PLASMA DIAGNOSIS IN THE PLUME OF THE 20mN ION THRUSTER FOR ETS-8

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ABSTRACT

Plasma diagnosis was performed in the plume of the 20mN xenon ion thruster for the Engineering Test Satellite 8 (ETS-8) by a Langmuir probe in the ground test chamber. ETS-8, a 3-ton class geosynchronous satellite, has an ion engine subsystem and high voltage solar arrays. It is essential to make clear the influence of the ion thruster originated plasma on the solar arrays. So plasma interaction between the ion thruster plume and the solar arrays has been investigated in both the numerical analysis and the ground experiment. As a part of this study, plasma parameters of the ion thruster plume were measured by a Langmuir probe. In beam extraction operation, the value of plasma density outside ion beam was below 1×10^{14} /m^3 at a distance of 500mm-1000mm from the thruster exit plane. In main discharge keeping operation, the value of plasma density on centerline of the thruster was below 7×10^{13} /m^3 at 500mm-1000mm from the exit plane.

NOMENCLATURE

D = probe diameter
e = electronic charge
g = gravitational acceleration
Ia = accel grid current, mA
Ib = beam current, mA
Ick = main hollow cathode keeper current, A
Id = discharge current, A
Ink = neutralizer keeper current, A
Ji = ion current into Langmuir probe
J_{e0} = electron saturation current
k = Boltzmann constant
L = probe length
M = mass of xenon
me = electron mass
m_{MHC} = main hollow cathode flow rate, SCCM
m_{MPF} = main propellant feeder flow rate, SCCM
m_{NHC} = neutralizer flow rate, SCCM
ne = electron density
ni = ion density
S = probe area
T = thrust, mN
Te = electron temperature
Va = accelerator voltage, V
Vb = beam voltage, V
Vck = main hollow cathode keeper voltage, V
Vd = discharge voltage, V
Vnk = neutralizer keeper voltage, V
vi = ion velocity, m/sec
η_T = propellant utillization efficiency
η_u = thruster efficiency

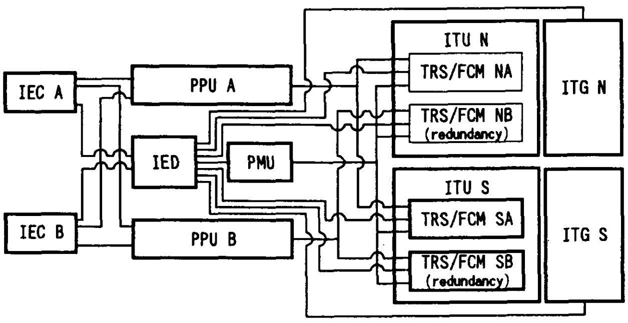
INTRODUCTION

The Ion Engine Subsystem (IES) for North-South Station Keeping (NSSK) of Engineering Test Satellite 8 (ETS-8) is under development at Mitsubishi Electric Corporation (MELCO). MELCO had developed the IES for NSSK of ETS-6 and Communications and Broadcasting Engineering Test Satellite (COMETS) under the contract with National Space Development Agency of Japan (NASDA)[1-6]. ETS-6 and COMETS were launched in 1994 and in 1998, respectively. Although both satellites unfortunately failed to be inserted into the planned orbits, the thrusters were successfully operated on orbit and the characteristics of the thruster agreed with the ground test results[7-9].

ETS-8 program was initiated in 1998 and the satellite will be launched in 2003. ETS-8 is a 3-ton class geosynchronous (GEO) satellite and the lifetime is 10 years. In this development, it is essential to extend the operating time of IES and the IES is under development including the life test of the thruster[10-15]. System block diagram and main design parameters of the ETS-8 IES are shown in Fig.1 and Table 1, respectively.

ETS-8 has an ion engine subsystem and high voltage solar arrays. Recently, there have been anomalies on GEO satellites that have led to failure of solar array performance because of plasma interaction. ETS-8 100V solar arrays will be exposed to comparatively dense plasma under the ion thruster operation. It is essential to make clear the influence of the ion thruster originated plasma on the solar arrays. So in the ETS-8 development program, plasma interaction between the ion thruster plume and the solar arrays has been investigated in both the numerical analysis and the ground experiment.

As a part of this study, plasma parameters of the ion thruster plume such as plasma density and temperature are measured by a Langmuir probe. This technique can be used to investigate the plasma parameters of the ion thruster plume[16-17]. In this paper, we describe the results of the plume measurement of ETS-8 EM ion thruster.



IEC : Ion Engine Controller, PPU : Power processing units
ITU : Ion thruster, PMU : Propellant management unit
IED : Ion engine driver, ITG : Ion thruster gimbal
TRS : Ion thruster, FCM : Flow control module

Fig.1 ETS-8 IES Block Diagram

Table 1 The Main Design Parameter

1.Thrust Method	Kaufman-type xenon ion thrusters
2.Operation configurations	One north thruster at ascending node and one south thruster at descending node
3.Average Thrust from BOL to EOL	Beyond 20mN
4.Average Isp from BOL to EOL	Beyond 2,200sec
5.Weight	95kg
6.Total Impulse	1.15×10^{6}N·sec
7.Total Operation Time	16,000hours (with average thrust of 20mN)
8.Total Number of Firing	3,000cycles

DESCRIPTION OF EXPERIMENT

Thruster

The schematic diagram of the ion thruster and the photograph of the thruster are shown in Fig.2 and Fig.3, respectively. The thruster is 12cm diameter Kaufman type ion thruster and the thrust level is about 20mN. The thruster is operated in five modes, idling mode (IDLG mode), activation mode (ACTV mode), neutralizer mode (NEUT mode), discharge mode (DISC mode) and beam mode (BEAM mode). In both IDLG mode and ACTV mode, electric power is supplied to two hollow cathode heaters without gas feed. In NEUT mode, only the NHC keeper discharge is ignited and kept with gas feed. In DISC mode, only the main discharge is ignited and kept. In BEAM mode, the thruster generates thrust. In both BEAM mode and DISC mode, comparatively dense plasma will occur around the thruster. In DISC mode, there are low energy ions, which flow out through the grid open area by thermal motion. In BEAM mode, there are high energy beam ions, neutralizer electrons and charge exchange ions.

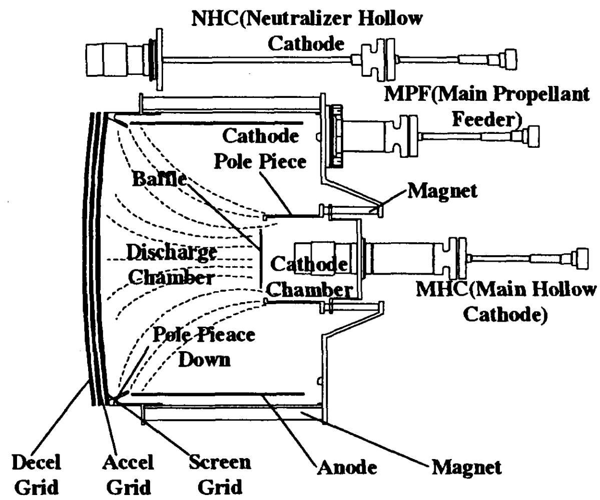


Fig.2 The schematic diagram of the thruster

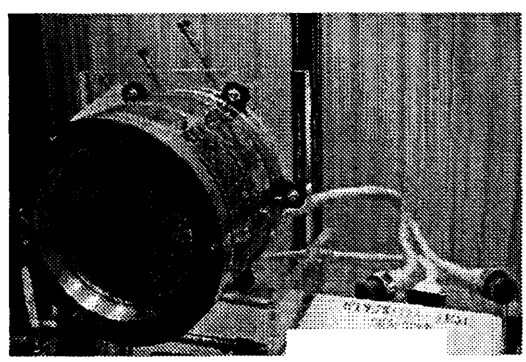


Fig.3. The photograph of ETS-8 EM Thruster

Measurement System

The measurement was carried out by a modified commercial plasma diagnostic system. The system is composed of a probe power supply, a personal computer with analytical software, a Langmuir probe and a probe positioning system. The plasma diagnosis system, a probe power supply unit and analytical software (ESPsoft™), is ESPION™ of Hiden Analytical. The value of scanning voltage is from –200V to +100V. The single probe and the positioning system for angular scan of the probe was modified. The probe is a cylindrical Langmuir probe (a 1 mm diameter × 10 mm long tungsten wire). It was mounted on an arm, rotated in the region of –80° - +80° by a stepping motor. The arm has two port for the probe at distances of 500mm and 1000mm from rotation axis. At the measurement, one probe was mounted on the one port and another port was blinded.

Test Configuration

The measurement of the plume was performed in Ion Engine Space Chamber at Kamakura Works of MELCO.

The space chamber is a 3-m in diameter and 5 m in length, and has a cryo-pumping unit. The thruster can be operated under the ambient pressure of 8×10^{-4} Pa with xenon flow. Ion thruster is located in the chamber. Ion beam is directed onto a titanium target plate, which is mounted on the end wall of the chamber and electrically floated from ground potential.

The thruster is operated using the same Power-Processing-Unit Bench-Testing-Equipment (PPU-BTE) in ETS-6 thruster development test. The power supply contains the seven power modules (screen, acceleration, discharge, two keepers, and two heaters). The power supply is controlled by a personal computer.

The propellant feed system provides a controlled flow of xenon to the thruster through three separate feed lines, for the MHC, MPF and NHC. Each propellant flow rate is independently controlled by three commercial mass-flow-controllers.

Measurement test configuration and photograph are shown in Fig.4 and Fig.5, respectively. The rotation axis of the arm was aligned with the thruster beam exit plane. The origin of the angle (0°) was the thruster centerline. The probe was explored within 80° on either side of the centerline at the horizontal plane including the thruster centerline. The NHC was symmetrically located with respect to the scanning area.

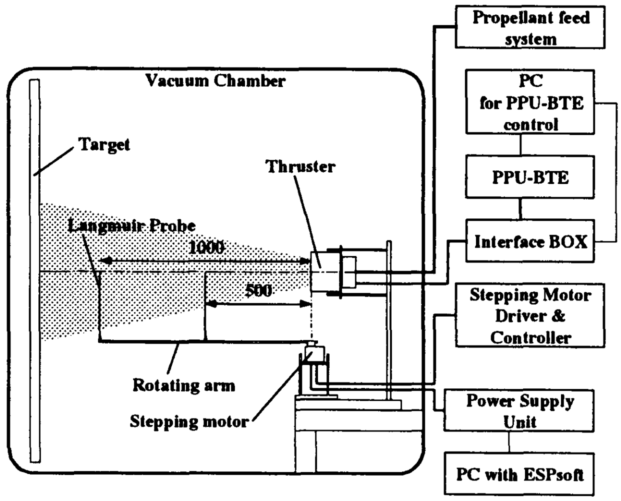


Fig.4 Test configuration

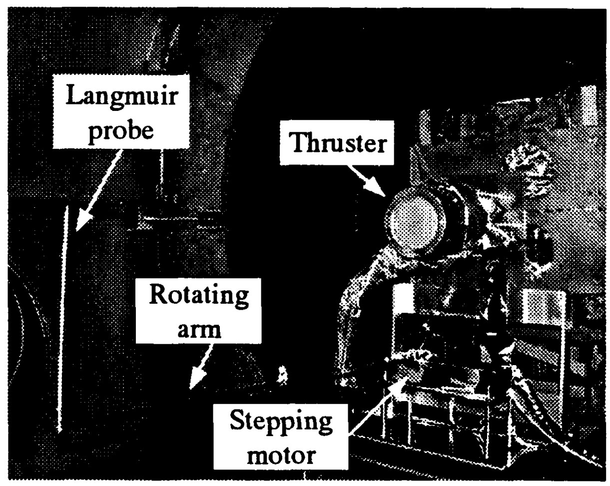


Fig.5 The photograph of the test configuration

RESULTS AND DISCUSSION

Operating parameters of the thruster are shown in Table 2 at the measurement. Id was changed from 3.25A to 4.0A by 0.25A. So T changed from 20.8mN to 23.3mN.

Typical current-voltage (J vs.V) data in BEAM mode and in DISC mode are shown in Fig.6. J-V plot in BEAM mode shifts right because the floating voltage of the beam target was about 25V, while J-V plot in DISC mode does not shift because the floating voltage was nearly zero.

The experimental results for plasma density determined at two distances from the exit plane in BEAM mode and DISC mode are shown in Fig.7. Inside ion beam, high energy (+1keV) beam ion can reach the probe against probe applied voltage (+100V max). So plasma density inside ion beam is calculated by using Eq.(1) from ion current within 12.5° from the centerline. The secondary electron from the probe surface was neglected. Plasma density outside ion beam is calculated by using Eq.(2) from electron current in the region beyond 12.5° .

$$J_i = DLen_i v_i \qquad (1)$$

$$J_{e0} = \frac{1}{4} S e n_e \sqrt{\frac{8kT_e}{\pi m_e}} \qquad (2)$$

Electron temperature in BEAM mode and DISC mode are shown in Fig.8.

The main results of the plume measurement test are summarized as follows:

1. In BEAM mode, the values of plasma density at 500mm and 1000mm in 20° were about $1\times10^{14}/m^3$ and $5\times10^{13}/m^3$, respectively. The values were not different in thrust level change by 10%. In DISC mode, the values of plasma density at 500mm and 1000mm at center were about $7\times10^{13}/m^3$ and $2\times10^{13}/m^3$, respectively.
2. In BEAM mode, the values of electron temperature were about 3eV inside ion beam and 5-15eV outside ion beam. The difference of electron temperature between inside and outside ion beam was due to the difference of plasma potential. The value of plasma potential inside ion beam was about 10V bigger than the one outside ion beam as shown in Fig.9. In DISC mode, the values of electron temperature were about 1-2eV at center.

Table 2. Operating parameter

Note : See Appendix about the calculation of T and Isp.

Parameter	Value				
	BEAM				DISC
	1	2	3	4	
Vb, V	999	999	999	999	N/A
Ib, mA	430	449	465	480	N/A
Va, V	-469	-473	-472	-474	N/A
Ia, mA	2.1	2.0	1.9	1.8	N/A
Vd, V	31.4	31.9	32.2	32.7	29.1
Id, A	3.26	3.51	3.76	4.00	3.27
Vck, V	6.2	5.7	5.1	4.6	5.8
Ick, A	0.50	0.50	0.50	0.50	0.50
Vnk, V	16.3	16.3	16.2	15.9	N/A
Ink, A	0.50	0.50	0.50	0.50	N/A
m_{MPF}, SCCM	6.5	6.5	6.5	6.5	6.5
m_{MHC}, SCCM	2.0	2.0	2.0	2.0	2.0
m_{NHC}, SCCM	0.6	0.6	0.6	0.6	0.6
T, mN	20.8	21.8	22.6	23.3	N/A
Isp, sec	2390	2500	2590	2670	N/A

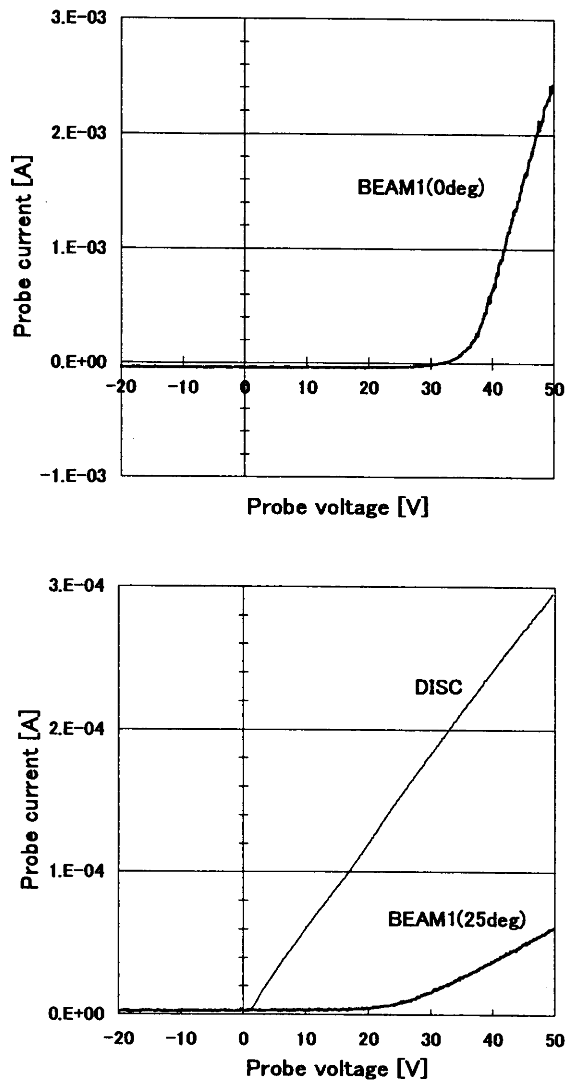


Fig.6 Example of current-voltage characteristics (at distance of 1000mm from the thruster exit plane)

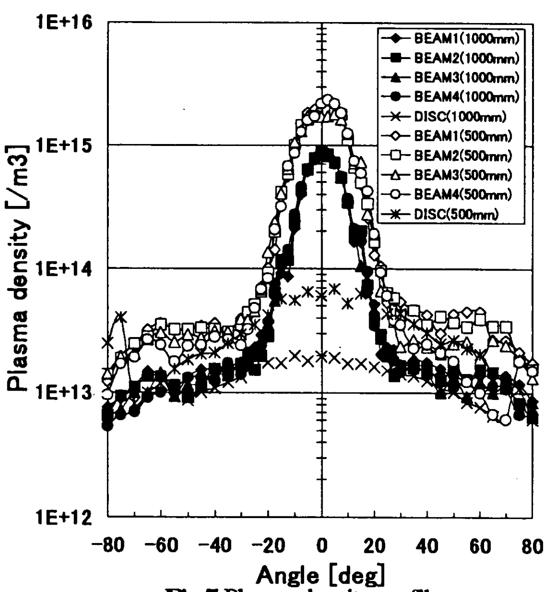


Fig.7 Plasma density profile

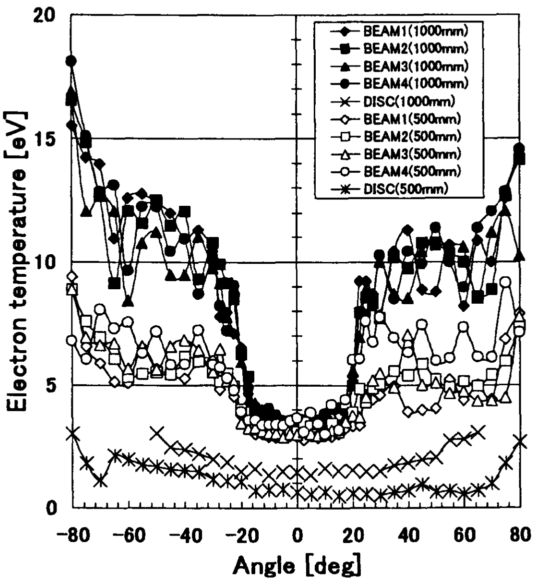


Fig.8 Electron temperature

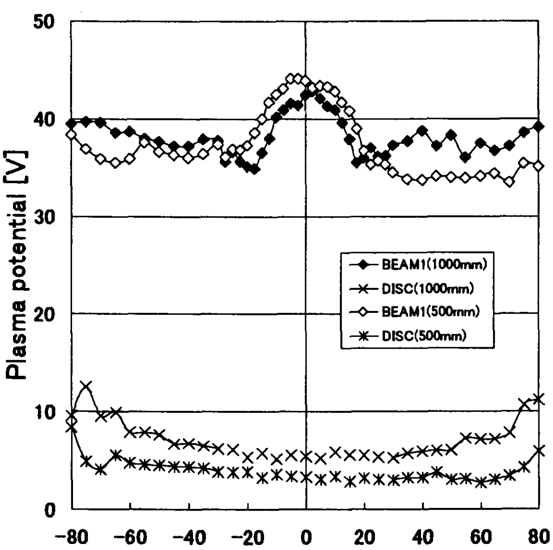


Fig.9 Plasma potential

CONCLUSION

ETS-8 has an ion engine subsystem and high voltage solar arrays. As a part of plasma interaction study between the ion thruster plume and the solar arrays, plasma diagnosis was performed in the plume of the 20mN xenon ion thruster for ETS-8 in BEAM mode and DISC mode by a Langmuir probe in the ground test chamber. The results of the test are summarized as follows:

1. In BEAM mode, the values of plasma density at 500mm and 1000mm in 20° were about $1\times10^{14}/m^3$ and $5\times10^{13}/m^3$, respectively. The values were not different in thrust level change by 10%. In DISC mode, the values of plasma density at 500mm and 1000mm at center were about $7\times10^{13}/m^3$ and $2\times10^{13}/m^3$, respectively.
2. In BEAM mode, the values of electron temperature were about 3eV inside ion beam and 5-15eV outside ion beam. In DISC mode, the value is about 1-2eV.

The plasma interaction between the plume plasma and the solar array paddle will be described in other paper[18-20].

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APPENDIX

The following equations were used in the calculation of performance parameters. The value of η_T is assumed as 0.93[6].

$$T = \eta_T I_b \sqrt{\frac{2MV_b}{e}}$$

$$Isp = \frac{\eta_T \eta_u}{g} \sqrt{\frac{2eV_b}{M}}$$

$$\eta_u = \frac{MI_b}{e\left(m_{MHC} + m_{MPF} + m_{NHC}\right)}$$