INITIAL TESTS OF THE MURA HIGH GRADIENT COLUMN

C. D. Curtis, G. M. Lee, and J. A. Fasolo
Midwestern Universities Research Association
Stoughton, Wisconsin

Abstract

The MURA high gradient column has been voltage tested to 600 kV with a brief conditioning time. Current drawn from the electrodes appears negligible. In tests for a few days with an ion source in operation, preliminary data on accelerated beam quality indicate quite small aberrations due to a focusing lens introduced following the source. Some indicated increase in emittance of the accelerated beam requires more careful measurement for confirmation. The column with beam has been operated thus far only to 370 kV with beam currents below 60 mA. Limitations have been imposed by inadequate pumping speed of an experimental titanium sublimation plus ion pumping system. Construction details of the column are shown in drawings and photographs. Also beam quality is indicated by flourescent plate photographs.

Introduction

Beam tests of the MURA column has just begun. Therefore, only a progress report is in order. Beam was first accelerated through the column two weeks ago, September 21, by use of the ANL high voltage test facility.

Design details of the column have been reported in MURA Report No. 707. The accelerating section of the column proper is a multi-electrode structure 30 cm in length. These electrodes are placed along already existing equipotential surfaces of spherical shape so that a slightly converging spherical field exists in the absence of space charge. The electrodes are made of 304 stainless steel. The ceramic ring spacers and end flanges are of titanium alloy.

The short column is placed in a fiberglass vessel, pressurized with SF_6 to 30 psi for the recent voltage tests. The electrodes are connected to corona rings outside the vessel where voltage division has been achieved thus far by means of a water resistor. Adjustable spark gaps across all electrode gaps are mounted external to the pressurized vessel. Structure of the column is shown by drawings and photographs in Figs. 1 - 6.

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

The duoplasmatron ion source used for present testing appears in Figs. 1 and 2. The original design goal was and still is to mount the source extraction electrode directly at the top of the high gradient accelerating section. The source at the present stage of development, however, yields an aberration-free beam only when the beam is permitted to diverge.[1] We have therefore constructed a focusing gap following the extractor capable of controlling a beam with a divergent half-angle up to approximately 0.23 radians. It is a gridded accelerating gap with an approximately spherical field. The grid is made of 2.4 mil tungsten wire with 20 mil spacing. Independently variable electrode voltages provide control of the potential distribution near the extractor aperture. Bench tests of this focusing gap following the source revealed very little aberration until focus gap to extraction gap voltage ratios exceeded 1.5.

In the column there is a low field drift space followed by the entrance aperture to the column proper where additional focusing lens action occurs.

High Voltage Tests

Initial conditioning of the column electrodes was done at MURA one accelerating gap at a time with the spark gaps adjusted to fire at 50 kV. Then two to four electrodes were connected in series for tests up to 200 kV. The aperture edges of the 1-mm thick electrodes were thus subjected to much higher field strengths than they experience when full voltage is applied across the complete column. A quenching resistance of 300 K ohms was used in these tests. A 75 l/sec Varian ion pump held the pressure near 10^{-7} mm Hg with voltage applied when conditioning was completed. A total time of approximately three days was devoted to this conditioning.

After transport to Argonne, the column was first tested with the ANL 600 kV supply while evacuated by the 75 l/sec ion pump. Initially the individual spark gaps were readjusted for 50 kV. Tests were then conducted on the complete column for a day or two at a time at widely separated intervals. Typically, in the beginning, one or two hours were used to raise the voltage to first about 500 kV, then to 575 kV, and finally to 600 kV, near the practical limit of the power

supply with its present surroundings. A current limiting resistor of 128 kΩ, later reduced to 32 kΩ, was always used in the high voltage line. The water resistor used for voltage division along the column for this testing was nonuniform by as much as 10 per cent.

Because of the desire to keep oil out of the column, the oil pumps previously used on the ANL test stand were removed. The vacuum box and valves were cleaned and a combination of ion pump and titanium sublimation filaments was prepared. After a period of seven weeks from the earlier voltage tests, we connected the column to the new vacuum system. Voltage up to 600 kV was again applied to the column with pressures in the range of $2 - 5 \times 10^{-6}$ mm Hg.

An attempt was made to detect any electron current flowing up the column or between electrodes because of high fields present at the rather narrow electrode projections. The simplest thing to do was to short the second and third corona rings from the top together and connect them to the water resistor through a microammeter. The focus and extractor electrodes then acted as electron collectors. With a full scale sensitivity of 15 μA, one read no average current for an applied high voltage of 575 kV. There was only a fluctuation of $\pm$ 0.1 μA, probably due to slight high voltage fluctuation. There were a few tenths of a microampere of capacitive current flow during raising and lowering of the voltage. No radiation external to the column was detected with a survey meter.

Performance of the New Pumping System

In addition to our desire for a clean vacuum system, there was interest in testing the hydrogen pumping performance of a relatively economical combination of an ion pump of moderate size together with a sublimation chamber containing titanium filaments. Accordingly, Dr. Perry's group built an aluminum sublimation chamber with a wall area of approximately 6000 cm^2. It contained two Ultek titanium filament holders and had water cooling at one end of the chamber. This chamber was attached to the vacuum system through a 10-in. diameter channel 18 in. long. A 400 l/sec Varian ion pump was attached to a separate 10-in. port.

Pumping speed for nitrogen in the low 10^{-5} mm and lower pressure range was no greater for one filament than for two filaments in operation. Above this range, the additional titanium from two filaments increased the pumping speed by roughly 60 per cent. Pumping speeds were disappointingly low for the total system, although increasing with decreasing pressure to ~1500 l/sec at 10^{-6} mm.

Pressure in the vacuum box below the column ran high, $2 - 3 \times 10^{-5}$ mm (gauge reading not corrected for hydrogen) with the source in operation at about 150 microns of pressure. There was the additional problem of the air-cooled Varian pump warming up sufficiently to outgas, after several minutes of operation at this pressure. This problem was troublesome principally in the early stages of running the source and may have been due to water vapor, which was eventually driven from the pump. The pumping performance was poor in comparison with experience on the ion source test bench at MURA. There, a 2400 l/sec (for air) Ultek ion pump holds the pressure typically at $1 - 2 \times 10^{-6}$ mm with the same source operating at a pressure of 200 microns. Incidentally, that pump has logged approximately 600 hours of hydrogen pumping thus far without any deterioration in performance.

A slight modification to the sublimation chamber consisted in addition of a 75 l/sec Varian ion pump to a chamber port. No noticeable change in performance of the total system occurred.

Another change was the replacement of the sublimation chamber with an air-cooled Ultek BoostiVac pump. This pump has a sublimation chamber ten inches in diameter of roughly half the wall area of the other chamber and contains one filament holder. Built into the wall are two ion pumping sections with a rating of 50 l/sec. The stated speed of the complete pump is 3600 l/sec. The pump was attached to our vacuum box by a six-inch long channel ten inches in diameter. The performance of the complete pumping system was comparable with that before the change, holding the gauge reading at 3×10^{-5} mm with the source operating at 140 microns.

The optimum performance of the sublimation pumps that have been tried would require more thorough testing, for example, of the pumping speed versus pressure and of the sublimation rate. Careful treatment of the current-carrying filaments is required. It might be desirable to go to an electron bombardment method of heating.[2] In any event, our present pumping speed is less than satisfactory and must be increased.

Ion Beam Test

The capability of the column with a proton beam has yet to be determined since there has

been an accelerated beam for only a few days and the vacuum system is not yet sufficient to handle the required hydrogen load. It has been necessary also to operate without a surge-limiting resistor in the high voltage lead to the column. Accelerated beam through the column has not exceeded approximately 60 mA thus far.

It has been possible to obtain in a preliminary fashion an indication of beam quality possibilities in the low current range. A 3-in. diameter copper slit plate with 0.015-in. wide slits with 0.200 in. between centers was inserted in the accelerated beam 2-2/3 ft. below the column exit aperture. An aluminized glass disk four inches in diameter followed the slit plate by seven inches. This disk was first viewed from below through a vacuum box window by a television camera. An example of the beam pictures with a beam energy of 322 keV is shown in Fig. 7, obtained by photographing the screen of the television receiver. The curvature detectable in the lines results from the television system.

Because of possible widening and distortion of the beam lines by television, the beam was next photographed directly. Some of the pictures are reproduced in Fig. 8. The sharpness of the lines indicates that a greater slit plate to viewing screen distance is desirable for greater accuracy in measurement of emittance. No attempt was made to optimize the exposure or vary it with changing power density on the glass plate. The exposure time accepted two to three beam pulses in all pictures with a pulse length of 200μ sec.

The approximate beam current measured for pictures a and b in Fig. 8 is 35 mA. The current for the other pictures is 25 - 30 mA except for 20 mA in f where other current is lost outside the picture boundary. Beam energies are 310 keV for pictures a and c, 322 keV for e and f, and 372 keV for b and d.

Measurement of the lines on the original photographs as they are, with varying power density, but with correction for finite slit width yield normalized emittance values ($\beta\gamma$ab) for pictures a through f respectively in mrad-cm of 0.068, 0.094, 0.049, 0.11, 0.037, and 0.020. The higher values tend to come from the more strongly focused beams. Careful inspection of the lines show some to have a very slight curvature convex toward the central line. This appears for the stronger lens strengths. The focusing lens was expected to produce some aberration. In pictures d, e, and f the ratio of focusing gap voltage to extraction voltage was varied through the approximate values of 1.6, 1.25, and 1.1. There is a progressive reduction in curvature with none appearing in f.

The noticeable asymmetry in the focused beam profile is possibly due to some imperfection in the shape of the focus electrode grid. This point remains to be investigated.

The normalized emittance values shown here are larger than those obtained for beams directly from the source,[2] which are typically < 0.05 mrad-cm for beam currents near 200 mA. Whether the column emittance will, in fact, prove significantly larger must be determined by more accurate measurements on higher beam currents at higher voltages. We are encouraged by these preliminary results which show very little distortion introduced by the focusing electrode. Later on we hope to dispense with this electrode when source modification gives us a less divergent beam.

Acknowledgements

The column testing program is a cooperative project with Argonne National Laboratory. The authors are grateful to Dr. Rolland Perry and his linac group for providing their preaccelerator test facilities. The sublimation chamber was constructed by ANL and pumping speed measurements made by W. O. Friesen and K. Graber. The general assistance of Vernon Stipp and Yorgen Madsen with equipment problems has been most valuable.

References

1. J. A. Fasolo et al. (These proceedings, p. 371).

2. C. L. Gould and P. Mandel, " A Sublimation Pump", BNL-6489 (September, 1962).

DISCUSSION

C. D. CURTIS, MURA

HENDRICKS, Univ. of Minnesota: What material was used to cement your column ceramics together?

CURTIS: The sealing compound was vinyl acetate.

HENDRICKS: Was this cementing done at an elevated temperature? If so, what was it?

CURTIS: Approximately 150°C.

VOSICKI, CERN: Did you have any damage on the extraction grid, i.e. the focusing grid, due to secondary electrons from the column.

CURTIS: I'm sorry I can't answer that because we haven't taken it out. John Fasolo has made some tests with a similar structure on the bench

with a similar focusing electrode. I believe that in the source bench test there was slight deformation on the grid, noticed just after the system was opened. However, it is not quite clear whether this deformation was due to heating or whether it was already there.

SLUYTERS, BNL: Could you detail your voltage divider?

CURTIS: The voltage divider is a water resistor. This is made in a similar fashion to the voltage divider that ANL uses on their operating Cockcroft Walton. It is seran tubing with water flowing through it, which has its conductivity stabilized. The uniformity of the tube in our test case is very poor. Although we will be improving this, so far it has not given any adverse effects, i.e., the accuracy of the voltage distribution on our electrodes is no better than 5% at the present time.

SLUYTERS: How accurate are your emittance figures when you use 50-mil slits?

CURTIS: The slit width is 15 mils, but it is true that there is a big subtraction to make, and the accuracy of the measurement is not very good although it is a significant measurement. Another source of error is the film exposure, which may not be optimized.

ALLEN, RHEL: Because appreciable currents to thin electrodes will distort the potentials and cause high fields, may I ask again: What is the current in the voltage divider?

CURTIS: Yes. We hope to keep the current off the electrodes, but let me answer your question. There are some 14 gaps and about 15 MΩ/gap, so you have something like 210 MΩ total resistance across the whole column. That has operated at 600 kV during voltage tests but only up to 370 kV so far with beam.

LEFEBVRE, Saclay: You have a converging electric field due to the shape of the electrode in the acceleration tube. Does this, combined with the focusing system at the outside of the source, give a cross-over point somewhere; and where would that be located?

CURTIS: It does not give a cross-over although it is possible that it could if we increased the strength of the focusing lens sufficiently. Incidentally, the ration of the voltage difference, across the focusing gap, to the voltage on the extractor is run somewhere between 1 and 2, and the pictures that I showed you were in the range 1.1 to 1.6. If one goes higher, it is possible to get a cross-over, but the column field is designed so that, if the beam travels along the converging field of the column, it will come out parallel owing to the lens action at the bottom of the column.

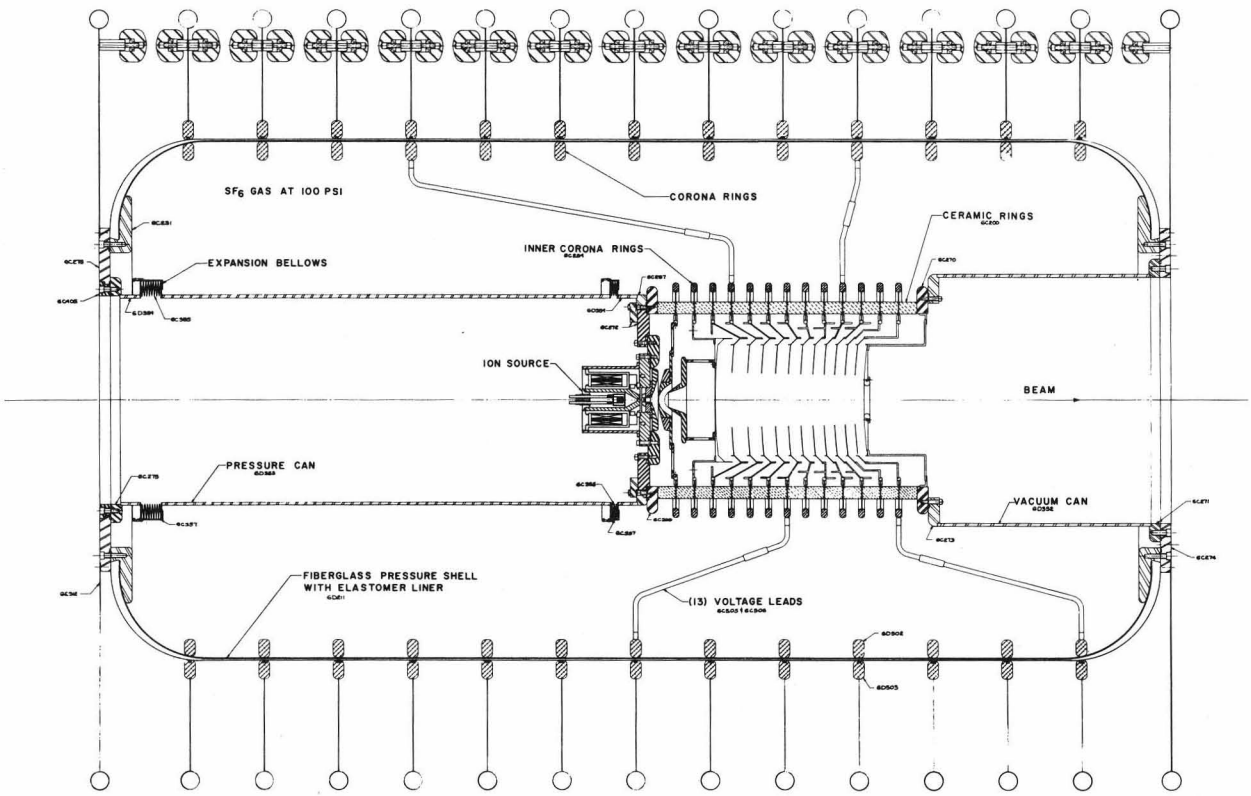

Fig. 1. Assembly drawing of column. Voltage tests have been made with SF_6 at 30 psi gage pressure.

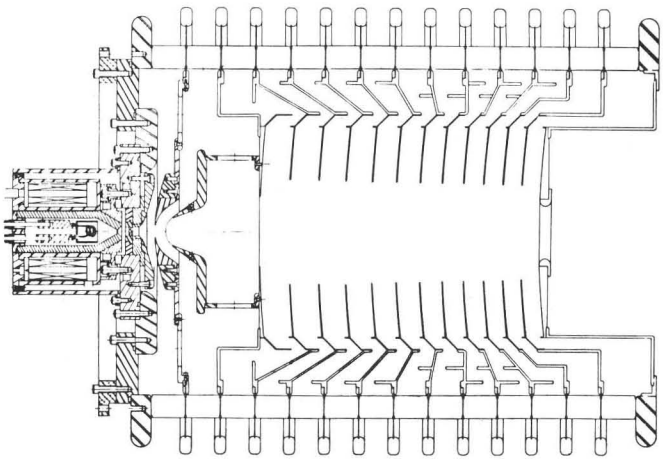

Fig. 2. Column proper with ion source and gridded focusing electrode.

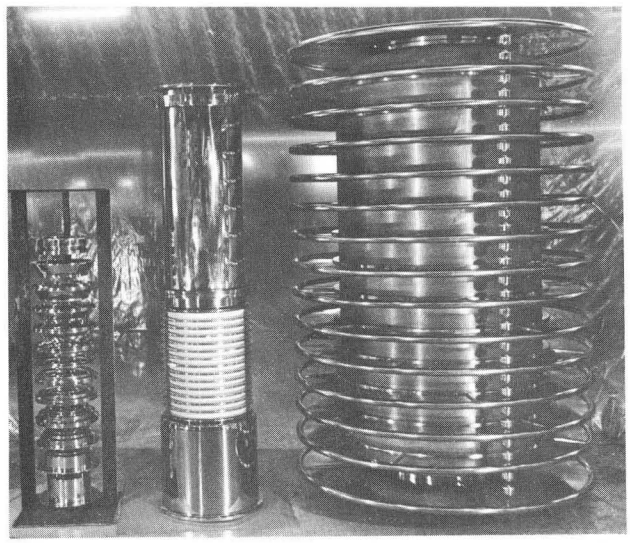

Fig. 4. Exploded view of column electrodes, ceramic rings with source and beam pipes, and fiberglass vessel with external corona rings and spark gaps.

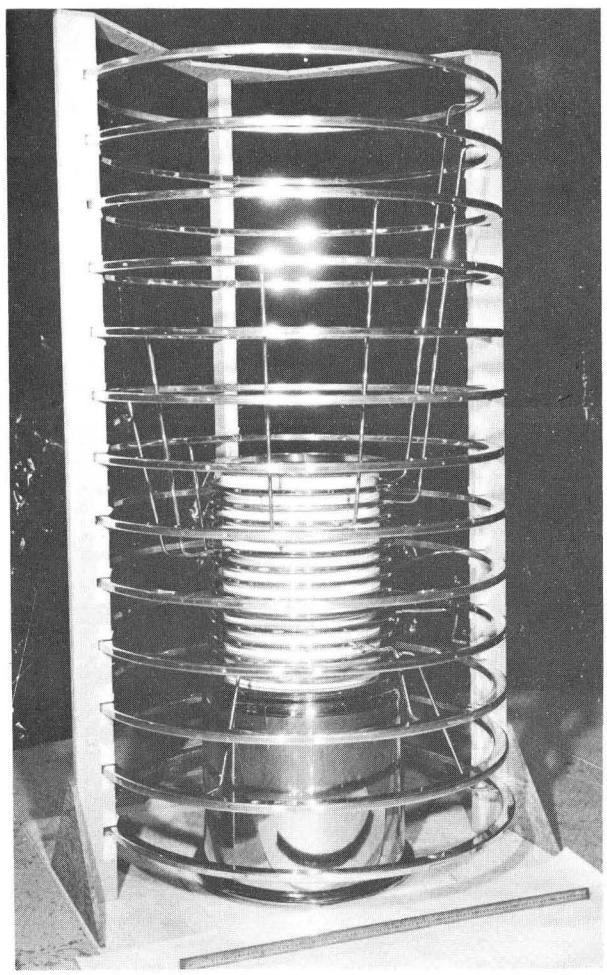

Fig. 3. Column showing voltage connections between electrodes and corona rings at inner wall of fiberglass shell.

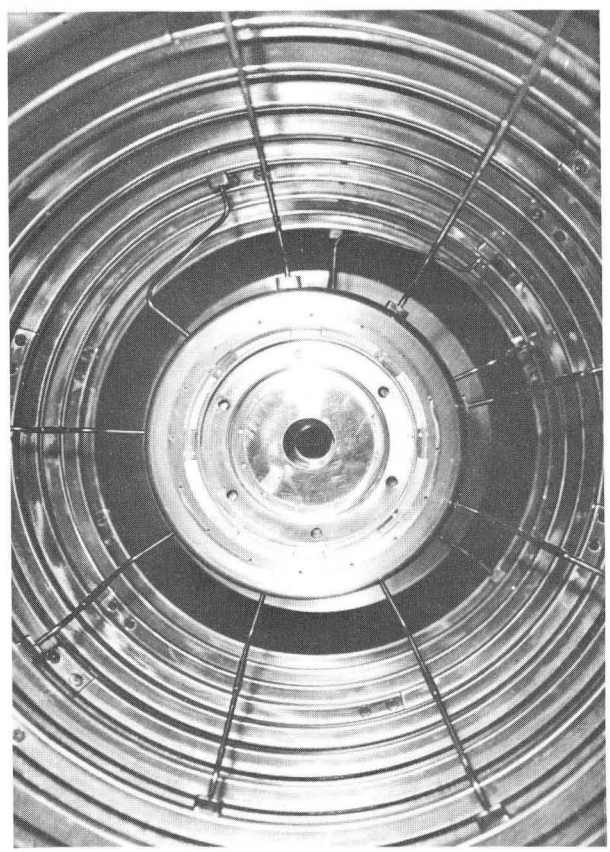

Fig. 5. Top view of column with source removed (looking down into fiberglass vessel).

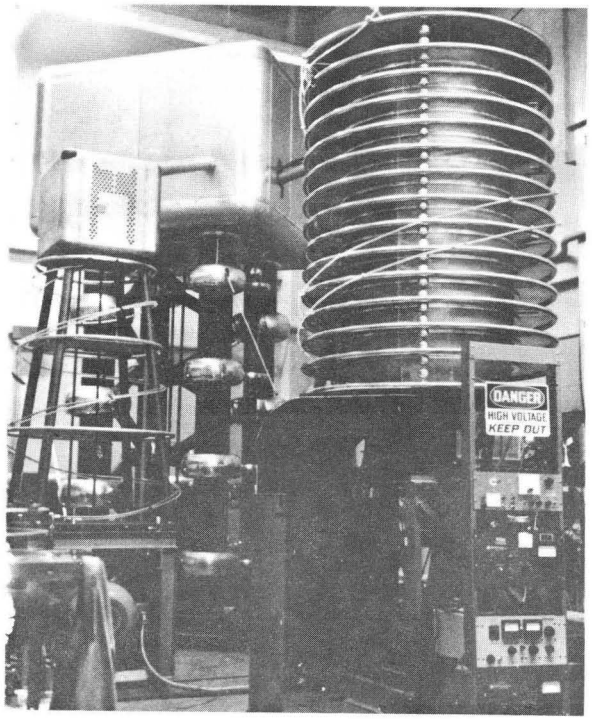

Fig. 6. Column set up at Argonne high voltage test facility.

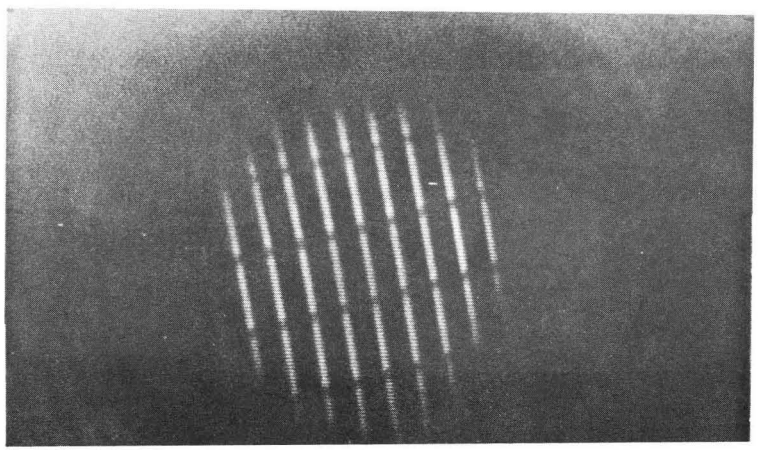

Fig. 7. Television view of accelerated beam on glass disk after passage through slit plate.

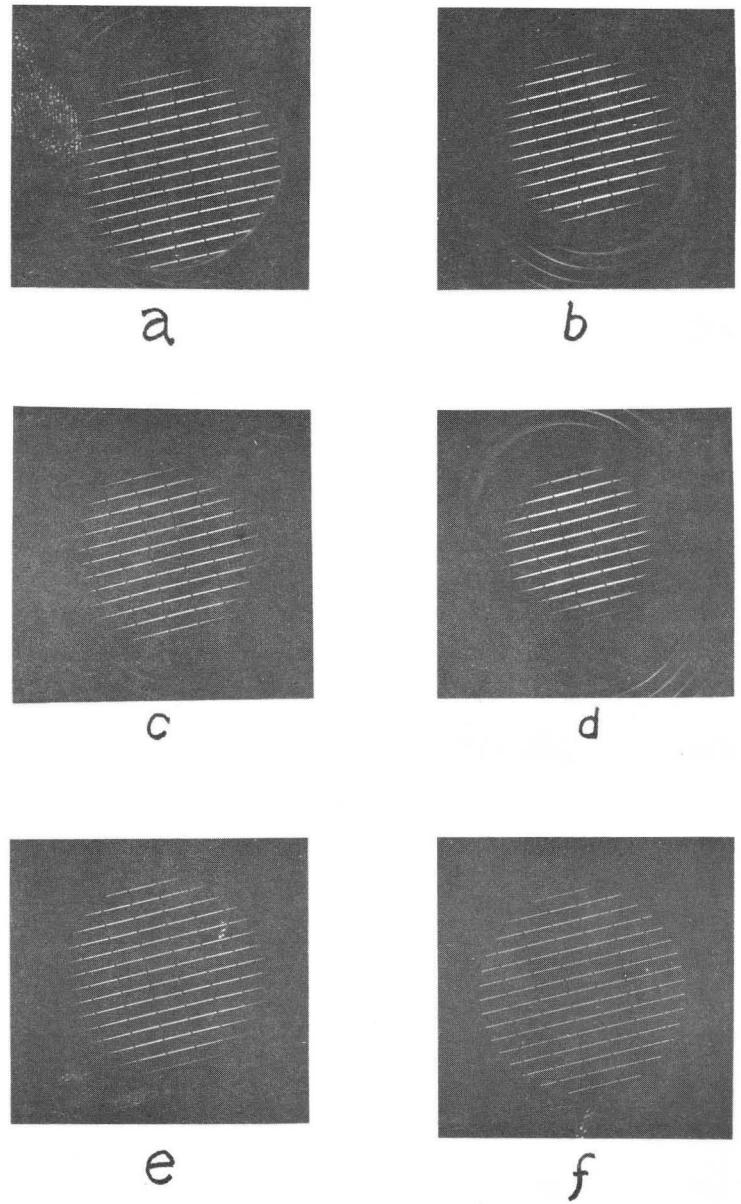

Fig. 8. Polaroid camera view of accelerated beam on glass disk after passage through slit plate.