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1000-HOUR TEST OF A DUAL GRID, ELECTROSTATIC BEAM DEFLECTION ACCELERATOR SYSTEM ON A 5-CENTIMETER-DIAMETER KAUFMAN THRUSTER

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SUMMARY

A two-grid accelerator system with electrostatic beam deflection capability was tested on a 5-cm diameter Kaufman thruster for 1000 hours. The accelerator system was designed and fabricated by the Hughes Research Laboratory under contract NAS3-14058. The thruster was operated at a positive voltage of 1200 volts, negative voltage of -1200 volts and beam current of 25 mA. Beam deflection was accomplished during the first 100 hours of the test to show performance and the remainder of the test was run in the undeflected mode. Typical undeflected accelerator currents were less than 1 percent of the beam current throughout the test. Increased accelerator currents were measured at deflection angles greater than about 8-10 degrees.

INTRODUCTION

Spacecraft in operation today have demonstrated impressive gains in reliability and useful life over earlier versions. Future orbiting spacecraft with design lifetimes of several years place severe requirements on attitude control and station keeping subsystems. The long life and high value of specific impulse available from low thrust, electrostatic thruster systems make them increasingly competitive for these functions. Work being done at Lewis Research Center under the 5-cm diameter Kaufman thruster program has been described in references 1 and 2. The final report for work done by Hughes Research Center on a structurally integrated thruster under contract NAS3-14129 is in preparation.

Recent developments in accelerator systems for these thrusters have made them even more useful. For example, the incorporation of ion beam deflection capability makes it possible to perform both station keeping and attitude control functions with the same thruster. This capability has been added mainly through the efforts of the Hughes Research Laboratory under contract NAS3-14058. Results of this contract effort are described in references 3 and 4.

Although the beam deflection capability of the accelerator system which resulted from the above contract was demonstrated, a problem arose during the required 100-hour test. Near the end of that test the inter-electrode ceramic spacers became coated with metallic deposits. This precluded additional deflection although the system could still produce an undeflected beam.

Several accelerator systems of this type were delivered to the Lewis Research Center. In a follow-on to contract NAS3-14058 the insulator shorting problem described above is being pursued, but it was felt that some lifetime data should be obtained prior to the expected delivery of the improved systems. Therefore, one of the delivered systems was installed on a 5-cm thruster for an undeflected life test of 1000 hours. This paper presents the results of this 1000-hour test. Data for the deflected mode, performed in the first hours of the test are included.

APPARATUS AND PROCEDURE

Beam Deflecting Accelerator System

Photographs of the deflection system as delivered to Lewis Research Center are shown in figure 1 and described in references 3 and 4. Figure 1(a) is the upstream side showing the circular screen holes and the downstream side with the "egg-crate" notched accelerator strips is shown in 1(b). The screen grid consists of a square array of circular holes 0.39 cm in diameter on a 0.44 cm center-to-center spacing. The notched strips are 0.25 cm wide and 0.025 cm (0.010 in.) thick. The resulting apertures are 0.34 cm square. The screen-to-accelerator spacing is 0.13 cm.

Beam deflection was accomplished by setting the potentials of the accelerator strips as shown in figure 2. Only the horizontal direction of beam deflection was used so that a comparison of erosion patterns could be made between deflected and undeflected strips. The beam supply was constant at 1200 volts. The accelerator supply was constant at -1200 volts. The two deflection supplies were reversible in polarity and were typically set so that one electrode was positive and the other negative with respect to accelerator potential. This procedure maintains the average potential in the aperture at accelerator potential. Current meters were provided in each supply to monitor changes in accelerator drain current because of increased interception of the beam by the electrodes in the direction of deflection.

Ion beam deflection angles were determined using the beam analysis equipment indicated in figure 3 and described in detail in reference 5. By comparing similar points on profiles taken at the same distance downstream of the thruster for both undeflected and deflected modes, it is possible to determine the average angle through which the ions have been displaced.

Thruster

The deflection grid system was mounted on a 5-cm thruster (see fig. 4) described in reference 1. A hollow cathode neutralizer of the enclosed type (ref. 2) was mounted on one side in the direction in which the beam was to be deflected. No attempt was made to optimize the neutralizer position but the selection was based on a compromise between an attempt to achieve a low beam coupling potential which increases as the distance between neutralizer and thruster increases and an attempt to keep the neutralizer out of the path of beam ions.

Facility

The test was performed in a 4.5 m long by 1.5 m diameter vacuum facility (ref. 6). A vertical metal target covered with fibrous inorganic insulation material was placed so as to divide the facility at approximately the middle of its length. The insulation material decreased the total amount of back-sputtered metal arriving at the thruster.

Unattended Operation

Data for the test were taken automatically by a digital data acquisition system set up to scan all pertinent thruster data at 15-minute intervals. During beam deflection tests the system was triggered at shorter intervals. Vaporizer temperatures and mercury flow readings were recorded by hand several times each day. Data taken by the automatic system were recorded on magnetic tape to facilitate data analysis and computer plotting of selected data as a function of time.

Thruster Controls

The only provisions for controlled operation were current limiters on the two hollow cathode keeper supplies. The main cathode keeper worked well holding the current to 180-200 mA throughout the test. Unfortunately the neutralizer keeper current limiter failed within the first 100 hours of the test which allowed the current to range up to about 0.5 A and down to a level which would cause the discharge to quench. High voltage (300 v) power supplies on each keeper were capable of restarting a quenched discharge if the neutral atom flow had not decreased too far because of cooling of the cathode and vaporizer.

RESULTS AND DISCUSSION

Thruster Operation

The performance of the thruster is shown in figure 5. Data were recorded by an automatic system at 15-minute intervals and the data tapes were run through a computer plot routine to produce the plots shown in the figure. The time shown is total elapsed time. Approximately 1200 hours were needed to produce a beam-on time of 1000 hours.

The first 425 hours of the test were marked with erratic operation and frequent quenching of both the main and the neutralizer hollow cathode plasmas. The three longest down times at 57, 200, and 368 hours into the test all occurred on weekends when no personnel were on duty to restart the thruster. However, during the last 550 hours there were only 12 hours of down time (caused by high voltage power supply failure). The thruster was completely off during these 12 hours.

For convenience, the performance is summarized in Table I. The run hour increments show periods of thruster operating time. Column 1 shows the average beam current for each increment and column 2 shows the average accelerator drain current. Comparison of columns 2 and 3 shows that the accelerator drain current is highly dependent on the main propellant flow for constant beam current. The neutralizer propellant was reasonably constant throughout the test.

As shown in column 5 the cathode keepeer current was controlled to approximately 180 mA for about the first half of the test and was increased to about 240 mA for the last half. Column 6 shows that the cathode tip heater power was periodically increased during the test. These changes were made to avoid frequent extinguishing of the keeper discharge. The frequent extinguishing during the early parts of the test is believed to have been caused by the fact that the main cathode had been installed on the thruster without having the standard barium carbonate insert placed inside the cathode tube. There are some indications that for low current cathodes, higher cathode temperatures and/or higher keeper voltages are required for operation without this insert. Initially, the keeper voltage was low (see fig. 5(a)) but after about 100 hours of heating, the keeper voltage gradually rose. Final stabilization was realized at about 425 hours at a tip heater power of 27.5 watts. The discharge continued to quench frequently, however, until the keeper current was increased to 240 mA. After the 450-hour mark, the maximum down time due to discharge quenching was 45 minutes with typical times of 15 minutes before thruster reignition would occur.

Accelerator Drain Current

The accelerator current was found to consist in general of three component parts. These are described as follows:

Base current. - About 0.060 mA was monitored with all discharges off. This current was felt to be caused partially by internal supply drain currents and partially by zero offset on the signal conditioning equipment.

Neutralizer-produced current. - At times when the beam was off because of the main chamber and cathode keeper discharges going out, an additional current amounting to 0.080 to 0.120 mA was recorded. This current was believed caused by ions from the neutralizer discharge falling back onto the accelerator grid and onto the shadow shielding which was common to the accelerator.

Charge-exchange current. - The remaining accelerator current, approximately 0.1 to 0.15 mA was attributed to charge-exchange ions formed in the primary beam region. The higher currents occurred with high propellant flows.

Ion Beam Deflection

Beam deflection data were taken early in the test before the interelectrode spacers became coated with backsputtered metal. Results of these tests are shown in figure 6. The solid line is drawn through the data which are shown with uncertainty bars. The dashed line represents Hughes data taken on a similar system (see fig. 27, ref. 4). Both tests were conducted at V_I = 1200 V and V_A = -1200 V. The HRL test was run at a beam current of 30 mA while the LeRC test was run at 25 mA. In general, the tests support each other, demonstrating the beam deflection capability of the grid system.

The ratio of the accelerator drain current to the beam current is shown in figure 7 as a function of deflection voltage for two different combinations of accelerating voltage and beam current values. In general, the ratio remained low throughout the entire range of deflection voltage. This curve compares favorably with the curve for a similiar grid reported in reference 4 (fig. 28).

Post Run Accelerator Condition

Photographs of the deflection system after the 1000-hour test are shown in figure 8. Figure 8(a) shows that the screen grid (the upstream grid) was unharmed. Figure 8(b) points out the existence of three problems.

First, the groove in the shadow shield in the upper quadrant indicates that the neutralizer position was not optimum. This type of erosion was found to be typical of SERT II (ref. 7) test results. Recent tests on other thrusters at Lewis Research Center have indicated a solution to this probelm by repositioning the neutralizer farther downstream, and future tests will use the new position.

The second major problem was caused by the perimeter holes which are partially masked by the pole piece (see fig. 8(b)). The resulting distortion of the beams through those holes caused severe erosion of the accelerator elements and even the shadow shield as shown on the right quadrant of figure 8(b). This edge hole erosion can be seen more clearly in figures 9(a) and 9(b) which show the disassembled strips. The erosion is apparent between the first and second row of notches on each end of each assembly. These areas correspond to the three edge apertures on the four sides or quadrants (see fig. 8(b)). In future tests attempts will be made to correct this problem either by eliminating the partially covered edge holes or modifying the pole piece configuration.

The third problem area, which is apparent from figure 8(b), is that some of the accelerator strips have warped. In future designs tensioning will be provided for each individual strip to compensate for thermal expansion.

Comparison of the center portions of figures 9(a) and 9(b) show a marked difference in erosion. The beam was deflected only in the horizontal direction and so the corresponding elements exhibit the most erosion. One reason for the severe erosion is because deflection angles up to 16 degrees were obtained. In the Hughes Research Lab tests of references 3 and 4, deflection angles were limited to 10^{o} or less. Correspondingly lower erosion damage resulted in their test.

CONCLUDING REMARKS

A successful 1000-hour test of a 5-cm accelerator system with beam deflection capability has been completed. Several structural design problems have been identified which are being corrected. No major conceptual problems were uncovered although additional longer duration tests will be needed to verify lifetime capabilities of the design.

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TABLE I

Run, hr	1 Beam current, mA	2 Accelerator current, mA	3 Main propellant flow, mA	4 Neutralizer propellant flow, mA	5 Cathode keeper current, A	6 Cathode tip power, W
0-8	25	0.22	43	5-6	0.18	14.5
22-57	24	.23	43	4-6	.18	14.5
92-186	24	.22	42	5-7	.18	14.5
186-200	25	.25	44	5-7	.18	19
260-368	25	.28	46	6-8	.18	23.5
426-444	25	.30	49	6-8	.18	27.5
450-530	26	.29	48	6-8	.18	27.5
530-545	22	.22	42	7-9	.18	27.5
545-924	26	.25	43	7-9	.24	27.5
936-1193	25	.25	43	6-9	.24	27.5

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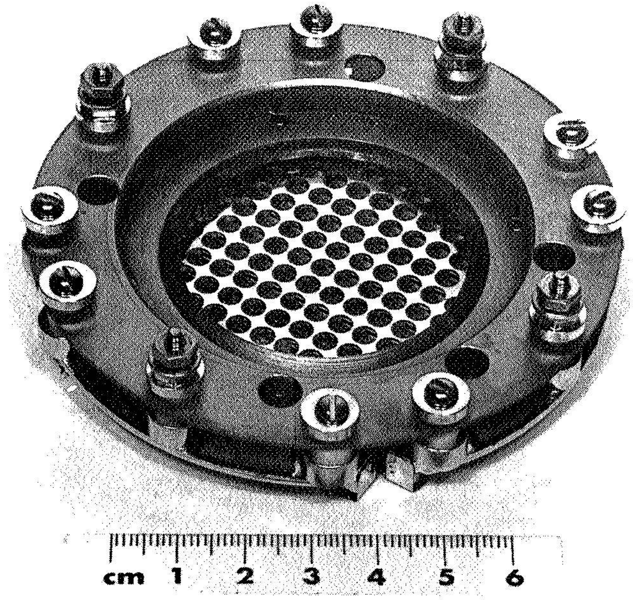
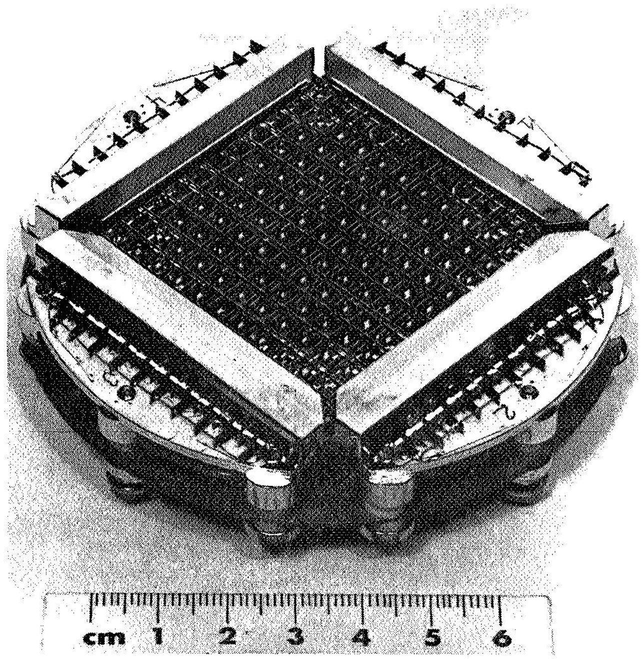


(a) Upstream side.



(b) Downstream side.

Figure 1. - Electrostatic dual-grid beam deflection system.

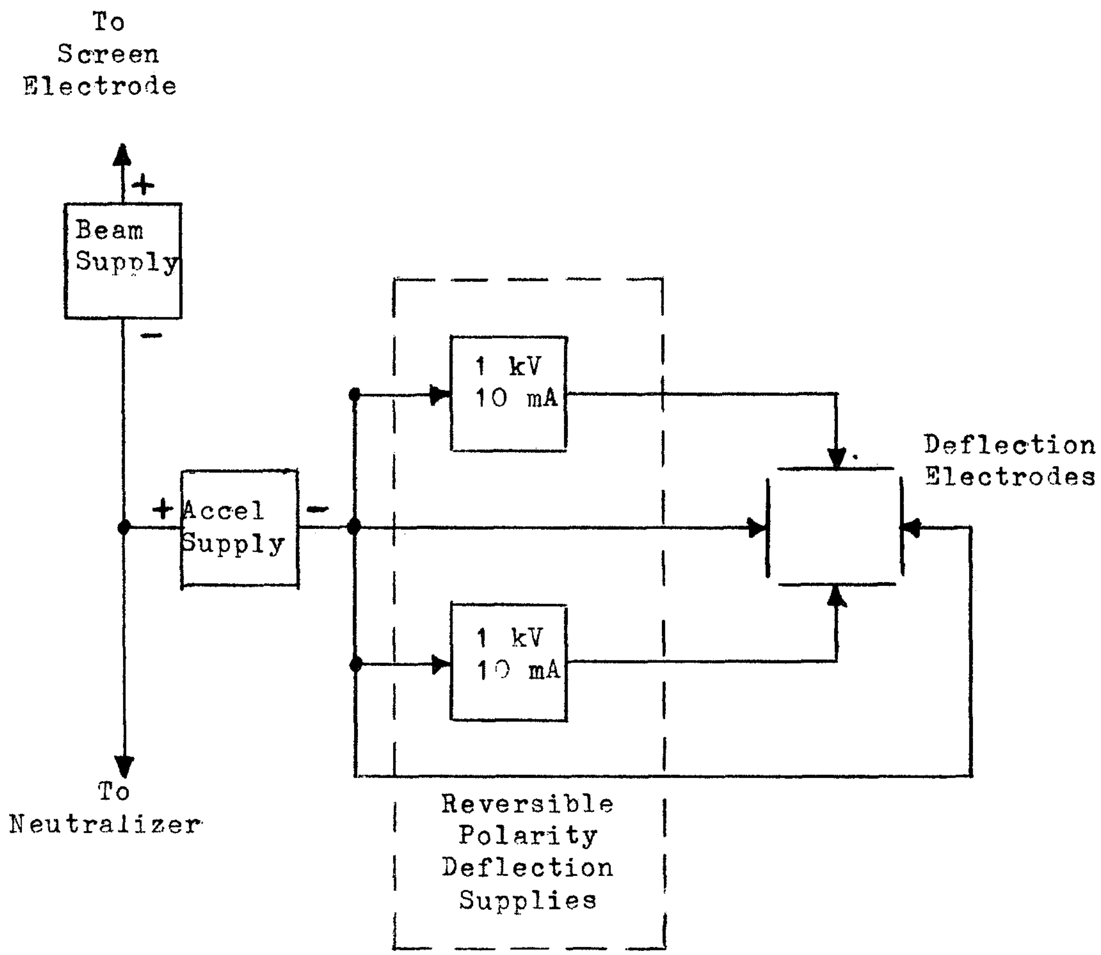


Figure 2. Functional diagram of deflection power supply setup for single axis deflection.

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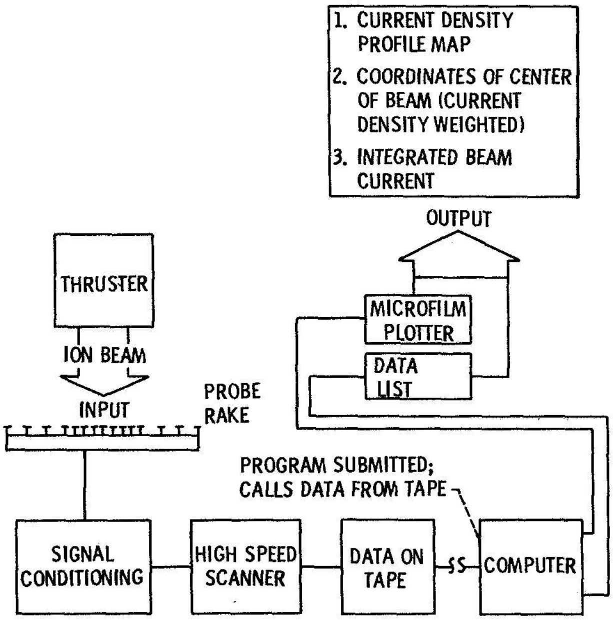

Figure 3. -Block diagram of system used to analyze the ion beam.

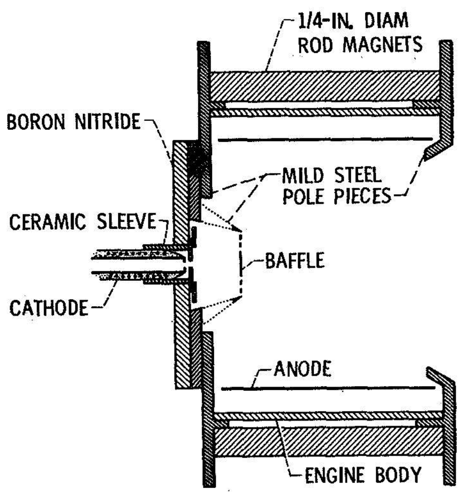

Figure 4. -Cross section of 5-cm diameter thruster discharge chamber without accelerator system.

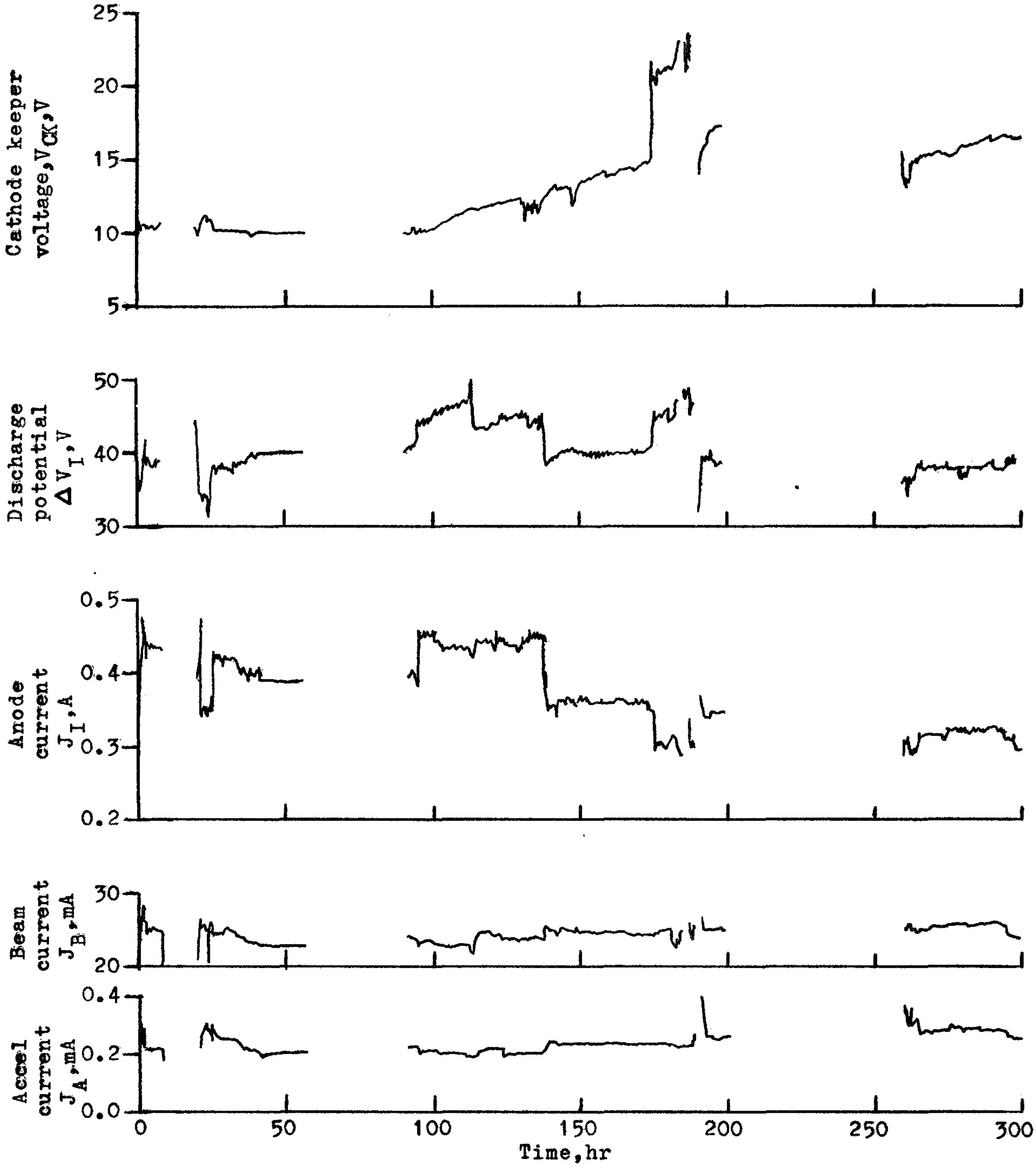

Figure 5. -Hourly performance plot of thruster parameters.

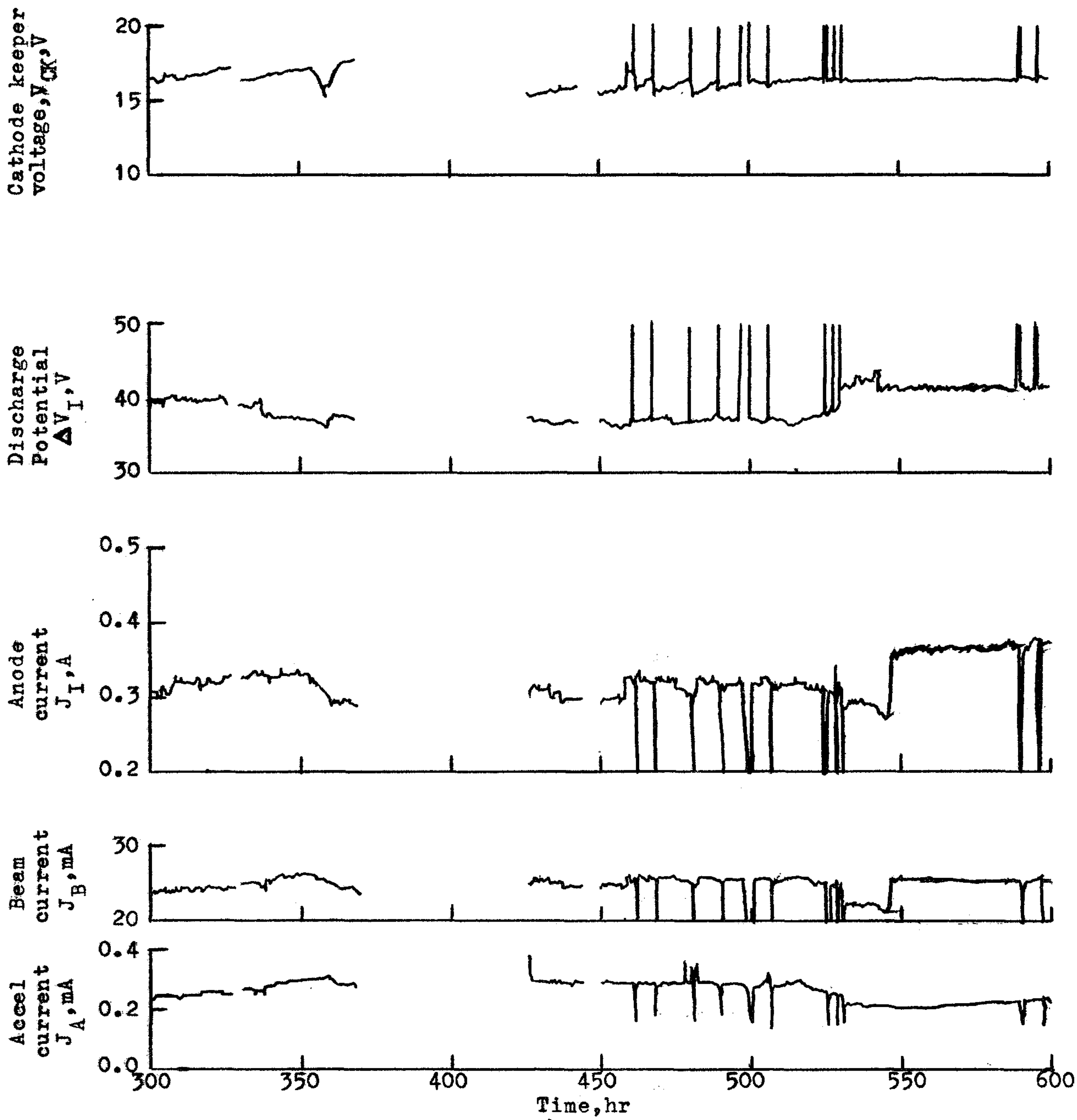

Figure 5. -Continued.

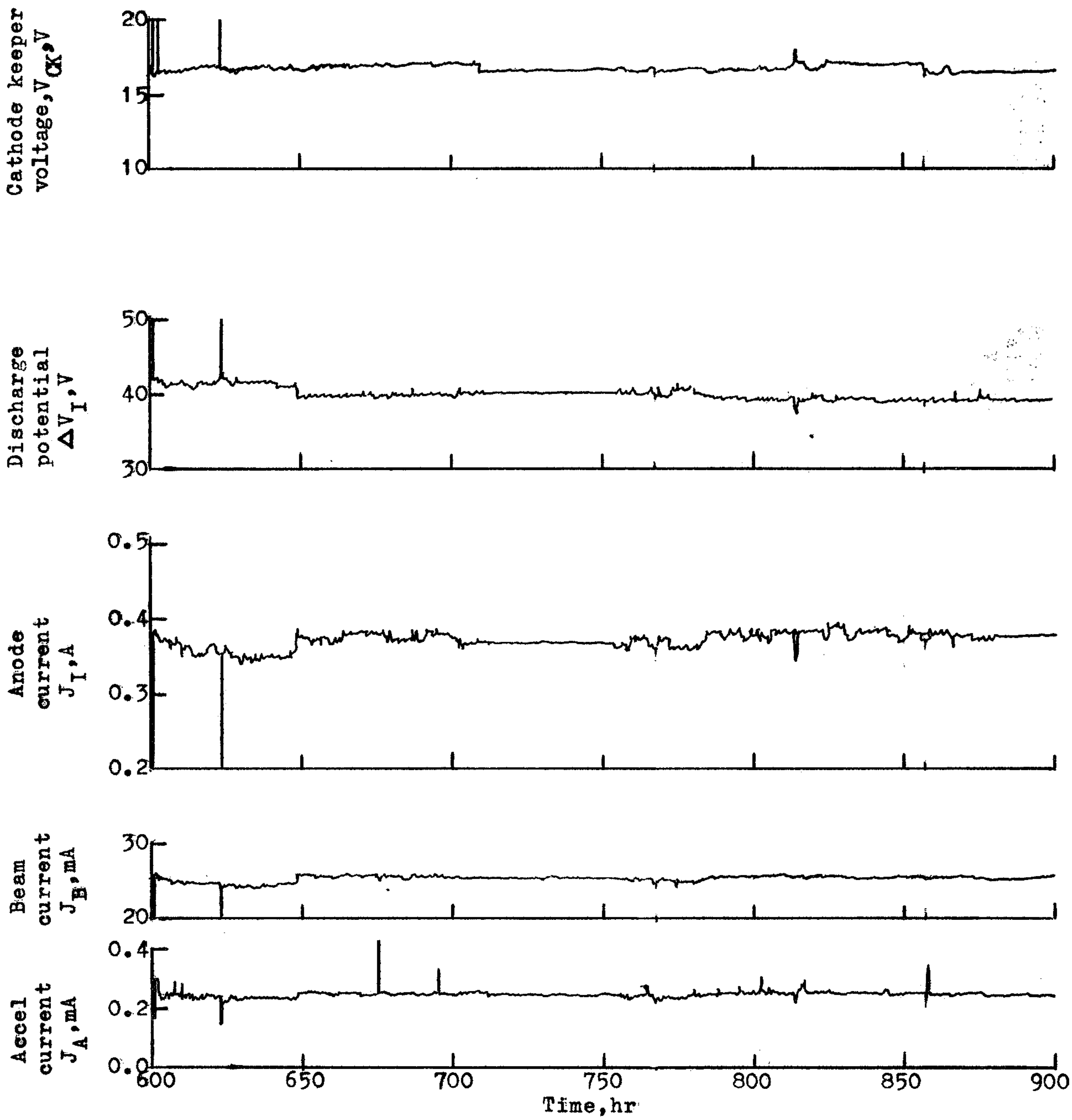

Figure 5. -Continued.

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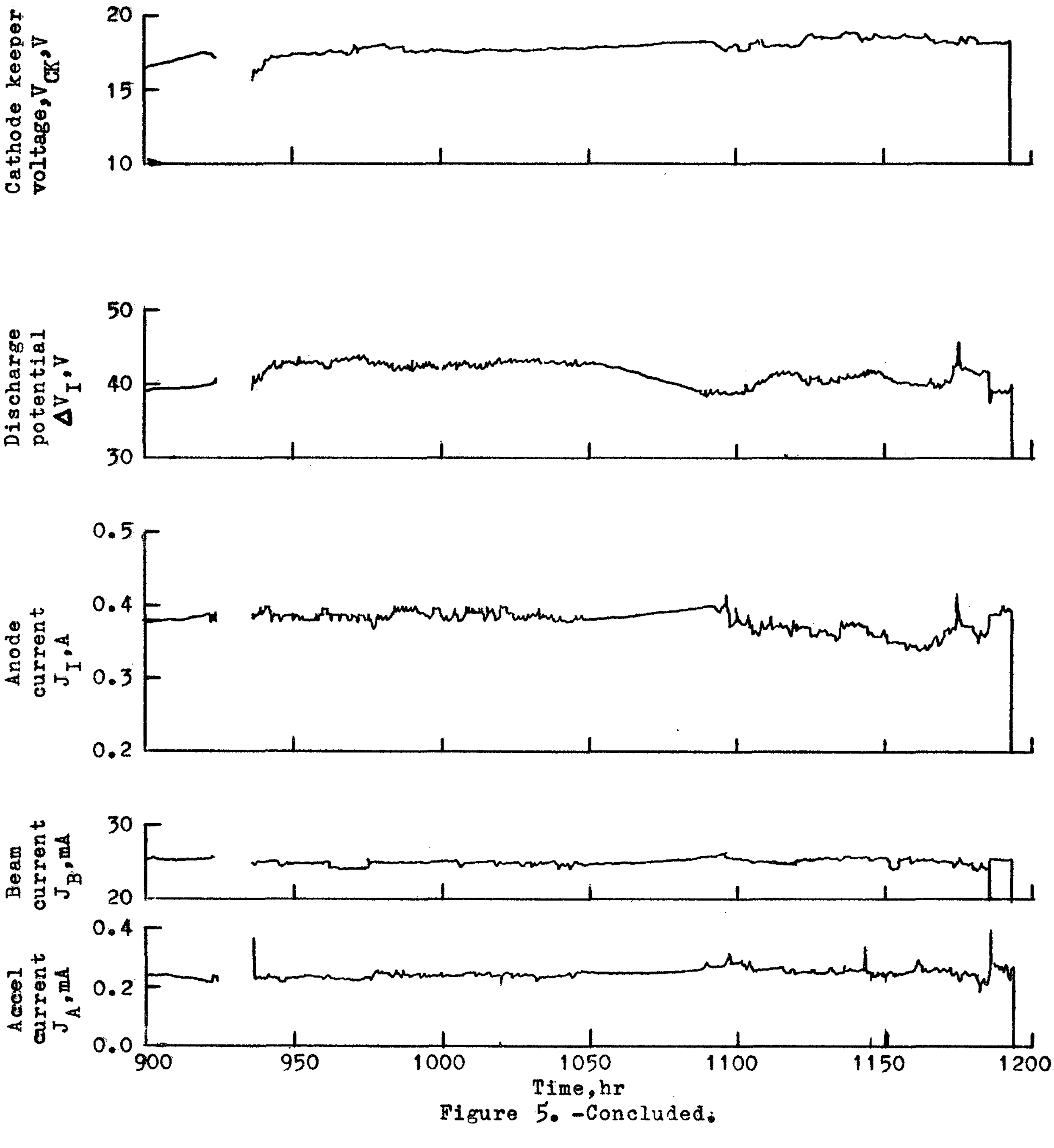


Figure 5. -Concluded.

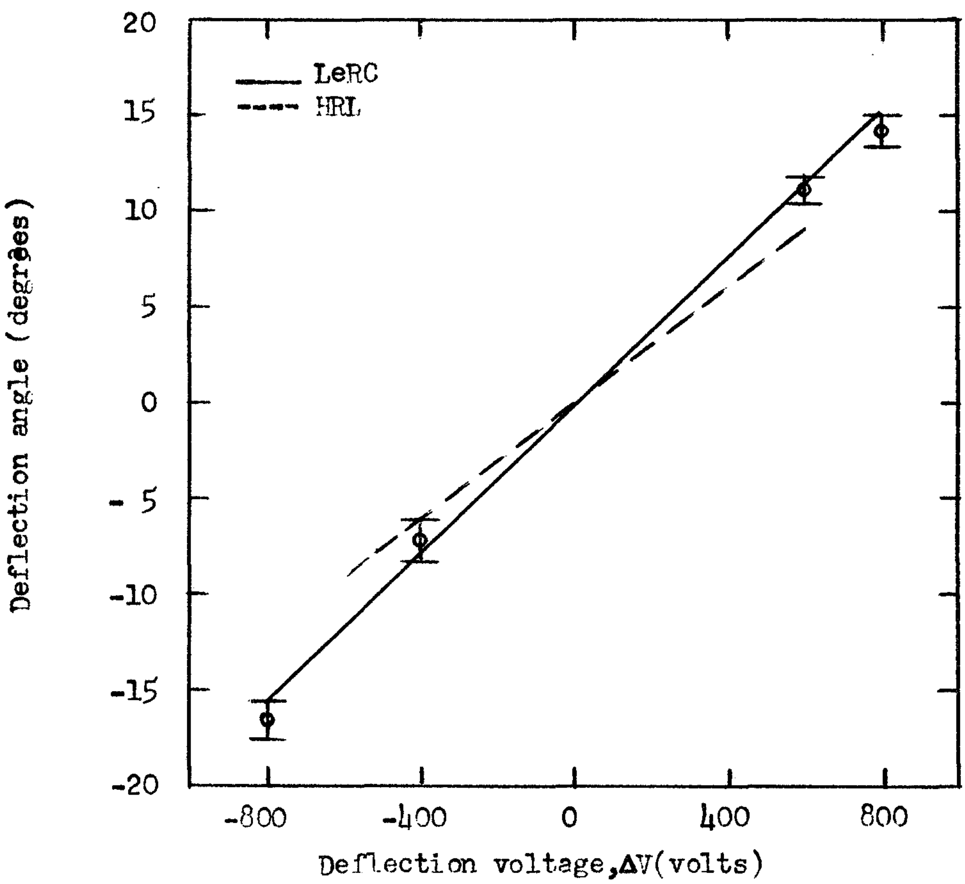


Figure 6. -Ion beam deflection angle as a function of the deflection voltage,ΔV.

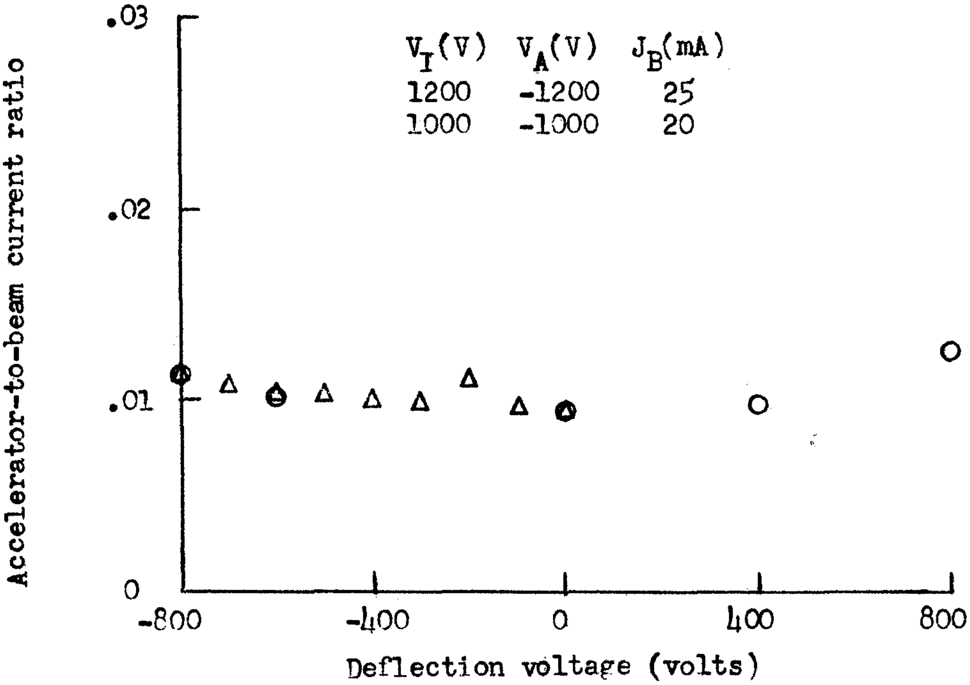
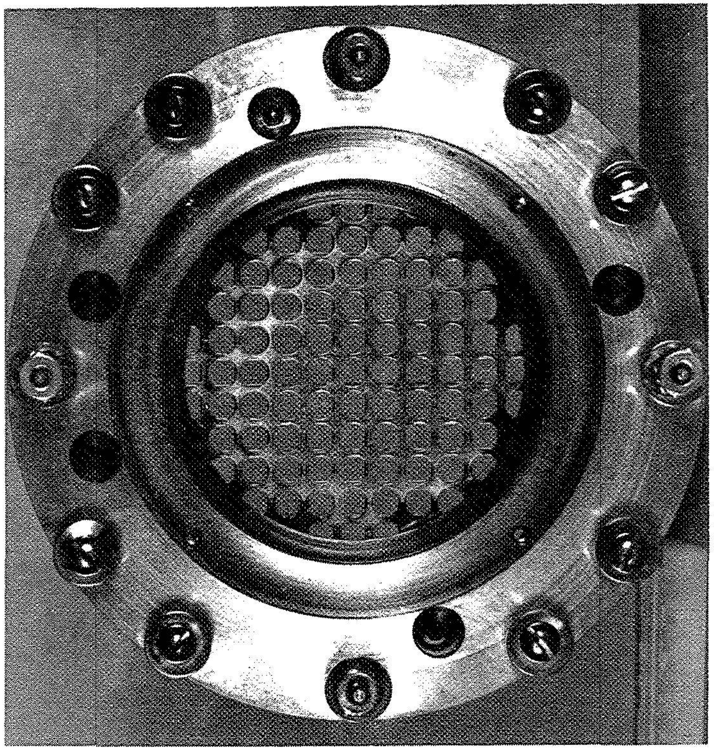
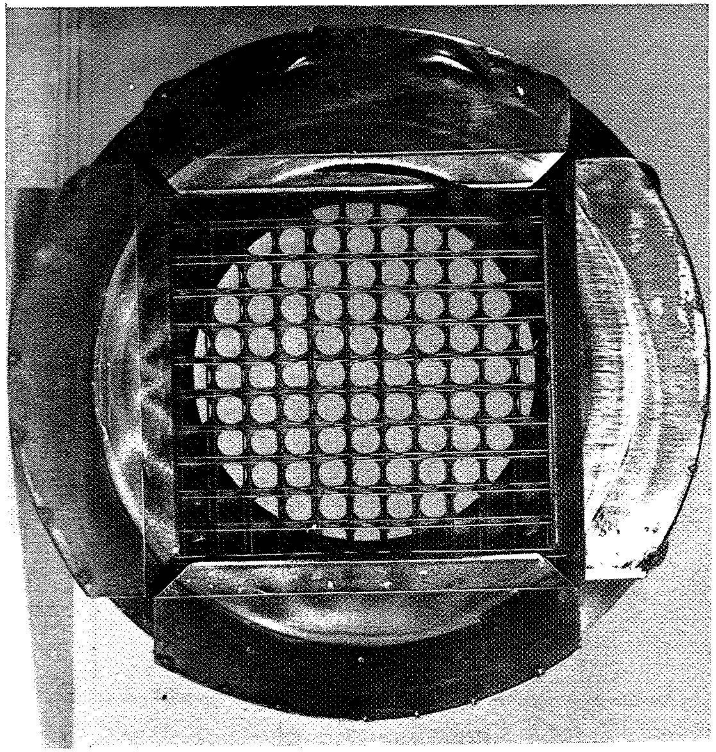


Figure 7. -Ratio of accelerator current to beam current as a function of beam deflection voltage.



(a) Upstream side.



(b) Downstream side.

Figure 8. - Electrostatic beam deflection system after 1000 hour test.

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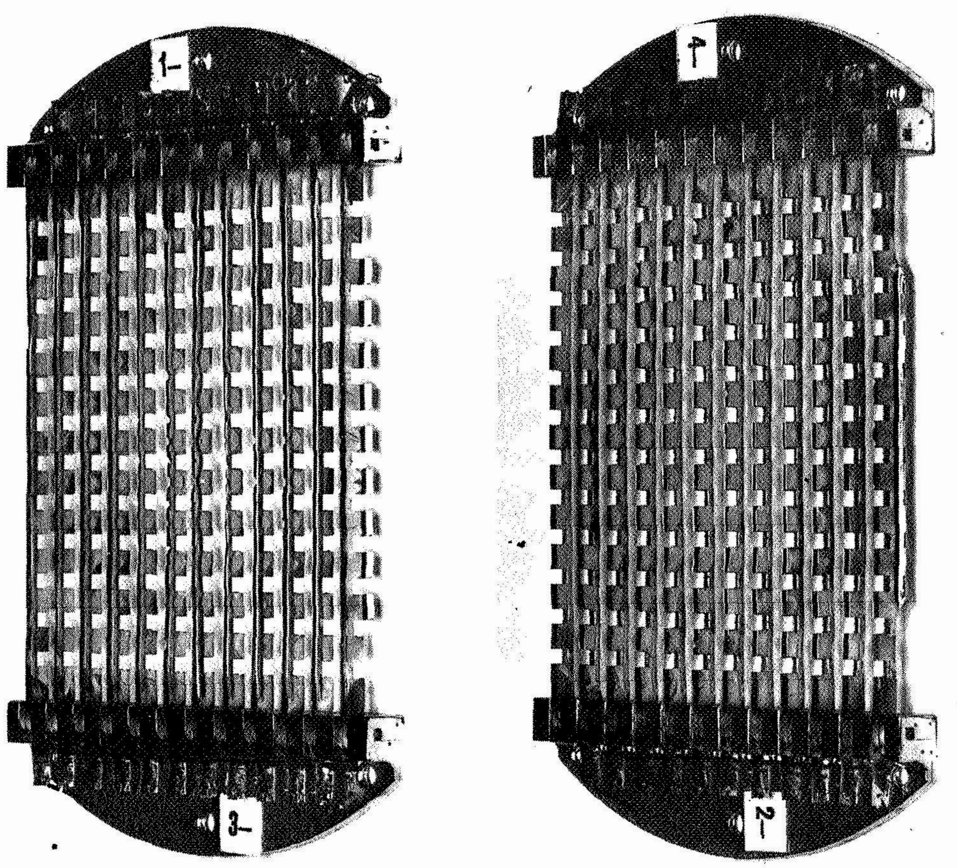

(a) Horizontal. (b) Vertical.

Figure 9. - Deflection elements after 1000 hour test.