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5000-HOUR TEST OF A GRID-TRANSLATION BEAM-DEFLECTION SYSTEM FOR A 5-CM DIAMETER KAUFMAN THRUSTER

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5000-HOUR TEST OF A GRID-TRANSLATION BEAM-DEFLECTION SYSTEM FOR A 5-CM DIAMETER KAUFMAN THRUSTER

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SUMMARY

A grid-translation type beam deflection system has been tested on a 5-cm diameter mercury ion thruster for 5000 hours at a thrust level of about 0.36 mlb. During the first 2000 hours the beam was vectored 10 degrees in one direction. No erosion damage attributable to beam deflection was detected. Results indicate a possible lifetime of 15,000 to 20,000 hours. An optimized neutralizer position was used which eliminated the sputter erosion groove observed on the SERT II thrusters.

INTRODUCTION

Increasing emphasis on orbiting spacecraft for Earth resources studies, meteorology, navigation, and communications is planned in this decade. Many of these satellites will have stringent, long duration stationkeeping and attitude control requirements. As satellite lifetime increases, the high specific impulse ion thruster becomes an increasingly competitive alternative to cold gas and chemical type thrusters. The Lewis Research Center is developing a 5-cm diameter electron-bombardment mercury-ion thruster with the durability (lifetime) and specific impulse to meet this satellite need. The Lewis 5-cm thruster program (both in-house and contract) has been described in references 1 and 2.

Present development of an ion thruster with beam deflection capability enhances its usefulness, since one thruster can perform both station-keeping and attitude control functions. Hughes Research Laboratories has investigated several techniques for varying the thrust direction of a mercury bombardment ion thruster under Contract NAS3-14058. The results of this work are described in references 3 and 4. Two beam deflection systems appear particularly promising -- the electrostatic dual-grid system and the grid-translation system. The electrostatic dual-grid system deflects the beam around two orthogonal axes by electrostatic biasing of the accelerator grid elements. The grid-translation system deflects the beam by purposely misalining the screen grid so that the beam is attracted more toward one side of the accelerator holes. The performance of this grid-translation beam-deflection system is the subject of this report.

Initial testing of this system by the contractor was reported in references 3 and 4. After delivery to LeRC a series of additional tests were performed. Operational characteristics, including an evaluation of the actuator mechanism, were obtained and reported in reference 5. A 2000-hour endurance test was performed and the results reported in references 6 and 7. An additional 3000 hours of testing has been performed and the results of that testing are presented herein. For additional information on the grid-translation system, see references 8 to 11.

APPARATUS AND PROCEDURE

A photograph of the grid-translation system for a 5-cm diameter thruster is shown in figure 1 as it was delivered to LeRC by the Hughes Research Laboratories under Contract NAS3-14058. Grid aperture dimensions are shown in table I. The accelerator grid is stationary with respect to the discharge chamber. The screen electrode is supported slightly away from the end of the discharge chamber and the position is maintained by four thin flexible support columns which provide the necessary axial support without constraining the transverse flexibility. The screen grid is held in static equilibrium by stretched coil springs (numbered 1 to 8 in fig. 1) with the spring axes perpendicular to the supporting columns. The outer ends of the springs are electrically isolated and four power supplies are connected such that the springs are heated in pairs. For example, current is passed through spring 1, through the screen grid, and then through spring 6. Heating springs 1 and 6 cause them to lose tension and springs 2 and 5 pull the screen grid sideways. The other four springs are flexible enough to allow this motion over small distances. By proper heating of the pairs, the screen grid can be misalined with respect to the accelerator grid in any azimuthal direction. This misalinement causes the ion beam to be deflected in the same direction as the screen grid is translated. Removal of the current causes the springs to cool and recover their prior tension.

For the first 2000 hours of endurance testing the grid system was mounted on the SIT-5 thruster (fig. 2). This thruster was developed for LeRC by Hughes under Contract NAS3-14129 and is described in reference 12. Detailed results of this test were reported in references 6 and 7. The test facility is described in reference 6.

When the electrostatic dual-grid system became available from the contractor, it replaced the grid-translation system on the SIT-5 thruster. Therefore, a new setup was prepared to continue the durability test of the grid-translation system. Enough SIT-5 parts were fabricated to reproduce the ion chamber configuration and the test was set up in a 4.5 meter long by 1.5 meter diameter vacuum facility (ref. 13). The tank pressure was maintained near 1×10^{-6} torr.

For the first 2000 hours of testing the beam was vectored 10 degrees in one direction. This was accomplished by mechanically locking the screen grid in a position such that each hole set was misalined by

0.32 mm (0.0125 in.). The final 3000 hours were run with the grids locked at zero deflection. Accelerator drain currents were monitored and periodic inspections were made to determine wear rates. Inspection points were at 2000, 3000, 3600, and 5000 hours into the test.

For the entire test the thruster was run at a 25 mA beam current with a net accelerating voltage of 1000 volts. The screen and accelerator voltages were of equal magnitude.

The entire test was run unattended with the operational engine data being sampled and recorded automatically every 15 minutes. The test was run unattended. The position of the neutralizer has been of concern since the neutralizer caused groove was observed on the SERT II thruster. Therefore, the position for this test, although not necessarily optimum, was documented and is shown in figure 3.

RESULTS AND DISCUSSION

At a number of scheduled inspection times, the thruster was shut down and the grid examined for erosion damage. In some cases the grid was removed and photographed. Results will be discussed in order of the inspection times. For most of the test, the accelerator current ranged from 70 to 120 microamperes with the typical value being 100 microamperes. The fluctuation in the base accelerator current value is believed to be due to mercury flow rate changes. For one period of 22 hours the positive voltage was inadvertently turned off and the accelerator current was nearly equal to the beam current.

2000-HOUR INSPECTION

Although results of the first 2000 hours were reported in references 6 and 7, portions are included here for completeness. After the grid system was removed from the SIT-5 thruster, photographs were taken (see fig. 4). Three general observations can be made about the results to this time. First, there was no neutralizer-caused erosion groove on the face of the accelerator. The neutralizer position and orientation had been chosen based on results of 30-cm thruster testing (ref. 14). Second, a large circular pattern of erosion shown on the grid in figure 4 about 1/2 centimeter outside the hole pattern was of minor importance. The maximum depth of this erosion, which was caused by a focusing effect of the ground screen mask, was only 0.1 mm or 8 percent of the grid thickness after more than 2000 hours of testing. Third, grid erosion directly attributable to beam deflection was small. The beam was deflected 10 degrees in one direction for the entire 2000 hours and a faint erosion pattern (at most one or two mils deep) could be seen on the inside walls of the accelerator holes in the direction of beam deflection. This erosion was less than 10 percent of the width of the grid webbing.

3000-Hour Inspection

At 3000 hours a visual examination of the grid revealed no new features that would merit removal of the grid for photographing. There still did not appear to be a pattern of charge-exchange pits. Also, there was no evidence of an erosion groove caused by the neutralizer. The absence of charge-exchange pits at this point was surprising because the grids were alined for zero deflection for the last 1000 hours. At the 2000 hour point it had been postulated that the 10 degree vectoring was possibly the reason for this absence of erosion pits.

3600-Hour Inspection

This was an unscheduled inspection point. At 3402 hours it was discovered that the positive high voltage supply was off. An examination of the automatically recorded data revealed that this condition had existed for 22 hours. An inspection was made at 3600 hours to determine the possible damage caused by this situation.

Photographs taken at this time are shown in figure 5. Figure 5(a) shows the best view of the damage caused by operating with no positive voltage. Under this condition the beamlets through each hole became very divergent causing primary ions to strike the inner hole walls of the accelerator. (The holes had been originally chamfered about halfway through from the downstream side as can be seen in the periphery holes, which are relatively undamaged.) Primary ions that did not directly strike the inner hole walls turned around and returned to the grid. The pattern of erosion that resulted from these ions was roughly equivalent to overlapping rings of erosion on the downstream side of the grid. Each hole produced one ring that was about five times the radius of the hole.

Figures 5(b) and 5(c) show that, in general, the holes remained relatively circular. This happened because the upstream edge of the accelerator holes received relatively little ion impingement. The effective thickness of the accelerator was considerably reduced, especially in the thin portion between adjacent holes where the thickness was cut in half. The areas central to each set of three adjacent holes became pyramidal in shape.

The erosion produced during the 22 hours of high voltage off condition was estimated by calculating the ampere-hours of ion impingement for this period and using a sputtering yield, 3.5 grams per ampere-hour, for normal incidence, 1000 volt energy mercury ions on molybdenum. At an ion impingement current of 20 milliamperes for this 22-hour period, the calculated grid erosion was 1.5 grams. This mass compares to a calculated erosion mass, 1.9 grams, for 4978 hours at 100 microamperes and 1000 volts for the steady-state erosion during the major portion of testing. Because the general integrity of the grid set was not destroyed, the decision was made to continue the life test to see what effect this damage might have on performance and subsequent erosion rates.

5000-Hour Inspection

After the damage due to operating with no positive voltage was assessed, the test was resumed and run for an additional 1400 hours. During this time no apparent change in either engine operation or in accelerator impingement current was noted. Two conclusions can be drawn from this.

First, the damage to the accelerator grid did not impair its ability to extract a well-focused beam. This is due mainly to the fact that the damage was all on the downstream surface of the grid, whereas the upstream surface has been found to be most critical. That is, as long as the shape of the hole on the upstream surface remains the same, the electrical field between the grids which is responsible for accelerating and focusing the beam should remain the same.

Second, the accelerator drain current did not change significantly. This result is primarily true because most of the current is made up of charge-exchange ions which fall back to the grid. With constant beam current and neutral flow rate, the charge-exchange current should be relatively independent of the shape of the accelerator.

At the 5000-hour point photographs were again taken and these are shown in figure 6. An attempt was made to duplicate as closely as possible the photographs taken at 3600 hours (see fig. 5). Close inspection reveals that no significant change has occurred during the last 1400 hours. Because of the complexity of the damage, it was not possible to obtain optical measurements which proved to be significant for comparison. The grid mass after 5000 hours was 53.5 grams. The grid unfortunately was not weighed initially, but using a molybdenum density of 10.2 grams per cubic centimeter, an initial grid mass of 56.8 grams was calculated. The difference, 3.3 grams, compares favorably with the calculated sputtering erosion of 1.5 grams and 1.9 grams, 3.4 grams total.

It was concluded that this grid could probably be run for an additional 5000 to 10,000 hours even in its damaged condition. If the damage had not occurred, it is almost certain that 15,000 to 20,000 hours could have been obtained. For example, after 2000 hours the accelerator had lost about 8 percent of its thickness because of a fairly uniformly distributed ion erosion pattern. A linear extrapolation would yield more than 20,000 hours.

It can be seen from all figures that no erosion groove attributable to the neutralizer has occurred. Thus is has been shown that the groove similar to the one observed on the SERT II thruster can be avoided on a 5-cm thruster.

The screen grid was little changed after 5000 hours of testing. The upstream surface (discharge chamber side) was slightly polished by low-energy ion sputtering, and the edges of the holes were worn or chamfered to a maximum of 0.012 centimeters by 45 degrees. The maximum chamfering occurred at the center holes and decreased to no chamfering for the outer holes. The downstream surface (side facing accelerator grid) was covered by a film of condensed sputtered accelerator material. This film, 5.3×10^{-3} centimeters thick, could be dislodged off the accelerator grid by gentle probing with a pick. The thickness of the screen grid with film removed was within 1×10^{-3} centimeters of the new thickness.

The entire surface of the anode was covered by a thin film 1.0×10^{-3}-centimeters thick of condensed sputtered metal. This film after atmospheric exposurer was dislodged from the anode by gentle tapping of the anode. The resulting flakes of film material were very small, about 0.1-centimeter square. These flakes, as well as film from the screen grid, did not become dislodged until after exposurer to atmosphere. Never during any time of the 5000 hours of thruster operation did perminent or temporary electrical shorting of the grid system occur due to dislodged flakes of sputtered material.

CONCLUDING REMARKS

A grid-translation beam deflection system has been tested on a 5-cm diameter Kaufman thruster for 5000 hours. It was run at a thrust level of about 0.36 mlb corresponding to a 25 mA beam current at 1000 volts. The accelerator voltage was -1000 volts. Typical accelerator currents were 100 microamperes.

During the first 2000 hours of the test the beam was vectored 10 degrees in one direction. No significant erosion damage was detected which could be attributed to this beam vectoring.

An optimized neutralizer location was used and this eliminated the sputter erosion groove observed on the SERT II thruster.

An extrapolated lifetime of 20,000 hours is estimated, based on analysis of grid damage for the 5000 hour test.

REFERENCES

1. Reader, Pauld D.; Nakanishi, Shigeo; Lathem, Walter C.; and Banks, Bruce A.: A Submillipound Mercury Electron Bombardment Thruster. J. Spacecraft Rockets, vol. 7, no. 11, Nov. 1970, pp. 1287-1292.

2. Nakanishi, S.; Lathem, W. C.; Banks, B. A.; and Weignad, A. J.: Status of a Five-Centimeter-Diameter Ion Thruster Technology Program. Paper 71-690, AIAA, June 1971.

3. Collett, C. R.; King, H. J.; and Schnelker, D. E.: Vectoring of the Beam from Ion Bombardment Thrusters. Paper 71-691, AIAA, June 1971.

4. King, H. J.; Collett, C. R.; and Schnelker, D. E.: Thrust Vectoring Systems. Part I - 5 cm Systems. Hughes Research Labs. (NASA CR-72877), 1971.

5. Lathem, Walter C.; and Hudson, Wayne R.: Operational Characteristics of a Translation Screen Grid Beam Deflection System for a 5-cm Kaufman Thrustor. NASA TM X-68008, 1972.

6. Nakanishi, Shigeo; and Finke, Robert C.: A 2000-Hour Durability Test of a Five-Centimeter Diameter Mercury Bombardment Ion Thruster.

7. Lathem, W. C.: Grid-Translation Beam Deflection Systems for 5-cm and 30-cm Diameter Kaufman Thrusters. Paper 72-485, AIAA, Apr. 1972.

8. Lathem, Walter C.: Effects of Electrode Misalinements in Kaufman Thrusters. J. Spacecraft Rockets, vol. 5, no. 6, June 1968, pp. 735-737.

9. Lathem, Walter C.; and Adam, Wallace B.: Theoretical Analysis of a Grid-Translation Beam Deflection System for a 30-cm Diameter Kaufman Thruster. NASA TM X-67911, 1971.

10. Fosnight, V. V.; Dillon, T. R.; and Sohl, G.: Thrust Vectoring of Multiaperture Cesium Electron Bombardment Ion Engines. J. Spacecraft Rockets, vol. 7, no. 3, Mar. 1970, pp. 266-270.

11. Seliger, R. L.; Nudd, G. R.; Brewer, G. R.; and Amboss, K.: Analysis of the Expected Thrust Misalignment of Kaufman Thrusters. J. Spacecraft Rockets, vol. 7, no. 4, Apr. 1970, pp. 422-428.

12. Hyman, Julius, Jr.: Design and Development of a Small Structurally Integrated Ion Thruster System. Huges Research Labs. (NASA CR-120821), Oct. 1971.

13. Keller, Thomas A.: NASA Electric Rocket Test Facilities. Transactions of the Seventh National Symposium on Vacuum Technology. C. Robert Meissner, ed., Pergamon Press, 1961, pp. 161-167.

14. Bechtel, R. T.: Performance of a Neutralizer for Electron-Bombardment Thruster. Paper 72-207, AIAA, Jan. 1972.

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Table I. - 5-cm System Grid Aperture Dimensions

	mm
Screen thickness	0.6
Screen aperture diameter	2.4
Accelerator thickness	1.3
Accelerator aperture diameter	2.4
Aperture center-to-center spacing	2.9
Grid to grid spacing	1.2

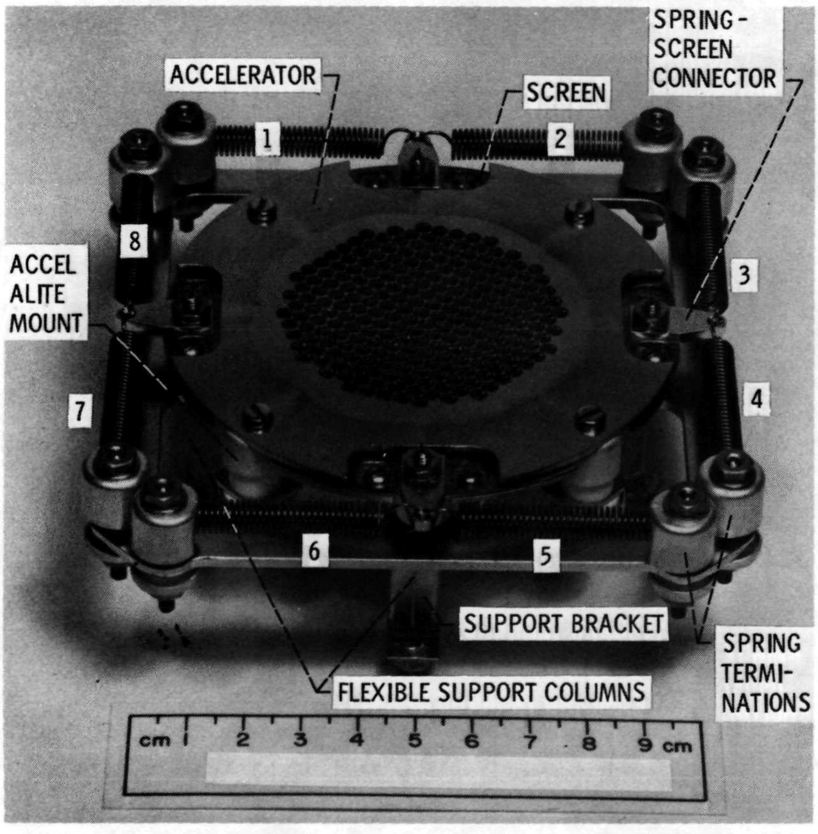

Figure 1. - Thermomechanical 5-cm vectorable grid. (Contract NAS 3-14058, Hughes Research Lab.)

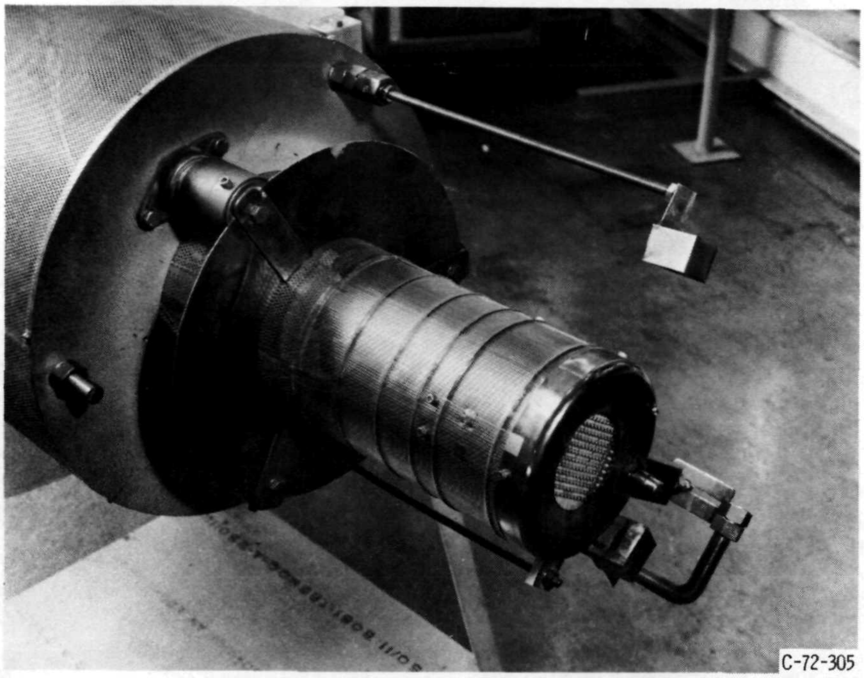

Figure 2. - Test installation of modified SIT-5 thruster.

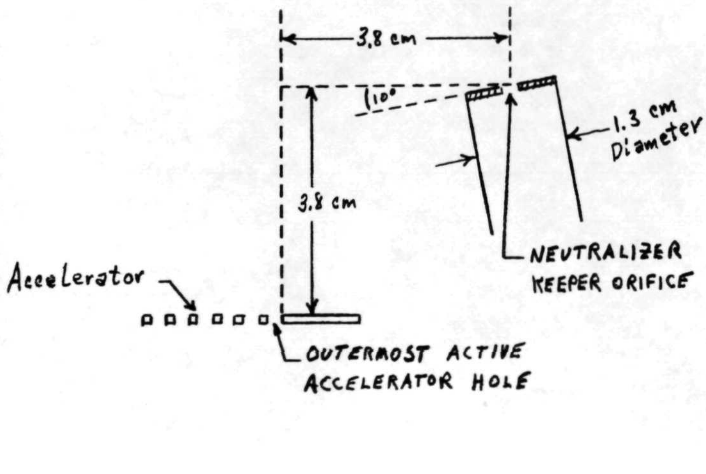

Figure 3. - Location of neutralizer with respect to accelerator.

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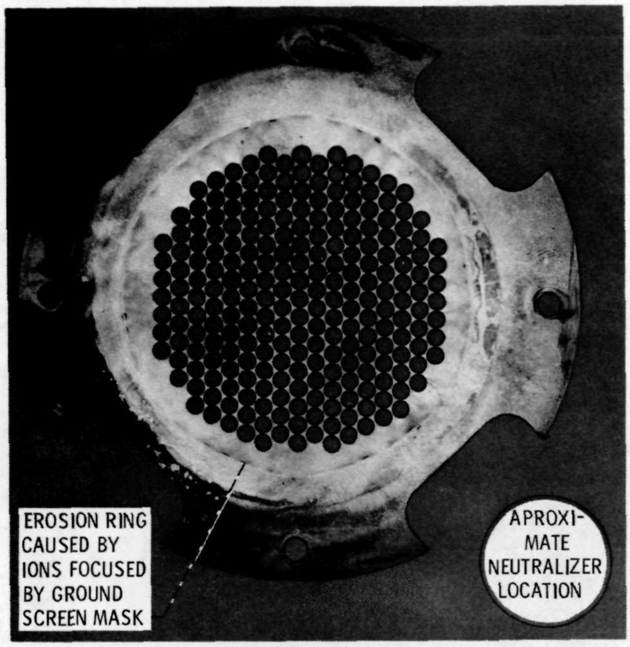
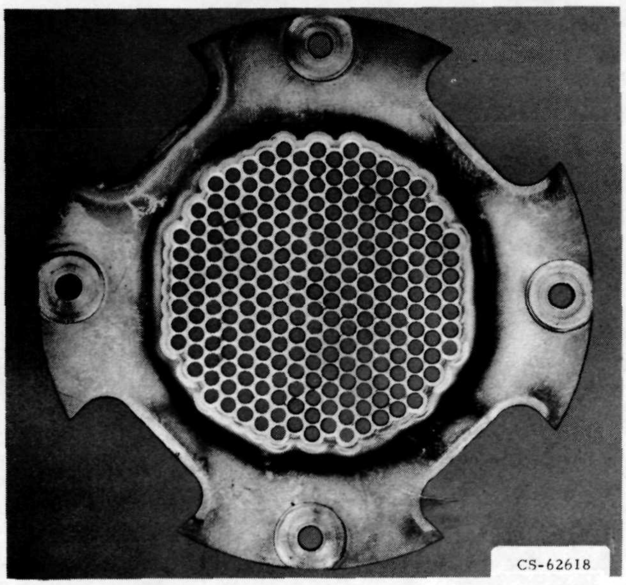
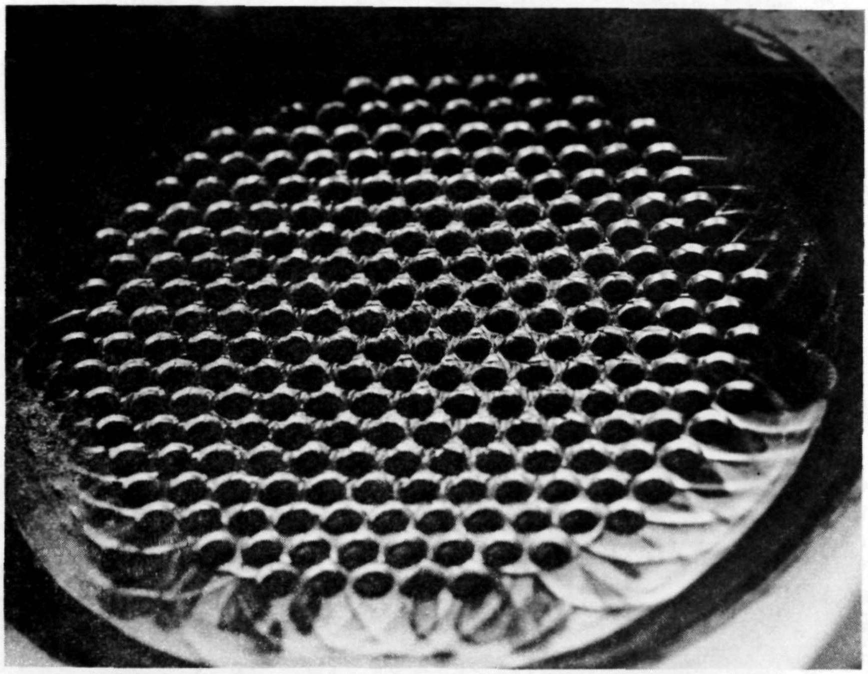


(A) DOWNSTREAM SURFACE.

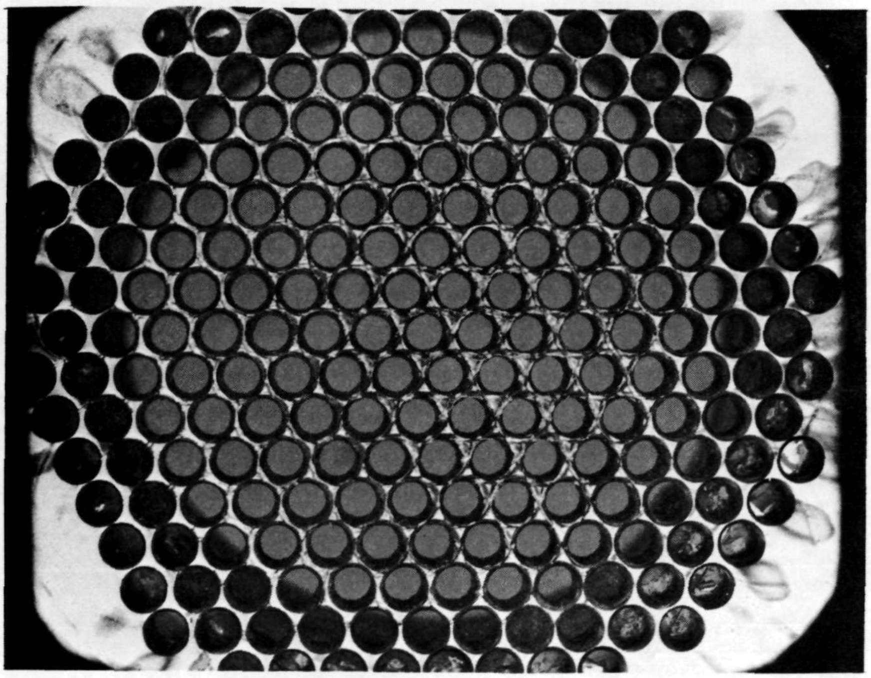


(B) UPSTREAM SURFACE.

Figure 4. - 5-Cm accelerator grid after 2026 hours at 25 mA beam current.



(a) View showing accelerator hole walls.



(b) Downstream face view.

Figure 5. - Accelerator grid after 3600 hours operation.

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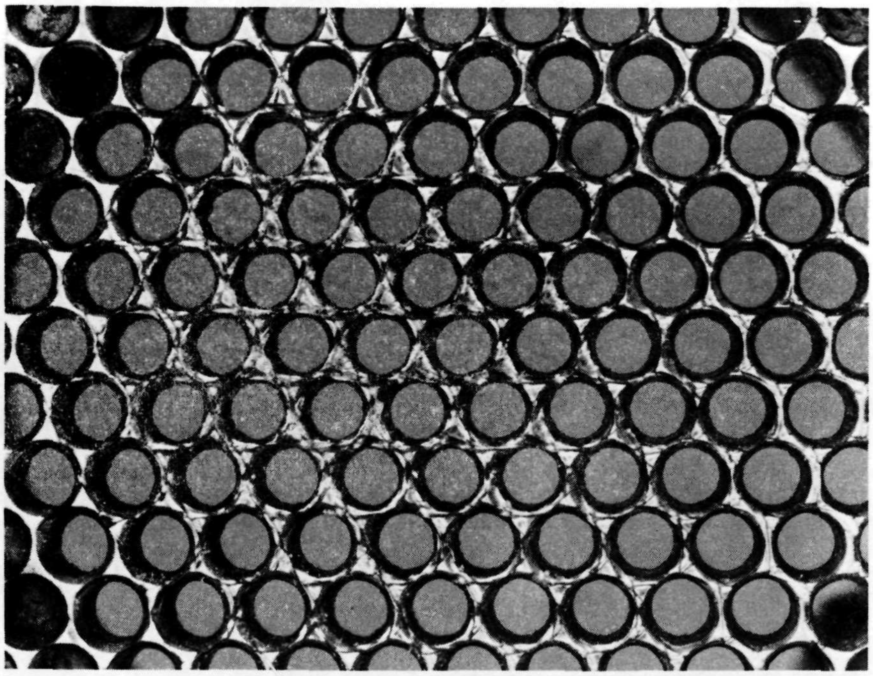
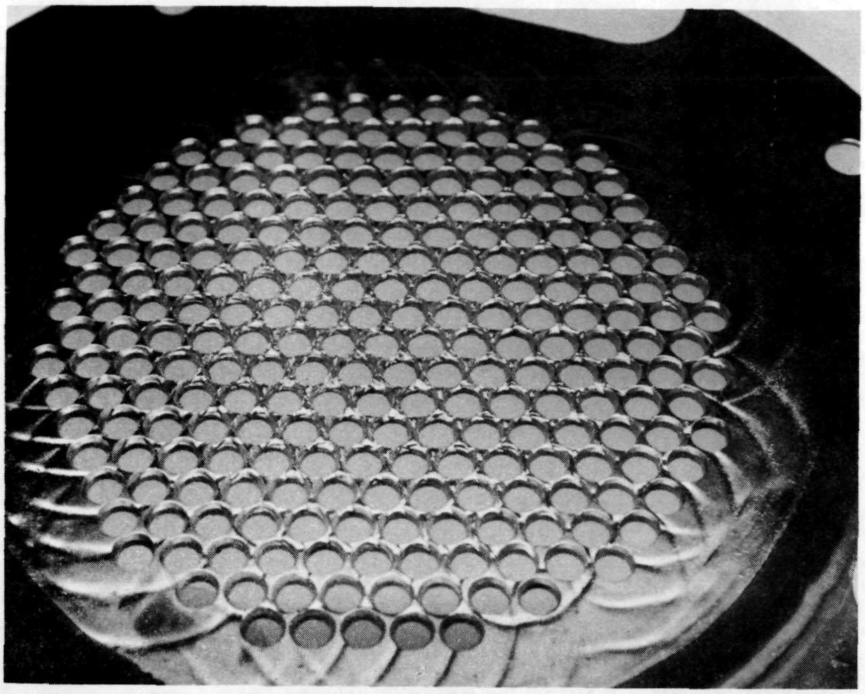
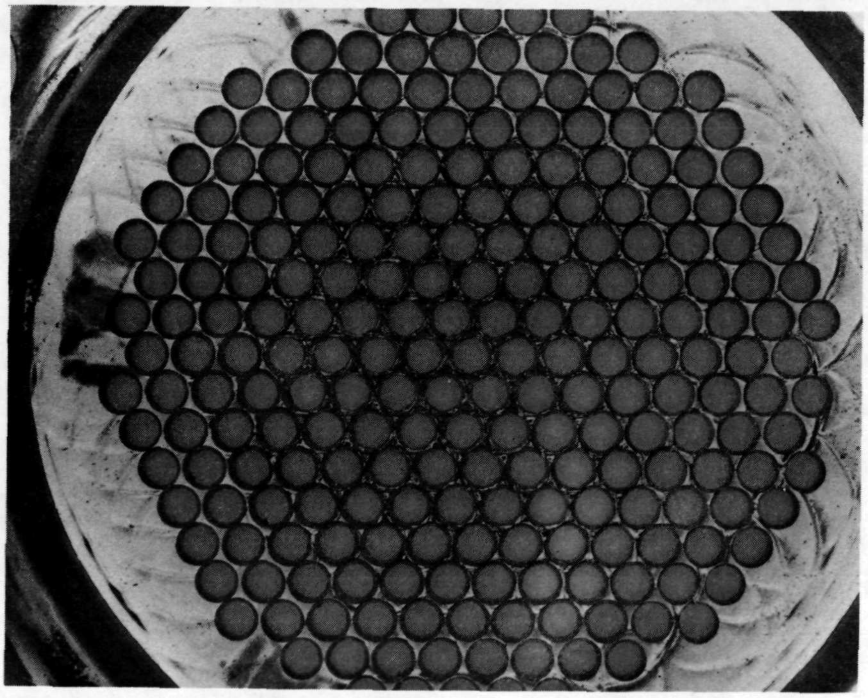


(c) Enlargement of downstream face.

Figure 5. - Concluded.



(a) View showing accelerator hole walls.



(b) Downstream face view.

Figure 6. - Accelerator grid after 5000 hours operation.

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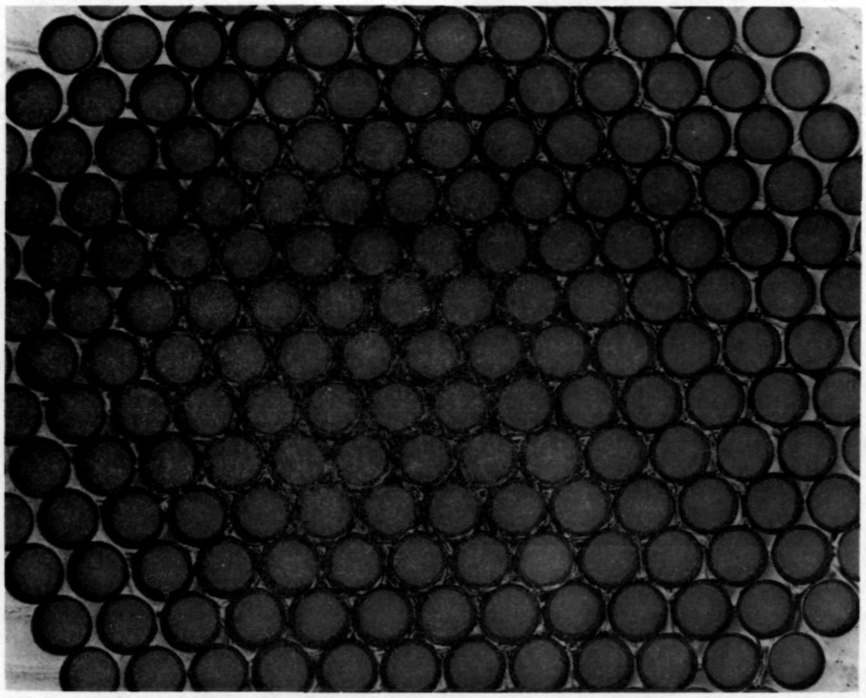

(c) Enlargement of downstream face.

Figure 6. - Concluded.