BEAR Electrostatic Analyzer: Flight Results

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The Electrostatic Analyzer (ESA) measured the intensity of charged particles returning to the BEAR payload during flight on 13 July 1989. These particles form part or all of the current that returns to the payload to neutralize the charge ejected with the beam. By measuring the return flux with high time resolution, we can study the physics of charging processes.

When the neutralizer was off, the payload emitted 10 mA negative and charged to several hundred volts with a maximum of ~800V. With the neutralizer on (normal configuration) the payload emitted ~ 1mA negative and received electrons with energies up to a few hundred volts in some attitudes. This suggests charging to a few hundred volts. The charging rate of the payload is consistent with the rocket body capacitance with respect to a vacuum.

INTRODUCTION

The Electrostatic Analyzer's (ESA) function on BEAR is to measure the energy spectrum of particles carrying current that returns to the payload to neutralize charge removed with the beam pulses. From these data it is possible, with some assumptions, to deduce the voltage to which the payload charges. The data directly show what particles are bombarding the surface of the payload.

The accompanying paper [Potter *et al.*, 1990] describes the ESA instrument in detail as well as its calibration and testing. In short, the ESA measures the energy spectra of electrons and ions from 20 eV to 3000 eV with 23% energy resolution and temporal resolution of 1 microsecond. The accelerator on BEAR produces 5 beam pulses per second, each 50 microseconds long. Operation of the gas neutralizer determined the composition of the emitted beam. A magnet captures stripped electrons, so only ions and neutrals escape. The ESA obtained data during and after each beam pulse; it steps through its energy range every fourteen pulses. The ESA mounts in the Physics/Telemetry Section of the BEAR payload looking radially outward perpendicular to the spin axis and at the 90 degree azimuth location.

We have obtained data from two sets of measurements: a series of experiments conducted in a space simulator prior to flight, and the flight of the BEAR rocket. Potter *et al.* describe the simulator data. From these data we conclude that we can infer the voltage applied to the ESA from the spectra it observes.

FLIGHT DATA

Charging data could be obtained under three major conditions during flight. During most of the flight the accelerator produced 10 mA of 1 MeV negative hydrogen ions at the output of the HEBT, and the neutralizer operated *normally* to produce a net beam current of about 1 mA negative. During two intervals the neutralizer was turned off so that the full negative ion output of the HEBT (10 mA when working correctly) left the payload. Finally, just before reentry the beam was *over-neutralized* so that about 1 mA positive was emitted. In addition the accelerator did not always produce any beam at the programmed times although its controller generated synch pulses regularly. That is, the output of the HEBT was zero although the synch pulse from the accelerator triggered ESA data collection.

The payload was initially aligned parallel to the geomagnetic field B so that beam injection was parallel to the field. In this orientation the ESA, because of its mounting, accepts only particles moving normal to B. The payload was then turned so that its axis and the beam injection were nearly perpendicular to B. In this condition the ESA scans all incoming pitch angles as the payload rolls. Neutralizer off and over-neutralize data were obtained only in this attitude, but the NORMAL neutralizer operation occurred in both attitudes.

INSTRUMENT PERFORMANCE

The ESA functioned correctly throughout the flight until increasing atmospheric density at about 95 km on the downleg caused the high voltage to arc over, as would be expected. Low voltage power was on before and during launch so that all housekeeping and digital functions were observed. High voltage turned on at the programmed time with no difficulties. There were virtually no extraneous counts in any channel from electronic pickup internal to the payload. The ESA was as quiet or quieter than it had been during systems tests.

Two secondary results are immediately evident in the data.

1. When the accelerator skips sending out beam, the ESA shows zero counts. This is particularly evident during the neutralizer off period, when there is a large response if beam is emitted.

2. During the period of over-neutralization the ESA did not see collection of ions. We believe that this is because the payload was so low, with consequent high neutral density, that little charging occurred and the ESA may have been operating with decreased efficiency.

During the other operating conditions the ESA measured return current as detailed below.

NEUTRALIZER OFF

During the first off period there were 16 pulses of 8 - 10 mA emission, and one with about 5 mA where the HEBT output was low. In the second off period there were two pulses with output above zero, and both of these had low HEBT current. The first neutralizer off lasted 9 seconds so that 45 beam pulses were possible. Figure 1 shows Channel D data for the neutralizer off period; missing pulses are evident. Figure 2 shows similar Channel C data. From these data one readily sees that electrons appear up to several hundreds of eV energy, and that the time history of the response depends upon energy. The next steps of analysis examine the temporal history of the pulses, and the energy spectrum of the returning particles.

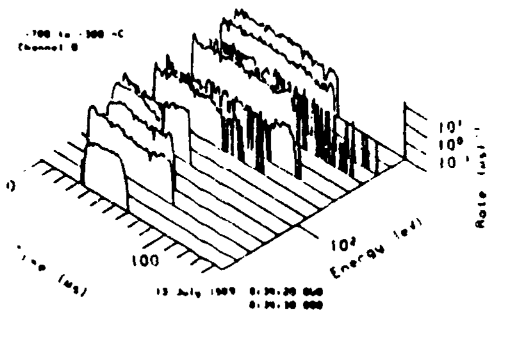

Figure 1. Channel D (20-300 eV electron) data with neutralizer off; emitted charge about 500 nC.

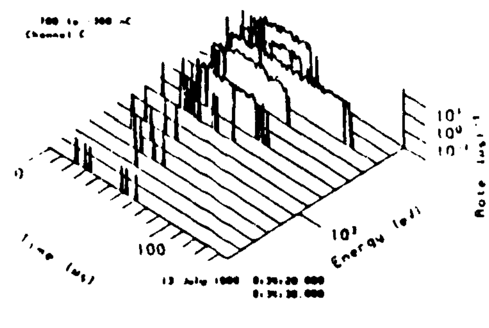

Figure 2. Same as Figure 1 for Channel C (200-3000 eV electrons).

To examine these data more carefully we plot the counting rates from the channels and the output of the beam current monitor *vs.* time. Figure 3 shows such data during and after one beam pulse. Figure 4 shows the temporal extent of all the data when the neutralizer was off. It is evident that the returning particles appear only *after* the beam starts coming out, and that more energetic particles appear after a longer delay. There is some tendency for more energetic particles to disappear more quickly, but the trailing edge is ragged. If the appearance of particles with increasing energy is interpreted as evidence of charging, then the observed response is consistent with vacuum charging of about 200 pf capacitance by the beam current. This is a reasonable capacitance value for the actual BEAR payload.

Figure 5 shows the average counting rates during the interval 20-80 microseconds after start of data collection, converted to a spectrum of intensity versus energy. The offset between channels C and D comes from our estimation that C has 85% efficiency, and D 30%. Using the same efficiency would make the two channels match in the 200-300 eV range, just as normalizing the flight data would. Note, however, that the two channels do not cover this range on the same accelerator pulses since when Channel D measures 300 eV, Channel C measures 3000, and so on. We hope to improve this normalization by further study of the space simulator results.

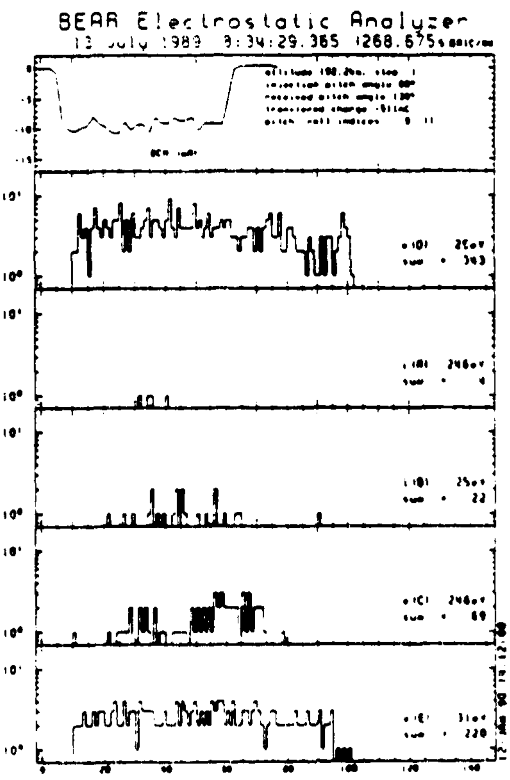

Figure 3. ESA response (counts/microsecond) and beam current (measured by BCM) vs. time with neutralizer off. Channels C and D are electrons; A and B are ions; and E is the RPA electrons.

Careful examination of the response to individual beam pulses shows that the spectra of returning particles are different for different pulses.

Thus Figure 5 represents an envelope of sorts. The maximum returning energy varies from 100 to near 800 eV.

Theory is not yet available to explain the details of time and energy dependence. It is likely that the continuum below the spectral edge is secondaries knocked off the skin of the payload. Based on the space simulator results, where the spectral edge corresponds to the voltage applied to the instrument, **we interpret the spectra as showing that BEAR charged to +100-800 volts when emitting 10 mA negative beam pulses. The level is different with different pulses for reasons not currently known.**

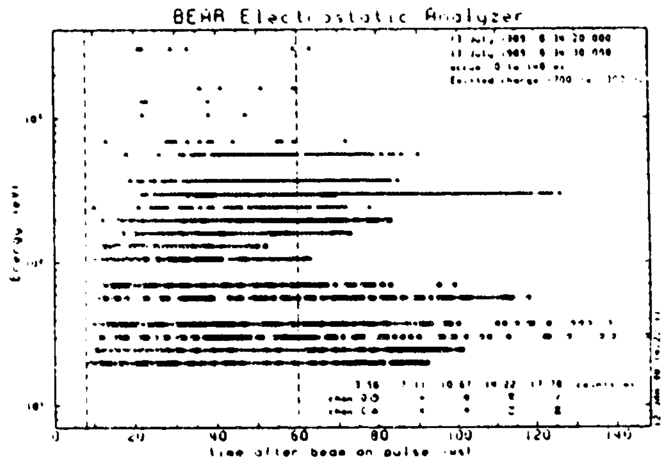

Figure 4. Duration of response at different energies for neutralizer off.

Neutralizer On

When the neutralizer was on, the accelerator produced about 265 pulses with net current negative 1 mA, the remainder being zero. The ESA measured some returning particles (2 or more counts) from about one-fifth of these; the others produced no response. At this writing we have not identified what conditions cause or prevent the response, although we are pursuing evidence that it may relate to thruster firings and associated depression in plasma density. We are able to sort the response by received pitch angle.

Figure 6 and Figure 7 show Channels D and C during the period when the payload was aligned with B (Pitch angle of injected beam is 0°). At this time the ESA received particles moving perpendicular to B. Figure 8 and Figure 9 show the same after the payload pitched over so that injection was near 90° pitch angle. In the latter data set the pitch angle of received particles varies from 0° to 180° as the payload rolls.

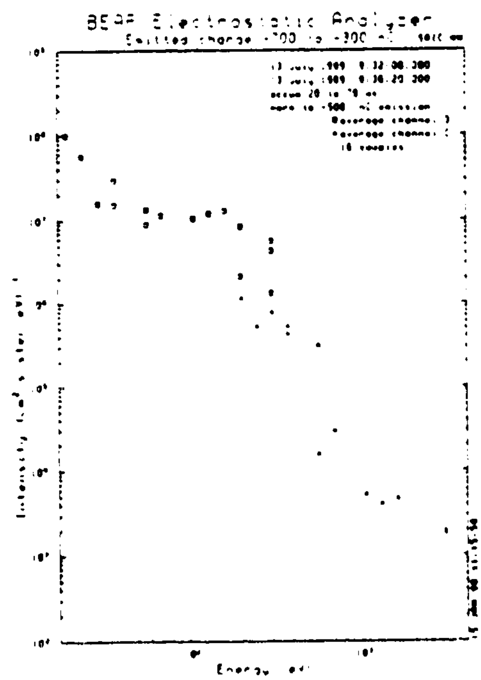

Figure 5. Envelope of intensity of return vs. energy with neutralizer off.

With this in mind we sort the data into three groups:

a) Injection near 0°;

b) Injection near 90° with receiving angle near 90°;

c) Injection near 90° with receiving angle away from 90°.

As with the neutralizer off data, we examine the duration of returning bursts and their energy spectra.

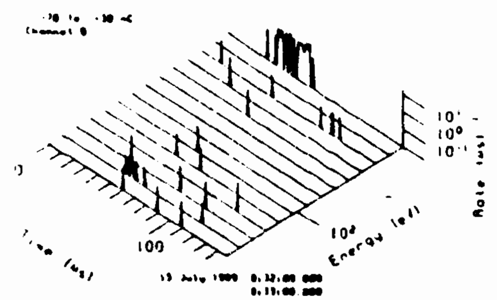

Figure 6. Channel D (20-300 eV electrons) data with neutralizer on (about 50 nC emitted). Payload is field aligned.

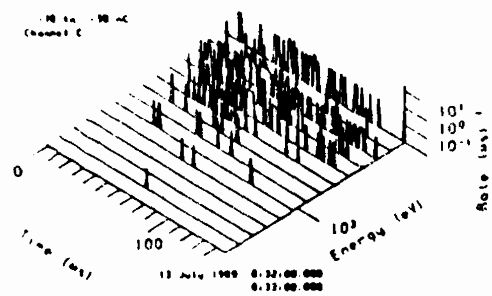

Figure 7. Same as Figure 6 for Channel C (200-3000 eV electrons).

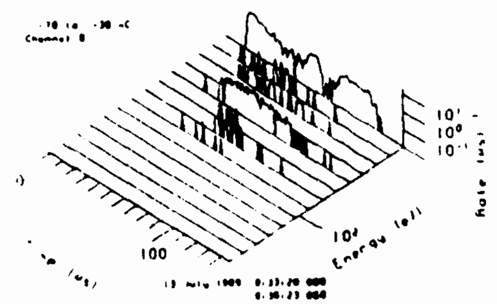

Figure 8. Same as Figure 6 except payload is aligned normal to B.

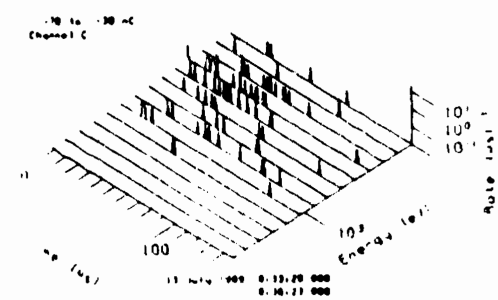

Figure 9. Same as Figure 6 for Channel C.

Figure 10 shows the spectrum for condition a). Note that almost entirely energetic electrons appear, but that both Channels C and D responded. Figure 11 shows conditions b) and c) together, while Figure 12 and Figure 13 show them separately. Note the similarity of conditions b) and a) and the difference of c). Clearly the receiving angle being near or far from 90° is significant; injection pitch angle (or equivalently payload attitude) are not. We expect that the charging might depend upon vehicle attitude, but not upon roll azimuth. The latter simply allows the ESA to sample different portions of the returning velocity distribution function. Charging would also depend upon ambient plasma density as perhaps modified in the vicinity of the vehicle by thruster firings.

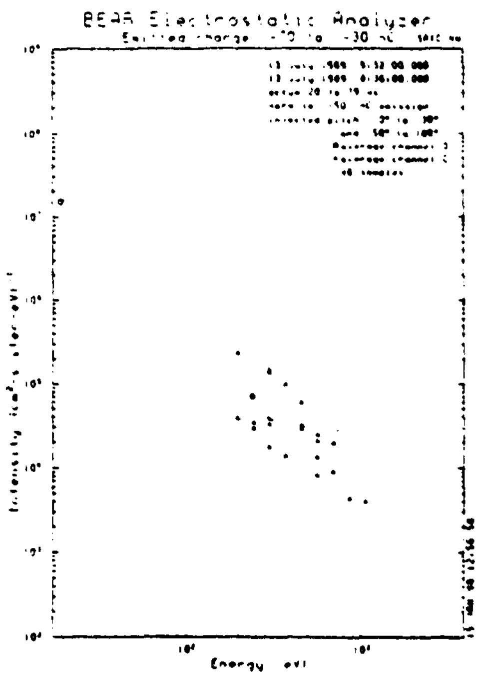

Figure 10. Intensity of returning electrons with neutralizer on. Payload is field-aligned with injection and receive pitch angles near 0° and 90°. The straight lines correspond to 1, 10, and 100 counts in 100 microseconds.

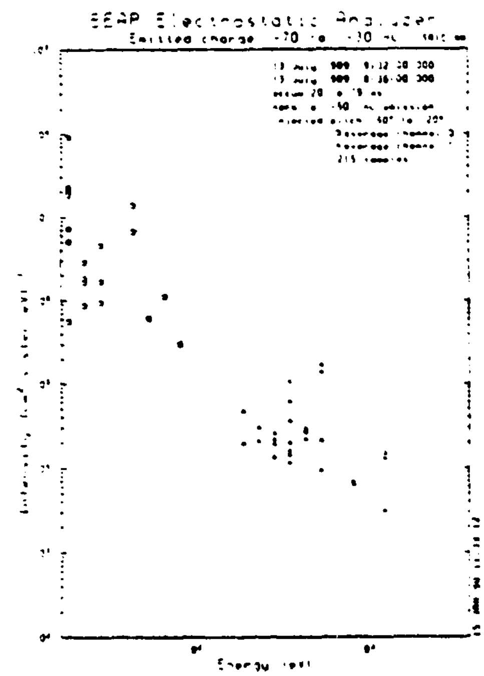

Figure 11. Intensity of returning electrons for payload perpendicular to B (90° injection angle) and all received pitch angles.

Figure 14 shows time durations under conditions b and c together. Note the contrast with Figure 4.

It is clear that some 1 mA beam pulses produced returning electrons of several hundred eV energy both before and after pitch over. The energetic electrons seem to move preferentially perpendicular to the local B field. It may be that every beam pulse produced such electrons, but that the ESA was not always positioned or set to detect them. These data demonstrate clearly that a more complete instrument would measure many energies and angles simultaneously with the high time resolution of the BEAR ESA. As is discussed in the accompanying paper, we recognized this during the design phase, but various constraints prevented our making a more elaborate instrument.

In the absence of current understanding of what controls the appearance of energetic returning particles it is difficult to make a detailed statement about charging. However it does appear that under some circumstances charging to several hundred volts resulted from emission of negative 1 mA. It is certain that electrons of such energy bombard the payload during emission of this and larger currents.

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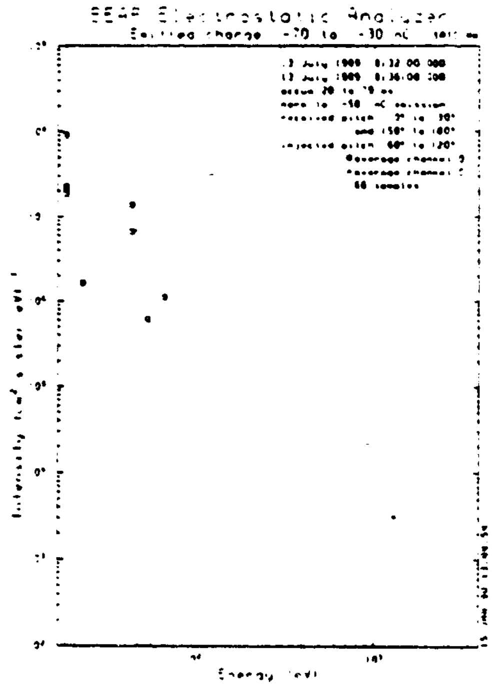

Figure 12. Same as Figure 11 but only received pitch angles *not* near 90°.

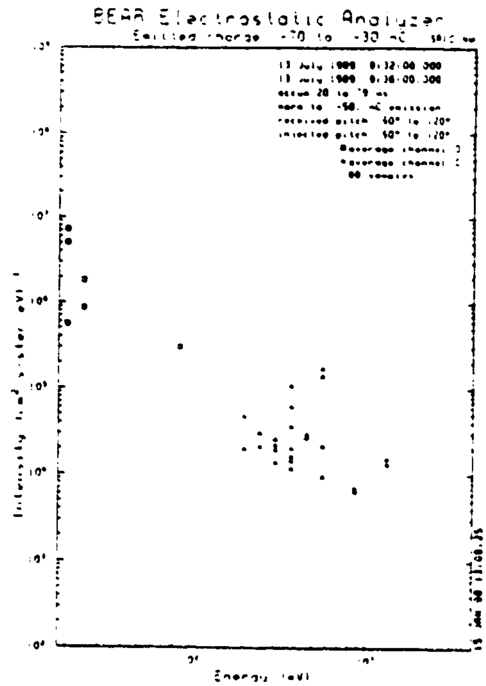

Figure 13. Same as Figure 11 but only received pitch angle near 90°

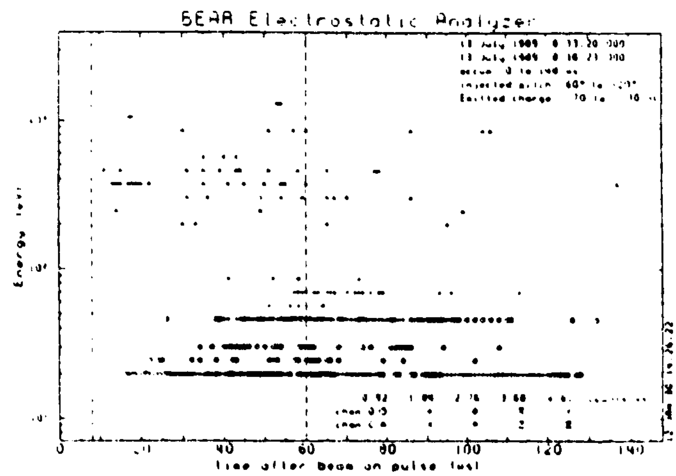

Figure 14. Duration of response for various energies with neutralizer on and injected pitch angle near 90°

REFERENCES

Potter, Douglas W., Hugh R. Anderson, and Joseph. R. Olson. BEAR Electrostatic Analyzer: Description and Laboratory Results. *These Proceedings*. 1990.