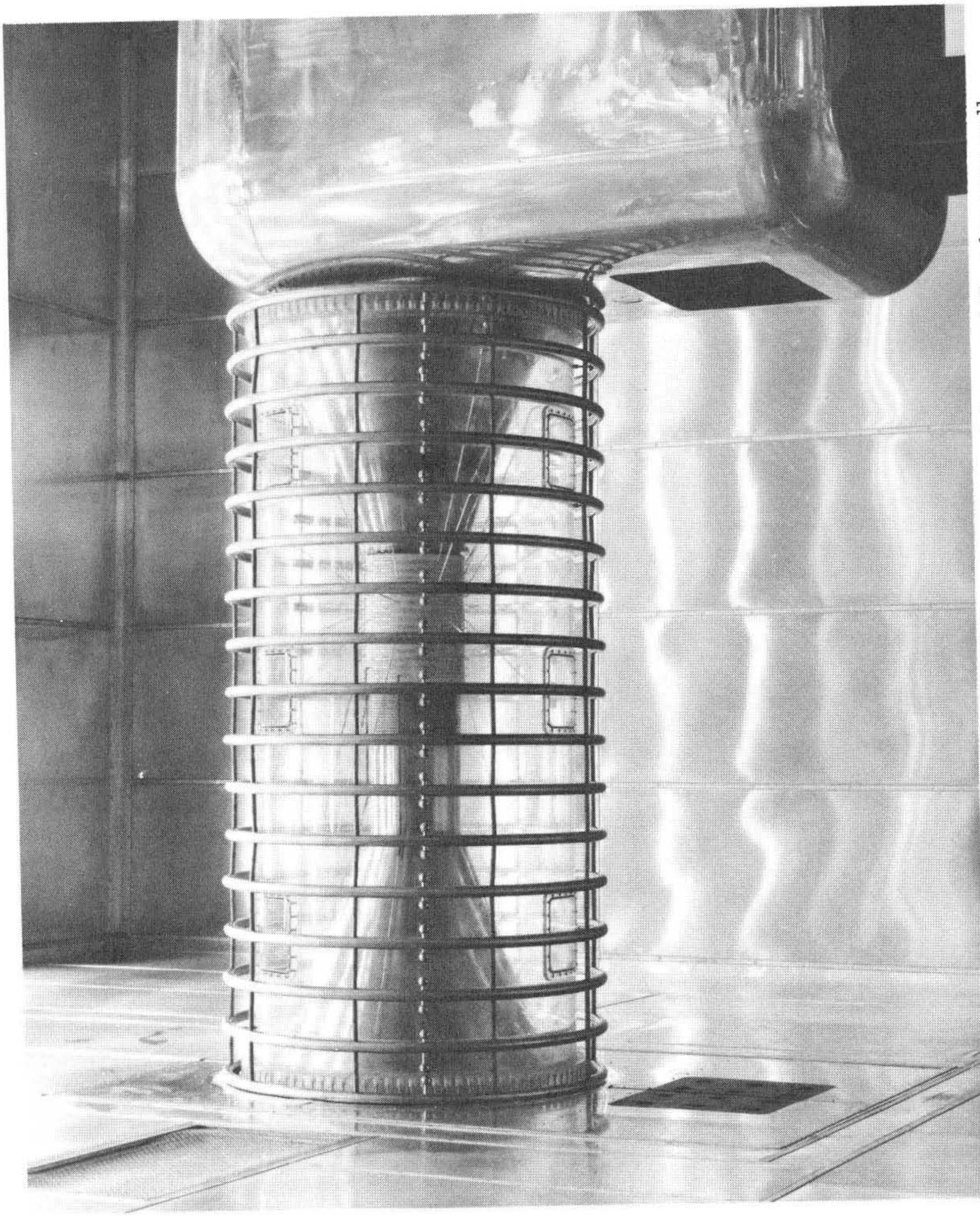

Fig. 13. Accelerating column mounted between the equipment dome and Faraday cage wall.

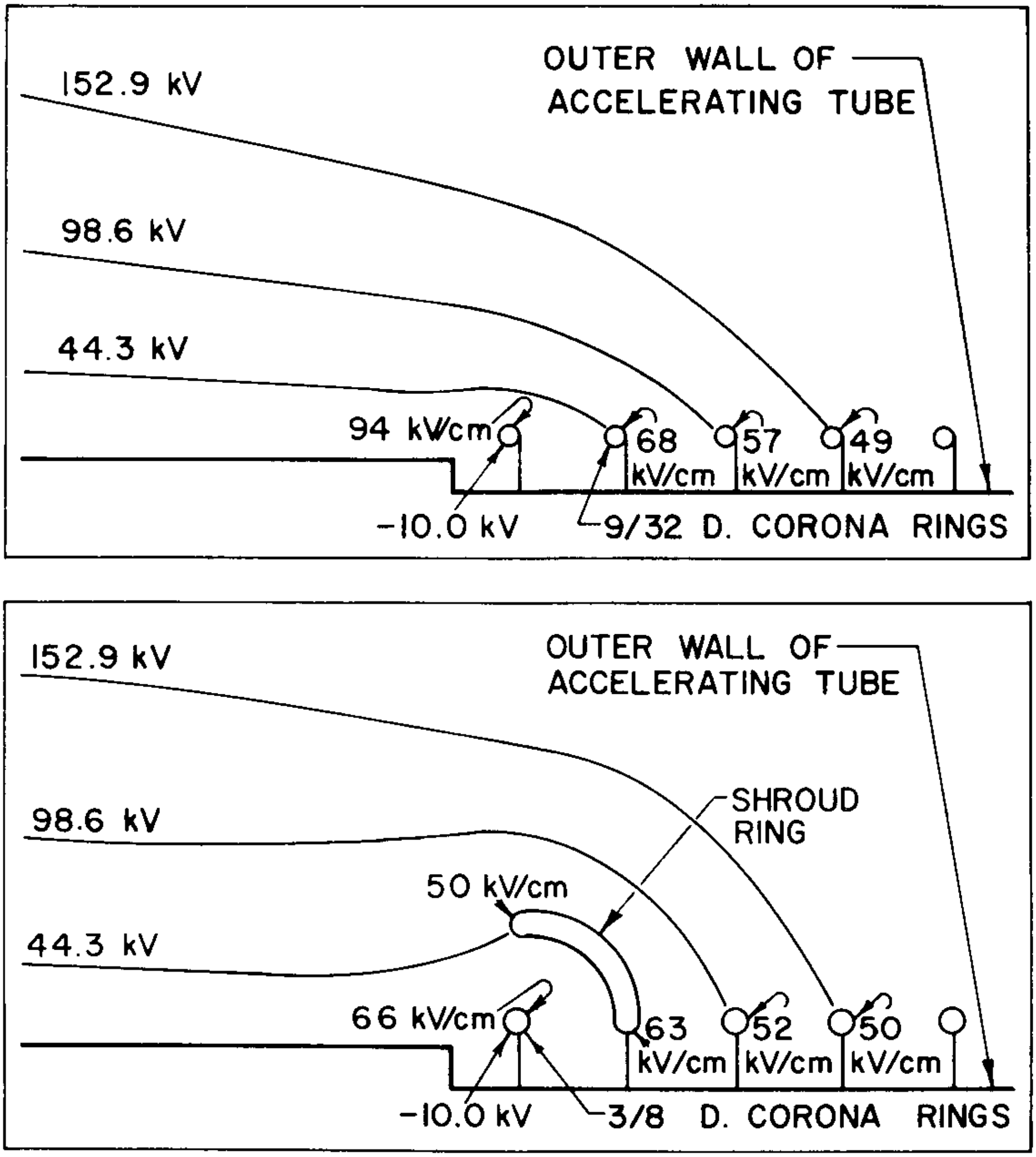

Fig. 14. Computer calculated potential contours and maximum gradients at ground end of accelerating tube. The top graph, with a maximum gradient of 94 kV/cm approximates the existing geometry. The lower graph shows a modification that will reduce the maximum gradient to 66 kV/cm.

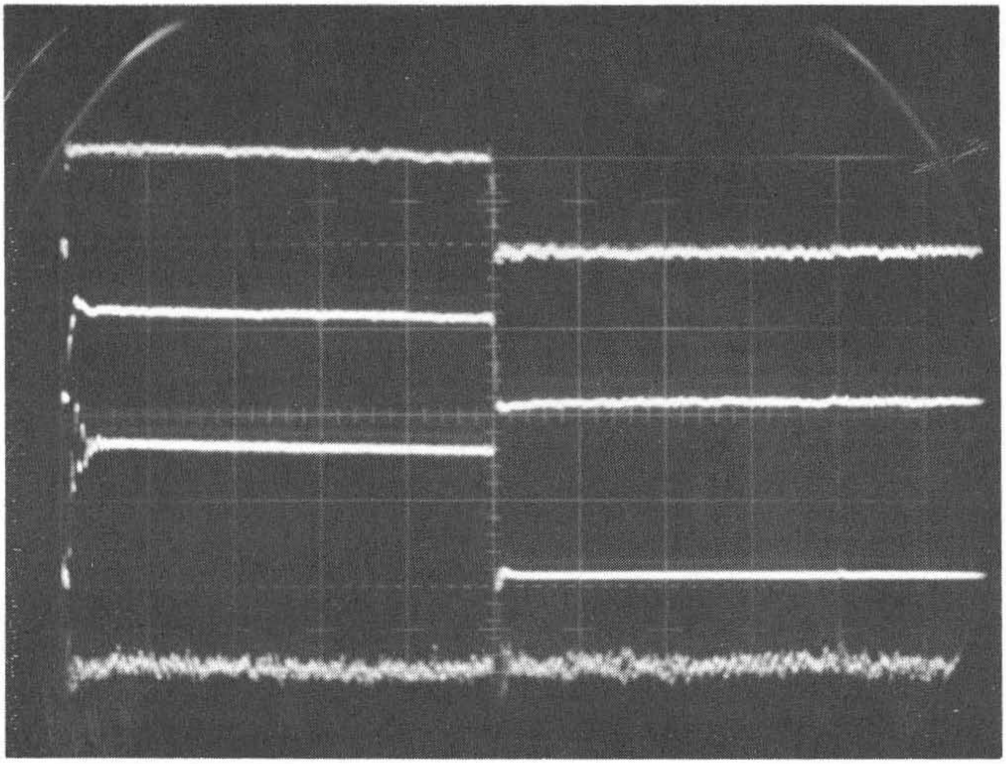

Fig. 15(a). Control room scope trace for a 38-mA, 500-μsec beam (3rd trace). Arc voltage (top), arc current and extraction current (bottom) signals are transmitted from the dome over light links.

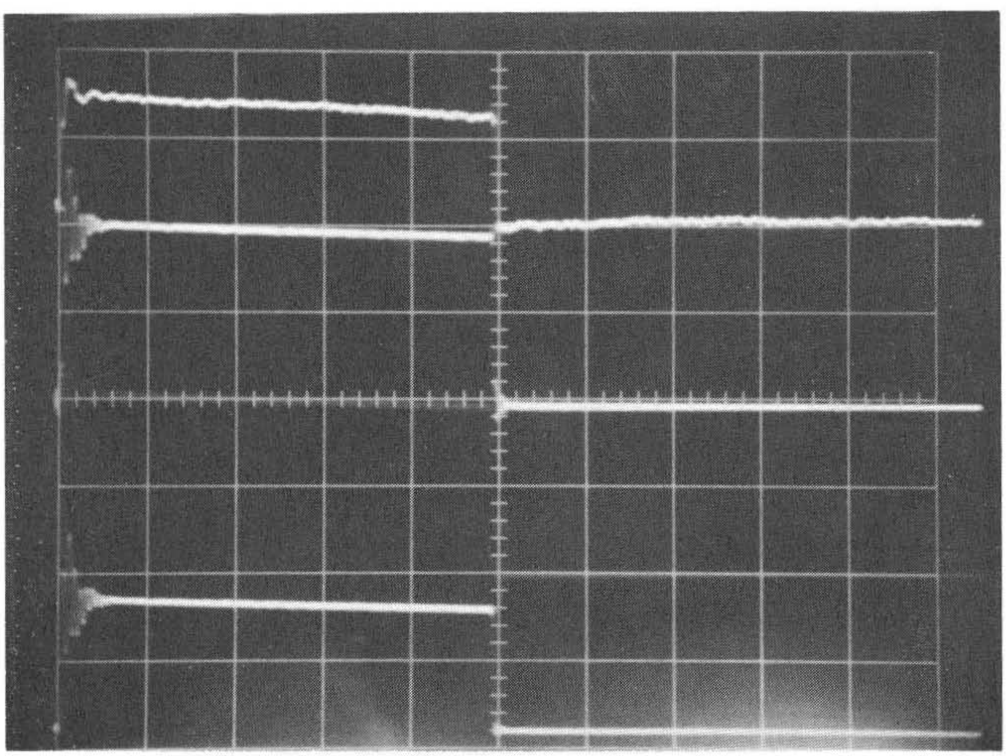

Fig. 15(b). This scope display compares the column exit aperture beam current, 38 mA (middle trace, with the proton beam current, 27 mA (lower trace) measured after the first two 45° bending magnets of the beam-transport system.

DISCUSSION

E. Regenstreif (Rennes): What are the dimensions of the beam at the entrance and exit of the accelerating column?

R. C. Emigh (LASL): The beam is 1.4 cm in diameter both at the exit and the entrance.

E. A. Meyer (LASL): The aperture of the lenses is 2 cm, but is 1.4 cm back at the cup. We lost no beam on the electrodes.

E. Regenstreif: So you have completely compensated space-charge behavior.

E. A. Meyer: The amount of current we get seems to be in accord with the theory.

R. C. Emigh: I might add that the resistors on the accelerator column are 600 megaohm resistors, so we can draw no current from the electrodes--that would destroy the voltage gradient along the tube and cause immediate sparkdown.

T. J. M. Sluyters (BNL): Emigh's point is very important. We have had some charging up of our electrodes at BNL.

I am surprised at the large emittance you get from your column at 25 mA. Do you have an explanation for it?

R. C. Emigh: That's what we measured.