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POTENTIAL STAR TRACKER INTERFERENCE FROM RADIATION PRODUCED BY MERCURY BOMBARDMENT THRUSTERS

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ABSTRACT

Spectrographic measurements of the radiation spectrum produced downstream of an operating 30-centimeter mercury bombardment thruster were obtained. Such measurements suggest a possible source of interference for the star tracker guidance system in spacecraft using electric propulsion systems if the tracker viewing axis intersects the thruster downstream exhaust region within two or three meters of the thruster. For distances greater than three meters, no radiation was observed in the wavelength range corresponding to star tracker photodetector sensitivity.

INTRODUCTION

Electric propulsion systems are presently being considered for application on spacecraft such as the Application Technology Satellite (ATS) or Solar Electric Multi-Mission Spacecraft (SEMMS). These spacecraft would use star trackers for guidance and/or attitude control. Depending on the location of the tracking system with respect to the propulsion system, the tracker line-of-sight may intersect the ion thruster beam exhaust region of space. Recently, it has been suggested that photo-excitation of expelled propellant from cesium ion thrusters by sunlight may scatter radiation into the tracking system (ref. 1). This radiation flux was calculated to be comparable to the starlight signal level, thus presenting a potential source of guidance interference.

The purpose of the present study was to investigate downstream excitation produced by processes characteristic of the propulsion system itself. Here the propulsion system consisted of a 30-centimeter diameter hollow cathode mercury bombardment thruster using a plasma bridge neutralizer. A spectrograph was used to detect mercury excitation in the region of the ion beam exhaust.

EXPERIMENT

The experiments were performed with 30-centimeter hollow cathode thrusters operating with composite glass grids. Descriptions of such thrusters and their performance characteristics have been given elsewhere (refs. 2 to 4). The thrusters were operated in a 7.6 meter diameter by 18.3 meter long vacuum facility. Operating pressure was maintained at about 10^{-7} torr. The experimental arrangement is shown in figure 1. A 0.75-meter focal length spectrograph was positioned such that its viewing axis intersected the thruster axis at an angle of 142°, measured with respect to the direction of ion beam exhaust. The downstream radiation was focused onto the spectrograph entrance slit by means of a 10 centimeter focal length condensing lens. An optically blackened 1.2 by 1.2 meter plate was mounted about 6.1 meters downstream along the line-of-sight and normal to the viewing axis in order to eliminate light reflected from the vacuum tank wall. To eliminate wide angle reflection, internal surfaces of the viewing port were also optically blackened. In this way radiation entering the condensing lens should only originate from the internal volume of the vacuum facility.

Radiation was detected on photosensitized glass plates. The photographic emulsion used (Kodak Spectrum Analysis 3) had the following characteristics (ref. 5) of particular interest to the present experiment: (1) very low level signals could be detected at reasonable exposure times (of the order of a few minutes); (2) the emulsion response cuts off at about 5000 Å; and

(3) a calibration curve obtained at a wavelength of 3000 Å was used at all observed wavelength. This procedure introduced a maximum error of about 20 percent in calculated line intensities. The calibration curve used in this study is given in figure 2 corresponding to a plate development time of about 6 minutes. The spectral line densities were obtained from microphotometer measurements of exposed plates. Spectral line intensities obtained in this manner represent approximations to actual intensities for the following reasons: (1) variations in the calibration curve at different wavelengths were neglected; (2) reciprocity (ref. 5) was assumed to hold; and (3) the transfer function of the optical system was assumed to be unity at all wavelengths.

In order to localize the source of detected radiation, the lens position was varied along the viewing axis, so that the image distance was varied in approximately 0.1 mm increments. Photographed line spectra obtained at the different lens positions were examined for maximum intensity and line sharpness. In this manner, the radiation source region was located within an approximate conical section, a cross section of which is shown crosshatched in figure 1. The region starts at a distance of about 1.3 meters from the lens (measured along the viewing axis) and extends to a distance of about 2.4 meters from the lens. The half-angle subtended at the vertex of the cone (lens position) was about 6°. Physically, this region extends at its nearest location (relative to the lens) from the effective ion beam edge to a downstream region where the mercury atom density was of marginal magnitude to permit excitation phenomena to occur. It should be noted that the atom density decreased quite rapidly with increased distance from the thruster.

RESULTS

Measurements were made on 30-centimeter diameter thrusters operating at an effective specific impulse of about 3000 seconds and about 80 to 90 percent propellant utilization (thrusters were operated by R. T. Bechtel and

V. K. Rawlin). Two composite glass grid extraction systems were used in these tests. The grids differed somewhat in design and operating age, or accummulated lifetime. As a result, performance characteristics as well as the observed spectra differed for the two systems. The spectra from the two systems were similar in the number and wavelengths of the observed spectral lines. For the purposes of the present work, the two beam extraction systems can be identified as "experimental grid" and "normal grid" systems. The "experimental grid" system was characterized by a high neutralizer-beam coupling voltage which can lead to more energetic electrons for excitation. The intensities of spectral lines for this system were substantially higher than for the normal grid system.

Table I summarizes the results of this investigation. Here, maximum observed intensities and the corresponding exposure times are given. Intensity values for the normal grid system at 2815, 3650, and 4358 Å represent extrapolated estimates, because the available calibrated response curve did not extend to the very low spectral line densities measured at these wavelengths.

With the exception of a weak line at 2815 Å, the observed spectrum corresponded to excitation of nonionized mercury atoms. The line at 2815 Å corresponds to the radiative decay of the $6^2D_{5/2}$ metastable state of singly ionized mercury. It is known (ref. 6) that this state is populated from the $6^2P_{3/2}$ level as a result of excitation collisions in the discharge chamber. The resulting metastable ions may then be extracted as beam ions, eventually radiatively decaying to the $6^2S_{1/2}$ ground state of the ion. Using a mean ion speed and the approximate location of the radiation source relative to the thruster, the lifetime of this metastable state was estimated to be of the order of 10^{-4} second. Such times are of sufficient length so as to suggest the possibility of a nonnegligible metastable ion contribution to downstream radiation.

Excitation of mercury atoms downstream of the thruster may be due to any of the following processes:

1. Neutralizing electron-atom collisional excitation followed by radiation decay of the excited state.

2. Charge exchange electron transfer resulting from ion-atom collisions. The transferred electron is captured in an atom excited state, decaying radiatively to the ground state.

3. Volume ion recombination with free electrons. Ions may recombine with electrons forming an excited atom, which radiatively decays to the ground state.

In general the 3650 Å ($6^3D_3 \rightarrow 6^3P_2$) line was substantially more intense than the 4358 Å ($7^3S_1 \rightarrow 6^3P_1$) line. The difference in intensity could not be accounted for by the difference in transition probabilities ($A(3650) \sim 2\times10^8$ sec^{-1} and $A(4358) \sim 1.2\times10^8$ sec^{-1}) indicating that the population of the 6^3D_3 exceeded the 7^3S_1 population. Either (2) or (3) may nonnegligibly contribute to the excited level population densities. These processes may produce an inverted excited state population in which states near the ionization potential (such as the 6^3D_3 at 8.86 eV above the ground state) would be more populated than lower lying states (e.g., the 7^3S_1 at 7.75 eV). Thus, lines emanating from the higher lying state would be more intense than the line resulting from the decay of lower lying states.

Electron-atom excitation probably dominated the radiation spectrum from the "experimental grid" thruster. Here neutralizer-beam coupling voltages may have been as high as 40 to 60 V, providing substantial energy for inelastic electron-atom collisions. Thus the $6^2D_{5/2}$ level of the ion may have been collisionally, rather than radiatively, depopulated. This would explain the fact that the 2815 Å ion line was not observed with this thruster.

The 2537 Å line was observed in all measurements. Although this wavelength lies outside the response of most star tracker photodetectors, its intensity was used to obtain an upper limit on line intensities at higher wavelengths. For the normal grid thruster the intensity of this resonant line exceeded the intensities of all other lines. An attempt was made to induce radiative absorption in the beam region using a 1000 watt tungsten filament lamp operating at about 3200 K. The light beam was collimated so as to intersect the thruster beam exhaust region with an intensity of the order of 10^{-4} W/cm^2 at 2500 Å. It was anticipated that absorption of 2537 Å radiation would have been detected as an enhancement of the observed line intensity. No such enhancement was detected and the intensity of the 2537 Å line was unaffected in any way by the incident radiation. The reason may be due to the fact that the light beam intercepted the thruster beam region at distances greater than two meters downstream of the thruster where the neutral density is greatly reduced. Future studies of this nature would require light beam intersection of the thruster exhaust region closer to the thruster, where neutral densities would be higher.

A thruster was also operated at a location on the vacuum facility forming an angle of about 125° between the ion beam exhaust direction and the spectrograph line-of-sight. In this case the region of intersection with the ion beam was located about 4.2 meters downstream of the thruster. Only the 2537 Å line was detected for a 10 minute exposure. The intensity level was estimated to be less than 10^{-14} W/cm^2. Thus, viewing through the ion beam at distances greater than about three meters downstream of the thruster produced no radiation capable of interfering with star tracker performance.

DISCUSSION OF RESULTS

An estimate of the extent of reciprocity failure was obtained by varying exposure times and measuring the 2537 Å line density, using the "experimental grid" thruster. The results suggested that reciprocity failure was not so severe as to alter the order of magnitude of the intensity estimates presented in table II.

In reference 1, the estimated power density incident on a Polaris star tracker system was given as 1.3×10^{-11} W/cm^2. From estimates based upon information presented in reference 7, star tracker systems can respond to signals as low as about 10^{-13} W/cm^2, depending upon the navigational star of interest and the photodetector used. From the measurements reported herein, it is possible that thruster - star tracker interference could occur. However, radiation produced by the normal grid thruster was substantially below the Polaris star tracker signal level of about 10^{-11} W/cm^2.

CONCLUDING REMARKS

Although the downstream radiation produced by a normally operating thruster was found to be quite small, it would be premature at this point to discount the possibility of thruster induced radiation interference of star tracker guidance systems. The present study suggests that an operating thruster could produce radiation at detrimental levels, particularly at unusual operating conditions such as might be encountered during thruster startup. This conclusion, of course, presumes the necessity of locating the star tracker system in the spacecraft so that its view axis intersects the thruster beam exhaust region within two to three meters downstream of the thruster. In any case, further studies are required under varying thruster operating conditions and perhaps using an actual tracking system. Also required are more extensive measurements on photoabsorption effects using a solar simulating light source whose beam intersects the beam exhaust region at varying axial distances from the thruster.

REFERENCES

1. Anon.: A Study of the Effects of a Cesium Ion Thruster upon a Polaris Star Tracker. Rep. HIT-452, Hittman Assoc., Inc., May 1970. (Work under Contract NAS5-9479).

2. Bechtel, Robert T.: Performance and Control of a 30-CM-DIAM, Low-Impulse Kaufman Thruster. J. Spacecraft Rockets, vol. 7, no. 1, Jan. 1970, pp. 21-25.

3. Bechtel, Robert T.: Component Testing of a 30-Centimeter Diameter Electron Bombardment Thruster. Paper 70-1100, AIAA, Aug. 1970.

4. King, H. J.; and Poeschel, R. L.: Low Specific Impulse Ion Engine. Hughes Research Labs. (NASA CR-72677), Feb. 1970.

5. Anon.: Kodak Plates and Films for Science and Industry. Publ. P-9, Eastman Kodak Co.

6. Milder, Nelson L.; and Sovey, James S.: Preliminary Results of Spectrographic Analyses of Kaufman Thrusters. Paper 70-176, AIAA, Jan. 1970.

7. Anon.: Space Vehicle Design Criteria (Guidance and Control), Spacecraft Star Trackers. NASA SP-8026, 1970.

TABLE I. - MAXIMUM OBSERVED INTENSITIES

Wavelength, Å	System			
	Experimental grid thruster		Normal grid thruster	
	Intensity, W/cm^2	Exposure time, sec	Intensity, W/cm^2	Exposure time, sec
2537	2.3×10^{-11}	210	$2.8-3.8\times10^{-12}$	180
2815 (HgII)	---------	---	$<10^{-15}$	600
3650	3.2×10^{-11}	210	$<5\times10^{-14}$	180
4358	9×10^{-12}	210	$<10^{-15}$	600

TABLE II. - INTENSITY OF THE 2537 Å LINE

Exposure, joule/cm^2	Exposure time, sec	Intensity, W/cm^2
1.7×10^{-9}	150	1.1×10^{-11}
4.8×10^{-9}	210	2.3×10^{-11}
1×10^{-8}	240	4.2×10^{-11}

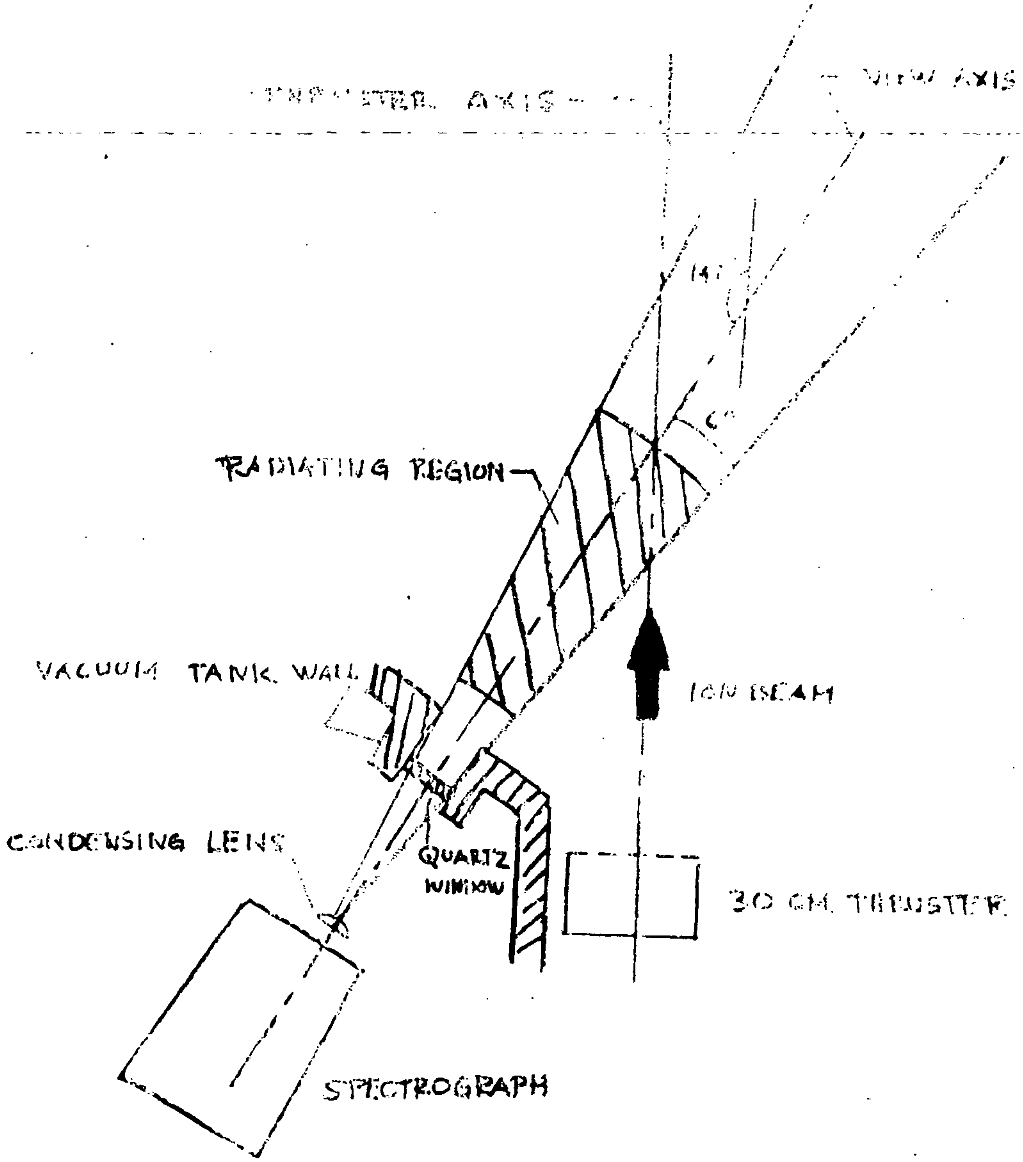

Fig. 1 Experimental Arrangement for Measuring Downstream Radiation

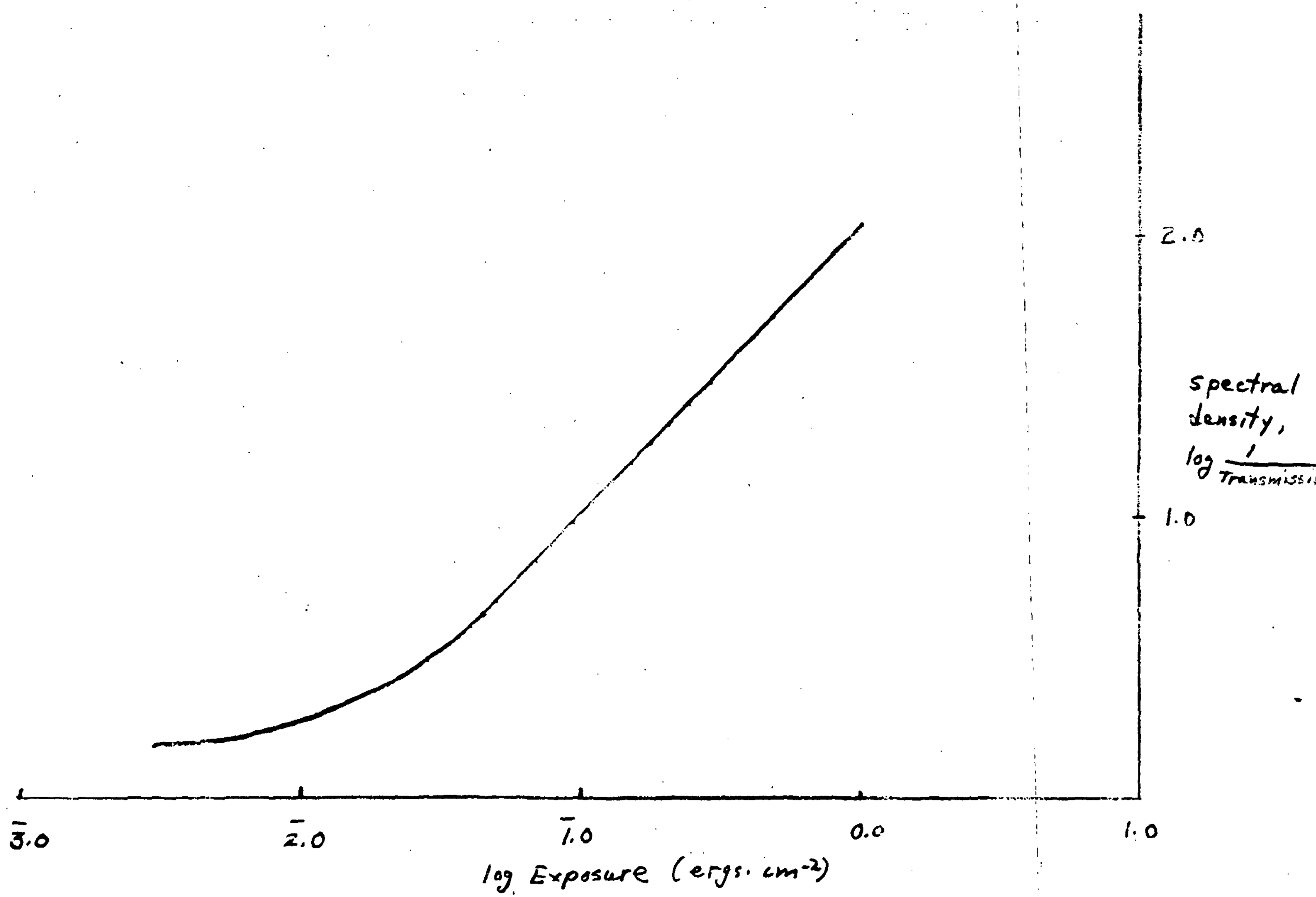

Figure 2 - Emulsion Calibration Curve, $\lambda = 3000$ Å (ref. 5)