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SEPAC Particle Accelerator Test in NASDA Space Chamber

By

Tatsuzo OBAYASHI, Kyoichi KURIKI, Nobuki KAWASHIMA,
Makoto NAGATOMO, Isao KUDO*, Keiken NINOMIYA
Akio USHIROKAWA, Masaki Ejiri and Susumu SASAKI

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* Electrotechnical Laboratory

Abstract: SEPAC (Space Experiment with Particle Accelerators) accelerators were tested in NASDA Large Space Chamber. The accelerators were Engineering Models of EBA (Electron Beam Accelerator) and MPD (Magnetoplasmadynamic arcjet). EMI (Electromagnetic Interference) data were obtained for EBA and MPD arcjet and no interference both electronic and via plasma was observed between these accelerators. Charge neutralization was successfully attained when MPD arcjet or NGP (Neutral Gas Plume) and EBA were simultaneously operated. Beam and plasma injections were clearly observed by a monitor TV camera.

1. INTROUCTION

An active space experiment SEPAC (Space Experiment with Particle Accelerators) is scheduled on board the Spacelab 1 under the collaboration of ISAS, University of Tokyo, and MFSC, NASA [*1*]. A beam ejection test has been already carried out in the large space chamber at JSC, NASA in December, 1976. In this experiment, laboratory models were tested [*2*, *3*]. At present the most of the payloads were revised to EM's (engineering models), and it was found essential to ensure the basis of payload design and integration on the Shuttle pallet. In order to assemble the SEPAC instruments altogether on one floor, and to minimize the effect of the chamber wall, the test was carried out in the large space chamber at Tsukuba Space Center of NASDA (National Space Development Agency) from November 8 through 14, 1977. NASDA members joined in this test to study the satellite charging problem. The objectives of the experiment prepared by ISAS were

1) Functional tests of EBA (Electron Beam Accelerator) and MPD (Magnetoplasmadynamic Arcjet) enginnering models, and check of interference between these accelerators,
2) Detection of charging associated with electron beam ejection, and observation of charge neutralizing effect by MPD and NGP (Neutral Gas Plume) operations,
3) Cathode activation test of EBA and observation of cathode degradation due to contamination,
4) EMI (Electromagnetic Interference) measurement during EBA and MPD operations.
5) Observation of radiation emitted by beam and MPD plasma using MTV

(Monitor TV),

6) Functional test of diagnostic probes, and observation of radiation and wave excitation.

2. Facility and instruments

2.1 *Space Chamber*

The general view of NASDA space chamber is shown in Fig. 2.1.1. This chamber was designed to be dedicated to the thermal vacuum test of satellites, and the inner wall was mostly covered by cryogenic shrouds. The chamber pressure was as low as 2×10^{-7} Torr. Preparatory works were;

1) Shrouds and mirror of solar simulator were covered by alminum sheet to prevent the direct bombardment of electron and plasma beams,
2) SEPAC instruments were distributed on a cart as shown in Fig. 2.1.2, which had been assembled outside the chamber and then pulled inside, and of which the bottom was covered by aluminum sheet,
3) Many of the SEPAC instruments were electrically isolated from the chamber ground. The cables for these isolated instruments were connected to the outside cable through insulating flanges. Outside cables were also suspended with insulation from the wall and ceiling,
4) All the control units, power supplies, and recorders which were connected to the floating instruments were assembled in an insulating room outside the space chamber.

2.2 *Instruments*

SEPAC EM's installed inside the space chamber are listed below.

2.2.1 *EBA*

a. Impregnated cathode (2 units)

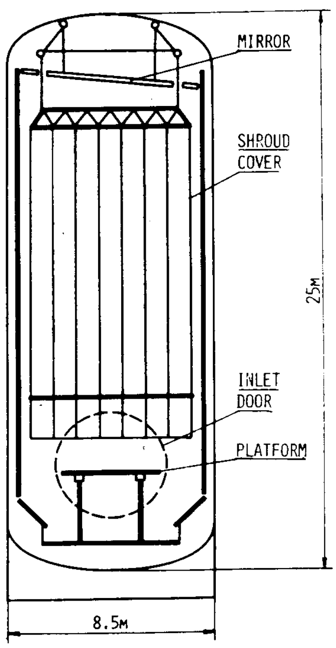


Fig. 2.1.1. NASDA Space Chamber

	voltage	7.5 kV
	Current	1.6 A
	Perveance	2.5
b.	Tungsten filament cathode	
	Voltage	6.0 kV
	Current	0.5 A
2.2.2	*MPD*	(2 units)
	Voltage (charge)	480 V
	(discharge)	240 V
	Current	8 kA
	Duration	1 msec
	Working gas (particles)	Ar (10^{19}/shot)
2.2.3	*DG*	
a.	FC (Faraday Cup)	
	Sensitivity	10^{-12} A
b.	RPA (Retarding Potential Analyzer)	
	Current Density	$10^{-6}-10^{-4}$ A/cm^2
	AC current	$10^{-7}-10^{-5}$ A
		(<4.2 MHz)
c.	LP (Langmuir Probe)	
	Bias	Fixed
d.	PHO (Photometer)	
	Wavelength	3914 Å, 5577 Å, 6300 Å

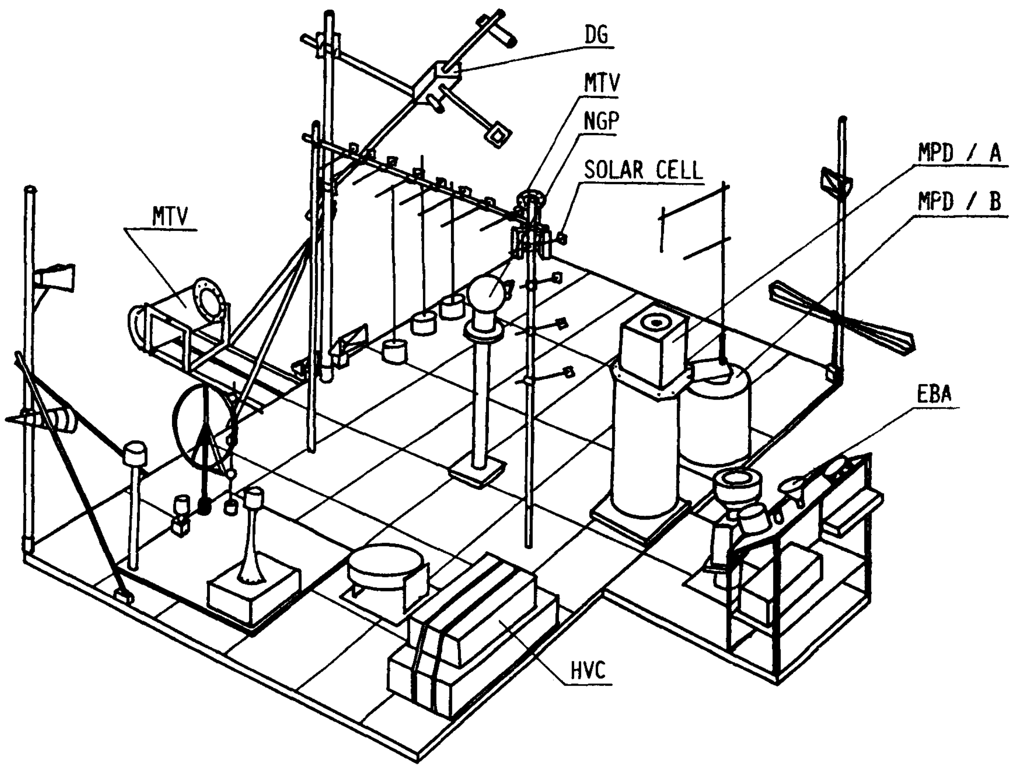


FIG. 2.1.2. SEPAC EM Arrangement

e. RF (Antenna)
   HF 100 KHz—15 MHz
   LF 500 Hz—10 kHz
f. FP (Floating Probe)
g. NIG (Nude Ionization Gauge)
   Pressure 10^{-3}—10^{-7} Torr
h. MTV (Monitor TV)

3. Test Procedure and Results

3.1 *EBA Test*

The following tests have been performed using the SEPAC EBA engineering models:

i) EBA electron gun performance to confirm the gun performance and to check the degradation due to the contamination poisoning,
ii) Floating experiment to simulate the space shuttle charging due to the electron beam emission in space,
iii) Charging neutralization experiment using the plasma beam from the MPD arcjet and the gas plume from the NGP.
iv) Performance test of high voltage converter (HVC) and gun power supply (GPS).

3.1.1 *EBA Electron Gun Performance*

Two units of SEPAC engineering model electron guns with an impregnated cathode and a tungusten cathode were used in the experiment. The latter was prepared for a fear that the gun with an impregnated cathode might not work well due to a contamination poisoning. The background pressure was always kept a little below 10^{-6} Torr, cryolgenically pumped.

The voltage-current characteristics of the electron gun is shown in Fig. 3.1.1. The designed perveance of the electron is 2.5×10^{-6} $(A/V^{3/2})$ (7.5 kV, 1.6 A

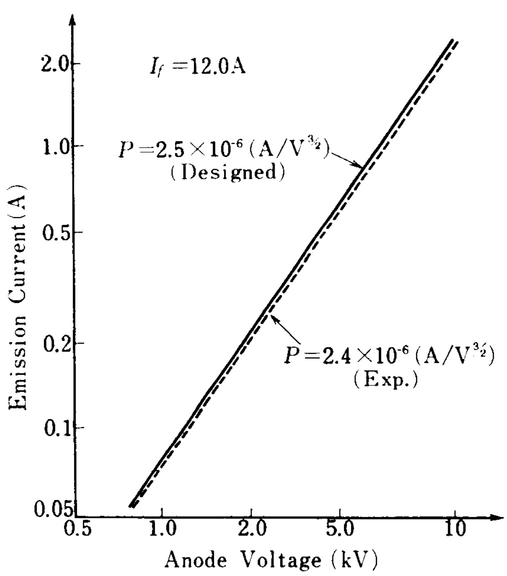


FIG. 3.1.1. EBA Current-Voltage Characteristics

max (+0, −0.4 A)) and the engineering model gun satisfies the specification. No degradation due to a contamination poisoning was observed during the experiment.

Previously, we experienced that the impregnated cathode degraded very rapidly in a vacuum chamber which was pumped by an oil diffusion pump though the pressure was always kept around 10^{-6} Torr. The difference may come from the cleanness of vacuum due to the cryogenic pumping in the case of this experiment. Moreover, no degradation was observed for one of the guns which had been left exposed to dry air for a week before the experiment. This was done to simulate the level I integration process of the Spacelab 1 at KSC. At present, the SEPAC EBA electron gun is to be kept sealed off in vacuum until the space shuttle orbiter closeout, which will be about 10 days before the liftoff. The seal will be opened just before the orbiter closeout and then it will be kept in a dry air atmosphere for about 10 days. The experimental results described above confirms that the electron gun with a Ba-impregnated cathode can be used on the space shuttle if the requirement of a clean vacuum and pressure below 10^{-6} Torr is satisfied. And it can withstand a rather poor environment during 10 days before the liftoff. More detailed data concerned with the electron gun performance is shown in Appendix A.

An interesting result was obtained in an unintended experiment related to the contamination poisoning. During the experiment, a certain part of a thermal control device for the high voltage converter (HVC) was overheated and a considerable amount of contaminant gas was evaporated from melted expoxy resin. The vacuum pressure at the vacuum monitor station did not change so much since it was located at a little distance from the heated spot, but it is expected that locally the pressure was raised considerably. No poisoning effect was observed in the electron gun performance though the gun was located near at the heated spot. It may be due to the fact that the electron gun is located inside the casing and since the mean free path at the pressure range of $10^{-6}-10^{-5}$ Torr is very long, the casing blocked the contaminant gas flow preventing the cathode surface to be exposed to it. On the space shuttle the ambient vacuum at the altitude of the shuttle orbit is far below 10^{-6} Torr but it is anticipated that a fairly large amount of gas leaks out from the cabin raising the ambient vacuum pressure on the shuttle. The above unintended experiment implies that on the shuttle, we can avoid the cathode contamination poisoning unless the cathode is faced to the contaminant gas flow.

The focussing and deflection capabilities of the engineering model were also verified by taking TV images of the beam. Unfortunately, the electron beam could not be observed at a pressure below 10^{-6} Torr by the TV. The image was taken at a vacuum pressure of around 10^{-5} Torr by using the neutral gas plume generator (NGP). Fig. 3.1.2 shows that the result. The deflection capability of more than 30 degrees and the focussing capability to a parallel beam with an appropriate focussing current are confirmed.

3.1.2 *Floating Experiment*

In order to simulate the space shuttle charging due to the electron beam emission, the whole EBA assembly was set floating from the chamber wall. The control and

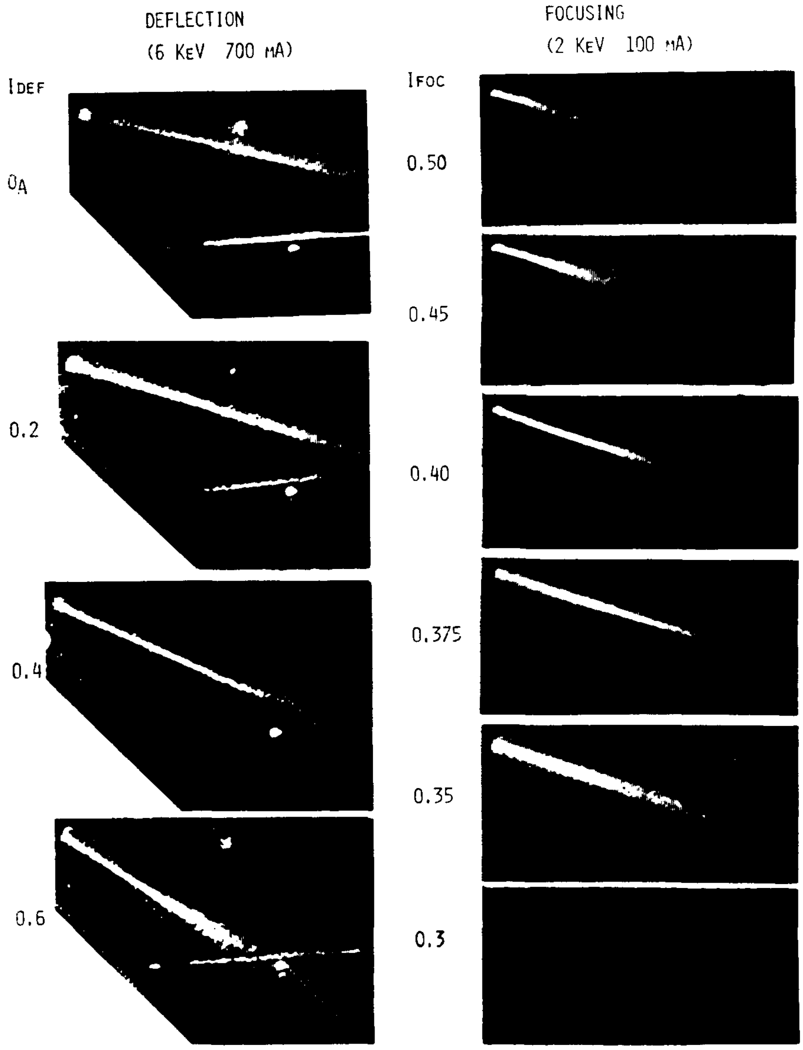


FIG. 3.1.2. Electron Beam Configuration monitered by MTV

display devices of the EBA assembly which were located external to the chamber were also set floating in an isolated control room. The floating volatge due to the beam emission was measured directly between the chamber wall and the common ground of the EBA system. Fig. 3.1.3 (a) shows the results for 5 keV 50 msec pulse beam when the beam current was changed. At a higher current, the floating voltage rises to the accelerating voltage immediately. At 0.6 mA, the beam current is not large enough so that the floating voltage stays at about 2 kV. The oscillation observed at the beginning of the pulse for higher currents is due to the characteristics of the high voltage power supply and it has no significance. When the beam is turned off, the floating voltage generally decays with a time constant determined by the capacitance between the chamber wall and the EBA common ground and the leak resistance between them. It should be noted, however, that the decay of the floating voltage immediately after the turn-off is very abrupt and it is more prominent for higher beam current. It is understood that when the beam is emitted, it ionizes the background gas and a plasma is formed. The time constant of the abrupt decay is determined by the charging neutralization effect of the plasma.

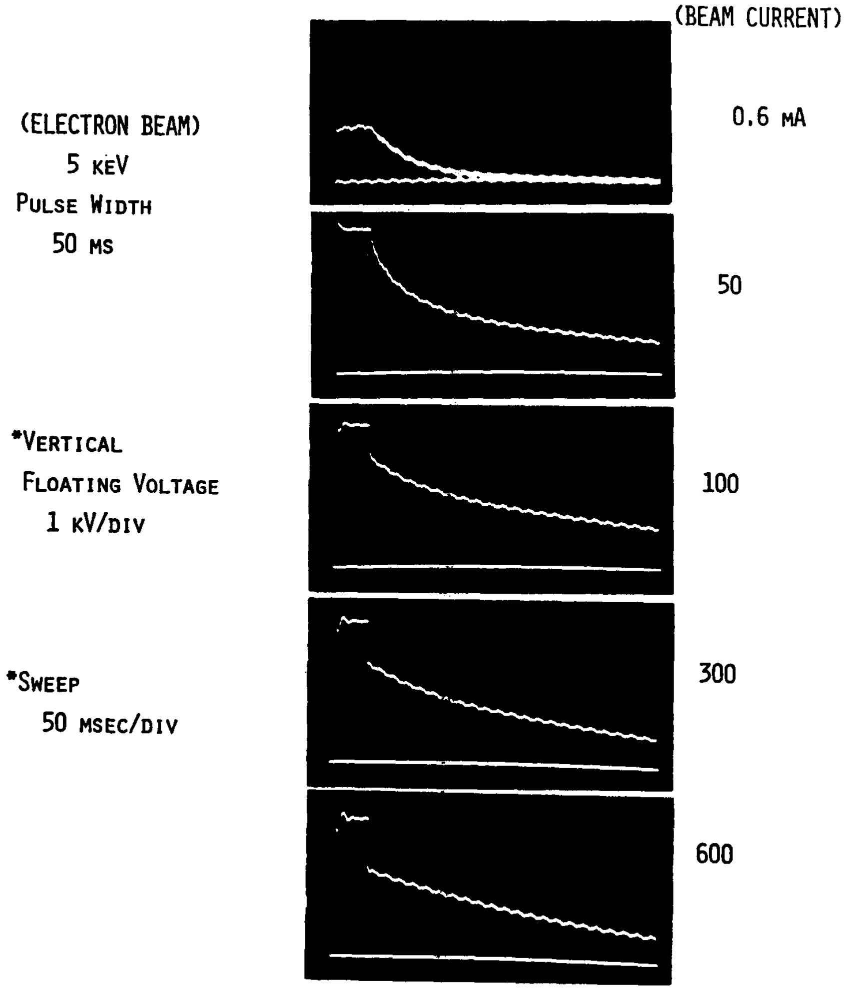


FIG. 3.1.3. (a) EBA Potential in floating mode operation

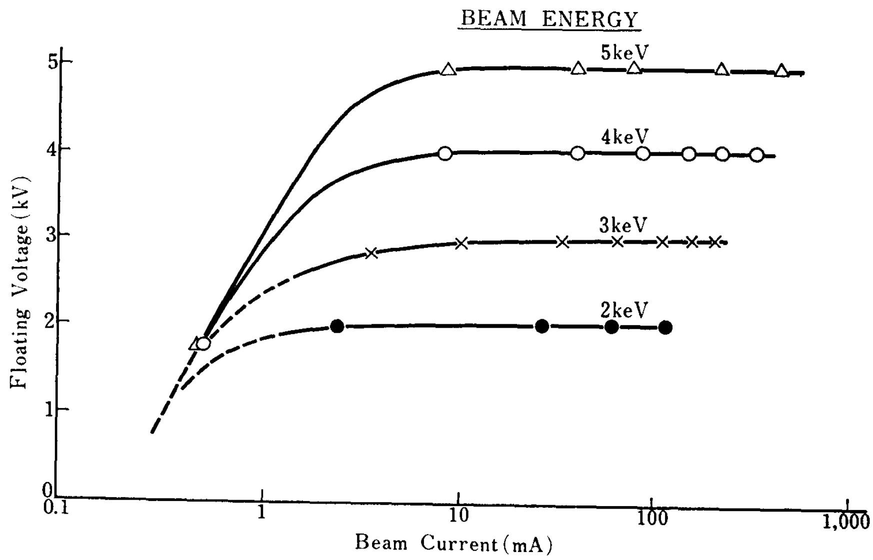


FIG. 3.1..3(b) The dependence of floating voltage on beam current. The floating voltage coincides with the beam acceleration voltage when the beam current is large enough.

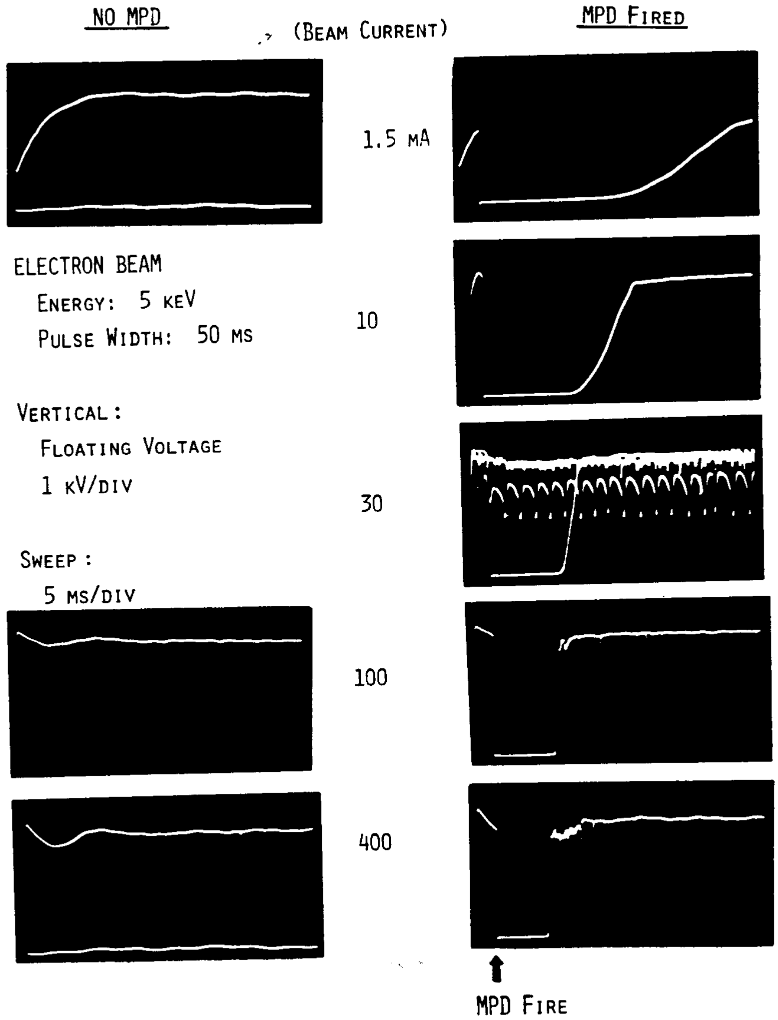


FIG. 3.1.4. (a) EBA charge neutralization by MPD Arcjet

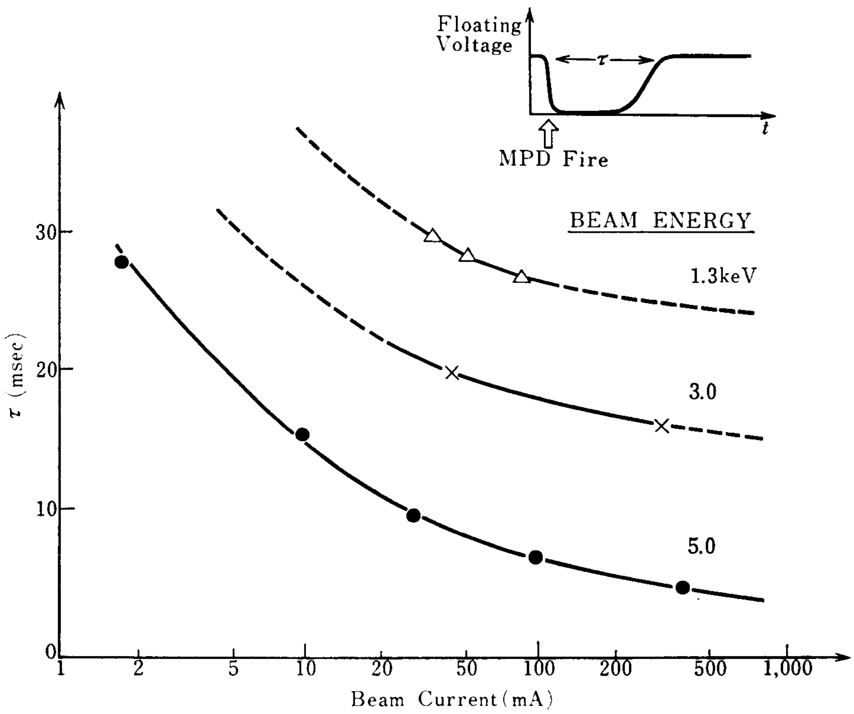


FIG. 3.1.4. (b) Neutralization time by MPD plasma

For higher beam current a more dense plasma is created and it survives longer so that the floating voltage drops more for higher current. The floating voltage during the beam emission is plotted as a function of the beam current for various values of the accelerating voltage in Fig. 3.1.3. (b). The potential of the EBA assembly rose up to the beam accelerating voltage immediately for a beam current above several mA.

3.1.3 *Charging Neutralization Experiment*

As was described in Section 3.1.2, the potential of the EBA assembly rose to the beam acceleration voltage in the floating mode experiment if the beam current was above several mA. In order to neutralize the charging, a plasma stream from MPD-arjcet and a neutral gas plume from NGP were used.

3.1.3.1 *MPD/EBA Experiment*

When a plasma stream is ejected from a spacecraft into space together with an electron beam, electrons in the plasma stream return to the spacecraft and ions go out with the electron beam neutralizing the spacecraft charging. In each shot MPD arcjet can create a plasma of about 10^{19} electron and ion pairs. When it expands to a size of 10 meters, the created ambient plasma density will be about $10^{10}/cm^3$.

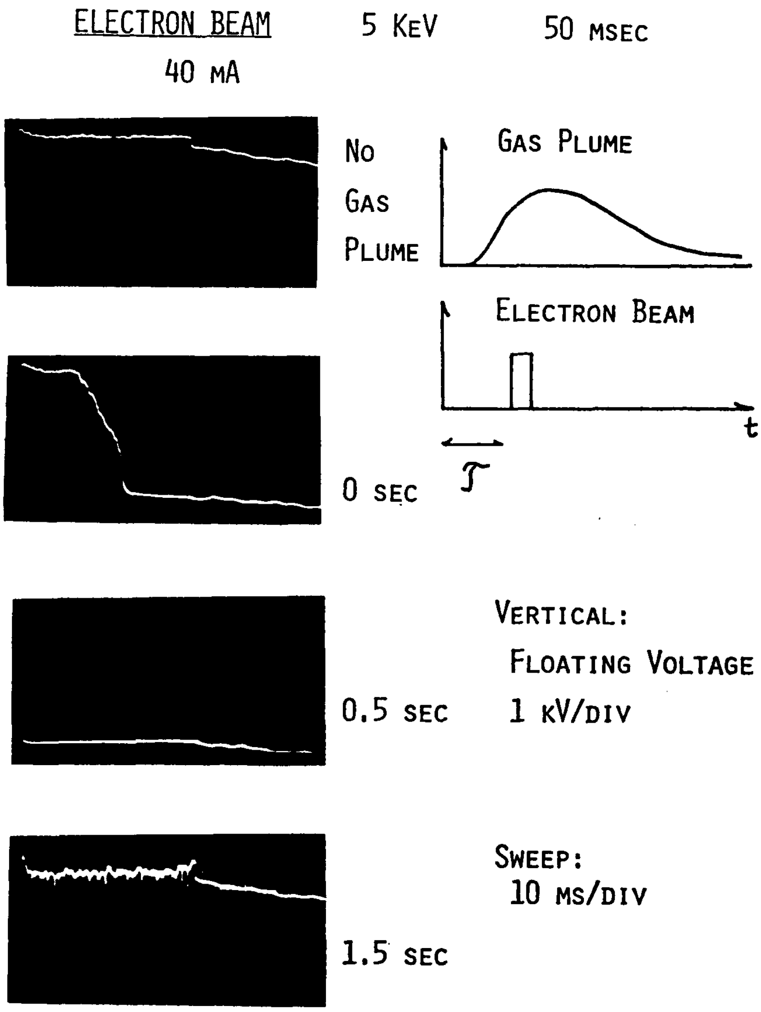


FIG. 3.1.5. (a) Neutralization by NGP operation

From this plasma, we can expect to collect a return electron current of mA/cm^2, which is enough to neutralize the charging. In the present experiment, an electron beam of pulse width of 50 msec was emitted and about 3 msec later, the MPD arcjet is fired. The result is shown in Fig. 3.1.4 (a). The floating voltage rises nearly to the beam accelerating voltage within 3 msce and keeps it. When the MPD arcjet is fired, the floating voltage drops suddenly to almost zero. It lasts about 20–50 msec depending on the beam current and voltage. The time duration of the charging neutralization by the MPD plasma as a function of the beam current and accelerating voltage is shown in Fig. 3.1.4 (b). The charging neutralization effect by the MPD plasma lasts longer for lower beam current and lower beam voltage. It may be due to the decay of MPD plasma at the wall of the chamber. As the beam voltage and current are increased, the amount of charge to be neutralized increases so that the supply of the compensating charge from the plasma cannot last long. This effect may come from the finiteness of the chamber we used in this experiment and we expect in the space shuttle experiment a much longer neutralization time by the MPD plasma.

3.1.3.2 *NGP/EBA Experiment*

In the SL–1 experiment, a neutral gas plume (cloud) is to be created by the NGP. The beam passing through the gas cloud ionizes the gas producing a plasma and electrons of the produced plasma return to the shuttle neutralizing the charging.

In the present experiment, a gas plume was generated by opening the valve of NGP for 0.1 sec. A 50 msec pulsed electron beam was emitted from EBA at various timing with respect to the opening of the NGP valve. The result is shown in Fig. 3.1.5(a). When the electron beam is emitted at the same time with the opening of the NGP valve, the floating voltage of the EBA assembly keeps the beam voltage level for a while since it takes about 10 to 20 msec for the gas to

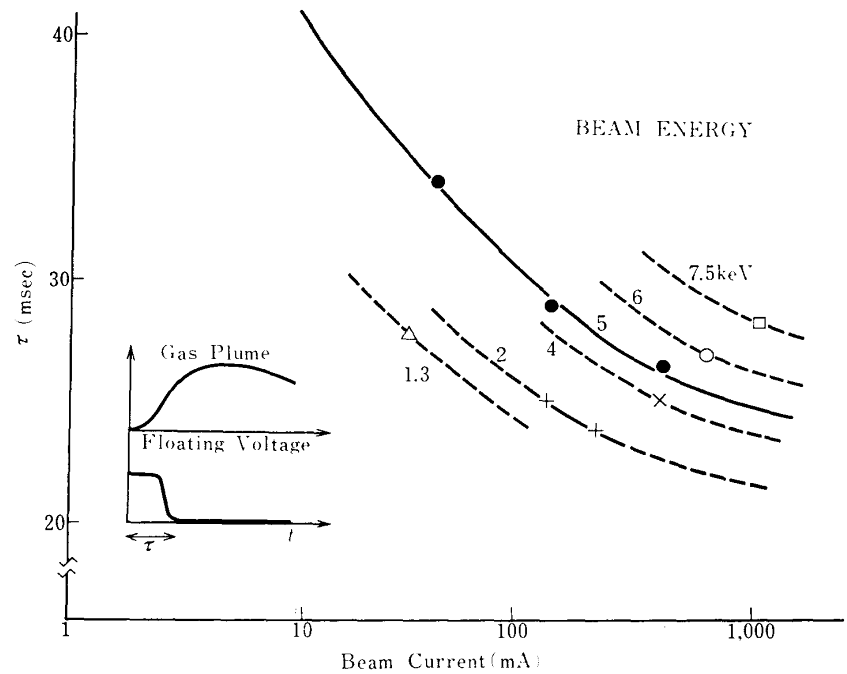


FIG. 3.1.5. (b) Time lag of neutralization by NGP

come out and expand. When a gas cloud of enough density is created, the beam ionizes the gas forming a plasma cloud around the beam and the floating voltage drops to zero (around 40 msec in the case of Fig. 3.1.5 (a)). The gas density in the chamber increases almost linearly until the end of closeout of the NGP valve and decays gradually. The neutralizing effect of the NGP gas plume last more than 1 sec. For all electron beam pulses that are emitted during that time interval, the floating potential drops to zero completely. To see the dependence of the charging neutralization effect on the beam current and voltage, the time from the opening of the gas valve when the charging neutralization becomes effective is plotted in Fig. 3.1.5. (b). The neutralization effect is more effective for a lower beam voltage and higher beam current. The dependence on the beam current is contrary to that for MPD plasma. It implies that the creation of the plasma by the beam is a non-linear phenomenon and a higher current beam produces more plasma. The dependence on the beam voltage might be natural because a higher beam voltage results in a higher floating voltage and the amount of charge to be collected from the plasma neutralization increases.

1 sec charging neutralization time is enough for the SL–1 experiment, however, it should be noted that the present experiment was conducted in a finite size vacuum chamber and the gas accumlates in that space and stays there until it is pumped out. The time constant of 1 sec is actually determined by the pumping capability of the vacuum chamber. Though the chamber used in this experiment is large, it is not enough to simulate the situation on the space shuttle completely.

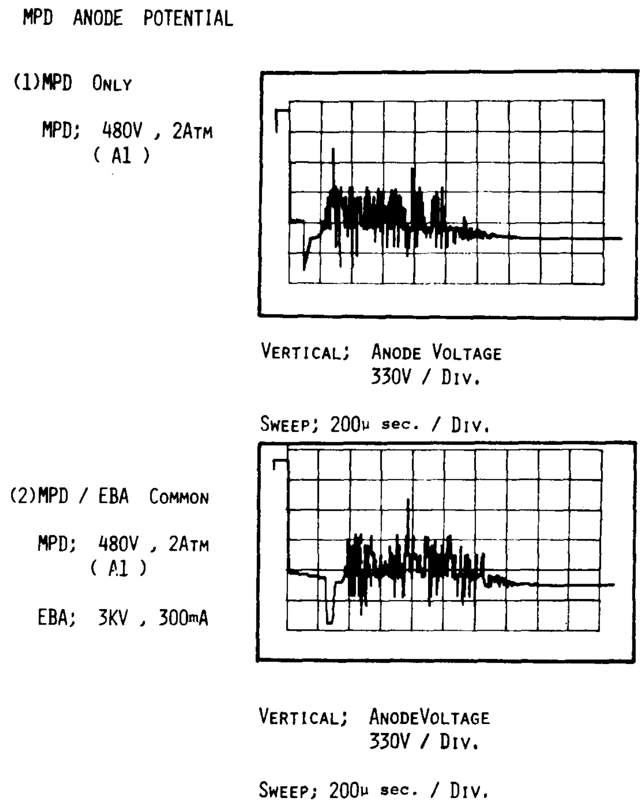


FIG. 3.2.1. MPD Anode Potential

3.1.4 *Other Experimental Results*

1. Performance Test of HVC (EM and GPS (BBM))

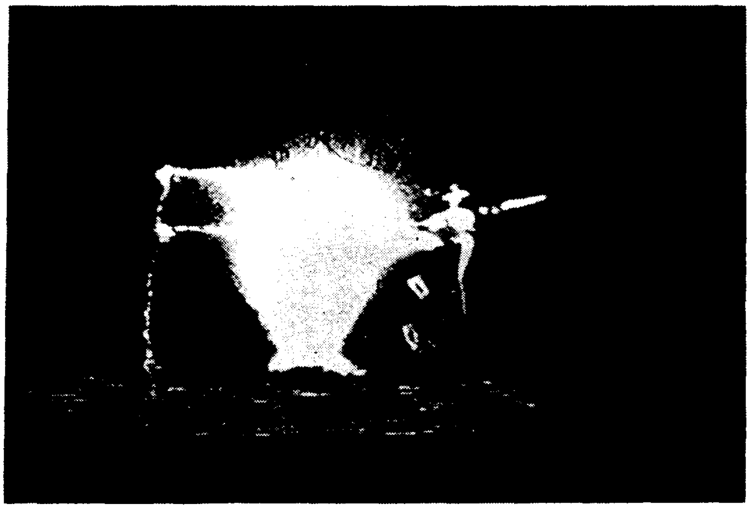
The engineering model of HVC worked fine at a level of 5 kV 800 mA even in a very noisy circumstance of floating mode experiment. The performance of a bread board model of GPS (HTR and MOD) was also tested.

2. Return current distribution was measured in both grounded and floating modes but since the instrument configuration were so complex and we could not say definitely about the return current distribution.

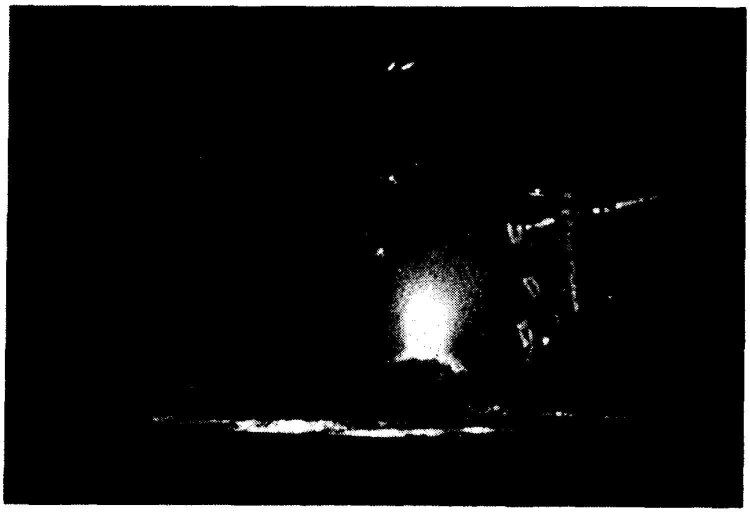
3.2 *MPD Test*

3.2.1 *Interaction between EBA and MPD*

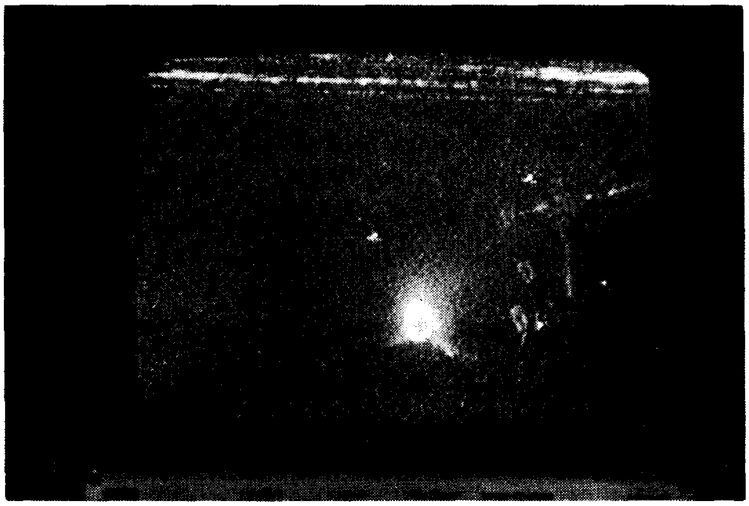
During the simultaneous operation of MPD and EBA, the effect of beam-plasma coupling on MPD was monitored by the measurement of MPD anode potential. Since the arc discharge circuit was isolated from the floating ground simulating the Shuttle pallet, it was afraid of that a large potential difference might appear inside the CAP container and cause damage to CAP components if the MPD-HD (Head) potential were to come close to the beam potential. The



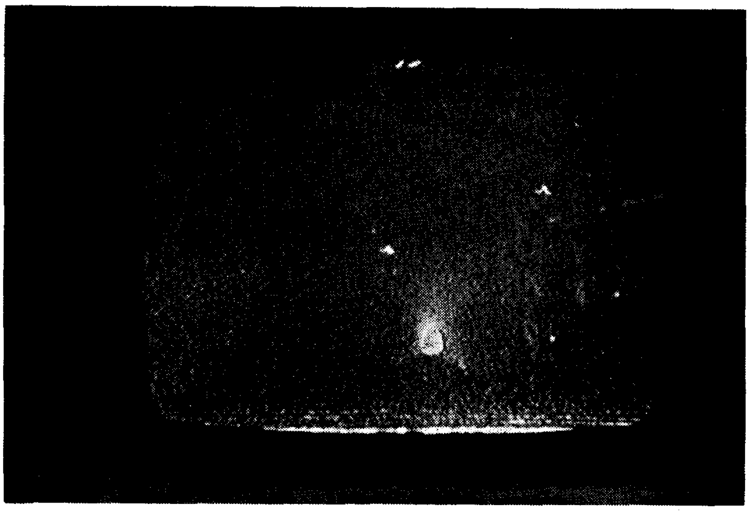
(a) 1st frame



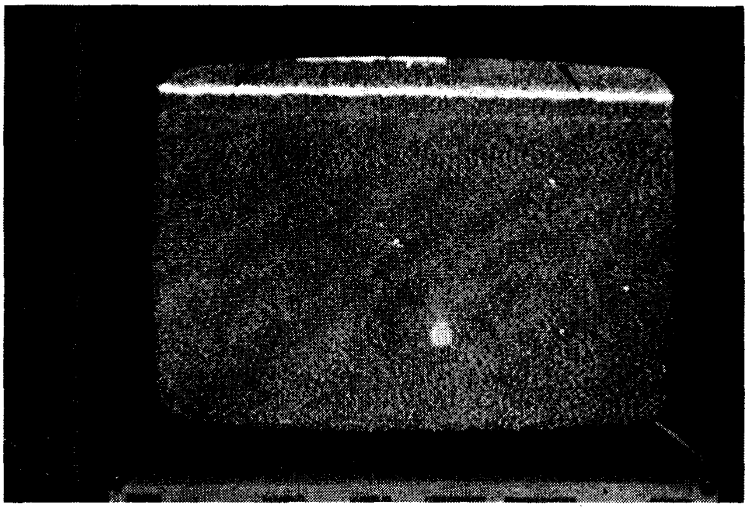
(b) 2nd frame



(c) 3rd frame



(d) 4th frame



(e) 5th frame

FIG. 3.2.2. Plasma Plume

MPD anode potential was measured with and without EBA operation. The separation distance between these two accelerators was 2.0 m, which was a little shorter than SEPAC requirement. As shown in Fig. 3.2.1, the anode potential, although high frequency noise is superposed, is close to the arc voltage on the average, and is almost unaffected by the EBA simultaneous operaion. EBA beam emission was also found to be insensitive to the MPD plasma as well as the neutral working gas. From these results, little interference between EBA and MPD was concluded.

3.2.2 *Contamination Measurement*

The contamination of solar cell surface exposed to the MPD plasma was measured by the light transmission. After 700 shots of MPD arcjet, which are the maximum number expected for Spacelab 1 experiment, the contamination level was measured. The most severe surface degradation was found for a cell placed inside 30° half apex angle and 1 m downstream of jet exit. For this cell, 30% decrease in shorting current and 2% decrease in open voltage were found [*4*]. The MPD EM was operated in an underfed condition of working gas throughout NASDA chamber test. The contamination will be relaxed for the flight model with optimum gas flow rate.

3.2.3 *Plasma Plume Observation*

The plasma plume was observed by MTV EM placed inside the chamber. The features of the plume on TV screen were photographed and shown in Fig. 3.2.2. The plasma luminosity at the jet exit appears on more than four TV frames. Such long-lasting view may be caused by the residual luminescence on TV image tube. The residual luminescence suggested by TV manufacturer is 8% of the initial value at 0.1 sec after the exposure.

3.2.4 *Experimental parameters of MPD and NGP Operations*

Experimental titles and parameters for MPD arcjet operation are given in Appendix B. Experimental parameters for MPD arcjet are

- DLYT: Delay time of trigger discharge measured from FAV start,
- FAVP: Argon gas pressure of FAV reservoir,
- CHGV1: Charging voltage of CAP PFN,

and those for NGP are

- EJNP: Secondary pressure of NGP,
- EJNT: Pulse width of gas jet.

EJNT was set constant at 3.6 ATM.

3.3 *EMI test*

3.3.1 *Scope*

Major purposes of the test are verification of EBA/MPD function and detection of charge up when EBA firing and its neutralization by MPD/NGP firing occur. At the same time, electromagnetic noise generated by EBA/MPD was measured. Since no special precaution for EMI suppression was made, all data were above the EMI specification. Test results should be treated as preliminary ones. It should be stressed that no malfunction occurred under such a heavy noise environment.

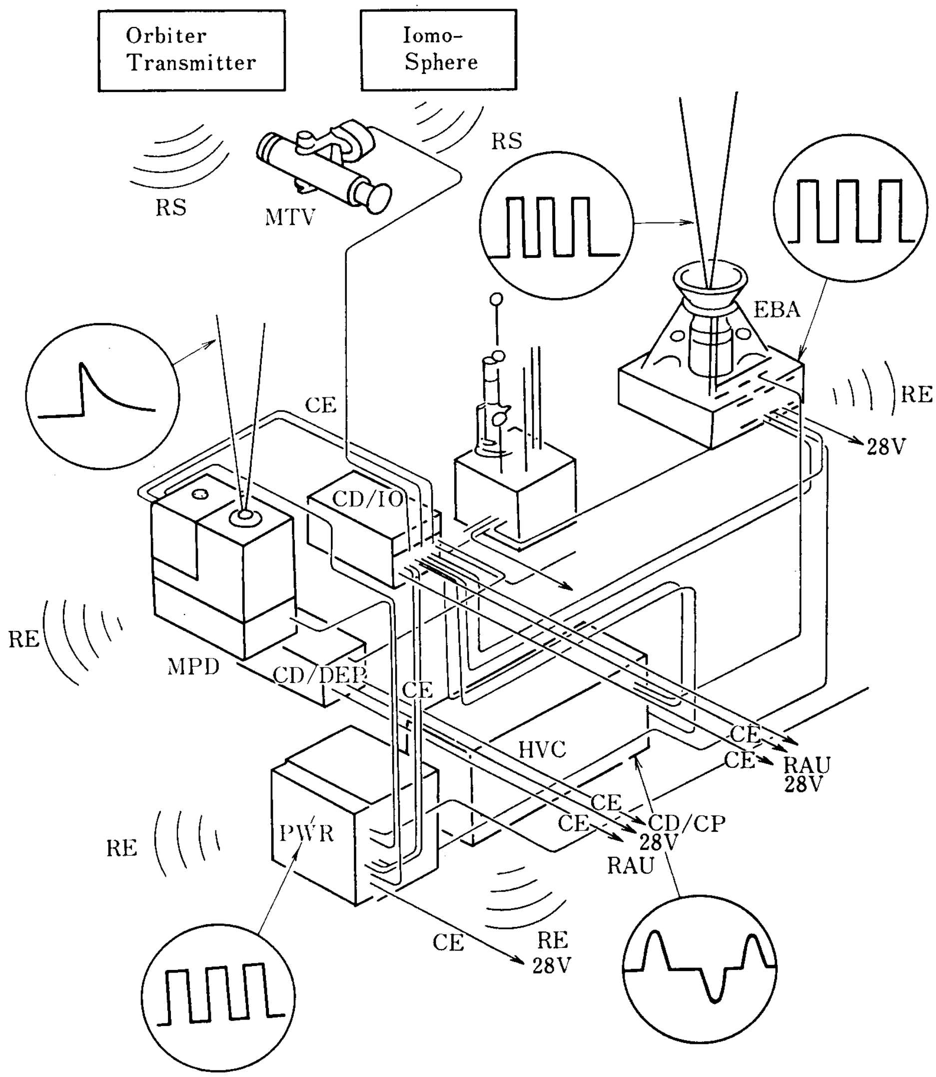


FIG. 3.3.1. Electromagnetic Environment

3.3.2 *Applicable documents*

SPACELAB PAYLOAD ACCOMODATION HANDBOOK
MIL-STD-462 ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS, MEASUREMENT OF.
INTERNAL ESTEC WORKING PAPER NO. 989
SEPAC NASDA CHAMBER TEST PROCEDURE

3.3.3 *Brief description of EBA/MPD nosie generation*

Electromagnetic noises generated from SEPAC system are schematically shown in Fig. 3.3.1. As EBA and MPD are the devices ejecting charged particle, noises originating from plasma oscillation, electron cyclotron resonance, ion cyclotron resonance and ion acoustic wave are regarded as scientific ones and will be exempted from obeying the EMI specification. But noises from their power supplies and wire harness must be controlled.

A charger in PWR assembly is a push-pull type DC/DC converter and generates rectangular wave. Its frequency varies from 5 kHz to 50 kHz depending on load characteristics. Output power of the charger is 0.5 kW.

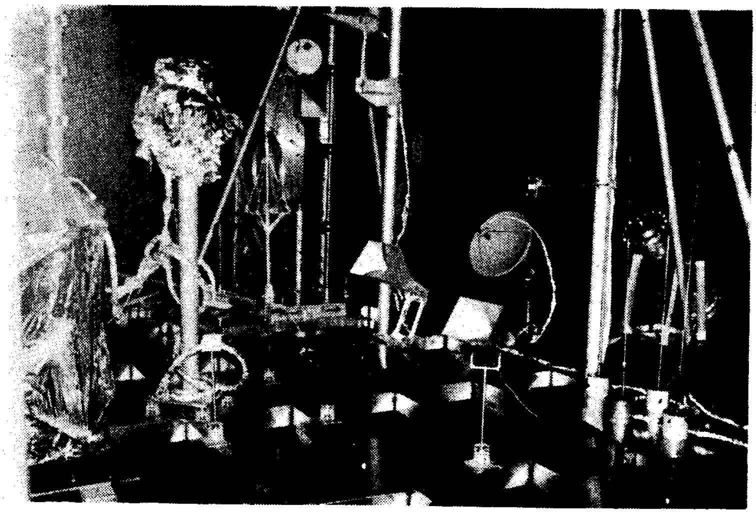


FIG. 3.3.2. (a) Instrument arrangement

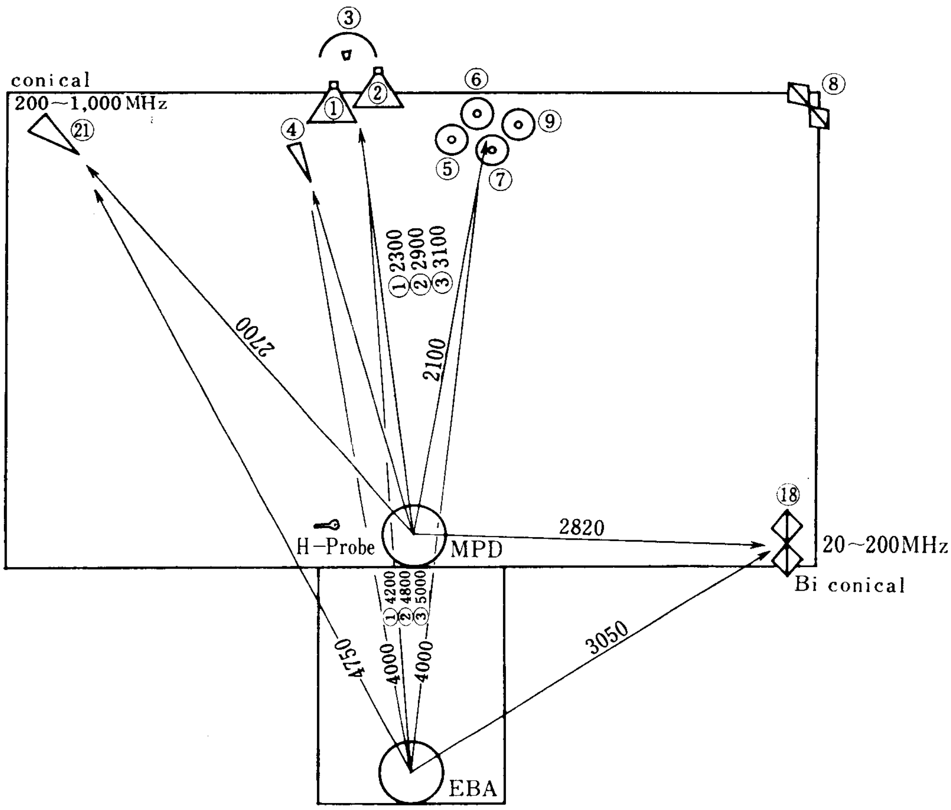


FIG. 3.3.2. (b) Antenna location

HVC is a 6-series-thyrister DC/DC converter. It can supply 12.5 kW power to EBA Head. Current wave form is quasi-sinusoidal and electromagnetic noise from the HVC can be expected to be relatively mild. Switching frequency is 15 kHz at max. load.

An EBA cathode heater power is a push-pull type DC/DC converter and its switching frequency is fixed at 15 kHz. Max. output power is designed to be 200 W.

±15 V and 5 V logic power supplies contained in PWR and GPS are also switching regulators. Noises from above converters are emitted at low frequency regions (<1 MHz). Spike noise from TTL or C-MOS logic is expected to appear from 1 MHz to 1 GHz.

3.3.4 *Measurement items*

1) EBA radiative emission 0.15 MHz to 10 GHz
2) MPD radiative emission 0.15 MHz to 10 GHz
3) MPD conductive emission 0.15 MHz to 30 MHz

3.3.5 *Test equipment*

Item	Manufacturer	Model
EMI RECEIVER	Singer	NM–17/27, NM–37/57
SPECTRUM ANALYZER	HP	HP–140T
SIGNAL GENERATOR	HP	605E
ROD ANTENNA	Singer	VA–105
BICONICAL ANTENNA	Singer	94455–1
LOG SPIRAL ANTENNA	Singer	93440–1
HORN ANTENNA	Singer	1010, 1020, 1001
CURRENT PROBE	Singer	CP–105 A
	TEK.	P6042

3.3.6 *Test setup*

EBA/MPD assemblies, MTV, DG and EMI measurement antennas are set in

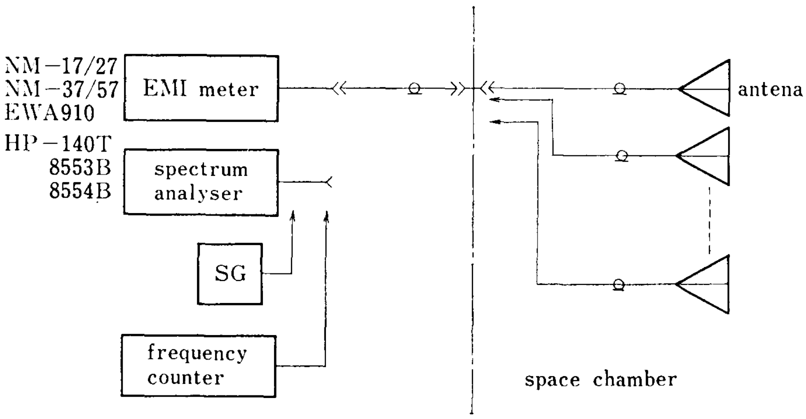


FIG. 3.3.3. (a) Block diagram of RE measuring setup

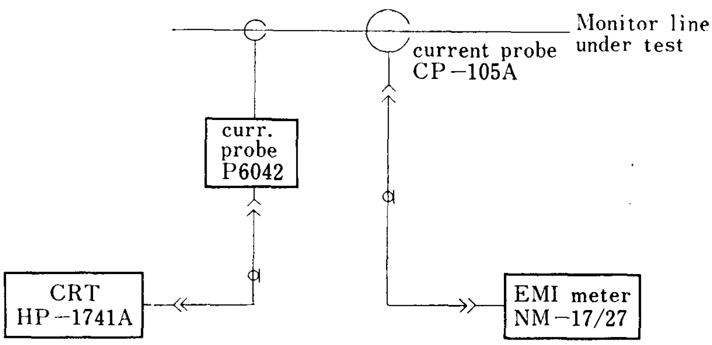


FIG. 3.3.3. (b) CE measuring setup

NASDA space chamber whose dimension is shown in Fig. 2.1.1. Disposition of SEPAC AL or DG subsystem is generally shown in Fig. 2.1.2. More detailed measurement setups are shown in Fig. 3.3.2(a) and (b). The BAT is set outside the chamber. Standby power supply is provided outside the chamber for EBA Gun. It will be energized when inside HVC fails. Block diagrams of RE measurement and CE measurement are shown in Fig. 3.3.3(a) and (b), respectively. Test was conducted in accordance with MIL-STD-462.

3.3.7 *Test results*

1) EBA RE

Broadband noise plot is shown in Fig. 3.3.4(a) and narrow band one is shown

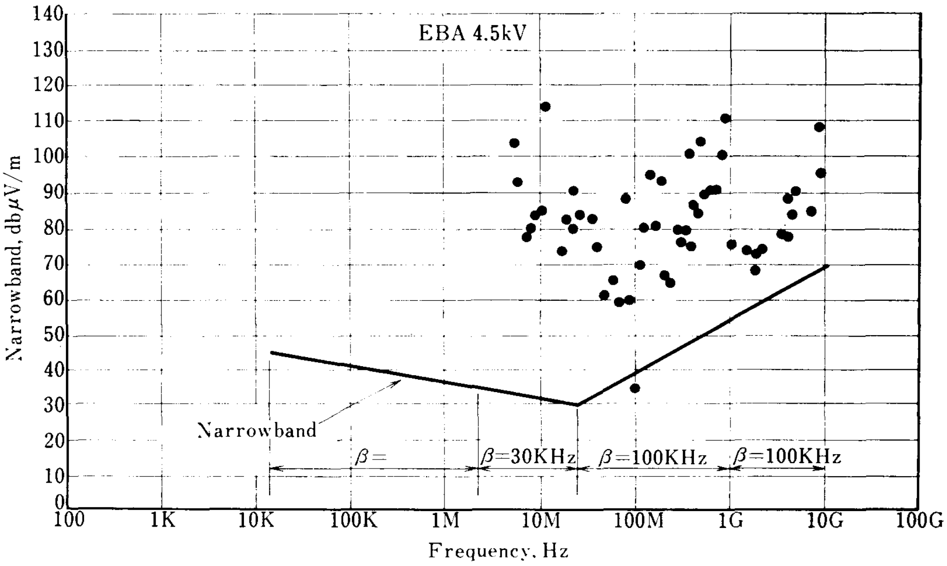


FIG. 3.3.4. (a) Narrow band noise spectrum of EBA

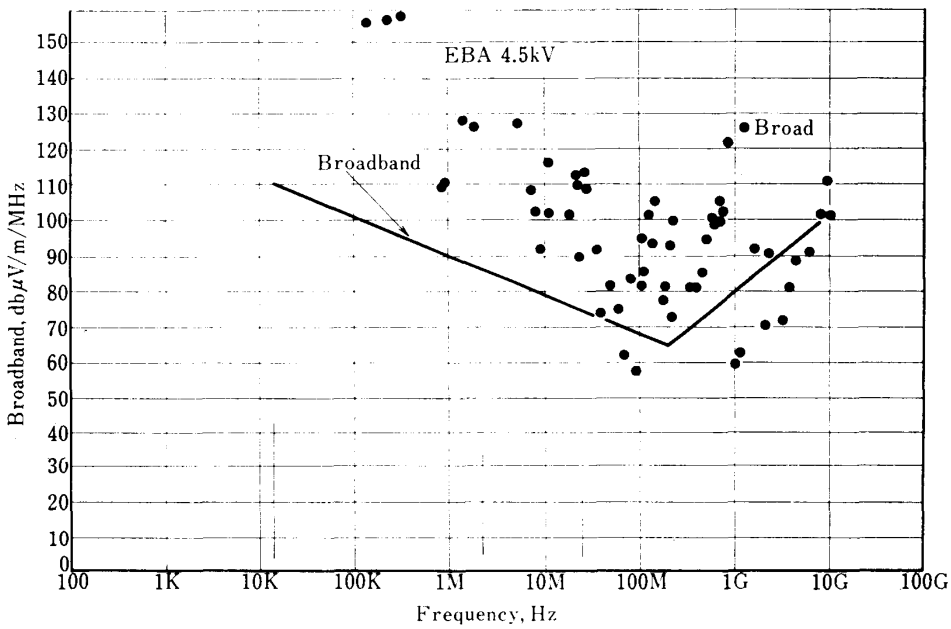


FIG. 3.3.4. (b) Broadband noise spectrum of EBA

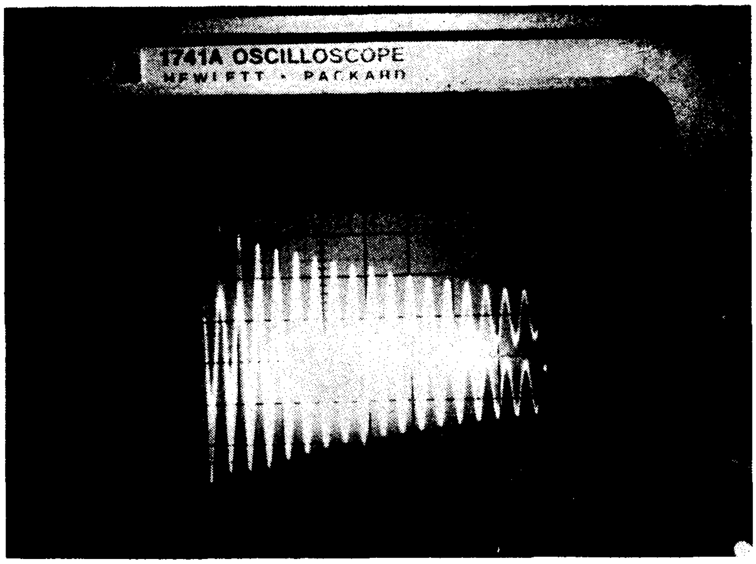


FIG. 3.3.5. EBA RE time domain wave form,
V: 0.005 V/div
H: 10 sec/div
Antenna: Lod antenna (0.15-0.35 MHz)
EBA: E-3 mode

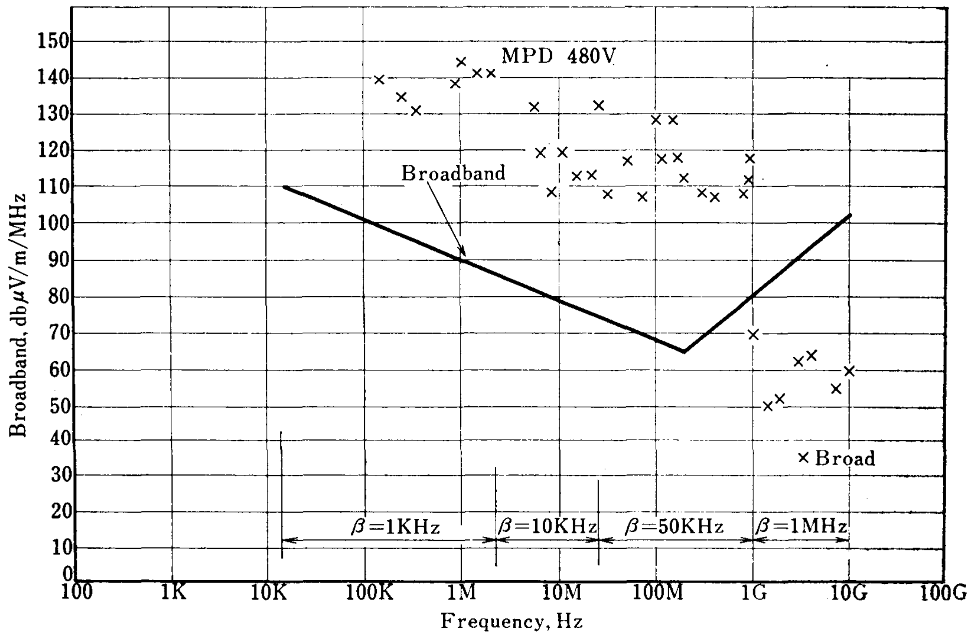


FIG. 3.3.6. (a) Broadband noise spectrum of MPD

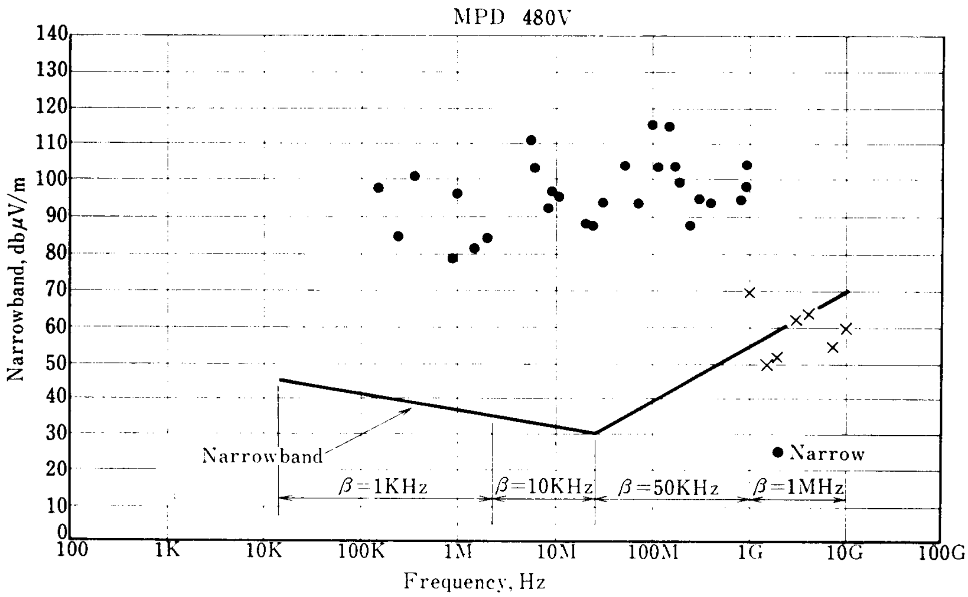


FIG. 3.3.6. (b) Narrowband noise spectrum of MPD

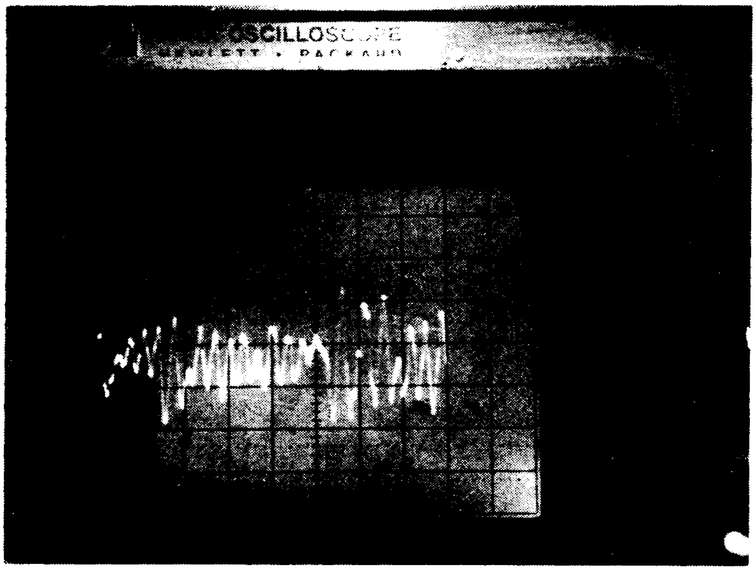


FIG. 3.3.7. MPD RE time domain wave form,
V: 0.02 V/div
H: 1 μsec/div
Antenna: Lod antenna (0.87-2 MHz)

in Fig. 3.3.4(b). A time domain photograph is also shown in Fig. 3.3.5. From above data, it is recognized that coherent noise is added to incoherent ones and strong emission at 0.2 MHz appears. Strong emission may result from switching noise of HVC. For EBA system, standby power supply and change over switch are provided outside the chamber. Therefore, power and signal lines are partially coupled. It may be the cause of strong interferance level.

2) MPD RE

As beam duration time of MPD is about 1-msec., point-by-point measurement is taken. Both broadband and narrow band radiative electromagnetic interferance data are shown in Fig. 3.3.6(a) and Fig. 3.3.6(b). The results are above the specification. Fig. 3.3.7 shows the data for time domain. Noise from MPD seems to be incoherent and it is relatively uniformly distributed for broad frequency region. It has not been clearly explained

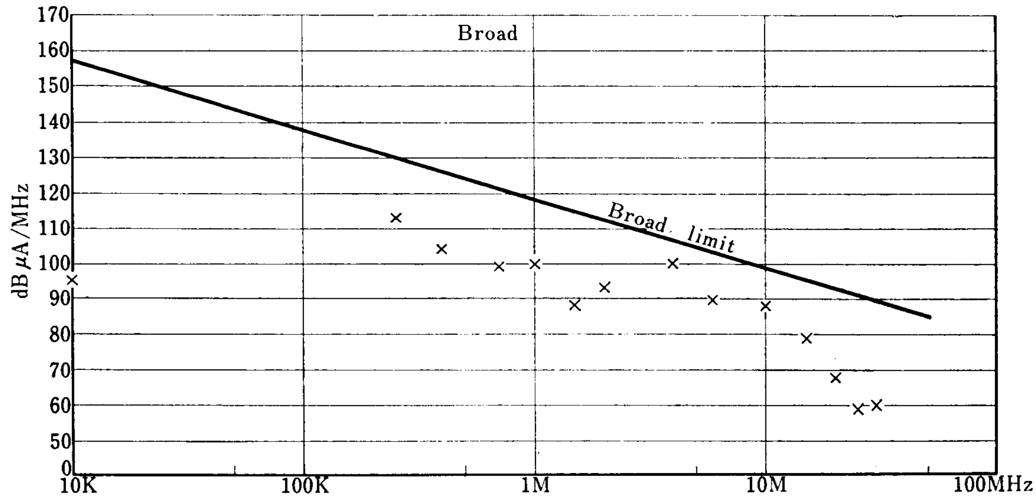


FIG. 3.3.8. (a) MPD power line CE

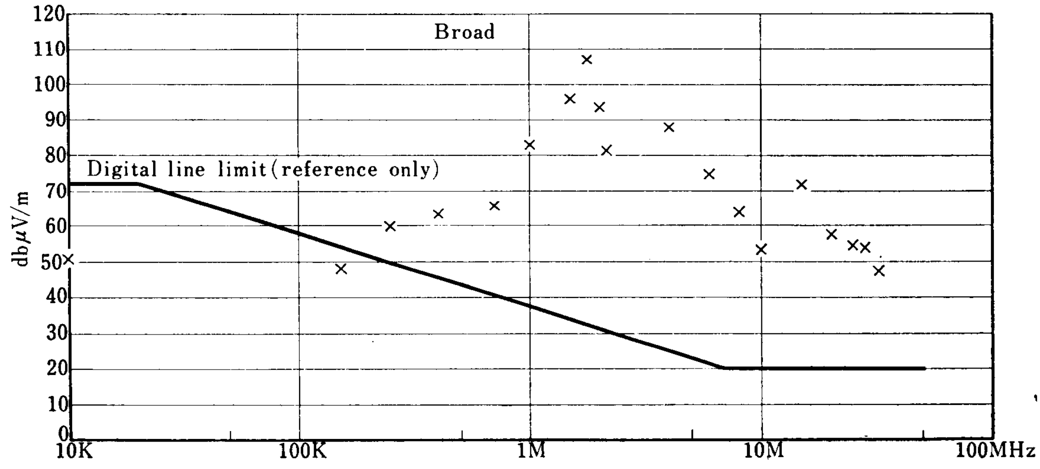


FIG. 3.3.8. (b) MPD telemetry line CE

whether the noise generated results from plasma oscillation or uncontrolled noise from wires or power supplies.

3) MPD CE

Results obtained are shown in Fig. 3.3.8(a) for power line and Fig. 3.3.8(b) for telemetry line.

4) Antenna calibration

After the EMI test, antenna calibration was made. It is concluded that space chamber resonance effect appeared below 30 MHz.

3.3.8 *EMI consideration*

All test results are above the Spacelab MEI specification. Following items are considered as the causes.

1) EBA/MPD assemblies tested were designed without any considerations for EMI. Therefore, it is expected that they are above the Spacelab specification to a certain extent.
2) Main objective of this chamber test is to verify EBA/MPD function in large vacuum chamber. Sufficient consideration is not taken for grounding, bonding, wiring and location of components. Especially, it is suspected that the test cables were the prime source of radiation, judging from the test results.
3) Noise estimate from MTV and DG was not made. For the former, noise emitted at high frequency region is suspected.
4) Arrangement of antennas was not optimized.
5) All GSE prepared for the test were not electromagnetically compatible.
6) Reflection of wave at space chamber wall has not been quantitatively estimated. Evaluation of reflection will be required.

Under these severe noise environment, EBA/MPD was operated without malfunction. It proves that these subsystem are relatively non-susceptible to noise.

In order to make next EMI test result to an acceptable level, following measures will be taken.

1) EBA/MPD PM is designed and fablicated under EMC CONTROL PLAN of which requirments are provided by ISAS.
2) EBA/MPD PM will be tested electromagnetically before next NASDA chamber test and must be below the specification.
3) Enough consideration for EMI shall be taken for any GSE used at NASDA test site.
4) Electron or plasma beam emitted from EBA/MPD is exempted from EMI control specification. But rise and fall times of the pulse must be as large as possible, if scientific experiment permits.

4. ISAS TEST PARTICIPANTS

The member of ISAS team participated in this experiment is listed below.

- General Test Conductor — T. Obayashi
- Test Manager — K. Kuriki

◦ Electron Beam Accelerator	
Manager	N. Kawashima
Member	S. Sasaki
	A. Yamori
	TOSHIBA Elec. Co.
◦ MPD Arcjet/Neutral Gas Plume	
Manager	K. Kuriki
Member	K. Nakamaru
	Y. Shimizu
	T. Araki
	MITSUBISHI Elec. Co.
	MEISEI Elec. Co.
	MITSUBISHI Heavy Ind.
◦ Diagnostic Probe	
Manager	M. Ejiri
Member	S. Miyatake
	MEISEI Elec. Co.
	TOSHIBA Elec. Co.
◦ EMI Test	
Manager	I. Kudo
Member	MITSUBISHI Elec. Co.
◦ Mechanical Structure	
Manager	T. Araki
Member	K. Kuriki
	USHIO Elec. Co.
	YUSHIYA Man. Co.
◦ Safety	
Manager (Mechanical)	T. Araki
Manager (Electrical)	N. Kawashima

5. Summary

SEPAC EM's were successfully operated in the NASDA Space Chamber. Experimental results were

1) EMI data were obtained,
2) 2.0 m EBA/MPD separation distance was sufficient to preclude hazardous interferance between these accelerators,
3) EBA cathode was successfully activated even after one-week exposure to air, and no degradation due to the contamination was observed during the test,
4) Neutralizing effect of MPD and NGP was ensured in the floating mode operation,
5) Features of plasma flow and electron beam were monitored by MTV EM.

Department of Space Science
Institute of Space and Aeronautical Science
University of Tokyo
May 24, 1978

References

[1] T. Obayashi, N. Kawashima, K. Kuriki, M. Nagatomo, I. Kudo, K. Ninomiya, M. Ejiri, and S. Sasaki, Proc. 12th Int'l. Symp. Space Tech. Sci., p. 911, 1977.
[2] S. Sasaki, N. Kawashima, K. Kuriki, K. Nakamaru, M. Nagatomo, T. Obayashi, H. Misawa, T. Okamoto, and K. Goma, ISAS Research Note No. 34, 1977.
[3] K. Kuriki, K. Nakamaru, H. Suzuki, S. Sasaki, N. Kawashima, M. Nagatomo, and T. Obayashi, ISAS Research Note No. 33, 1977.
[4] M. Ueda et al., NASDA ET-53-1009, 1978.

Appendix A

SEPAC EBA
ELECTRON BEAM EMISSION PERFORMANCE AT NASDA TSUKUBA SPACE CENTER, VACUUM CHAMBER EXPERIMENT

SEPAC EM vacuum chamber expeirment was performed at NASDA Tsukuba Space Center in November 1977. This Appendix describes the experimental results on electron beam emission of EBA (Electron Beam Accelerator). A satisfactory EBA performance was verified, that is:

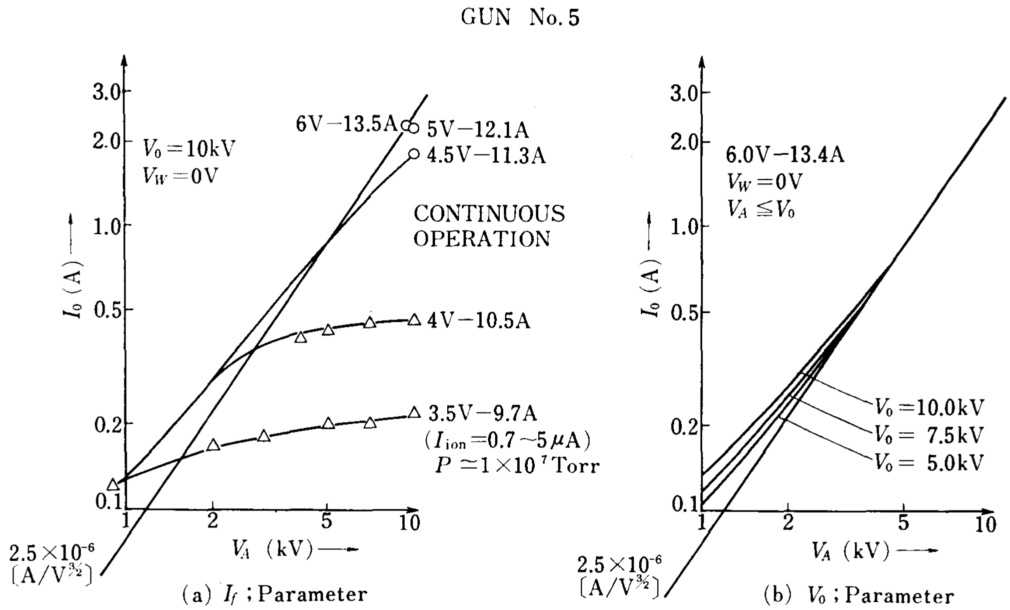
1) Gun perveance, $2.3 \sim 2.5 \times 10^{-6}$ (A/V$^{3/2}$) (7.5 kV/1.6 A) was verified.
2) No degradation due to contamination poisoning was observed during the experiment (for 1 week).
3) No degradation was observed for one of two tested electron guns which had been kept exposed to air (dry) for one week before the experiment, in order to simulate the level I integration process.

1. Electron Gun

Two electron guns were tested in this experiment (Gun No. 5–Main and Gun No. 4–Subsiduary). The cathode is a 20 mm dia. impregnated cathode. Gun No. 5 is equipped with focusing and deflection coils. Prior to this experiment, good beam emission characteristics of the gun No. 5 and No. 4 were verified, as shown in Fig. A–1 and Fig. A–2, in the form of vacuum tube (with dummy collector) which was sealed off after fully exhausting and baking out (450°C × 100 Hrs.)

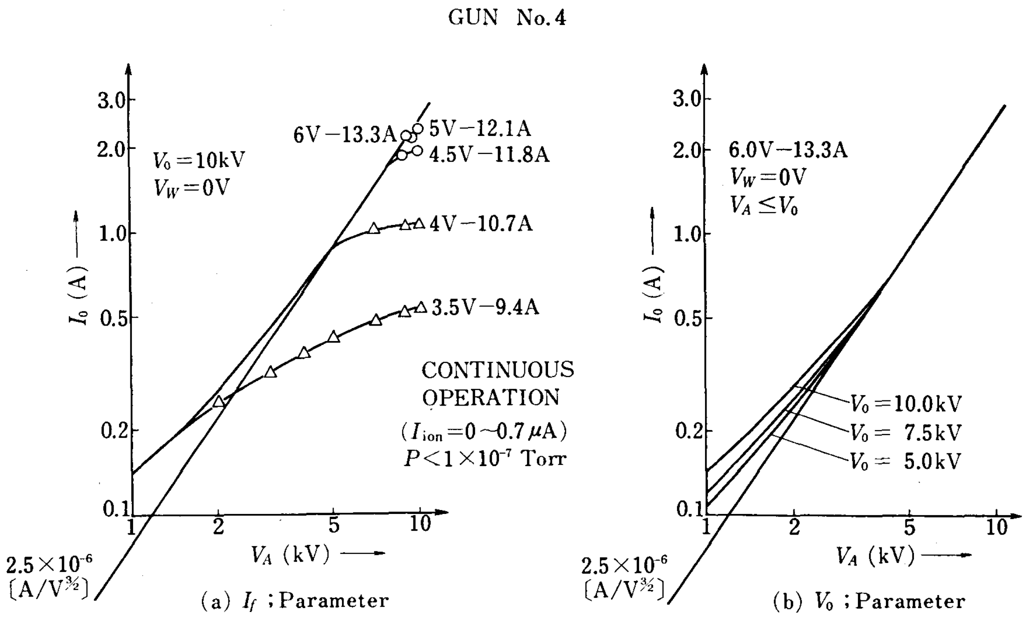
$$\text{Perveance} = 2.5 \times 10^{-6} (\text{A/V}^{3/2}) \qquad (I_0 = 1.6\ \text{A/V}_A = 7.5\ \text{kV})$$
$$I_f = 12\ \text{A/V}_f = 5\text{V}.$$

For the NASDA experiment, the electron guns were demonuted from the vacuum tube and they were transported to NASDA.



Sealed Off Vacuum Tube with Dummy Collector
(before NASDA Experiment)

FIG. A-I. I_0 vs V_A CHARACTERISTICS (GUN No. 5)



Sealed Off Vacuum Tube with Dummy Collector
(before NASDA Experiment)

FIG. A2. I_0 vs V_A CHARACTERISTICS (GUN No. 4)

In the case of the actual Space Shuttle use, the electron gun is exposed to the air for 7～10 days (level I integration process) before launch. So, at this experiment, the gun No. 4 had been kept exposed to air (dry) for one week before the experiment in order to investigate the influence of the gun (cathode) exposure to air on the emission degradation. Table A-1 and A-2 show the operational data of two experimental guns before and during the experiment.

2. Experimental Results

At each time as shown in Table A-2, the emission test (beam current I_0 vs anode voltage V_A) was carried out.

Condition:

* pulse operation

TABLE A-1. Operational Data of Electron Guns/NASDA Experiment

1977 DATE		GUN No. 5 (Main) (with Foc./Def. Coils)	GUN No. 4 (Sub) (without Foc./Def. Coils)
PES.	26		Exhaust & Bake (450°C)
	30		Seal off
OCT.			Vacuum Tube (with Dummy Collector)
	21	Exhaust & Bake (450°C)	Beam Emission Characteristics (Fig. 2)
	26	Seal off	
	29	Beam Emission Characteristics (Fig. 1)	(9: 00) Demounting the Gun
	30		
	31		
NOV.	1	Vacuum Tube	
	2		1-Week Exposure to Air (Dry)
	3		
	4		
	5	Demounting the Gun	
	6	Transportation to NASDA (with N_2-Gas Sealed)	
	7	(9: 00) Mounting the Gun into Vacuum Chamber (8 Hrs. Exposured to the Air.) (17: 00) Pumping Started	
	8 ～ 15	Vacuum Chamber Experiment (Table A-2)	

TABLE A-2. Operational Data of Electron Guns/NASDA Experiment

NOV. 1977			
DATE	Time	GUN No. 5 (Main)	GUN No. 4 (Sub)
9	12	12: 50 Activation	
	18	Emis. Test	Note) ⊓; indicates that the Gun is at operation.
	0		
10		3: 00	
	6		
	12		
	18		
11	0	0: 00 Emis. Test	
	6		
	12		
		16: 30	17: 00 Activation
	18	19: 00	18: 30 Emis. Test
		21: 30	
12	0		
	6	7: 00	
	12		
	18		
13	0	3: 00 Emis. Test	
	6	8: 00	
	12		
	18	Emis. Test	
14	0		
	6		
	12	12: 00 Emis. Test	Emis. Test

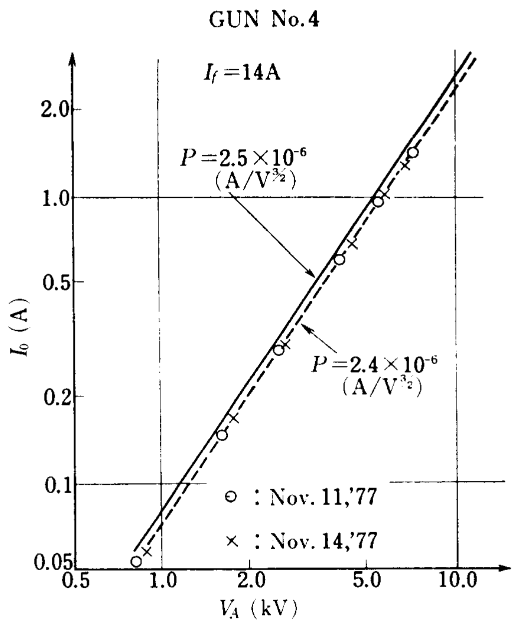


FIG. A-3. Emission data for the gun No. 4

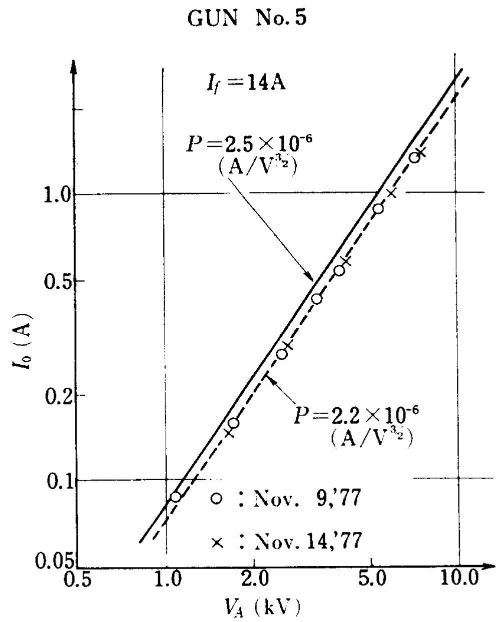


FIG. A-4. Emission data for the gun No. 5

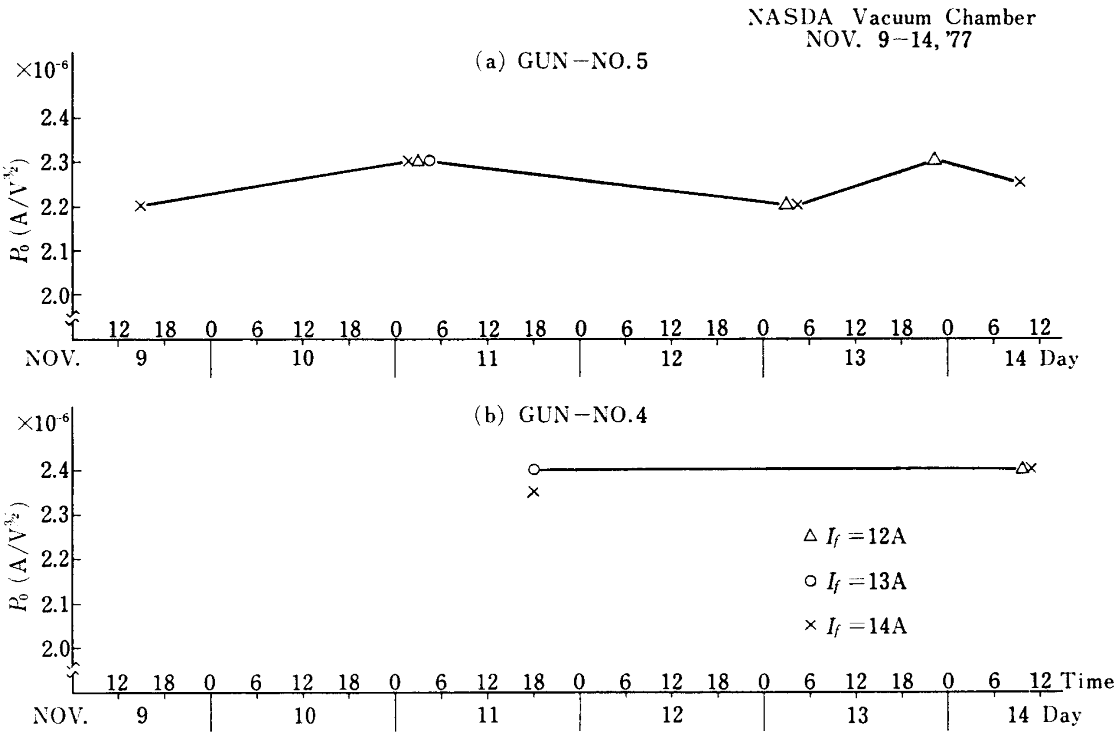


FIG. A-5. Variation of beam emission (perveance) with time

Pluse width/repetition = 50 ms/5 s.

* Beam voltage, V_0 = Anode Voltage, V_A.
* Heater current I_f = 12, 13 and 14 A.
* Vacuum pressure

NASDA vacuum gauge: 5∼10×10^{-7} Torr.

Vacuum gauge near the gun: 1∼7×10^{-6} Torr.

(About 1 meter apart form the guns)

Pumping; Cryogenic pumping.

Fig. A–4 show the activation and emission test data for the gun No. 4 and emission test data for the gun No. 5 are shown in Fig. A–5.

2–1. *Variation of beam emission with time*

Fig. A–6 illustrates the variation of gun perveance with time. Total gun operating time was about 80 Hrs. and 2 Hrs. for the gun No. 5 and gun No. 4, respectively. As is evident from Fig. A–6, high perveance of $2.2 \sim 2.4 \times 10^{-6}(A/V^{3/2})$ was verified and no emission degradation was observed during the experiment.

2–2. *Influence of the gun exposure to the air*

Gun No. 4 was exposured to the air for one week before the experiment. But no emission degradation due to the exposure was observed (as compared with gun No. 5).

2–3. *Influence of vacuum pressure*

Though the indication of vacuum gauge (about 1 meter apart from the guns)

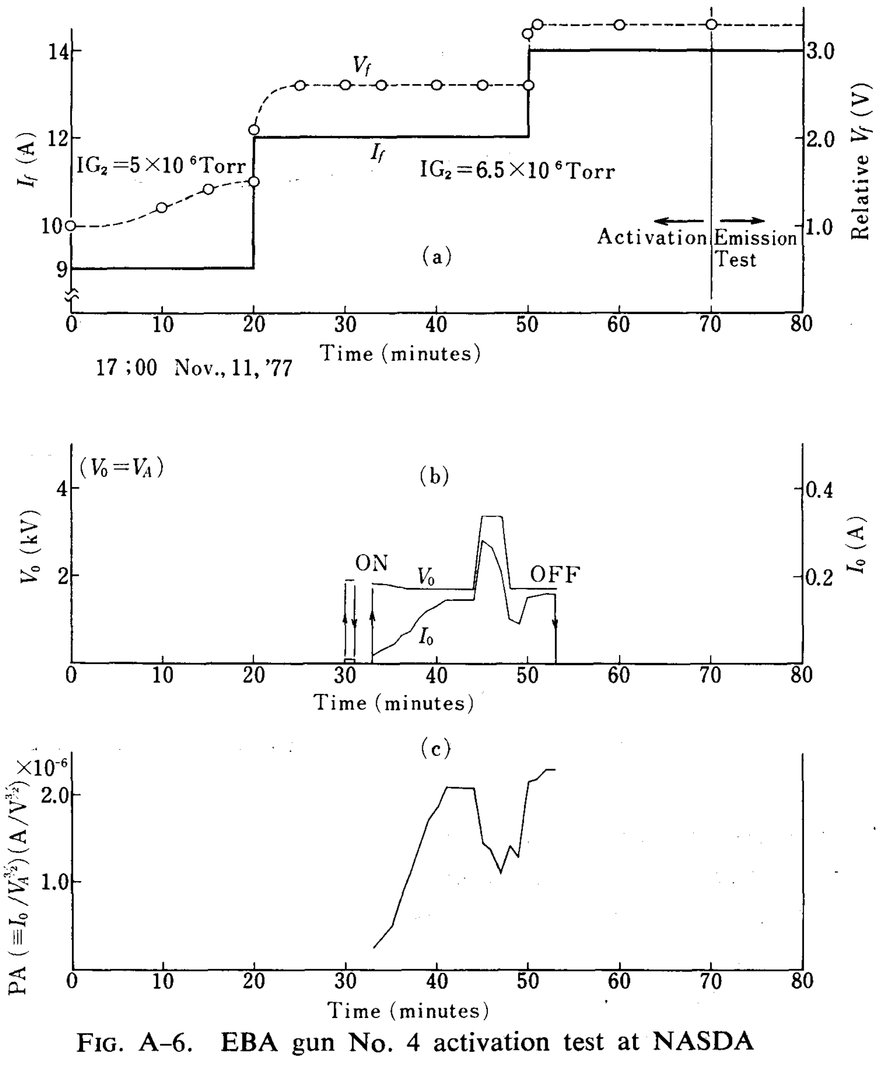


FIG. A–6. EBA gun No. 4 activation test at NASDA changed from 1×10^{-6} Torr (at the beginning of the experiment) to 7×10^{-6} Torr (at near the end of the experiment), the influence pressure on the emission was not observed in this experiment.

2–4. *Cathode activation*

Cathode activation was carried out in accordance with the process shown in Fig. A–7(a). Fig. A–7(b) and Fig. A–7(c) show the beam emission capability during the activation process. From this activation test, it is verified that 70 minutes are required in order to fully activate the cathode.

Appendix B: AL TEST CONDITIONS

I. MPD-AJ (MELCO)

ID	DLYT	FAVP	CHGV 1
A1	1.2 ms	2 AT	480 V
A2			400
A3			350
A4			300
A5		1 AT	400
A6			350
A7			300

DLYT: Delay time
FAVP: Fast Acting Value Pressure
CHGV 1: Charger Voltage

II. MPD-AJ (MEC)

ID	DLYT	FAVP	CHGV 1
B 1	0.8 ms	1.5 AT	480 V
B 2			400
B 3			350
B 4			300
B 5		1 AT	400
B 6			350
B 7			300
B 8	1.2 ms	1.5 AT	480
B 9			400
B10			350

III. NGP

ID	EJNP	EJNT
C1	3.6 At	0.1 s
C2		0.2
C3		0.5
C4		1.0

EJNP: Ejection Pressure
EJNT: Ejection Time duration

IV. EBA

ID	V (kV)	I_H (A)	I_B (mA)	τ (ms)	F/E*
E-1-1	1.3	13	700	50	E
2	2				
3	4				
4	6				
5	7.6				
E-2-1	1.3	14			
2	2				
3	4				
4	6				
5	7.5				
E-2-1a	1.3		400	20	
b			500		
c			600		
d			700		
e			800		
f			900		
g			1000		
h			1100		
3a	2.0		400		
b			600		
c			800		
d			1000		
3a	4.0		500		
b			700		
c			900		
d			1000		

* F: Floating mode; E: Earth mode
τ: emission duration time
I_B: Beam Current
I_H: Heater Current

V. EBA/MPD

ID	V (kV)	I_H (A)	I_B (mA)	τ (ms)	F/E	MPD
E-7-1	1.3	14	40	50	F	A1
2			90			
E-8-1	3		45			
2			270			
E-9-1	5		3			
2			10			
3			30			
4			100			
5			300			
6			400			
E-10-1	5		400			A1
2						A2
3						A3
4						A4
5						B1
6						B3
E-11-1	7.5		900			A1

VI. EBA/NGP

ID	V (kV)	I_H (A)	I_B (mA)	τ (ms)	τNE (S)	F/E	NGP
E-11-1	6	14	500	14	0	F	C1
2					0.5		
3					1.0		
4					1.5		
5					1.25		
6					1.75		
7					2.0		
E-14-1a	5		4		0		
b					0.5		
c					1.5		
2a			40		0		
b					0.5		
c					1.5		
3a			400		0		
b					0.5		
c					1.5		
E-16-1a	2		110		0		
b					0.5		
c					1.5		
2a	5				0		
b					0.5		
c					1.5		

τNE (s): time delay of EBA firing from NGP ejection (sec).