ACTIVE EXPERIMENT WITH HIGH-POWER ELECTRON GUN IN THE POLAR REGION (PLAN)

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Abstract: A plan of a high-power electron beam experiment in the polar region is discussed. An electron beam is quite useful for studying space plasma phenomena as one of the active experiments. The main objective of the experiment is to study the aurora/airglow and various kinds of waves artificially excited by the electron beam, as compared with natural ones. It can be also used to trace the magnetic field line in the polar region.

1. Introduction

Energetic electrons of 1 keV–100 keV play principal roles in various phenomena in the polar region and the study of their behavior (beam-plasma or beam-atmosphere interactions) is an important problem in polar magnetosphere/ionosphere/atmosphere research. Artificial reproduction of natural phenomena in space by a high-intensity electron beam injection is a new way to study this problem. The production of artificial aurora by energetic electrons is one of the most interesting topics in this field and was first performed by HESS' group (HESS *et al.*, 1971; DAVIS *et al.*, 1971). Their experiments and subsequent experiments (HALLINAN *et al.*, 1978; O'NEIL *et al.*, 1978a,b) show a feasibility of artificial aurora by a rocket-borne electron gun.

Another usefulness of the electron beam is that the electron itself can be used as a tracer of the geomagnetic field configuration or the electric field distribution in the magnetosphere. The electron echo experiments were performed for this purpose, and showed that this method is successful for investigating the magnetic field topology in the magnetosphere (HENDRICKSON *et al.*, 1975; WINKLER, 1975).

We have performed electron beam injection experiments by seven rockets, K-10-11, K-10-12, K-9M-57, K-9M-58, K-9M-61, K-9M-66 and K-9M-69. The development of our experiments is shown in Fig. 1. In the first two experiments K-10-11 and K-10-12, a small electron gun was used and main objectives of these experiments were to control the rocket potential by emitting an electron beam. This attempt was successfully done in both experiments and, in addition to this result, some interesting phenomena were also observed such as ambient plasma heating and wave excitations.

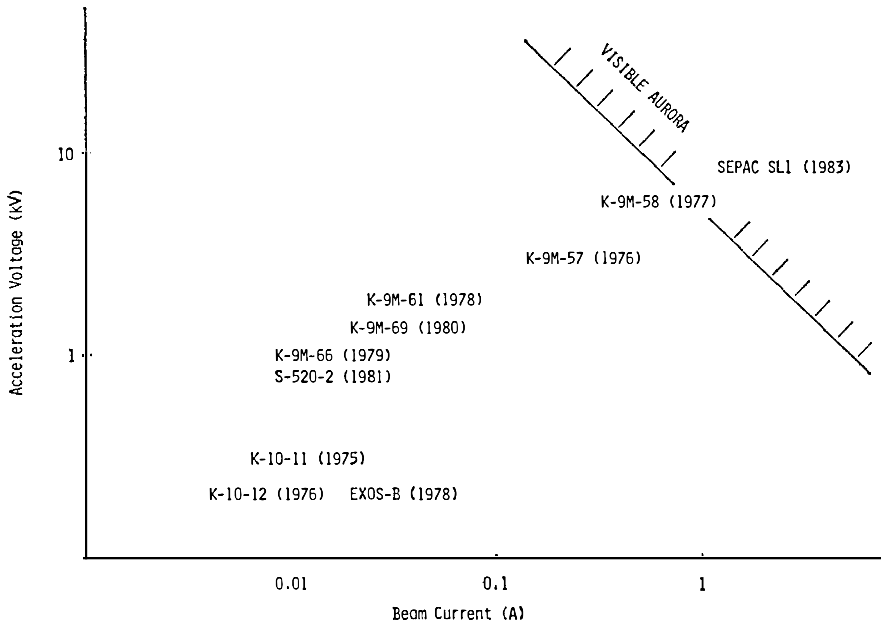

Fig. 1. Developments of our rocket experiments. Shaded area means the possibility of aurora excitation which can be observed from the ground. Seven rockets and one satellite have been used for the electron beam experiments.

Table 1. Summary of our rocket experiments with an electron gun performed at Uchinoura.

Date	Rocket	EBA power	Results
1975. 9	K-10-11	300 eV, 3.75 mA DC	Potential rise
1976. 1	K-10-12	200 eV, 3 mA DC, pulse	Potential rise, wave excitation (VLF/HF) Ambient plasma heating
1976. 8	K-9M-57	3 keV, 100 mA Pulse	Potential rise, wave excitation (VLF/HF)
1977. 1	K-9M-58	5 keV, 300 mA Pulse	Potential rise, visible emission (3914/5577)
1978. 1	K-9M-61	2 keV, 35 mA DC	Potential rise, visible emission (3914/5577) Return electron energy spectrum
1979. 1	K-9M-66	1 keV, 10 mA DC	Return electron spacial distribution Return electron energy spectrum
1980. 1	K-9M-69	150 eV, 30 mA DC	Wave excitation Return electron energy spectrum

In the next two experiments K-9M-57 and K-9M-58, high-power electron beam injection were performed. The diagnostics were to be well prepared for the high-power experiments. A high distortion of the medium around the rocket and an artificial airglow excitation of 3914 Å and 5577 Å were successfully observed. In K-9M-61 and K-9M-66 experiments, a medium-power electron beam injection experiment was performed with a more elaborate diagnostic system. In this experiment distortion of the ambient plasma was weak and several useful results were obtained. Recently, a tethered payload experiment with a medium-power electron gun was done in K-9M-69. The experimental results obtained in these experiments are summarized in Table 1.

A severe problem in injecting a high-intensity electron beam from the rocket in space is the charging of the rocket. Theoretical predictions (BEARD and JOHNSON, 1961; PARKER and MURPHY, 1967; LINSON, 1969) show that the vehicle potential rises to the level where the electron thermal current collected on the surface of the sheath is eqqal to the beam current. Since the ambient plasma density is small in the ionosphere, the potential of the vehicle can be very high when the beam current is large enough to simulate natural aurora. However, contrary to the predictions, the experimental results show that the rocket charging is considerably suppressed by a large amount of plasma production when the beam current is large, as shown in Fig. 2. This plasma production is considered to be caused by the ionization effect of outgas from the rocket surface.

Based on our rocket experiments at the Kagoshima Space Center, we have a

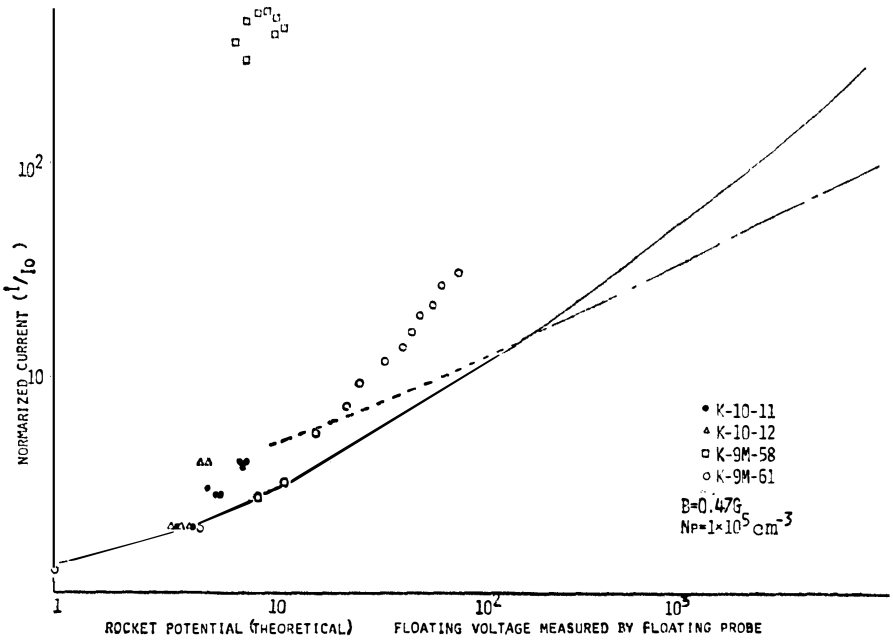

Fig. 2. Summary of the floating probe data in the rocket experiments. The solid line shows the theoretical model of BEARD and JOHNSON. The experimental data depart from the line as the beam current increases because a considerable amount of plasma is produced surrounding the rocket body.

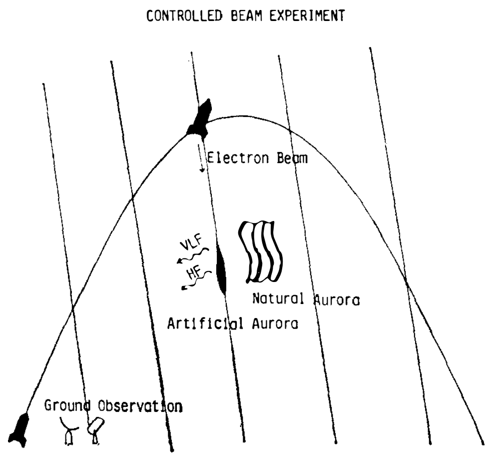

Fig. 3. Schematics of the high-power electron beam experiment in the polar region. We can compare the phenomena excited by the electron beam with those by natural energetic electrons.

plan to make a high-power electron beam experiment in the polar region. S-520 rocket will be used for the experiment. Different from the middle latitude, there exists a lot of energetic electrons in the polar region. We can directly compare the plasma phenomena excited by the artificially ejected energetic electrons with those by natural ones, as shown in Fig. 3. Since the magnetic field line is configured almost vertical to the ground there, we can observe the artificial aurora from the rocket launch base when the rocket is launched with a high elevation angle. This is convenient to combine the observation and the monitoring of the payload operation.

2. Experiment Plan

Electron gun system: The electron gun system consists of electron gun, heater power supply and high-voltage power supply. The designed output power is 7 kV 1.5 A (10.5 kW) in maximum. The electron gun is a diode type with a direct heated cathode. A Ni-Cd battery stack is used for high-voltage power supply. 300 shots of 1 s pulses are scheduled during the flight. So the energy storage system of at least 5MJ is needed considering preflight check operation and safety factor.

Diagnostics and monitors: Diagnostics are composed of Langmuir probes, floating probes, particle energy analyzers, photometers and VLF/HF receivers. Langmuir probes are to measure plasma density and temperature during the beam emission. The floating probes are used to measure the potential rise of the rocket body due to the beam emission. The range of measurements is from -10 kV to 100 V and its input impedance is 10 MΩ. Five floating probes on one support deployed from the rocket will be used to measure the floating potential distribution in/outside sheath region. In order to measure the excitation of the auroral line (N_2^+ 3914 Å, OI 5577 Å, OI 8446 Å) excited by the electron beam, photometers with optical filters will be equipped. A high frequency receiver (0.5 MHz$\sim$10 MHz) and

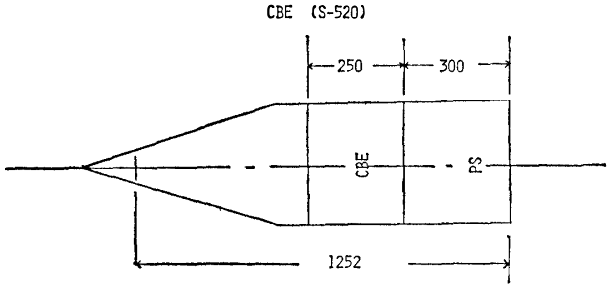

Fig. 4. Payload space required for the high-power electron beam experiment in the case of S-520 rocket.

a very low frequency receiver (1 kHz~10 kHz) are used to measure the electrostatic waves excited by the electron beam and returning electrons to the rocket body. An electron energy analyzer with measurable range up to 12 keV is used to measure the energy of returning electrons. Several monitors which give the experimental information such as electron beam energy, beam current, high voltage of photomultipliers and probe/antenna deployment will be also equipped. The space required for the experiment is estimated in the case of S-520 rocket as shown in Fig. 4.

Ground observation: The artificial aurora and various kinds of waves can be detected from the ground in the high-power electron beam experiment and they are no less important than the on-board observations. Three low light level television cameras which are usually used to observe the natural aurora should be configured separately at the intervals of at least 50 km. The time-varied location of the artificial aurora is studied from the multi-point observation. The photometers are also used to get the time-varied spectrum of the artificial aurora. Emissions in a very low frequency region (0.1~30 kHz) and a high frequency region (0.5~50 MHz) are observed at the launch base.

Operation: The rocket should be launched with a high elevation angle when the natural aurora appears near the rocket trajectory. The diagnostic package including the wave receivers and a telemetry system will be ejected from the rocket before the start of the beam emission. The electron gun system is operated from the height of 150 km. The ground observation will be performed synchronizing the beam emission which is monitored at the launch site.

3. Expected Results

Artificial airglow excitation: The possible lines are the first negative band of nitrogen molecular ion (N_2^+ 3914 Å), the green line (OI 5577 Å), red line (OI 6300 Å) and infrared line (OI 8446 Å) of oxygen neutral atom. The red line will not be observed by the on-board photometer because of its longer life time ($\tau \simeq 110$ s) and

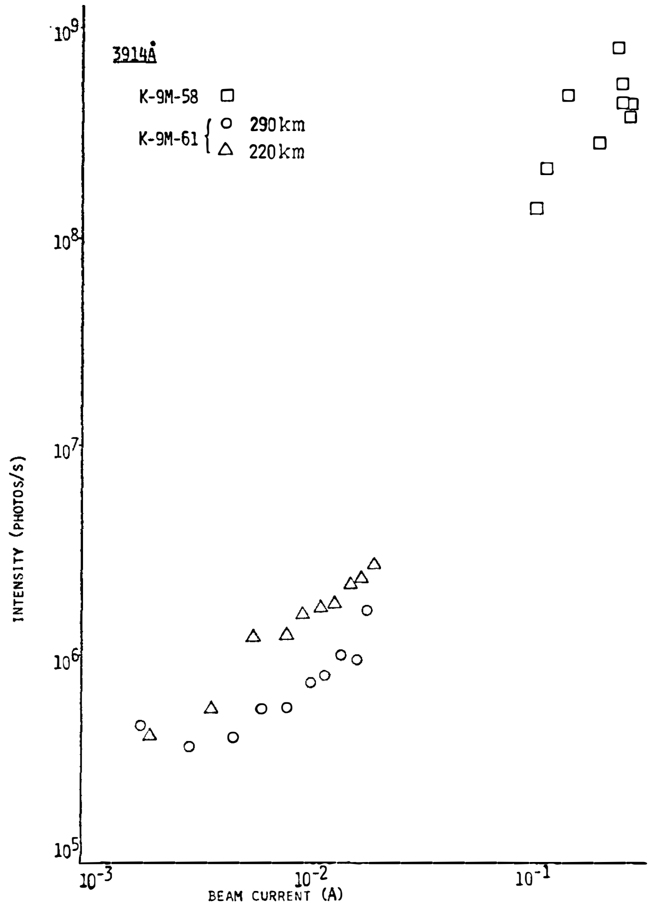

Fig. 5. Intensity of 5577 Å in K-9M-58 and in K-9M-61 experiment as a function of the beam current. Photon intensity of 10^{10} photons/s cm^2 is expected in the high-power electron beam experiment.

the large rocket velocity ($\sim$2 km/s) but other lines will be detected by photometers both on board and on the ground. The first negative band of nitrogen molecular ion and green line have been observed in the past rocket experiments and 10^9 photons/s cm^2 were detected by on-board photometers for 10^{-1} A beam (Fig. 5). In this experiment, photon intensity of 10^{10} photons/s cm^2 is expected.

Wave excitation: Emissions will be excited by a considerable plasma disturbance in the rocket's environment (beam plasma discharge) and by beam-plasma interaction on a large scale. The ignition of the beam-plasma discharge is caused by the ambient electrons heating by the electrostatic waves generated by the beam. We have observed a strong wave excitation in the past experiment. An example of the spectrogram in VLF range is shown in Fig. 6. There were strong emissions over the wide frequency range. There were also strong emissions in HF range, especially from 1 MHz to 3 MHz. No significant coherent emissions have been detected either

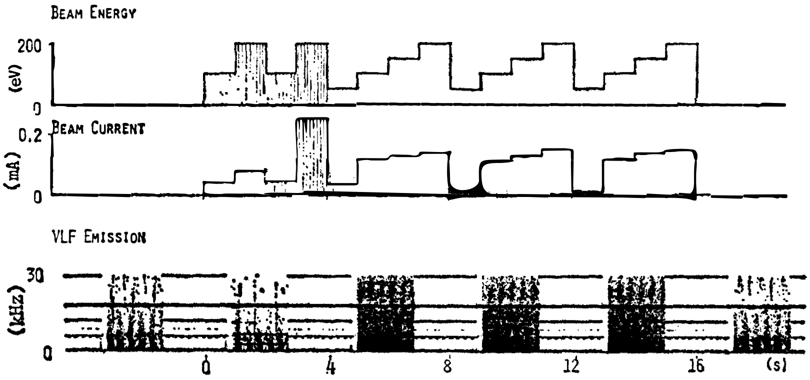

Fig. 6. VLF ionogram in K-10-12 experiment. Emissions with broad frequency spectrum are observed. Intensity is modulated by a spin motion.

in VLF or HF range so far in our experiments, but they have been observed by other group's experiments.

Magnetic field line tracing: When the electron beam is emitted upward with a high pitch angle, the electron beam will be reflected at the magnetic conjugate point in the hemisphere if the magnetic field line is closed. Detecting the electron beam returning, we can study the magnetic field line configuration at the tail of the magnetosphere. When the electron beam is ejected downward parallel to the magnetic field, it propagates along the magnetic field line. Beam trajectory observed from the ground corresponds precisely to the local magnetic field line.

4. Conclusion

The feasibility of the high-power electron beam experiment in the polar region is discussed. This enables a direct comparison of the aurora phenomena generated by natural energetic electrons with those excited artificially by the high-power electron beam. We can expect additional information on the generation mechanism of aurora and accompanying emissions to those obtained by the current passive experiment.

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